# THE VALIDITY OF CLINICAL TESTS FOR CRANIOVERTEBRAL INSTABILITY

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#### STATEMENT OF ORIGINALITY

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## LIST OF ABBREVIATIONS

3D	three dimensional
AAD	atlantoaxial dislocation
AAS	atlantoaxial subluxation
ADI	atlantodental interval
A-P	anterior-posterior
BDI	basion dental interval
C1	first cervical vertebra
C2	second cervical vertebra
C3	third cervical vertebra
C6	sixth cervical vertebra
С7	seventh cervical vertebra
CI	confidence interval
CSA	cross sectional area
СТ	computed tomography
CV	cervical vertebra
CVI	craniovertebral instability
DICOM	Digital Imaging and Communications in Medicine
FOV	field of view
ICC	intraclass correlation coefficient
mm	millimetres
MPA	Musculoskeletal Physiotherapy Australia

MRI	magnetic resonance imaging
MVA	motor vehicle accident
NA	not available
0	occiput
PADI	posterior atlantodental interval
PAL	posterior axial line
PD	proton density
PG	post-graduate
PLL	posterior longitudinal ligament
PPIVM	passive physiological intervertebral movement
r	Pearson's correlation coefficient
SD	standard deviation
SE	spin echo
SLE	systemic lupus erythematosus
Т	Tesla
TE	echo time
TR	repetition time
TSE	turbo spin echo
WAD	whiplash associated disorder

#### ABSTRACT

The work contained in this thesis encompasses four studies to examine the validity of clinical testing for clinical instability of the craniovertebral region. Validity was explored through the utilisation and exploration of the constructs of convention, biological plausibility and empirical proof.

Consensual validity for clinical testing was explored through a survey of knowledge and attitudes to instability testing in a nationwide survey involving 1528 Australian physiotherapists. Details of respondents' understanding of the concept of instability, potential clinical presentations of patients with segmental hypermobility of the upper cervical spine, knowledge of published clinical stress tests, attitudes toward performing these clinical tests and inclusion of craniovertebral testing procedures in clinical guidelines were all assessed. On the basis of the information returned, it appears that the level of knowledge and understanding of these disorders, their clinical presentation, assessment and their risk factors is low. Understanding of the clinical testing manoeuvres was also poor, with the majority of respondents never applying these tests clinically. Completion of post-graduate coursework in musculoskeletal physiotherapy clearly improved exposure to these concepts and tests in respondents, but did not significantly affect use of testing for screening prior to treatment of the upper cervical spine overall. Consensual validity for clinical testing of craniovertebral instability must be considered to be low based upon the absence of agreement of the existence, presentation and assessment of the disorder.

Biological plausibility of testing was explored through examination of the morphology of the ligaments of the craniovertebral region. Observations made during the dissection of 11 cadaveric specimens were mostly in accordance with descriptions of the anatomy upon which the clinical test procedures have been based. However, the tectorial membrane was observed to be a more complex structure than has previously been understood with its fibre arrangement suggesting a role as a potentially limiting structure to axial rotation of the upper cervical segments. The existence of the previously reported 'atlantal' portion of the alar ligaments was also challenged. It was not observed in any specimen examined and the presence of these bands of tissue in any individual should be considered an anatomical variant. Overall, the gross morphology of the craniovertebral ligaments observed being consistent with the basis of the clinical tests confers face validity on the testing procedures.

The biological basis for testing was further explored using magnetic resonance imaging of six specimens at high (4.6T) and clinical (3.0T) definition acquisitions. Observations were confirmed by dissection and the accuracy of measurements and observations assessed. Again, the gross morphology was consistent with the structural assumptions underpinning the clinical tests, thus enhancing their face validity. Clinical acquisitions were compared using three different sequences to assess the optimal acquisition sequence to be used in subsequent patient studies. Proton density-weighted sequences were found to be superior in identification, delineation and measurement of the ligaments of this region.

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Empirical proof that clinical tests are capable of influencing the ligaments of this region was addressed in the final study. The upper cervical spines of 16 healthy volunteers were imaged using MRI in both neutral and end-range clinical test positions. Ligaments were assessed using both direct measurement and indirect estimates of bony displacement. Statistically significant changes in ligament dimension were demonstrated for the ligaments in all tests examined. Direct evidence that the ligament may be influenced in a predictable manner through the imposition of clinical tests provides a strong case for the establishment of construct validity for each of these described clinical tests.

Through utilising the three axioms of convention, biological plausibility and empirical proof, a number of aspects of the validity of clinically testing the craniovertebral region for instability have been assessed. Whilst the consensual validity of testing appears poor, the case for face validity and construct validity for the ligament stress tests is strong suggesting that further research is warranted which may now potentially involve individuals with demonstrable instabilities of this region.

# PUBLICATIONS AND PRESENTATIONS ARISING FROM THE WORK IN THIS THESIS

Parts of the work presented in this thesis have been published and/or presented in the following forums:

### **PUBLISHED PAPERS**

Osmotherly PG, Rivett DA. (2011). The knowledge and use of craniovertebral instability testing by Australian physiotherapists. *Manual Therapy*. *16*(*4*):*357-363*.

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## **CHAPTER 1**

#### **INTRODUCTION**

In clinical diagnosis, we do not expect certainty. Judgements are made upon the best evidence available under the specific circumstances available when we consider an individual patient. Test findings supposedly indicative of a diagnosis may occur in patients who do not have the diagnosis (false positives) and may be absent in those people who have the diagnosis (false negatives) (Sox, 1996). The issue must then turn to what is considered evidentiary in the understanding and interpretation of the imperfect information we collect during clinical testing.

In the absence of assessment against an available 'gold standard', the validity of any clinical test may be approached from the perspective of constructs. Such an approach has previously been proposed in the appraisal of treatment techniques (Bogduk & Mercer, 1995) and this form of appraisal can equally be extrapolated to assessing techniques of clinical assessment.

By drawing together the various constructs of validity as they relate to craniovertebral ligament testing, we may demonstrate through a process of structural corroboration the degree to which validity of these tests may be conferred (Eisner, 1998). Structural corroboration may be defined as a means through which multiple types of data are related to each other to support or contradict the interpretation or evaluation of a concept (Eisner,

1998). A confluence of evidence improves credibility and confidence in our observations, interpretations and conclusions by producing a coherent case.

According to Bogduk and Mercer (1995), the propriety of clinical techniques may be appraised against three distinct but complementary axes. These are reported as:

- 1. Convention
- 2. Biological basis, and
- 3. Empirical proof.

#### **1.1 Convention (consensual validation)**

Convention amongst clinicians is a socially powerful dimension but is the intellectually least rigourous construct of the three approaches (Bogduk & Mercer, 1995). More commonly referred to as clinical experience, convention is prone to bias from influences including clinician recall, misperception and lack of a reference standard against which to judge the clinical effectiveness of the assessment techniques.

In the context of considering validity of craniovertebral ligament testing, convention may be described as consensual validation. Consensual validation determines the validity of a notion or test through agreement amongst competent others that the description, interpretation and evaluation of the notion or test are correct (Corsini, 2002; Eisner, 1998; Onwuegbuzie & Leech, 2007). This process of achieving a collective opinion is then used to establish the content validity of the construct, a first step in establishing the validity of the clinical procedures themselves (Westmoreland, Wesorick, Hanson, & Wyngarden, 2000). This process does not depend on the existence of an absolute truth or reality but only upon the existence of ways of assessing opinions that in some way relate to the topic under examination (Onwuegbuzie & Leech, 2007).

#### **1.2 Biological basis**

The general principle upon which the performance of ligamentous stress testing is based is that one bone to which the ligament is attached should be fixed and another bone to which it is also attached should be moved away from it such that the connecting ligament is stretched maximally (Meadows, 1999a). In order for this principle to be fulfilled, the anatomical description of the ligament's structure should be well defined so that the tests themselves reflect the described structure. Only under these circumstances is the test satisfying the requirement of biological plausibility.

#### **1.3 Empirical proof**

In its simplest form, test validity may be regarded as the extent to which a test measures what it purports to measure ("Dorland's Illustrated Medical Dictionary," 2003). Each clinical stress test is described on the basis of our understanding of the attachments of the ligaments and the biomechanics of the region in which they are located. To establish empirical proof of their validity, we must examine the direct effect of these stress tests on the ligaments themselves in order to establish whether there is an observable and reliably measurable influence of these stress tests on the length of the ligaments under scrutiny.

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There is no gold standard for assessment of these ligament tests as radiological assessment of lesions of the craniovertebral ligaments is not yet considered valid and reliable. Therefore, the validity of the tests will be assessed using these series of constructs; consensual, anatomical and radiological, and empirical.

#### **1.4** Structure of this thesis

This thesis will draw together the three complementary constructs of convention, biological basis (anatomical and radiological) and empirical proof to form a coherent examination of the validity of craniovertebral instability testing by reporting the findings of a series of studies designed to examine each of these constructs.

Chapter 2 provides an overview of the topic of instability in the craniovertebral region, discussing concepts of spinal stability and instability, and presenting a review of published research exploring the potential causes of ligamentous instability of the craniovertebral region, the incidence and prevalence of ligamentous instabilities of this region, and the clinical presentation of patients with recognised craniovertebral instabilities.

The convention axis is explored in Chapter 3. In this study, the membership of Musculoskeletal Physiotherapy Australia, the musculoskeletal interest group of the Australian Physiotherapy Association, was surveyed to determine their knowledge of, and attitudes toward, testing for craniovertebral instabilities. The consensual validation of clinical testing was examined through the exploration of agreement of competent others
on the description, interpretation and evaluation of the tests used in clinical practice. The formation of a collective opinion was thus used to evaluate the content validity of the constructs of testing.

Chapters 4 and 5 explore the biological basis of the clinical tests from an anatomical perspective. Chapter 4 provides a review of the literature examining the descriptive anatomy of the ligaments of the craniovertebral complex. Chapter 5 presents the findings of a study of the morphology of the transverse and alar ligaments and the tectorial membrane using fine dissection in a sample of eleven cadaveric specimens. This study sought to provide a measure of consistency to the descriptions of these ligaments which has been absent in previously published work, thereby conferring face validity upon descriptions of the clinical tests for ligamentous instability which have been based upon descriptions of ligament structure.

The literature review provided in Chapter 6 provides background to the interpretation of imaging of the ligaments of the craniovertebral region and their lesions. The subsequent study, described in Chapter 7, was conducted to achieve two main outcomes. By comparing clinical resolution images with high resolution images and finally dissection of the imaged specimens, the findings describing the morphology of the ligaments in the previous anatomical study could be strengthened, thereby addressing the face validity of the clinical tests for these ligaments again. Consistency of findings between each stage of this study was essential in ascertaining the accuracy of imaging techniques in reflecting the structure of the ligaments. Together with an exploration of various clinical imaging

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sequences to ascertain the optimal sequence for imaging the craniovertebral ligaments, this study provides a scaffold upon which subsequent imaging studies of the clinical tests themselves could be based.

Chapters 8, 9 and 10 address the clinical tests directly, thereby drawing on the construct of empirical proof. Chapter 8 provides a review of the biomechanics of the craniovertebral segments in relation to ligament function. Chapter 9 uses this background to present a review of descriptions of the clinical tests for craniovertebral instability and the mechanisms by which they are considered to demonstrate the integrity, or otherwise, of the craniovertebral ligaments. Finally, Chapter 10 describes a study of the construct validity of selected clinical tests for the alar ligaments (rotation stress test and the sidebending stress test), the transverse ligament (the anterior shear test) and the tectorial membrane (distraction test). In this study, 16 healthy volunteers underwent MRI in neutral and end-range test positions. A reproducible methodology for measurement of the effects of the clinical tests was developed and measurements of the change in target ligament length, corroborated by changes in distance between selected bony landmarks, were used to demonstrate direct effects of the clinical tests on the ligaments themselves.

Chapter 11 draws together the findings of each study in the context of the three complementary constructs upon which the examination in this thesis is based. Conclusions drawn from the studies are discussed and recommendations for future research in this area are presented.

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# **CHAPTER 2**

# WHAT IS CRANIOVERTEBRAL INSTABILITY?

## 2.1 Concepts of spinal stability and instability

Instability in the spine is a controversial topic in both clinical and research literature (Panjabi et al., 1994; Swinkels, Beeton, & Alltree, 1996). In great part, this controversy arises from a lack of a clear and accepted definition of spinal instability (Cattrysse, Swinkels, Oostendorp, & Duquet, 1997; Swinkels & Oostendorp, 1996).

The dictionary definition of instability provides little assistance in improving our understanding of this concept. Here, instability is defined as "lack of stability" ("Concise Oxford English Dictionary," 2008). Understanding stability thus becomes pivotal to understanding this concept. Stability is defined as "the state of being stable" and the appropriate given definition of stable is "not likely to give way or overturn" ("Concise Oxford English Dictionary," 2008).

None of these elemental definitions provide insight into defining this complex clinical problem. Given that the definition of the broader concept is confusing, it is not surprising that descriptions of clinical characteristics, diagnosis and treatment are also ambiguous (White & Panjabi, 1990).

Various authors have attempted to define spinal instability (Frymoyer, 1997; Panjabi, 1992b; Panjabi et al., 1994; Scher, 1979; White & Panjabi, 1990). In possibly the first invivo investigation of linear vertebral movement as a source of spinal pain, Knutsson (1944) related the presence of instability to degenerative anatomical changes occurring between adjacent spinal segments. These were reported as demonstrable radiographic changes including "parallel displacement" of the vertebral bodies and "abnormal tilting movements between the vertebra" (Knutsson, 1944).

In consideration of two clinical case presentations reporting anterior subluxation in the cervical spine, Scher (1979) defines instability as "abnormal mobility occurring between any pair of vertebrae, with or without pain or other clinical manifestation". Scher attributed the subluxation reported in the cases to injury of the cervical ligamentous complex. As a definition of clinical instability, this is problematic since this could equally describe hypermobility of a joint at any specified level of the cervical spine and, in the absence of any pain or clinical signs, the clinical importance of any such finding may be questioned.

Of paramount importance in the discussion of spinal instability is the differentiation of the terms instability and hypermobility. Confusingly, these terms are used interchangeably in published literature discussing spinal instability. Some authors have highlighted the need to recognise differences in meaning ascribed to each term (Pettman, 1992a). Hypermobility may be defined as an excessive range of motion for which there is complete muscular control, thus ensuring stability (Maitland, 2005). It is frequently

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considered to represent an abnormal increase in angular motion at the joint (Pettman, 1992a). Instability may be considered to mean an excessive range of abnormal movement for which there is no protective muscular control (Maitland, 2005). It is usually associated with an abnormal increase in linear or accessory motion and is caused by a breakdown of anatomical structures (Pettman, 1992a). In essence, instability usually implies a pathological situation, whereas hypermobility may be considered to lie at one end on the continuum of normal movement (Swinkels et al., 1996).

The importance of anatomical integrity is repeated in various descriptions of the unstable spinal segment. Farfan and Gracovetsky (1984) noted that under normal circumstances, both soft tissue and bone will deform under load and recover once the load is removed. By this reasoning, injury will result when the capacity to recover from deformation is exceeded. The definition of clinical instability proposed by these authors is a symptomatic state where, in the absence of new injury, a physiologic load induces abnormally large deformations at the intervertebral joint (Farfan & Gracovetsky, 1984). Pope and Panjabi (1985) defined spinal instability as a loss of segmental stiffness, defining stiffness as the ratio of load applied to a segment to the motion that results as a consequence of that load. This alteration in optimal physical equilibrium of the spinal segment was postulated to be caused by damage to or laxity of the restraining structures of the spine (Pope & Panjabi, 1985).

The basic concept of instability has been that abnormally large intervertebral movements either mechanically effect inflamed neural elements or abnormal deformation of ligaments and other soft tissues which are known to have a significant density of nociceptors (Panjabi, 1992a). Central to this view of instability is that stability of the spinal segment is entirely dependent upon inert tissues. However, clinical instability has been reconsidered in light of the stabilising sub-system paradigm proposed by Panjabi (1992a).

The spinal stabilising system conceptualised by Panjabi consists of three sub-systems (Panjabi, 1992a). The passive musculoskeletal subsystem includes vertebrae, joint articulations, spinal ligaments and joint capsules, in addition to the passive mechanical properties of the muscles. The passive sub-system does not provide any significant stability to the spinal segment in the neutral position, however, toward the end of motion ligaments develop reactive forces that resist spinal motion. In the vicinity of the neutral position, the passive components are thought to act as transducers for measuring vertebral position and motions and are, therefore, also part of the neural control subsystem. The active musculoskeletal subsystem consists of the muscles and tendons surrounding the spinal column. The muscular components generate the forces required to provide stability to the spine. The magnitude of force generated by the muscles is monitored by the mechanoreceptors contained within the tendons. Therefore, this aspect of the tendons is part of the neural control subsystem. The neural and feedback subsystem consists of the force and motion receptors located in ligaments, tendons and muscles, and the neural control centres. The neural control system determines the specific requirements for spinal stability, causing the active subsystem to provide the required tension. Although they

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may be considered independent systems, each of these subsystems is functionally interdependent as indicated in Figure 2.1.



**Figure 2.1** Functioning of the spinal stability system. The information from the (1) passive subsystem sets up (2) specific spinal stability requirements. Consequently, requirements for (3) individual muscle tensions are determined by the neural control unit. The message is sent to the (4) force generators. Feedback is provided by the (5) force monitors by comparing the (6) 'achieved' and (3) 'required' individual muscle tensions (Panjabi, 1992a).

Dysfunction in any of the subsystems will affect the overall stability of the spinal system.

The ability to restore stability is dependent on the capacity of the overall stabilising

system to compensate for any any stability loss (Figure 2.2).



**Figure 2.2** Dysfunction of the spinal stability system. (1) Injury, degeneration and/or disease may decrease the (2) passive stability and/or (3) active stability. The neural control unit (4) attempts to remedy the stability loss by increasing the stabilising function of the remaining spinal components: (5) passive and (6) active. This may lead to (7) excessive degeneration, abnormal muscle loading and muscle fatigue. If these changes cannot adequately compensate for the stability loss, a (8) chronic dysfunction or pain may develop (Panjabi, 1992a).

Clinical spinal instability has thus been refined in this model as a "significant decrease in the capacity of the stabilising system of the spine to maintain the intervertebral neutral zones within the physiological limits so that there is no neurological dysfunction, no major deformity, and no incapacitating pain" (Panjabi, 1992b). Panjabi suggests that the size of the neutral zone within physiological intervertebral motion is a better indicator of spinal instability than overall range of motion.

This concept of instability has gained widespread acceptance in standard literature discussing spinal instabilities (Frymoyer, 1997; Krag, 1997; White & Panjabi, 1990), yet these definitions provide little value for the clinician assessing spinal stability prior to the application of any passive manual procedure to the upper cervical spine. In vitro studies have documented changes in spinal motion due to the transaction of ligaments. However, there is no measure of pain or other symptoms and therefore abnormal motions cannot be related to any aspect of patient presentation (Panjabi et al., 1994). Nor can the effect of compensatory muscle action be assessed and the extent to which it might mask ligamentous insufficiency (Swinkels & Oostendorp, 1996).

Functionally and anatomically the craniocervical region differs from the mid and lower cervical spine. These differences render this region more vulnerable to compromised stability and subluxation, particularly at the atlantoaxial joint where the requirement for stability is balanced against the need for mobility, consequently increasing the demands on the ligamentous, osseous and muscular supporting structures (Oda, Panjabi, Crisco, & Oxland, 1992; Swinkels et al., 1996). Given the limited inherent stability of the osseous configuration of this region, the structural integrity and the intrinsic translatory and rotatory stability of the craniocervical region relies upon the integrity and interaction of the ligaments extending between the axis and the occiput, the most important ligaments being the transverse ligament, the alar ligaments and the tectorial membrane (Beeton, 1995; Harris, Duval, Davis, & Bernini, 1993; Swinkels et al., 1996; White & Panjabi, 1990).

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## 2.2 The pathogenesis of craniovertebral instability

The potential of the three subsystems in maintaining the stability of the craniovertebral region may provide some indication as to the diversity of conditions, their pathogenesis and their clinical implications which may be considered under the term 'instability'. These conditions may range from the life threatening involved with transverse ligament insufficiency or rupture, to minor instabilities which may be associated with many of the chronic complaints frequently seen by physiotherapists (Swinkels et al., 1996). Upper cervical instability can arise from congenital, inflammatory and traumatic causes.

## 2.2.1 Congenital causes

Congenital anomalies of the craniovertebral junction are considered to be the result of faulty development of the cartilaginous neural cranium and adjacent vertebral skeleton during development (Menezes, 1997). Osseous anomalies of this region, occurring as either a part of a developmental syndrome or as an isolated congenital anomaly, may lead to an increased risk of segmental instability and spinal cord encroachment (Hosalkar et al., 2008). An appreciation of the normal developmental anatomy of the craniovertebral region is essential to understanding the causes of these anomalies.

#### Developmental anatomy of the craniovertebral region

The development of the craniovertebral joints and associated structures is the result of migration and fusion of mesenchymal cells from three separate sclerotomes; the 4<sup>th</sup>

occipital sclerotome or proatlas, and the 1<sup>st</sup> and 2<sup>nd</sup> cervical sclerotomes (Greenberg, 1968).

The hypocentrum of the proatlas forms the anterior tubercle of the clivus. The centrum itself forms the apical segment of the odontoid process and the apical ligament. The neural arch component of the proatlas divides into a rostral ventral segment and a caudal segment. The ventral segment forms the primordia of the rim of the foramen magnum and the occipital condyle. The caudal division forms the lateral atlantal masses and the superior portion of the posterior arch of the atlas. The cruciate ligaments and the alar ligaments are condensations of lateral portion of the proatlas (Greenberg, 1968; Hosalkar et al., 2008; Menezes, 2008).

The 1<sup>st</sup> cervical sclerotome forms the posterior and inferior portions of the arch of the atlas (Menezes, 2008) and the base of the odontoid process, which is considered to be an anlage of the body of the atlas (Greenberg, 1968). The body of the axis and its vertebral arches are derived from the 2<sup>nd</sup> cervical sclerotome (Greenberg, 1968).

From the eighth week of development, the membranous vertebral column is succeeded by a cartilaginous vertebral column. Ossification centres later begin to appear. Centres for each lateral half of the atlas may appear around the second month of development (Greenberg, 1968). However, the primary anterior ossification centre has rarely formed by birth, developing between nine and twelve months later (Labrom, 2007). Fusion of the anterior ossification centre to the posterior syndochondrosis occurs between the ages of three (Menezes, 2008) and five years (Labrom, 2007).

The body of the axis begins to ossify from a single centre around the fourth or fifth month of development (Greenberg, 1968). At approximately six months of development, two laterally situated centres of ossification develop in the base of the odontoid process. These centres later combine to form the dentocentral synchrondrosis, a cartilaginous band separating the odontoid process from the body of the axis. At birth, the odontoid process remains separated from the body of the axis, the synchrondrosis closing when the child is between five and eight years of age (Labrom, 2007; Menezes, 2008). The tip of the odontoid process has a separate ossification centre. This terminal portion of the odontoid process begins to ossify around three years of age, fusing with the remainder of the odontoid process between the ages of 10 and 13 (Labrom, 2007; Menezes, 2008).

## Anomalies of the craniovertebral region

Anomalies in this region may be broadly divided into congenital and developmental malformations (Menezes, 1997). Congenital malformations include (i) occipital sclerotome malformations such as clivus segmentations, variants of the atlas and odontoid process, condylar hypoplasia and assimilation of the atlas; (ii) malformations of the atlas such as atlantoaxial fusion, and (iii) malformations of the axis such as atlantoaxial segmentation defects and odontoid process dysplasias. Developmental anomalies include conditions affecting the foramen magnum including foraminal stenosis in achondroplasia, secondary invagination associated with osteogenesis imperfecta,

Paget's disease and renal rickets. Developmental anomalies may also include conditions frequently associated with atlantoaxial instability such as Down syndrome or metabolic disorders such as Morquio's syndrome or Hunter's syndrome (Menezes, 1997).

Basilar invagination is a deformity of the osseous structures that form the base of the skull at the margin of the foramen magnum (Hensinger, 1986). It is often associated with defects of fusion of the atlas or occipitalisation of the atlas and is commonly present in Chiari malformations and syringohydromyelia (Menezes, 1997). It is characterised by indentation of the floor of the skull by the cervical spine and the tip of the odontoid process is located in a more cephalad position, and may protrude into the foramen magnum where it can encroach on the brainstem (Hensinger, 1986). Primary basilar invagination is often associated with a variety of vertebral defects including atlanto-occipital fusion, hypoplasia of the atlas, skeletal dysplasias such as achondroplasia, and with odontoid process anaomalies and Klippel-Feil syndrome. This may be distinguished from secondary basilar invagination where a softening of the osseous structure at the base of the skull results in deformity occurring later in life. This form is more commonly associated with severe osteoporosis, osteomalacia, rickets, renal osteodystrophy, Paget's disease, osteogenesis imperfect or rheumatoid arthritis (Hensinger, 1986).

Assimilation or fusion of the atlas is a failure of segmentation between the proatlas and the first spinal sclerotome (Menezes, 2008). Occurring in approximately 0.25% of the population, it may be unilateral, bilateral, segmental or focal (Menezes, 1997). The resulting fusion creates excessive stress on adjacent spinal segments, potentially resulting

in chronic atlantoaxial instability (Hensinger, 1986; Swinkels et al., 1996; Wiesel, Kraus, & Rothman, 1978). Assimilation of the atlas frequently occurs in Klippel-Feil syndrome in conjunction with basilar invagination and segmentation failures of the second and third cervical vertebra, producing a large potential for atlantoaxial instability amongst this group of individuals.

The frequency of anomalies of the odontoid process is unknown since they usually only come to attention following trauma. Their occurrence is associated with an arrest of migration of mesenchymal cells from the proatlas and first cervical sclerotome leading to incomplete formation of the membranous odontoid or incomplete fusion of the odontoid process to the body of the membranous axis (Greenberg, 1968). There are three recognised anomalies:

- 1. Aplasia which is associated with the complete absence of the base of the odontoid.
- 2. Hypoplasia where the odontoid process forms as a short, stubby peg projecting just above the level of the atlantoaxial facet joint articulation, and
- 3. Os odontoideum, where there is a congenital absence of union between the odontoid process and the axis (Hensinger, 1986).

In the case of an aplastic or hypoplastic odontoid process, the cruciate ligaments are incompetent resulting in atlantoaxial instability (Menezes, 1997). Odontoid dysplasia has been described in people with Morquio-Braislford disease, a connective tissue disorder resulting in dwarfism (Swinkels et al., 1996).

Os odontoideum occurs where the dens has developed normally but has failed in a bony fusion with the body of the axis (Greenberg, 1968). This malformation is classified into two types. An orthopic presentation involves an ossicle that moves with the anterior arch of the atlas. When occurring, the caudal fragment may provide insufficient stability for the atlantoaxial joint and lead to subsequent instability or dislocation (Wang & Wang, 2011). The more common form of congenital os odontoideum is the os terminale where there is failure of fusion of the apical segment of the odontoid process to its base, the base being normally fixed onto the axis (Greenberg, 1968). The apical segment may lie free or the ossicle may be fused with the clivus. Where the ossicle is fused, it is considered a dystopic presentation (Wang & Wang, 2011). Unlike most other congenital anomalies affecting the upper cervical spine, os odontoideum is not usually associated with other regional malformations (Hensinger, 1986).

A variety of genetic syndromes have craniovertebral junction anomalies with the potential for atlantoaxial instability occurring as part of their presentation. Briefly, these include Conradi syndrome, Goldenhar syndrome, Klippel-Feil syndrome, Morquio syndrome, Pierre-Robin syndrome, spondyloepiphyseal dysplasia and Weaver syndrome (Menezes & Vogel, 2008). Although significant in their own right, individuals with these syndromes are unlikely to be considered for cervical spine interventions where prescreening with craniovertebral ligament stress testing would be considered necessary.

Congenital incompetence of the transverse ligament may be divided into those cases where there is no known cause and those found in association with Down syndrome. The idiopathic group is diagnosed by exclusion as they have no known trauma, infection, rheumatoid disease or associated congenital anomaly that might overstress the transverse ligament (Greenberg, 1968). Individuals with Down syndrome may have exaggerated laxity of the transverse ligament or complete agenesis of the ligament (Coutts, 1934). Concomitant underdevelopment of the odontoid process or os odontoideum also frequently occurs in Down syndrome (Karol, Sheffield, Crawford, Moody, & Browne, 1996; Uno, Kataoka, & Shiba, 1996). While most focus on instability in these individuals has focussed on the atlantoaxial joints, increased translation has also been demonstrated at the atlanto-occipital joints in children with Down syndrome compared to age matched controls, with estimates of up to 79% of individuals demonstrating excessive atlantooccipital translation (Matsuda, Sano, Watanabe, Oki, & Shibata, 1995; Uno et al., 1996). These findings suggest that the entire craniovertebral complex should be considered in the light of ligamentous laxity when evaluating upper cervical instability in Down syndrome (Uno et al., 1996).

## 2.2.2 Inflammatory causes

Atlantoaxial subluxation (AAS) or dislocation (AAD) may follow infection in the region of the neck and nasopharynx, or may be associated with systemic inflammatory conditions such as rheumatoid arthritis or ankylosing spondylitis (Aspinall, 1990; Swinkels et al., 1996; Yochum & Rowe, 1985). Cases of AAS and AAD associated with infection have been documented after tonsillitis, nasopharyngitis, retropharyngeal abscess, scarlet fever, rheumatic fever, influenza, viral upper respiratory tract infection, pertussis, periostitis of the mandible, alveolar periostitis and mastoiditis, as well as following infection of middle ear, teeth and nose (Galer, Holbrook, Treves, & Leopold, 2005; Greenberg, 1968; Hunter, 1968; Locke, Gardner, & van Epps, 1966b; Parker, Selwyn, & Bradley, 1985; Sullivan, 1949b; Tsai, Zhong, Chen, Wu, & Lin, 2009). AAD has also been reported as sequelae to surgeries of this region, including tonsillectomy, adenoidectomy, cochlear ear implant and mastoid surgery (Coutts, 1934; Gibb, 1969b; Parker et al., 1985; Pilge, Prodinger, Burklein, Holzapfel, & Lauen, 2011; Sullivan, 1949b). Dislocation has been observed to occur spontaneously approximately one-week following such surgery (Gibb, 1969b).

Cases of AAS following local infection have been most frequently reported in younger patients, particularly children (Coutts, 1934; Roche, O'Malley, Dorgan, & Carty, 2001b; Sullivan, 1949b), however numerous cases have also been reported involving mature adults (Edwards, Britz, & Johnston, 2002; Hunter, 1968; Swanberg, 1919). Many paediatric examples of AAS have been categorised under the term Grisel's syndrome. Emanating from the case description published by Grisel (1930), this term is generally used to denote a non-traumatic atlantoaxial subluxation secondary to ligamentous laxity following infection or surgery (Roche et al., 2001b). It is typically described as an atlantoaxial rotatory fixation mostly occurring in children under the age of 13 years, manifesting as either a unilateral or bilateral subluxation of the atlas on the axis (Coutts, 1934; Roche et al., 2001b; Sullivan, 1949b). The exact mechanism for this phenomenon remains unclear, although a number of theories have been proposed. Early theories suggested the cause of atlantoaxial subluxation to be contraction of the suboccipital and paravertebral muscles following cervical lymphadenitis due to nasopharyngeal infection (Grisel, 1930), or the distension of the craniocervical ligaments while maintaining the bone-ligament attachment (Witek, 1908). A number of authors have proposed a direct effect of infection upon the transverse ligament resulting in distension, insufficiency, weakening and rupture (Coutts, 1934; Grieve, 1981; Hensinger, 1986; Hunter, 1968; Roche et al., 2001b).

More commonly, explanations have centred on the effects of hyperaemia associated with inflammation within the nasopharyngeal region. The pharynx is known to have lymphatic and venous connections with the atlantoaxial region (Coutts, 1934; Locke et al., 1966b; Shapiro, Youngberg, & Rothman, 1973). Infection of this region is considered to have the potential to drain into the upper cervical spine resulting in hyperaemia which may lead to decalcification and bone resorption of the odontoid process and the atlas in the area of bony attachment of the transverse ligament, with subsequent loosening of the ligament structure and weakening of the ligament itself (Coutts, 1934; Galer et al., 2005; Locke et al., 1966b; Pilge et al., 2011; Yochum & Rowe, 1985). Lymphatic drainage of the atlantoaxial joints is primarily into the retropharyngeal glands which drain into the nasopharynx and into the deep cervical glands (Shapiro et al., 1973). In addition, a plexus of lymphovenous anatomoses exists throughout the pharyngobasilar fascia and the

suboccipital epidural sinus (Parke, Rothman, & Brown, 1984). This may provide a direct route for the haematogenous spread of infection and an anatomical explanation for atlantoaxial hyperaemia (Parke et al., 1984; Pilge et al., 2011; Roche et al., 2001b).

Inflammatory diseases that have been associated with craniovertebral instabilities include rheumatoid arthritis, juvenile rheumatoid arthritis or Still's disease, ankylosing spondylitis, psoriatic arthritis gout, systemic lupus erythematosus and Reiter's syndrome (Yochum & Rowe, 1985). Of these, the most common is rheumatoid arthritis.

Rheumatoid arthritis involves an autoimmune response to antigens present in articular cartilage. Target tissues include type II cartilage, link proteins (Boszcyk, Boszcyk, Putz, Benjamin, & Milz, 2003; Milz et al., 2001). Link proteins serve to stabilise the interaction between aggregan and hyaluronan in the cartilage matrix. Aggregan accounts for the compressive tolerance properties of articular cartilage by enabling it to imbibe large quantities of tissue fluid. The destruction of the link proteins reduces the organisation and stability of the cartilage matrix (Milz et al., 2001). Aggregan is not only present in articular cartilage but is also found in fibrocartilage of tendons and ligaments where they are subject to compression, for example where they wrap around bony pulleys, and at insertional entheses (Boszcyk et al., 2003; Milz et al., 2001).

Pannus formation in rheumatoid arthritis is composed of proliferating fibroblasts and inflammatory cells formed by granulation tissue during the inflammatory process. The pannus produces collagenase and other proteolytic enzymes capable of destroying cartilage, ligaments, tendon and subchondral bone (Kontinnen et al., 1988; Nguyen et al., 2004; Stevens et al., 1971; Yochum & Rowe, 1985). Inflammatory hyperaemia augments the destruction by promoting osseous decalcification, bony erosion and loosening of the ligament attachments, leading to further instability (Iai et al., 1994; Nguyen et al., 2004; Yochum & Rowe, 1985). Bony destruction may affect the odontoid process, lateral masses of the atlas and the occipital condyles (Castor et al., 1983; Puttlitz et al., 2000). In rheumatoid arthritis, the posterior aspect of the odontoid process may be eroded by granulation tissue between it and the transverse ligament to the point where it may be fractured at its base with minimal trauma (Grieve, 1981; Stevens et al., 1971). The prevalence of this erosion was highlighted by Castor et al. (1883), recording it to be evident in 19 of 33 patients with rheumatoid arthritis examined by computerised tomography.

The transverse ligament has been frequently reported as undergoing atrophy or destruction in individuals with rheumatoid arthritis (Grieve, 1981). It is estimated that up to 20% of chronic rheumatoid arthritis patients exhibit transverse ligament degeneration to the extent that the stability of the atlantoaxial articulation is compromised (Milz et al., 2001). This degeneration results from vascular and fibrinoid necrosis which ultimately produces failure throughout the fibrocartilaginous region of the ligament (Milz et al., 2001; Stevens et al., 1971). Degenerative changes of the transverse ligament in individuals with rheumatoid arthritis were recently highlighted through the presence of high signal changes on MRI where 31.8% of individuals with rheumatoid arthritis demonstrated grade 2 or 3 changes of the transverse ligament (Vetti et al., 2010). Whilst most attention has been paid to changes in the transverse ligament in the presence of rheumatoid arthritis, all of the ligaments comprising the craioniocervical articulations are subject to the same pathological processes (Boszcyk et al., 2003; Stevens et al., 1971; Vetti et al., 2010). Changes in the alar ligaments have been documented with advancing cases of the disease, most likely related to the fibrocartilage content of the ligaments (Puttlitz et al., 2000; Vetti et al., 2010). Using immunochemical histological examination, Boszcyk et al. (2003) demonstrated differences in the extent of type II collagen, aggregan and link proteins at the two entheses of the ligament, with three times the prominence of fibrocartilage at the odontoid enthesis than the occipital enthesis. This composition would suggest the odontoid enthesis of the alar ligaments would be susceptible to the autoimmune response indicative of rheumatoid arthritis. High signal changes in the alar ligaments have been demonstrated on MRI in patients with rheumatoid arthritis, with 15 of 46 adult patients showing grade 2 or grade 3 lesions in a recent study (Vetti et al., 2010).

Alongside the creation of a degrading enzymatic environment associated with inflammatory synovitis and pannus, the mechanical environment associated with ligament weakening and laxity also predisposes the articulation to soft tissue and bony destruction and resorption, further accelerating the changes leading to instability of the craniovertebral region (Puttlitz et al., 2000; Vetti et al., 2010).

One of the most frequently cited complications of instability secondary to rheumatic disease is atlantoaxial subluxation (AAS) (Boszcyk et al., 2003; Grieve, 1981; Swinkels et al., 1996) often indicated by greater than 10° of flexion of the atlas on the axis (Locke et al., 1966b), with the most common cause of arthritic atlantoaxial subluxation being rheumatoid arthritis (Yochum & Rowe, 1985).

The traditional view of atlantoaxial subluxation associated with rheumatic disease is weakening and degeneration of the transverse ligament leading to antero-posterior instability of the atlantoaxial articulation (Grieve, 1981; Mathews, 1969; Milz et al., 2001; Puttlitz et al., 2000), reducing the antero-posterior diameter of the spinal canal at C1 and possibly resulting in cervical myelopathy (Milz et al., 2001; Stevens et al., 1971). More recent discussion of instabilities of this region have noted that subluxations following destructive changes in this region may be anterior, posterior, lateral or vertical (Riise, Jacobsen, & Gran, 2001). Assessment of anterior atlantoaxial subluxation is usually made by measurement of the anterior atlantodental interval on lateral radiograph, this being considered the only pathgnomonic radiological sign of AAS (Coutts, 1934). Separation of the odontoid process from the anterior arch of the atlas of more than 3 mm in adults and 4 to 5 mm in children is considered indicative of anterior atlantoaxial subluxation (Greenberg, 1968; Locke et al., 1966b; Rosa, Alves, Querios, Morgado, & Mendonca, 1993; Sharp & Purser, 1961).

Spinal cord damage resulting from atlantoaxial subluxation may result from direct compression of the spinal cord. However, the slip at this level may also compromise the

blood flow through the vertebral arteries resulting in vertebral artery occlusion or stenosis, and possibly ischaemic damage to the spinal cord (Meijers, van Beusekom, Luyendijk, & Duijfjes, 1974; Stevens et al., 1971).

Despite the focus on the importance of the transverse ligament in maintaining stability of the atlantoaxial articulation, it is now considered that stability of the region is maintained by all the ligaments of the craniovertebral region, including the alar ligaments, acting as a whole and subsequent dysfunction should also be considered a failure of the entire ligament complex (Boszcyk et al., 2003; IIzuka et al., 2012). This view is consistent with previous experimental findings where dislocation of the atlantoaxial joints was extremely difficult following transection of the transverse ligament in isolation (Wadia, 1967) and where only the superior portion of the joint space could be opened after division of this ligament (Zinn 1968, cited in Matthews 1969).

Juvenile rheumatoid arthritis, or Still's disease, has similar effects on the craniovertebral region as the adult version of the disease. In children with this disease, the odontoid process may become wider following the growth stimulation from the inflammatory hyperaemia. Fusion of the atlas to the odontoid process and to the base of the skull has also been recorded. (Yochum & Rowe, 1985). This would function to increase the stress on surrounding structures and articulations, potentially contributing to instability at the atlantoaxial level.

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Craniovertebral instabilities related to ankylosing spondylitis are less frequently reported than those associated with rheumatoid arthritis (Sharp & Purser, 1961). However, it does represent a potential cause of articular derangement. Radiologically, erosion of the odontoid process and an increase in anterior atlantodental interval has been reported in this patient group. Osteolysis of the anterior arch of the atlas and the odontoid process has also been reported. Fusion of adjacent levels typical of ankylosing spondylitis may occur in an anteriorly subluxed position (Yochum & Rowe, 1985).

Psoriatic arthritis involving the upper cervical spine is considered rare. However, when this involvement is present it resembles the pattern described for rheumatoid arthritis with a non-specific inflammatory involvement of the transverse ligament with consequent laxity and subluxation of the atlantoaxial segment. Severe erosion of the odontoid process and the anterior arch of the atlas has also been observed in some cases (Yochum & Rowe, 1985).

Craniovertebral involvement in Reiter's syndrome is also unusual. One case has been published where this disease was associated with atlantoaxial subluxation and erosion of the odontoid process (Latchaw & Meyer, 1978).

Whilst gout commonly affects the peripheral joints, involvement in the upper cervical spine has been recorded. Changes reported have included softening of the cervical vertebrae with atlantoaxial subluxation and erosive changes of the odontoid process and

vertebral end-plates in patients with long duration since diagnosis of the disease (Yochum & Rowe, 1985).

Cases of atlantoaxial instability and subluxation have also been reported in patients with systemic lupus erythematosus. These cases have only been reported in individuals with advanced disease. Unlike other rheumatic disease presentations, when present in the upper cervical complex, no bony erosions are observed on radiographic investigation (Yochum & Rowe, 1985).

## 2.2.3 Traumatic causes

Traumatic injury resulting in craniovertebral instability may be caused by a variety of lesions, from minor ligament strains to cervical fractures and dislocations (Beeton, 1995). Many of these injuries result from trauma to the head rather than direct injury to the cervical spine itself (Shapiro et al., 1973). Injuries sustained to the occipito-atlanto-axial complex are typically influenced by position of the cranium relative to the cervical spine and the vector and the intensity of the force applied (Levine & Edwards, 1886; Levine & Edwards, 1989; Shapiro et al., 1973). The long-term degree of ligamentous stability in individuals following these injuries is generally unreported.

#### Fractures associated with craniovertebral instability

Not all fractures of the craniovertebral region are associated with instabilities since clinical instability of the occipito-atlanto-axial complex is far more dependent on the integrity of the ligamentous structures due to the joint configuration (Levine & Edwards, 1989). However, a number of fractures of this region have been associated with ligament damage (Swinkels et al., 1996).

Fractures of the occipital condyles are usually associated with high energy trauma and may occur in conjunction with other significant cranial or cervical trauma (Levine & Edwards, 1989; Scherping & Kang, 1997). Recognition of these fractures is considered important because of their association with instability of the occipito-atlanto-axial complex due to alar ligament and tectorial membrane compromise (Hanson et al., 2000). The fractures themselves are thought to be under-diagnosed since the clinical manifestation of the disorder is highly variable and the results of physical examination are non-specific (Leone et al., 2000). The majority of reported case series note that the patients are usually neurologically intact, although the concomitant rate of closed head injury makes this difficult to ascertain (Anderson & Montesano, 1988; Bloom et al., 1997).

Occipital condyle fractures are classified according to three types (Figure 2.3). Type I is an impacted occipital condyle fracture caused by axial loading of the skull onto the atlas. There is comminution of the occipital condyle with minimal or no displacement of the fragments into the foramen magnum. A type II fracture occurs as a part of a basilar skull fracture extending through the occipital condyle and entering the foramen magnum. The mechanism of injury is usually a direct blow to the skull. A type III occipital condyle fracture is an avulsion fracture of the occipital condyle by the alar ligament caused by a forced rotation of the skull with or without a lateral bending component. The fragment is frequently displaced from the inferomedial aspect of the occipital condyle into the foramen magnum (Anderson & Montesano, 1988).



**Figure 2.3** Types of occipital condyle fracture. The proximity of the fracture to the alar ligaments is illustrated in each diagram. A. Type I comminuted, impacted fracture. B. Type II fracture of the skull base extending to the occipital condyle. C. Type III avulsion fracture of the occipital condyle by the alar ligament (Anderson & Montesano, 1988).

Type I and type III occipital condyle fractures are linked to instability of the craniovertebral region and the long-term implications of these fractures for stability of the region is unknown (Bloom et al., 1997). Unilateral type I fractures are often described in the orthopaedic literature as 'stable' fractures since it is assumed that the contralateral alar ligament and the tectorial membrane will maintain stability (Anderson & Montesano, 1988). However, by the definition of this fracture, the ipsilateral alar ligament will be compromised due to its attachment onto the now comminuted occipital condyle. Bilateral type I fractures of the occipital condyles are always unstable (Leone et al., 2000). Type III, or avulsion fractures of the occipital condyle, are potentially unstable due to coexisting loss of integrity of the alar ligaments (Anderson & Montesano, 1988). The risk of instability is increased since the loss of integrity of the ipsilateral alar ligament may result in increased loading or stressing of the contralateral alar ligament and tectorial membrane, leading to partial tearing or complete disruption of these structures (Anderson & Montesano, 1988; Leone et al., 2000).

Hanson et al. (2000) performed a retrospective audit of occipital condyle fractures presenting to a trauma centre. All 95 patients exhibiting 107 occipital condyle fractures had received high energy traumatic injuries, predominantly from motor vehicle accidents. Type I fractures were reported in three patients. Twenty-four type II fractures were noted in 23 patients. The majority of fractures reported were type III, occurring on 80 occasions in 69 individuals and constituting 75% of all occipital condyle fractures reported (Hanson et al., 2000). Bloom et al. (1997) examined patients presenting with high energy blunt trauma to the head or upper cervical spine using contiguous axial computer tomography. Nine of the 55 patients in this series had fractures of the occipital condyles, with 11 fractures demonstrated overall. Six of these fractures were classified as type I, two fractures as type II, and three fractures as type III. Radiographic examination of the soft tissue structures revealed that alar ligament injuries could be clearly detected in four cases of type I fracture, and tectorial membrane injuries were evident in two cases of type III fracture (Bloom et al., 1997).

Fractures of the atlas are estimated to comprise 3-7% of all fractures sustained in the cervical spine (Oda et al., 1991). The two most commonly discussed fractures of the atlas are fractures of the posterior arch and comminuted fractures. Fracture of the posterior arch of the atlas is usually caused by a hyperextension injury with axial loading causing the posterior arch of the atlas to be compressed between the occiput and the posterior elements of the axis (Levine & Edwards, 1989; Scherping & Kang, 1997; Shapiro et al., 1973). This fracture is generally considered to be a stable fracture in orthopaedic literature (Levine & Edwards, 1986). However, clinically it is often accompanied by traumatic spondylolisthesis of the axis or an odontoid process fracture, and may present with gross instability if the transverse ligament has been ruptured (Levine & Edwards, 1989; Scherping & Kang, 1997).

Comminuted fractures of the atlas may be unilateral or bilateral (Scherping & Kang, 1997). The greatest threat to stability of the region occurs with the bilateral burst fracture, also known as Jefferson's fracture (Levine & Edwards, 1989). An atlantal burst fracture occurs when axial loading is sustained through the cranium, transmitted caudally through

the occipital condyles. Mechanisms of injury reported in case studies have included motor vehicle and diving accidents (Scherping & Kang, 1997). Because of their oblique inward orientation, the occipital condyle displacement has a direct bilateral effect causing a burst fracture with bilateral lateral displacement of the lateral masses of the atlas (Levine & Edwards, 1989; Scherping & Kang, 1997; Shapiro et al., 1973). Classically, this fracture is described as disruption of the atlantal ring in four places; two in the anterior arch and two in the posterior arch bilaterally (Oda, Panjabi, Crisco, & Oxland, 1992; Shapiro et al., 1973). However, this pattern does not always occur and more recently this fracture has been characterised by the magnitude of the spread of the lateral masses of the atlas regardless of the number of fracture sites (Oda, Panjabi, Crisco, & Oxland, 1992).

The stability of an atlantal burst fracture is estimated clinically by the status of the transverse ligament of the atlas. If the transverse ligament is considered intact, then the fracture is managed conservatively. Clinically, this judgement is usually made on the degree of separation of the lateral masses of the atlas on X-ray or magnetic resonance images with displacement estimates greater than 5.7 mm to 6.9 mm considered to be indicative of transverse ligament rupture (Spence, Decker, & Sell, 1970; Vilela & Peterson, 2009). The alar ligaments and the tectorial membrane usually remain intact with an injury created by an axially directed force. Hence, gross instability is thought to be prevented by maintenance of the secondary passive restraints (Levine & Edwards, 1986; Oda et al., 1991). Should there be a severe flexion component to the injury, then the alar and capsular ligaments may also be compromised and gross clinical instability

can ensue (Levine & Edwards, 1986). The adoption of this indirect method of estimating transverse ligament integrity may be questioned by experimental findings following induced atlantal burst fractures in fresh cadavers. In one series involving induced fractures in 10 cadavers, nine specimens were identified as sustaining either a transverse ligament midsubstance tear or an avulsion of the transverse ligament at one of its attachments on computed tomography, disabling the function of the ligament in controlling the antero-posterior stability of the atlantoaxial segment (Panjabi, Oda et al., 1991). A subsequent study of seven cadavers using the identical methodology to create the fracture reported that five specimens sustained bony avulsions of the transverse ligament, with the remaining two specimens sustaining a mid-substance tear (Oda, Panjabi, Crisco, & Oxland, 1992). The total range of sagittal plane motion between the occiput and the atlas in these specimens increased by 41.7% following fracture, together with a 93.7% increase in neutral zone range compared to pre-fracture measurement.

Fractures of the odontoid process may be related to instability of the craniovertebral region due to associated compromise of the alar and transverse ligaments (Dross & Rizvi, 1998; Fielding & Griffin, 1974; Fuentes, Bouillot, Palombi, Ducolombier, & Desgeorges, 2001) as the alar ligaments attach to the superior aspect of the odontoid process and the transverse ligament encompasses the odontoid process posteriorly. Patients sustain this injury usually either as a result of a high energy accident such as a motor vehicle accident or may be elderly with existing osteoporosis and sustain the injury as a result of a lower energy injury such as a fall (Pepin, Bourne, & Hawkins, 1985; Schatzker, Rorabeck, & Waddell, 1971; Scherping & Kang, 1997). Associated ligament injury is common. In a

review of 22 traffic fatalities in which the individuals sustained skull fracture, all odontoid process fractures were associated with ruptures of the transverse ligament and the tectorial membrane (Jonsson, Bring, Rauschning, & Sahlstedt, 1991). Clinically, they may present with high neck pain. However, neurological involvement is evident in only 15% to 25% of cases (Anderson & D'Alonzo, 1974; Scherping & Kang, 1997).

Odontoid process fracture is classified according to the system proposed by Anderson and D'Alonzo (1974). A type I fracture is an oblique fracture through the upper part of the odontoid process and represents an avulsion of the alar ligament from its attachment onto the odontoid process. A type II fracture occurs at the junction of the odontoid process and the body of the axis. A type III fracture extends inferiorly into the cancellous portion of the body of the axis. The patterns of fracture are seen in Figure 2.4. These fractures are further classified as displaced or non-displaced. Type II fractures are often displaced or may frequently become displaced if not displaced initially (Anderson & D'Alonzo, 1974). Displacement may be associated with the mechanism of injury, with hyperflexion injuries causing the odontoid process to displace anteriorly with the atlas, and hyperextension injuries associated with posterior displacement (Pepin et al., 1985).



**Figure 2.4** Classification of odontoid fractures according to the system proposed by Anderson and D'Alonzo (1974).

The relative incidence of these fracture types has been investigated in two studies. Anderson and D'Alonzo (1974) classified 49 patients with odontoid process fracture, reporting two type I undisplaced fractures (4.1%), 32 type II fractures (65.3%) of which 18 were displaced by more than 2 mm, and 15 type III fractures (30.6%) of which 10 were judged to be displaced. Pepin and colleagues (1985) undertook a retrospective analysis of 262 cervical spine fractures including 41 odontoid process fractures. Their audit revealed one type I fracture (2.4%), 19 type II fractures (46.3%) and 21 type III fractures (51.2%), with displacement evident in 31 fractures in the series. Schatzker et al. (1971) reviewed 37 cases of odontoid process fracture, noting displacement of the process in 25 (67.6%) of these cases.

Non-union of fractures of the odontoid process is of particular concern due to the subsequent tendency toward acquired os odontoideum and instability at the atlantoaxial joint (Aspinall, 1990; Fielding & Griffin, 1974; Levine & Edwards, 1986; Pepin et al., 1985). Non-union has been related to displacement of the fracture, particularly when displaced greater than 5 mm, as well as to the age of the patient and type of immobilisation (Levine & Edwards, 1986; Schatzker et al., 1971). In the series described by Schatzker et al. (1971), non-union of the fracture occurred in 23 of the 37 (62%) patients studied. Of the 25 patients reported to have displaced fractures, 18 (72%) failed to unite. Anderson and D'Alonzo (1974) described non-union in terms of fracture classification. Of eight patients with displaced type II fractures, three (37.5%) failed to achieve union. This was similar to the rate of non-union in patients with undisplaced type II fractures, with five non-unions in 14 patients (35.7%). Only one non-union was noted from 13 type III fractures and no non-unions occurred in patients with a type I fracture (Anderson & D'Alonzo, 1974). Interposition of the transverse ligament within the gap created in the odontoid process by a type II fracture has been identified as a major factor in non-union of this class of fracture (Jonsson et al., 1991; Moskovich & Crockard, 1990). Instability following type II fracture is primarily due to the inability of the atlantoaxial facet joint capsules and the longitudinal and interspinous ligaments to

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adequately prevent excessive motion (Fielding, Hawkins, & Ratzen, 1976; Moskovich & Crockard, 1990).

Os odontoideum, an independent ossicle located posterior to the anterior arch of the atlas and separated from the base of the odontoid process by a transverse gap (Dross & Rizvi, 1998) is usually associated with congenital abnormality (Stevens, Chong, Barber, Kendall, & Crockard, 1994). However, it has been proposed that it may be an acquired lesion after trauma to the head and neck resulting in weakness of the atlantoaxial joint and compromise of the transverse ligament (Dross & Rizvi, 1998; Fielding & Griffin, 1974; Ricciardi, Kaufer, Louis, & Arbor, 1976). Based upon presentation of three paediatric cases, Fielding and Griffin (1974) have suggested that os odontoideum may develop subsequent to an unrecognised fracture through the base of the odontoid process, particularly in children, which compromises the blood supply to the proximal segment of the process resulting in partial or complete failure of development of the segment. An avascular mechanism of development of the lesion is supported by Ricciardi et al. (1976) in their report of a child developing os odontoideum after motor vehicle trauma, with interruption of the blood supply to the odontoid process which arises from the anterior and posterior ascending branches of the vertebral artery occurring with separation of the fracture fragment. With time, it has been suggested that the alar ligaments contract and pull the fragment away from its base toward the occiput, compromising the blood supply and rendering the inferior portion of the odontoid process avascular (Dross & Rizvi, 1998; Ricciardi et al., 1976). Further support for a post-traumatic cause of os odontoideum is provided in the recent publication of a case where traumatic displacement of the terminal portion of the odontoid process following a fall resulted in development of the condition (Wada, Matsuoka, & Kawai, 2009).

The development of such an abnormality may be responsible for reported cases of delayed myelopathy subsequent to fractures of the odontoid process reported in the literature. Myelopathy following non-union of the odontoid process has been reported in over 50 cases, occurring as late as 44 years after a fracture (Anderson & D'Alonzo, 1974; Osgood & Lund, 1928; Pepin et al., 1985; Schwarz & Wigton, 1937; Vetti, Krakenes, Ask et al., 2011). The mechanism of late injury may be explained by the case reported by Dross and Rizvi (1998). This case report described injury of a 68 year-old male following a fall in which contact was made with the back of the head. MRI examination revealed blood and oedema on both sides of the attachment of the transverse ligament secondary to a posterior displacement of an os odontoideum.

## Ligament lesions in the absence of fracture

Dislocation of the atlanto-occipital joints is a rare but frequently fatal injury (Congress of Neurological Surgeons, 2002; Levine & Edwards, 1989; Scherping & Kang, 1997; Shapiro et al., 1973). The majority of reported cases have involved high energy trauma involving a motor vehicle accident, with the injured individuals more likely to be pedestrians than occupants of the vehicle (Congress of Neurological Surgeons, 2002; Levine & Edwards, 1989; Scherping & Kang, 1997; Wiesel et al., 1978). Occurring with twice the frequency in children than adults, the injury involves a complete ligamentous disruption at the level of the atlanto-occipital joints (Levine & Edwards, 1989; Scherping
& Kang, 1997). These dislocations have been classified into three types; type 1 being an anterior dislocation, type 2 being a longitudinal dislocation, and type 3 being a posterior dislocation (Congress of Neurological Surgeons, 2002). Rotational, lateral or multidirectional dislocations are not considered under these criteria. A summary of case reports described in the literature has reported that of 79 published cases, 29 were type 1 dislocations and 32 were type 2 dislocations (Congress of Neurological Surgeons, 2002). Survivors of this injury will often experience severe upper cervical or occipital pain (Scherping & Kang, 1997). Most have neurological impairment including lower cranial neuropathies, unilateral or bilateral weakness, and quadriplegia (Congress of Neurological Surgeons, 2002; Levine & Edwards, 1989). Approximately 20% of survivors will have a normal neurological examination (Congress of Neurological Surgeons, 2002).

Traumatic rotary fixation of the atlantoaxial joints is a relative infrequent injury in adults and should be considered as a different pathology to rotary subluxation and deformity in children (Levine & Edwards, 1989). It is usually related to motor vehicle trauma (Levine & Edwards, 1986; Levine & Edwards, 1989) with patients reporting neck pain, usually in the absence of neurological compromise (Scherping & Kang, 1997). In more severe cases of subluxation or dislocation, a significant deformity in the form of a torticollis may be evident. However, little or no deformity may be seen on minimal subluxation (Levine & Edwards, 1989; Scherping & Kang, 1997). Simply defined, a rotary fixation is an asymmetrical positioning of the odontoid process with respect to the atlas which cannot be corrected by counter rotation (Shapiro et al., 1973). Rotary fixation is a purely ligamentous injury classified into four types. A type I rotary fixation occurs without anterior displacement of the atlas and the transverse ligament remains intact. A type II rotary fixation involves an anterior displacement of 3 to 5 mm resulting in deficiency of the transverse ligament and unilateral anterior displacement of one lateral mass while the opposite lateral mass remained stationary, acting as a pivot. A type II rotary fixation consists of an anterior displacement greater than 5 mm with total compromise of the transverse ligament and the secondary passive restraints. A type IV rotary fixation is the posterior displacement of one lateral mass (Levine & Edwards, 1989; Scherping & Kang, 1997).

Rupture of the transverse ligament mostly occurs in individuals older than 50 years of age (Levine & Edwards, 1989; Scherping & Kang, 1997). Most ruptures are sustained as a result of either a motor vehicle accident or a fall backwards with a blow to the occiput imposing forced flexion (Ebraheim, Lu, & Yang, 1998; Levine & Edwards, 1986; Scherping & Kang, 1997). Ruptures of the transverse ligament may occur either at its mid portion or laterally near the tubercle of the atlas to which it attaches, rendering the atlantoaxial segment prone to anterior subluxation (Levine & Edwards, 1986; Scherping & Kang, 1997). Experimental examination of transverse ligament injury supports this clinical finding. Applying an anterior shear force through the atlas in 20 fresh cadavers, Fielding et al. (1974) reported that failure occurred in the body of the transverse ligament in 15 specimens, with the other five failing by the tubercle of the atlas. The degree of displacement of the odontoid process required to rupture the transverse ligament was 3

mm. As secondary restraints, the alar ligaments were inadequate to prevent further significant displacement of the atlas on the axis after transverse ligament rupture (Fielding, Cochran, Lawsing, & Hohl, 1974). This is consistent with the earlier findings of Werne (1957) who reported that experimentally atlantoaxial subluxation did not occur until the transverse ligament had been sectioned completely. A similar biomechanical study to the work of Fielding provides support to their findings of ligament rupture with the transverse ligaments of 11 of 13 fresh cadavers exposed to a purely anterior force on the atlas rupturing in mid substance and two specimens suffering bony avulsion laterally (Heller, Amrani, & Hutton, 1993). Unlike the study by Fielding, the magnitude of anterior displacement required to rupture the transverse ligament varied greatly, with rupture occurring at between 2 and 14 mm of displacement. Both of these findings differ from the experimental report of Dvorak et al. (1988) who recorded transverse ligament rupture at the atlantal insertion in all seven fresh cadavers subjected to load.

Whilst the majority of transverse ligament ruptures are associated with an older population, other cases have been reported in younger patients where hyperflexion injury occurring without fracture of the atlas has resulted in atlantoaxial subluxation. One published case records an anterior atlantoaxial subluxation suffered by a rugby player where hyperflexion of the neck caused while making a tackle resulted in disruption of the transverse ligament (Miyamoto et al., 2004).

Identification and stabilisation of these injuries becomes paramount as instability and myelopathy may be progressive (de Beer, Thomas, Walters, & Anderson, 1988) and the

risk of serious complication following the application of manual techniques to the upper cervical spine is elevated (Swinkels & Oostendorp, 1996). In a review of seven patients with atlantoaxial subluxation missed on primary emergency contact, three patients progressed to develop long tract neurological deficits, one patient 13 years after the initial injury (de Beer et al., 1988). Healing of the transverse ligament is unlikely following rupture (Ebraheim et al., 1998). Dickman and colleagues (1996) prospectively examined 39 patients following acute transverse ligament rupture using radiographs, thin section computer tomography and magnetic resonance imaging. The majority of these patients were initially managed non-operatively. Injuries were classified into two types; type I being a disruption of the substance of the transverse ligament (n=16) and type II being a fracture or avulsion involving the tubercle for the insertion of the transverse ligament onto the lateral mass of the atlas without disruption of the ligament substance (n=23). None of the 16 type I lesions healed with non-operative treatment leading the authors to conclude that when the transverse ligament is torn or completely disrupted, it is incapable of repair and the original strength and function of the disrupted ligament cannot be restored (Dickman, Greene, & Sonntag, 1996).

The prominence of the association between craniovertebral ligament injury and vehicular injury implies that injuries due to this mechanism are worthy of separate discussion. Ligament lesions sustained to the craniovertebral complex during vehicular trauma, including sub-failure lesions, have been suggested to have limited capacity to heal due to their relatively poor blood supply (Ito, Ivancic, Panjabi, & Cunningham, 2004) and the potential for altered kinematics and ultimately clinical instability (Ito et al., 2004;

Jonsson, Cesarini, Sahlstedt, & Rauschning, 1994; Kaale, Krakenes, Albrektsen, & Wester, 2007; Klein, Mannion, Panjabi, & Dvorak, 2001; Panjabi, Nibu, & Cholewicki, 1998). The argument for the potential development of altered kinematics is credible based upon a published functional radiographic examination of 35 patients with neck pain following motor vehicle accident compared to control data. Patients in the injured group exhibited a clear anterior shift of the centre of rotation of the upper cervical segments compared to non-injured individuals (Dvorak, Panjabi, Grob, Novotny, & Antinnes, 1993).

In one review of 155 traffic fatalities, craniovertebral ligament derangement without evidence of dislocation were demonstrated in 21 individuals (Adams, 1993). Two of these cases had transverse ligament injury with one full and one partial rupture, and 13 demonstrated injuries of the tectorial membrane. Twenty of the 21 cases had received injury to one or both alar ligaments. On the basis of these findings, Adams (1993) suggests that ligament injuries following vehicular trauma are under-diagnosed in clinical and radiological studies.

Vetti and colleagues (2009) used magnetic resonance imaging to quantify injuries of the transverse and alar ligaments in a consecutively recruited group of 1266 patients with whiplash associate disorder (WAD) classified as grade one or grade two using the Quebec Task Force classification system. Patients were referred from a primary care setting rather than a trauma centre suggesting that the level of injury or disability may be

lower than studies based on examination of trauma fatalities. Lesions were graded according to the following criteria:

- Grade 0 indicated that no increased high signal intensity was present beyond that found in a normal ligament.
- Grade 1 indicated that less than one-third of the cross-sectional area of the ligament showed increased signal intensity.
- Grade 2 indicated that more than one-third but less than two-thirds of the crosssectional area of the ligament showed increased signal intensity.
- Grade 3 indicated that more than two-thirds of the cross-sectional area of the ligament showed increased signal intensity.

Grade 2 or grade 3 transverse ligament lesions were reported in 24.6% of participants and alar ligament injury in 35.5% of participants. Injuries to both structures were reported in 10.4% of participants. There was no association between injury and participant age indicating degenerative changes of the ligaments was not a confounding factor (Vetti et al., 2009).

Lesions persisting in the craniovertebral ligaments have been demonstrated up to two years following vehicular trauma. Comparing MRI examinations of 92 cases with WAD type I or II with 30 healthy controls, Krakenes and colleagues (2002) reported the presence of alar ligament lesions in 94 ligaments of 78 individuals. Fifty-two of these lesions were classified as grade 2 or 3 according to the previously outlined classification system (Krakenes et al., 2002). Higher grade lesions of the transverse ligament were observed in 21 patients (Krakenes, Kaale, Nordli et al., 2003). Tectorial membrane lesions, assessed by reduction in tectorial membrane thickness, were also common in the WAD group with 31 lesions of grade 2 or 3 observed (Krakenes, Kaale, Moen et al., 2003).

Lindner (1986) used computed tomography to examine 31 individuals with persisting neck pain following trauma which had been unresponsive to conservative treatment. The majority of cases examined exhibited a tear or rupture of the alar and/or transverse ligaments, with alar ligament injuries clearly predominant in the sample (Lindner, 1986).

Isolated injury of the alar ligaments was first reported in a published case report of a 25 year-old women involved in a motor vehicle accident (Derrick & Chesworth, 1992). The mechanism of injury involved frontal impact with the patient having her head rotated at the time of impact. This mechanism of injury is consistent with previous biomechanical and histological studies of the alar ligaments which suggest that the alar ligaments could potentially be irreversibly stretched or ruptured when the head is rotated and simultaneously flexed and extended during a motor vehicle impact (Dvorak, Panjabi, Gerber, & Wichmann, 1987; Saldinger, Dvorak, Rahn, & Perren, 1990). However, this has been challenged by the findings of Hartwig and colleagues (2004). In a simulated low-intensity side impact collision using six fresh cervical spine columns, these authors were unable to find evidence of injury to the alar ligaments in any specimen even when failure had occurred in the lower cervical spine (Hartwig et al., 2004).

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Imaging of paradoxical rotation of the atlas has been used to infer alar ligament insufficiency in patients following substantial trauma (Antinnes, Dvorak, Hayek, Panjabi, & Grob, 1994). Under normal circumstances, the atlas and axis rotate in opposite directions when the upper cervical spine is side-bent. When paradoxical motion occurs, the segments rotate in the same direction indicating an altered ability of one or both alar ligaments to stabilise the craniovertebral segments (Antinnes et al., 1994; Johansson & Arvidsson, 2006). Using functional MRI and comparing these results to the findings of surgery in nine patients with demonstrated alar ligament lesions, Johansson and Arvidsson (2006) demonstrated paradoxical motion of the atlas in eight of the nine patients.

Head position at the time of vehicle impact and resultant ligament injury has been explored in individuals with grade 2 WAD. In this cohort, 61.7% of patients with a rotated neck position at impact were reported to have grade 3 lesions of the alar ligaments (Kaale, Krakenes, Albrektsen, & Wester, 2005). The effect was more pronounced in individuals who sustained rear-end impact which would infer that upper cervical flexion was imposed in addition to the rotation, which would likely further tension the contralateral alar ligament (Dvorak, Hayek, & Zehnder, 1987b). Grade 3 lesions of the transverse ligament and tectorial membrane were present in 29.8% and 10.6% respectively of individuals with their head turned at impact, compared with only 8.9% and 0% of those with their head in a neutral position. These findings have not been supported in experimental simulation of head turned impact (Maak, Tominaga, Panjabi, & Ivancic, 2006). Using six whole cervical spine columns with a substitute weight representing the head, the specimens were positioned in left rotation and subjected to a simulated side impact force in increments from 2g to 8g. No significant increases were recorded in alar or transverse ligament strain at any impact acceleration, indicating that no injury to these structures would be sustained. One explanation for this difference in findings could relate to the speed of trauma simulation and the resultant elongation rate of the ligaments. Speed of elongation has been shown experimentally to influence failure of the alar and transverse ligaments, with fast extension rates inducing mid-substance tears and avulsion injuries at relatively small ligament deformations (Panjabi, Crisco, Lydon, & Dvorak, 1998).

Direction of impact in relation to ligamentous injury of this region has also been considered both in patients and experimentally. In their MRI study of WAD grade 2 subjects, Kaale et al. (2005) reported that severe changes in the transverse ligament were consistently more common in front-on collisions than rear end collisions, with 31.5% of patients sustaining grade 3 changes after frontal impact compared to 2.6% of those who had experienced rear-end impact. No significant difference was noted for alar ligament and tectorial membrane injuries between front and rear impact accidents. Findings of ligament damage due to impact direction are also supported by finite elements modelling of frontal impact (Fice & Cronin, 2012). At a 22g impact, the alar ligaments displayed the highest ligament distraction recordings, frequently physiologically failing at this force.

It should be noted that the findings of many of the MRI studies of transverse and alar ligament injury have recently been brought into question. The issue of controversy in these studies relates to the veracity of reported lesions and the rate of high intensity signals observed in individuals with no recorded trauma or disease of the cervical spine. Comparisons of persistent pain WAD patients and asymptomatic controls have yielded similar rates of high signal intensity in both the alar and transverse ligaments, with reports of 40% to 50% in some studies (Dullerud, Gjertsen, & Server, 2010; Myran et al., 2008). Imaging of 114 acute grade 1 and grade 2 WAD patients and 157 non-injured controls showed that high signal changes, assumed to indicate lesions of these ligaments, did not differ between cases and controls suggesting that acute trauma does not induce high signal changes on MRI (Vetti, Krakenes, Damsgaard et al., 2011). The grading of ligament high intensity signal did not alter when these individuals were re-examined on 12 month follow-up (Vetti, Krakenes, Ask et al., 2011).

#### Considerations in paediatric trauma

Spinal trauma in children younger than eight years of age is mainly centred on the craniovertebral region. This is because of the high fulcrum of cervical spine motion. Trauma to the region more often results in ligamentous injuries than fracture (Menezes, 2005).

Partial or complete atlanto-occipital dislocation is 2.5 times more prevalent in children than adults (Lustrin et al., 2003). The reasons for this include that younger children have smaller hypoplastic occipital condyles, horizontally oriented atlanto-occipital joints, a larger head size compared to the body, and greater laxity of the craniovertebral ligaments (Bulas, Fitz, & Johnson, 1993; Lustrin et al., 2003). Thus, they are less stable in this region. This injury is considered to entail either injury or rupture of the tectorial membrane and the alar ligaments (Bulas et al., 1993; Grabb et al., 1999).

Grabb et al. (1993) reported five cases of survivors of traumatic atlanto-occipital dislocation aged between six and twelve years of age. MR imaging of these children revealed one case with complete disruption of all ligaments of the craniovertebral junction, one case with disruption of the tectorial membrane, ascending crucuiform and apical ligaments, and two cases with focal ligament injuries and the tectorial membrane partially torn. The remaining case exhibited focal ligament damage but the tectorial membrane remained intact. A larger case series followed 15 children between three and seventeen years of age diagnosed with atlanto-occipital dislocation, all survivors of high speed trauma (Pang, Nemzek, & Zovickian, 2007). Tectorial membrane injury was reported on MRI in 11 cases with eight frank ruptures of the tectorial membrane and three cases with no rupture but an elevation of the tectorial membrane off the incline of the clivus and/or the posterior aspect of the odontoid process. These authors proposed that the complete ruptures were a product of hyperextension-distraction injuries and the remaining disruptions resulted from hyperflexion injury. The fact that only 11 of the 15 cases had tectorial membrane involvement suggests that its involvement is common but is not required for this injury to occur, as has been previously suggested.

Despite the prevailing opinion that os odontoideum is usually a congenital anomaly, case reports have demonstrated the development of this condition following traumatic injury. In a series of 35 cases of os odontoideum, the development of the ossicle could be demonstrated to occur three to five years following a traumatic episode in 17 patients (Fielding, Hensinger, Arbor, & Hawkins, 1980). This temporal sequence could be established since no abnormality of the odontoid process was evident on initial radiographic investigation at the time of injury. The age of injury of these patients ranged from four months to 10 years. These authors have suggested that unrecognised fracture of the odontoid process or interruption of the blood supply to the developing odontoid process resulted in the formation of the independent ossicle. The development of an os odontoideum following acute ligamentous disruption has also been reported (Ricciardi et al., 1976). This case describes a motor vehicle injury involving a 15 month old infant where the head of the child impacted against the dashboard of the vehicle. Whilst there was no evidence of fracture on radiographic assessment, the atlas was anteriorly displaced a distance of 12 mm indicating rupture of the transverse ligament. The child represented at age 4½ years due to neck pain with no preceding trauma. Radiographs revealed the absence of the caudal two-thirds of the odontoid process.

Traumatic os odontoideum appears to be associated with trauma between the ages of one and four years, possibly associated with an undiagnosed fracture (Menezes, 2005). The fracture in children is likely to occur through the cartilaginous synchondrosis (Lustrin et al., 2003). The gap between the axis and the free ossicle usually extends above the level of the superior articular process of the axis, leading to incompetence of the transverse ligament and subsequent atlantoaxial instability (Menezes, 1997, 2005).

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Isolated disruption of the alar ligaments is considered rare in children (Caird, Hensinger, Vander Have, Gelbke, & Farley, 2009). However, several cases of isolated disruption have been reported. Two cases of low intensity trauma have been reported on the basis of MRI examination, both occurring as a result of hyperflexion injuries sustained during school sports (Briem, Linhart, Dickmann, & Rueger, 2002). High energy trauma has also been associated with reports of isolated alar ligament disruption in adolescents and children. In a report of three cases ranging between five and 17 years of age presenting with neck pain and persistent torticollis, isolated alar ligament disruptions were again detected through MRI (Caird et al., 2009).

Tectorial membrane injuries can be sustained by children without concomitant atlantooccipital dislocation. In a case series of three children aged between three and six years of age injured by high energy frontal collision, each child sustained significant tectorial membrane injuries including longitudinal splits of the structure and substantial haematoma between the clivus and tectorial membrane (Farley, Gebarski, & Garton, 2005). All children were restrained passengers in the vehicle.

A curious association exists in published case reports whereby traumatic fracture of the clavicle in young children is associated with atlantoaxial rotatory fixation. To date, 14 cases have been reported. In a case series of five children between six and nine years of age sustaining clavicular fracture due to a fall on the shoulder, each child presented with a 'cock robin' torticollis which was initially presumed to be a pain related deformity due to the fracture. A later diagnosis of atlantoaxial rotatory fixation was made in each case

and management initiated (Goddard, Stabler, & Albert, 1990). All patients in this series were female. Four comparable reports of children aged between six and twelve have been published subsequently, each detailing similar presentations and low energy mechanisms of injury and associated with later diagnosis of the condition (Al-Etani, Dastous, Letts, & Yeadon, 1998; Bowen, Hah, & Otsuka, 2003; Nannapaneni, Nath, & Papastefanou, 2001; Wounlund, Konradsen, & Wagn, 1995). Interesting, of the 13 cases reporting low energy accidents, 11 have involved females and only two males. One example of this relationship following high energy impact has also been published. In this case, the subject was a nine year-old male injured as a pedestrian in a motor vehicle accident. MRI imaging of this patient subsequently revealed unilateral alar ligament rupture, in addition to the atlantoxial rotatory fixation (Niibayashi, 1998).

Various explanations have been offered for the association of these two conditions, including the cervical spine undergoing forced rotation and flexion as a direct result of the trauma (Goddard et al., 1990) and differences in the morphology of the immature skeleton with flatter atlantoaxial facets combined with greater ligament laxity in children permitting anterior subluxation of the atlas on the axis (Nannapaneni et al., 2001). Al-Etani and colleagues (1998) have suggested that the combination of minor trauma and associated sudden rotation movement of the cervical spine may permit the lateral altantoaxial joint to exceed its cartilaginous boundaries causing the inferior facet of the atlas to rotate anteriorly with respect to the superior facet of the axis resulting in 'locking' of the joint. A quite different mechanism has been proposed by Bowen et al. (2003). These authors have suggested that the deformity is acquired after the initial trauma due to

functional shortening of sternocleidomastoid as the medial portion of the clavicle is pulled proximally. The pain produced by this shortening is suggested to cause the patient to adopt a protective posture which becomes fixed when sustained. This mechanism would seem unlikely as it would not explain differential translation of the inferior articular processes of the atlas. Additionally, many of the reported cases sustained greenstick fractures where displacement of the medial end of the clavicle does not occur.

## 2.3 Incidence and prevalence of craniovertebral instability

2.3.1 Prevalence of cranioverterbal instability associated with congenital conditions The frequency of instabilities in the upper cervical spine due to most congenital malformations is largely unknown. Whilst abnormalities may be present, individuals may not exhibit symptoms prompting further investigation (Swinkels et al., 1996). Many of these disorders are only discovered following specific trauma (Morton, Khan, Murray-Leslie, & Elliott, 1995).

Instabilities in children with Down syndrome, however, have received considerable attention. Congenital laxity of the transverse ligament has been reported in up to 20% of individuals with Down syndrome (Hensinger, 1986). Radiographic studies have mostly focussed on the prevalence of atlantoaxial instability in this population, with estimates of up to 30% published (Brockmeyer, 1999; Cattrysse et al., 1997; Greenberg, 1968). One Australian study based upon survey responses of parents of children with Down syndrome estimated that 7% of these children had demonstrable atlantoaxial instability on lateral X-ray (Selikowitz, 1992). Martel and Tishler (1966) were amongst the first to

investigate upper cervical spine instability in this population. Examining 70 subjects from childhood through to adulthood, they estimated that 14 subjects (20%) in the sample displayed measured atlantodental intervals greater than previously published norms (Martel & Tishler, 1966). A larger study radiographically examining 279 children with Down syndrome in the Netherlands found 41 of the 279 children (14.6%) possessed an atlantodental interval in excess of 4 mm (Cremers, Ramos, Bol, & van Gijn, 1993).

Whilst abnormalities on radiological investigation may be common, the incidence of symptomatic instability is low (Menezes, 1997), with around only 18% of individuals with radiological findings of atlantoaxial instability becoming symptomatic (Morton et al., 1995). Peuschel and Scola (1987) assessed 404 individuals with Down syndrome and judged 59 (14.6%) to be classified radiologically as subluxing at the atlantoaxial joint. Fifty-three of these individuals did not exhibit symptoms of any nature related to this instability (Pueschel & Scola, 1987). Ferguson and colleagues (1997) examined the atlantodental intervals of 84 individuals with Down syndrome on lateral X-ray taken in flexion. Using a criterion for atlantoaxial subluxation of an atlantodental interval greater than 4 mm, they reported that 17 subjects (20%) showed subluxtion. Only five of these people demonstrated any neurological signs (Ferguson, Putney, & Allen, 1997).

Relative instability at the atlanto-occipital joint has also been investigated in this population as underdevelopment of the odontoid process or os odontoideum is encountered in people with Down syndrome (Karol et al., 1996). Matsuda et al. (1995) examined the magnitude of atlanto-occipital translation in 38 subjects with Down

syndrome, comparing their measurements to 34 control subjects. Seventy-nine percent of the Down syndrome group demonstrated translation in excess of 1 mm, with mean translation in the Down syndrome group of 2.3 mm (range 0 - 6.4 mm) compared to 0.61 mm in the control group (range 0 - 2.1 mm). Only one patient in this sample demonstrated any symptoms associated with instability (Matsuda et al., 1995). These findings are consistent with a similar study examining atlanto-occipital translation in 75 children and adolescents with Down syndrome in which hypermobility at this level was only found when excessive atlantoaxial movement was also exhibited, highlighting the need to consider the stability of the entire occipito-atlanto-axial complex in the light of ligament laxity in individuals with Down syndrome (Uno et al., 1996).

2.3.2 Prevalence of craniovertebral instability in rheumatoid arthritis patients The prevalence of upper cervical spine instabilities in rheumatoid arthritis patients is still debated with rates of reported instability between 17% and 88% and between 11% and 70% of these individuals reported to experience neurological complications. This variance is a function of the differing populations studied and different neurological and radiological classification systems employed (Riise et al., 2001; Swinkels et al., 1996). Atlantoaxial instabilities are estimated to represent up to 65% of all cervical spine subluxations in the rheumatoid spine (Nguyen et al., 2004), with the duration of disease and corticosteroid treatment found to be correlated to the incidence of instability (Mathews, 1969; Yochum & Rowe, 1985). Males with rheumatoid disease are more likely to be diagnosed with atlantoaxial instability than females (Swinkels et al., 1996). In outpatient based settings, estimates of atlantoaxial instability show considerable variation. Mathews (1969) radiologically examined 76 patients with established rheumatoid arthritis of between less than one and 20 years duration since diagnosis. He reported 19 patients (25%) demonstrated atlantoaxial subluxation, judged as an atlantodental interval of greater than 3 mm. Using the same diagnostic criteria for subluxation, Stevens and colleagues (1971) reported that 36 of 100 patients with rheumatoid arthritis drawn from a hospital outpatient clinic had demonstrable atlantoaxial subluxation with 24 of the 36 (66.7%) displaying signs of cervical myelopathy. Floyd et al. (1989) reported that 90 of 250 (36%) rheumatoid arthritis patients drawn from a clinic population could be considered to have atlantoaxial instability judged by an atlantodental interval of greater than 4 mm. Forty of these 90 individuals (44.4%) had some form of neurological abnormality on examination. Castor et al. (1983) used computed tomography to assess 33 rheumatoid arthritis patients referred to a specialist clinic. Twenty (60.6%) showed some evidence of atlantoaxial subluxation, with three patients displaying severe subluxation. Twenty-six of the 33 patients (78.8%) were considered to have changes in the transverse ligament as a premonitory sign of ligament rupture.

In contrast, Riise et al. (2001) examined the cervical radiographs of 222 patients referred to a specialist rheumatology centre. On the basis of a measured atlantodental interval of greater than 4 mm, only 11 patients (5%) were assessed as demonstrating atlantoaxial instability. Similarly, 14 of 162 rheumatoid arthritis patients assessed radiographically were considered to demonstrate atlantoxial subluxation (Kontinnen et al., 1989). This

pathology occurred in the absence of visible changes in joint cartilage or subchondral bone, indicating that ligamentous instability was a prerequisite for this subluxation.

In their landmark study on atlantoaxial instability in patients with rheumatic disease, Sharp and Purser (1961) examined the lateral radiographs of 186 individuals with rheumatoid arthritis. Using an atlantodental interval of greater than 3 mm as their diagnostic standard, they reported a prevalence of 32 cases of atlantoaxial subluxation per 1000 patients in the community and 189 cases per 1000 patients in an inpatient setting.

Dvorak and colleagues (1989) examined 34 inpatients with rheumatoid arthritis admitted to a neurological unit using functional MRI. Nine of these patients (26.5%) presented with cervical myelopathy related to spinal cord compression and narrowing of the spinal canal to less than 10 mm in the cervical flexion position (Dvorak et al., 1989).

Overall, it is difficult to make definitive comment on the prevalence of instability in this population given the variation in reported rates of atlantoaxial subluxation. Different assessment criteria of the anterior atlantodental interval of 3 or 4 mm do not appear to affect the reported rates. Whilst this form of measurement has typically been used as a standard for assessing atlantoaxial instability, it has been suggested that it may not be reliable for discriminating patients at risk of subluxation. The posterior atlantodental interval (PADI) has been proposed as a more reliable indicator of change, with a PADI less than 14 mm predicting deficit in these patients (Nguyen et al., 2004).

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2.3.3 Incidence and prevalence of craniovertebral instability associated with trauma The incidence and prevalence of craniovertebral ligamentous instability following traumatic injury is completely unknown (Swinkels et al., 1996). While estimates have been given for many of the fracture types associated with instability, no information is available regarding the rate of subsequent major or minor instability existing in these patients following initial management.

Furthermore, the frequency and extent of isolated ligament damage is subject to considerable conjecture. Isolated ligament rupture is considered more likely in patients greater than 50 years of age (Levine & Edwards, 1989), however some authors consider that pure rupture of the craniovertebral ligaments is rare proposing that vertebral fracture is more common than rupture of the main supporting ligaments (Shapiro et al., 1973; Willauschus et al., 1995). Identification of ligament injury remains an area of controversy due to technical limitations of the radiographic techniques available, with only an estimated one in ten gross ligament disruptions suspected on routine radiographic examination (Jonsson et al., 1991). Thus, hypermobility in the craniovertebral region may frequently go unrecognised (Mathers, Schneider, & Timko, 2011). Swinkels et al. (1996) note that there is little information available in the literature on the presence of relatively minor instabilities. Studies have generally examined for complete rupture of these structures, failing to consider the presence of grade 1 and grade 2 ligament injuries.

Whilst concerned with the higher end of the trauma spectrum, one frequently cited study reporting findings in 427 high speed trauma fatalities may provide some insight into the rate of trauma related disorders (Saternus, 1981). In this large sample, 25% of subjects examined post mortem had sustained isolated injuries located between the occiput and axis. The remaining 75% demonstrated combined lesions of both the upper and lower cervical spine. Within the occipito-atlanto-axial complex, 340 disruptions of the liagmentous complex were identified compared with only 57 fractures, resulting in a rate of five soft tissue injuries sustained to one bony injury. Bleeding beneath the tectorial membrane in the area over the clivus was common, recorded in 30% of cases. In a follow-up study of 31 traffic fatalities, 37% of specimens exhibited significant alar ligament injury (Saternus & Thrun, 1987). These findings would suggest that ligamentous injury to the craniovertebral region is more frequent than had previously been assumed.

#### 2.4 Clinical presentation of craniovertebral instability

The type and nature of symptoms documented to be associated with craniovertebral instability have been extremely varied. Many patients exhibit no symptoms at all, even in the presence of demonstrable instability (Stevens et al., 1971; Swinkels & Oostendorp, 1996). In isolation, many of the described symptoms could suggest any number of disorders of the cervical spine (Pettman, 1994; Rosa et al., 1993). There currently appears to be a lack of consensus as to any distinctive cluster of symptoms that may indicate the presence of clinical instability in this region (Osmotherly & Rivett, 2005; Stevens et al., 1971). The severity of symptoms has been reported to vary from vague discomfort to severe distress indicative of long tract compromise of the spinal cord (Fielding & Griffin, 1974; Meadows, 1999b). Furthermore, symptom severity often appears unrelated to the degree of pathological change present (Castor et al., 1983; Grieve, 1981).

Neck pain is the most frequently reported symptom recorded in up to 76% of adults and 85% of children with symptomatic instabilities (Greenberg, 1968; Menezes, 1997; Rana, Hancock, Taylor, & Hill, 1973; Stevens et al., 1971). This usually presents as upper cervical or suboccipital pain (Beeton, 1995; Nguyen et al., 2004; Sharp & Purser, 1961; Swinkels & Oostendorp, 1996) but may radiate to the mastoid, occipital, frontal, temporal, facial and retro-orbital regions (Aspinall, 1990; Derrick & Chesworth, 1992; Nguyen et al., 2004; Pettman, 1994; Rana et al., 1973; Sharp & Purser, 1961). The radiation of pain may be either unilateral or bilateral (Beeton, 1995) and may be continually present or episodic (Sharp & Purser, 1961). The pain may be reported to be aggravated by sudden movements of the head and neck and lancinating on jarring movements (Beeton, 1995). Occipital headache is often reported as being present with instabilities of this region (Aspinall, 1990; Coutts, 1934; Nguyen et al., 2004) and may be associated with scalp pain and tenderness (Dugan, Locke, & Gallagher, 1962).

A sensation of a 'falling forward' of the head or reported difficulty in returning the head and neck to a neutral position after flexing has been associated with symptoms of atlantoaxial instability. This symptom was proposed as a commonly reported feature by Sharp and Purser (1961) in their examination of atlantoaxial subluxation in 48 patients with ankylosing spondylitis or rheumatoid arthritis. Stevens et al. (1971) were unable to support this observation in 100 individuals with rheumatoid arthritis, finding the description infrequent and unrelated to the presence or absence of atlantoaxial subluxation in their sample.

Afferent convergence of the spinal nerves of the upper three cervical segments will result in a variety of potential symptoms in the presence of upper cervical dysfunction. The trigeminocervical nucleus receives afferents from the trigeminal nerve and from the three upper cervical spinal nerves, together with additional fibres from cranial nerves VII, IX and X. These afferents ramify in the pars caudalis as far caudally as the 3rd or 4th spinal segment. Afferents from the first three spinal segments ramify at the segment at which they enter the spinal cord, but also send collateral branches to more rostral and caudal segments. The trigeminocervical nucleus is the essential nociceptive nucleus of the head, throat and upper neck and all nociceptive afferents from the trigeminal, facial, glossopharyngeal and vagus nerves ramify into this single column of grey matter (Bogduk, 1995). Reflex stimulation of the vagus nerve secondary to input from the upper cervical nerves may produce visceral symptoms referable to its sensory distribution, producing chest and abdominal pain, nausea, vomiting, tachycardia and other visceral symptoms (Braaf & Rosner, 1975). Other symptoms may be related to the trigeminal nerve. These include earache, tinnitus or 'popping' of the ears secondary to stimulation of the mandibular branch of the trigeminal nerve supplying the tensor tympani (Pettman, 1992b).

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Other symptoms reportedly related to instability of the craniovertebral region have included a metallic taste in the mouth, a sensation of a lump in the throat, paraesthesia of the lips or face, and hoarseness of the voice (Beeton, 1995; Grieve, 1981; Pettman, 1992b). Reflex swallowing, gagging and dysphagia may indicate subluxation causing compression affecting the nasopharynx (Grieve, 1981; Meadows, 1998).

In their examination of rheumatoid arthritis and ankylosing spondylitis patients with atlantoaxial instability, Sharp and Purser (1961) and Dugan (1962) noted a typical resting posture in these patients. They observed that the cervical lordosis exhibited a flattened appearance and the presence of a degree of torticollis. This torticollis, often referred to as a 'cock robin' position (Figure 2.5), has been observed by a number of authors and is characterised by slight cervical flexion, rotation away from the painful side and lateral flexion toward the dysfunction (Hunter, 1968; Parker et al., 1985; Sullivan, 1949b).

On examination of neck movements of patients with craniocervical instabilities, active movement in all directions is severely limited with upper cervical spine movement possibly absent due to muscle spasm (Hunter, 1968; Niibayashi, 1998; Sharp & Purser, 1961; Stauffer, 1989). A clicking or clunking sensation may be present on neck movement, usually associated with severe pain (Sharp & Purser, 1961). Patients may also demonstrate a marked inability to push the chin up or down against resistance (Aspinall, 1990; Beeton, 1995).



**Figure 2.5** A "cock robin" torticollis suggested to be indicative of atlantoaxial instability.

Neurological signs are frequently discussed by authors describing instabilities of the craniocervical region, many of these in relation to potential atlanto-axial subluxation. These signs are primarily attributable to direct compression on the medulla, cranial nerves and upper portion of the spinal cord or diminution of the microvascular blood supply of those structures due to anterior subluxation of the atlas (Coutts, 1934; Meijers et al., 1974; Menezes, 1997; Sanchez-Martin, 1992; Sharp & Purser, 1961). The majority of traumatic injuries of the upper cervical spine presenting for treatment will not exhibit

signs of neurological injury, differentiating these injuries from lower cervical spine trauma. This is primarily because of the smaller proportion of the spinal canal occupied by the spinal cord at the upper cervical levels (Levine & Edwards, 1886; Sanchez-Martin, 1992).

Neurological signs due to spinal cord compression reported in patients with demonstrated atlantoaxial instability include ataxia and difficulty walking (Aspinall, 1990; Beeton, 1995; Meadows, 1998; Nguyen et al., 2004; Stevens et al., 1971); trunk heaviness (Beeton, 1995); bilateral, hemilateral or quadrilateral paraesthesia or hypoaesthesia; and alteration of sensation for deep pressure, vibration and proprioception (Hensinger, 1986; Mathews, 1969; Meadows, 1998; Rana et al., 1973; Stevens et al., 1971); cardiac and respiratory distress (Akpinar, Tekkok, & Sumer, 2002; Meadows, 1998); bilateral or quadrilateral paresis of the limbs (Akpinar et al., 2002; Aspinall, 1990; Beeton, 1995; Greenberg, 1968; Mathews, 1969; Meadows, 1998; Meijers et al., 1974; Nguyen et al., 2004; Rahman, Jamjoom, & Jamjoom, 2000; Stevens et al., 1971); loss of sphincter control (Aspinall, 1990; Beeton, 1995; Meijers et al., 1974; Rahman et al., 2000; Rana et al., 1973; Stevens et al., 1971); hyper-reflexia of tendon jerk reflexes (Aspinall, 1990; Floyd, Learmonth, Mody, & Meyers, 1989; Hensinger, 1986; Mathews, 1969; Meadows, 1999b; Rana et al., 1973; Stevens et al., 1971); an extensor plantar response (Beeton, 1995; Floyd et al., 1989; Greenberg, 1968; Meadows, 1999b; Meijers et al., 1974; Rahman et al., 2000; Rana et al., 1973; Stevens et al., 1971); ankle clonus (Aspinall, 1990; Meadows, 1999b); Horner's signs (ptosis, endothalamos, anahydrosis, miosis,

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facial flushing) (Meadows, 1999b), and Brown Sequard syndrome indicating corticospinal tract involvement (Aspinall, 1990; Marks, Bell, & Boumphrey, 1990).

If cardinal signs are elicited, reproduced or aggravated by passive linear motion tests applied to the upper cervical spine, Pettman (1992) suggests that it is reasonable to assume that instability exists in the craniovertebral joint complex.

Despite the focus of discussion on the presence of myelopathic symptoms in patients with atlantaxial instability, the majority of patients with demonstrable instability exhibit no neurological signs (Sharp & Purser, 1961). Where signs have been present, no correlation has been found to exist between the degree of subluxation of the atlas and the severity or type of neurological symptoms observed (Locke et al., 1966b; Mathews, 1969).

Unilateral subluxation of the atlantoaxial joint has been associated in case series with 'neck-tongue syndrome'. In each patient report, a sudden rotation of the head produced a sharp pain on one side of the neck or occiput followed by transient ipsilateral numbness of the tongue. The mechanism proposed for this phenomenon is communication between the lingual and hypoglossal nerves where they course together over the hypoglossal muscle beneath the tongue, the hypoglossal nerve also being connected with a loop between the first and second cervical nerve roots. Afferent impulses may thus travel from the lingual nerve via the hypoglossal nerve to the second cervical nerve root (Lance & Anthony, 1980).

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Neurological signs in patients with craniovertebral instability may also be a consequence of vertebral artery insufficiency (Dvorak & Panjabi, 1987; Grieve, 1981; Meadows, 1998). The vertebral arteries are tethered within the foramina transversaria at each cervical level. Hence, they are most vulnerable at the atlantoaxial joint where the range of movement is greatest. Insufficiency of the transverse or alar ligaments may permit excessive translation or subluxation of the atlas on the axis or excessive rotation resulting in interference with blood flow through the vertebral arteries (Aspinall, 1990; Braaf & Rosner, 1975; Dvorak & Panjabi, 1987; Meijers et al., 1974; Nguyen et al., 2004). Signs reported associated with vertebral artery insufficiency in individuals with demonstrated instability of the upper cervical spine include dizziness and loss of equilibrium, tinnitus, paraesthesia of the face, visual disturbances including blurred vision, diplopia and nystagmus, syncope, dysarthria, dysphagia, seizures, ataxia, nausea and vomiting (Beeton, 1995; Dvorak & Panjabi, 1987; Hensinger, 1986; Meijers et al., 1974; Nguyen et al., 2004; Swinkels & Oostendorp, 1996). Signs and symptoms may be either permanent or transient, occurring following subluxation of the atlantoaxial joints (Beeton, 1995; Greenberg, 1968).

Hypoaesthesia in the area of the greater occipital nerve has also been reported as an infrequent manifestation of craniovertebral instability. When present, it has been associated with displacement at the occipito-atlantal joint (Steel, 1968).

The majority of signs and symptoms described in published cases relate to either complete ligament rupture or demonstrated subluxation of a large magnitude. Little

information is available regarding relatively minor instabilities which some authors regard as usually asymptomatic (Stevens et al., 1971), whilst others regard these minor instabilities as potentially responsible for many of the chronic cervical spine complaints treated by manual therapists (Swinkels et al., 1996).

# **CHAPTER 3**

# A SURVEY OF KNOWLEDGE AND ATTITUDES OF PHYSIOTHERAPISTS REGARDING CRANIOVERTEBRAL STABILITY TESTING IN CLINICAL PRACTICE

Content from this chapter has been published as;

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### 3.1 Introduction and aims

Internationally, manual therapy has moved towards formalised guidelines for premanipulative screening of the cervical spine. A controversial aspect to emerge from this involves craniovertebral instability (CVI) testing. The application of stress tests for the ligaments linking the upper cervical spine and skull is considered by some authorities to be a routine safety exercise prior to the treatment of a patient with pain or dysfunction of the upper cervical spine using manual techniques, particularly if the treatment involves high velocity thrust or end-range techniques (Cattrysse et al., 1997; Hing & Reid, 2004; Pettman, 1994).

Clinical screening tests are considered to be capable of detecting hypermobility and instability of the cranio-cervical ligaments, i.e. transverse and alar ligaments and tectorial membrane (Aspinall, 1990; Pettman, 1994). Detection of these problems should allow the manual therapist to select a treatment regime with a lesser risk of severe complications

for these patients (Cattrysse et al., 1997). Potential complications arising from high velocity or end-range treatment techniques applied to an undiagnosed unstable upper cervical segment can be catastrophic and include the onset of cardinal neurological signs as the segment is displaced toward the brainstem, a situation that may be life threatening (Pettman, 1994). Consequences may include cerebrovascular accident (Rivett & Milburn, 1997), arterial dissection and brainstem injury (Di Fabio, 1999).

Interpretation of these tests frequently involves recognition of presence or ablation of symptoms other than pain. A review of the published literature indicates that there is considerable disagreement about the actual symptoms and signs exhibited by an individual with craniovertebral ligament lesions (Osmotherly & Rivett, 2005). Furthermore, there is inconsistency in the anatomical descriptions upon which clinical testing has been based (Osmotherly, Rivett, & Mercer, 2008). Despite the recent work of Kaale et al (2008) corresponding the results of specific manual tests with MRI findings in patients following whiplash trauma, the absence of a body of research establishing validity for most of the clinical stability tests used in manual therapy of the upper cervical spine (Mintken, Metrick, & Flynn, 2008; Swinkels & Oostendorp, 1996) and the varying estimates of reliability of these tests (Cattrysse et al., 1997; Olson, Paris, Spohr, & Gorniak, 1998; Swinkels & Oostendorp, 1996) ensures inclusion of stress testing for CVI in pre-manipulative screening will remain contentious.

A first step in assessing the validity of these pre-manipulative screening tests is consideration of their consensual validity. This seeks to determine the validity of the concept of the tests through agreement amongst competent others that the description, interpretation and evaluation of the test is correct (Corsini, 2002; Eisner, 1998; Onwuegbuzie & Leech, 2007), thus seeking a collective opinion which may used to establish the content validity of the construct (Westmoreland et al., 2000). To achieve this aim, this study sought to examine the knowledge, understanding and practical application of CVI testing in Australian physiotherapists by surveying physiotherapists working in the management of musculoskeletal disorders.

#### **3.2 Methods**

#### **3.2.1 Ethical approval**

Ethical approval for this study was granted by The University of Newcastle's Human Research Ethics Committee on 14 December 2005. (HREC Approval No: H-174-1205).

#### 3.2.2 Study sample

A survey designed to elicit the knowledge and understanding of CVI screening testing was disseminated by post to all 1528 members of Musculoskeletal Physiotherapy Australia (MPA). MPA is the special interest group of the Australian Physiotherapy Association for clinicians with an interest or specialist skills in manual and musculoskeletal physiotherapy. By surveying the entire membership, a more complete understanding of the knowledge and practice across differing levels of experience and post-graduate education was anticipated.

#### 3.2.3 Study design

A cross-sectional design was used. A 21-item questionnaire was developed and validated prior to dissemination. Following this process, surveys were distributed by post with a covering letter and a reply-paid envelope. Participants were assured of confidentiality with regard to the responses they provided. After six-weeks, a follow-up questionnaire was posted to all non-respondents. Management of all postage was undertaken by the Australian Physiotherapy Association to maintain participant confidentiality.

#### 3.2.4 Survey instrument

The survey instrument was designed following an exhaustive review of the literature published in the area of craniovertebral instability. Using open and closed questions and checklist responses, items were constructed to permit respondents to demonstrate their understanding of the clinical problem, signs and symptoms of these instability disorders, assessment techniques available for diagnosing craniovertebral instability, attitudes and current practice toward screening for instability disorders of the upper cervical spine.

Demographic information collected by questionnaire included gender, type of practice in which currently employed, years of experience in the treatment of musculoskeletal disorders, level of physiotherapy qualifications, frequency of treating disorders of the upper cervical spine and types of manual therapy techniques used in this region.

The instrument was further refined following a process examining face and content validity. The draft survey was circulated for comment to all convenors of post-graduate manipulative physiotherapy programs in Australia and New Zealand (n=10) and all authors who had published on the subject of craniovertebral instability in the English language literature in the previous 20 years (n=8). Authors were identified through a search of the databases Medline, CINAHL and Embase. Authors of chapters were identified via textbook and reference list searches from previously identified literature. Responses were received from eight program convenors and four of the authors approached. Respondents were asked to comment on completeness of domains examined, make comment on any other domains or content that may be required to assess current knowledge and practice appropriately and express an opinion on the capability of the instrument to reflect knowledge, opinion and current practices of physiotherapists treating cervical spine problems.

Peer review of the validated survey to clarify feasibility and language acceptability was performed in a convenience sample of six physiotherapists with post-graduate qualifications and clinical experience in musculoskeletal physiotherapy. Participants were asked to examine and complete the questionnaire and then provide feedback in a structured open-ended interview examining item selection and terminology used in the questionnaire. The final instrument is presented in Appendix C.

#### 3.2.5 Statistical analysis.

Closed questions were evaluated by a frequency analysis of responses and expressed as a proportion of respondents in the sample. Open ended responses were listed and examined by three physiotherapists with post-graduate qualifications and in excess of 20 years experience each in musculoskeletal physiotherapy. Responses were discussed until saturation with respect to categorisation of response was achieved.

Subgroup analysis was performed with respect to respondent post-graduate qualifications in musculoskeletal physiotherapy. Between-group comparisons were subject to formal hypothesis testing using chi squared statistics.

#### **3.3 Results of the survey**

#### 3.3.1 Response rate

In total, 578 surveys were completed and returned. This equated to a response rate of 37.8%.

#### 3.3.2 Respondents

The respondents were 49.3% female. The majority (76.1%) worked in a private practice setting. The mean reported years of experience treating musculoskeletal disorders was 17.0 years. The vast majority of respondents were Australian educated (90.0%), the

remainder representing qualifications achieved in ten other countries, and 66.4% of respondents reported to hold post-graduate qualifications in musculoskeletal physiotherapy. A complete description of the study respondents is given in Table 3.1.

TABLE 3.1	Characteristics	of survey	respondents
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Characteristic	Number (%)
Gender	
Male	268 (46.37%)
Female	285 (49.31%)
Missing data	25 (4.32%)
Employment status	
Full-time	380 (65.74%)
Part-time	160 (27.68%)
Non clinical	23 (3.98%)
Missing data	15 (2.60%)
Employment setting	
Public hospital	58 (10.03%)
Private hospital	28 (4.84%)
Private practice	440 (76.12%)
Other	31 (5.36%)
Missing data	21 (3.63%)
# Employment region

Metropolitan	428 (74.05%)
Rural	128 (22.15%)
Missing data	22 (3.81%)
Entry qualifications in Physiotherapy	
Bachelor degree	440 (76.12%)
Diploma	55 (9.52%)
Graduate Diploma	50 (8.65%)
Masters degree	16 (2.77%)
Missing data	17 (2.94%)
Country of qualification	
Australia	520 (89.97%)
Canada	3 (0.52%)
Germany	1 (0.17%)
Hong Kong	2 (0.34%)
India	1 (0.17%)
New Zealand	5 (0.87%)
Republic of Ireland	2 (0.34%)
Republic of South Africa	3 (0.52%)
Sweden	2 (0.34%)
United Kingdom	15 (2.60%)
United States of America	5 (0.87%)
Missing data	19 (3.29%)

Post-graduate qualifications in	
musculoskeletal physiotherapy	
None	194 (33.56%)
Graduate certificate	12 (2.76%)
Graduate diploma	26 (4.50%)
Coursework Masters	320 (55.36%)
Research Masters	23 (3.98%)
Professional Doctorate	1 (0.17%)
Doctor of Philosophy	14 (2.42%)
Other	9 (1.56%)

Clinical assessment of a patient with an upper cervical spine disorder was performed at least once per week by 74.92% of respondents. Manual treatment options for the upper cervical spine utilised by respondents included upper cervical mobilisation (93.94%) and upper cervical high velocity thrust manipulation (27.85%) (Table 3.2).

	All respondents	Post-graduate	No post-graduate	
		qualifications	qualifications	
	N (%) of	N (%) of	N (%) of	
	respondents	respondents	respondents	
Frequency of upper cervical				
spine patient assessment				
More than once/day	193 (33.39%)	143 (39.29%)	50 (26.04%)	
Once/day	72 (12.46%)	43 (11.81%)	29 (15.10%)	
Less than daily/ more than	120 (20.76%)	73 (20.05%)	47 (24.48%)	
weekly				
Once/week	47 (8.13%)	27 (7.42%)	20 (10.42%)	
Less than weekly/ more	52 (8.97%)	34 (9.34%)	18 (9.38%)	
than monthly				
Once/month	21 (3.63%)	13 (3.57%)	8 (4.17%)	
Less than once/month	51 (8.82%)	31 (8.51%)	20 (10.42%)	
Missing data	22 (3.81%)	4 (1.09%)	1 (0.52%)	
Manual therapy in the upper				
cervical spine				
None	8 (1.40%)	5 (1.37%)	3 (1.56%)	
Manipulation only	4 (0.69%)	4 (1.10%)	0 (0.00%)	
Mobilisation only	386 (66.78%)	219 (60.00%)	167 (86.98%)	
Mobilisation and	157 (27.16%)	136 (37.26%)	22 (11.46%)	
manipulation				
Missing data	23 (3.98%)	3 (0.82%)	2 (1.03%)	

**TABLE 3.2** Respondent clinical characteristics and background knowledge of CVI

### 3.3.3 Defining craniovertebral instability.

Following review and categorisation as described above, participants' responses to the open-ended question "What do you understand by the term "instability" in the upper cervical spine?" fell into five broad categories. Most respondents described instability in terms of a loss of anatomical integrity including descriptions of excessive joint range or translation (46.7%). Other responses included alteration in upper cervical biomechanics (24.8%) or changes in neuromuscular control (18.1%). Some respondents defined the problem clinically in terms of presenting signs and symptoms (6.5%). Responses, stratified by respondents' post-graduate qualifications in manual therapy, are given in Table 3.3.

**TABLE 3.3.** Responses provided for definition of the term 'instability' in the upper cervical spine.

	All respondents Post-graduate		No post-graduate	
		qualifications	qualifications	
	N (%) of	N (%) of	N (%) of	
	respondents	respondents	respondents	
Anatomical	307 (46.66%)	196 (44.85%)	111 (50.23%)	
Biomechanical	163 (24.77%)	122 (27.92%)	41 (18.55%)	
Neuromuscular control	119 (18.08%)	76 (17.39%)	43 (19.46%)	
Clinical (signs and	43 (6.53%)	30 (6.86%)	13 (5.88%)	
symptoms)				
Other	26 (3.95%)	13 (2.97%)	13 (5.88%)	

#### **3.3.4 Detection of craniovertebral instability.**

Twenty –two percent of respondents reported detecting a previously undiagnosed craniovertebral instability using clinical stress tests. When stratified by post-graduate qualification, clinicians with further qualifications were significantly more likely to report detecting an upper cervical instability in patients presenting to their clinic (chi squared = 7.31, p=0.007) (Table 3.4).

Respondents were asked to identify from a checklist which signs and symptoms they would associate with a presentation of craniovertebral instability. All 42 checklist items had been previously reported as associated with published clinical presentations of CVI. Only seven items on this list were considered to be possible components of a CVI presentation by more than 50% of respondents. These items are given in Table 3.4. Hypothesis testing illustrated some statistically significant differences between nominated signs and symptoms when examined by post-graduate qualification. However, the direction of the differences was inconsistent.

Figure 3.1 lists percentage of responses to the item "Would you test for CVI when treating an upper cervical spine disorder in a patient with any of the following problems?" stratified by post-graduate qualifications. All disorders listed in this item had been identified as associated with CVI in published literature. In total, clinicians responded with a clear association between CVI and cervical spine trauma (67.9%) including whiplash associated disorder (64.8%), as well as rheumatoid arthritis (64.4%). Other possible inflammatory conditions associated with CVI received lesser recognition as potentially requiring screening including recurrent pharyngitis (10.6%), recurrent tonsillitis (8.6%) and systemic lupus erythematosus (19.1%). Headache was considered a disorder worthy of screening by 24.3% of respondents.

	Number (%)	Number (%)	Number (%)
Past detection of CVI using			
stress tests.			
Yes	125 (21.63%)	95 (24.74%)	30 (15.46%)
No	443 (75.47%)	279 (72.66%)	164 (84.54%)
Missing data	10 (1.73%)	10 (2.60%)	0 (0.00%)
Recognised signs and			
symptoms of CVI			
Increased mobility on passive	429 (77.16%)	277 (76.1%)	152 (79.17%) p=0.413
testing			
Dizziness	375 (67.45%)	231 (63.46%)	144 (75.00%) p=0.006
Headache	370 (66.55%)	234 (64.29%)	136 (70.83%) p=0.120
Upper cervical pain	341 (61.33%)	215 (59.06%)	126 (65.63%) p=0.116
Nausea or vomiting	321 (57.73%)	203 (55.77%)	118 (61.46%) p<0.001
Suboccipital pain	303 (54.59%)	191 (52.62%)	112 (58.33%) p=0.198
Bilateral/quadrilateral paraesthesia	299 (53.78%)	214 (58.79%)	85 (44.27%) p=0.001

**TABLE 3.4** Detection of craniovertebral instability



Abbreviations: PG = post graduate, SLE = Systemic Lupus Erythematosus, WAD = Whiplash Associated Disorder

FIGURE 3.1 Instability testing in the presence of disorders prone to craniovertebral instability

### 3.3.5 Recognition and use of clinical stress tests.

Table 3.5 summarises affirmative responses to items asking if respondents recognised CVI stress tests by name, were able to perform these stress tests and whether they used these tests clinically. Respondents with post graduate qualifications were, on average, 1.4 times more likely to recognise the tests and 1.6 times more likely to report using the tests in clinical practice than those without post graduate qualifications.

For the item "How often do you test for CVI?", the most common response given was "whenever indicated" (56.0% of therapists with and 47.9% without post graduate qualifications). Testing prior to upper cervical manipulation (15.6% of therapists with and 6.2% without post graduate qualifications) or end range mobilisation of the upper cervical joints (10.2% of therapists with and 20.1% without post graduate qualifications) was reported. The majority of respondents indicated that they either rarely or never used stress tests to screen for CVI (54.4% of therapists with and 62.4% without post graduate qualifications). Table 3.5 summarises participant responses stratified by post graduate qualifications. This indicates that clinicians with post graduate qualifications in manual therapy were more likely to report screening for CVI in patients with cervical spine disorders ( $Chi^2 = 28.2$ , p<0.001).

# **TABLE 3.5**Self report of knowledge and use of craniovertebral stress tests

CVI Stress Test	Post-graduate qualifications			No post-graduate qualifications		
	N (%) of respondents			N (%) of respondents		
	Recognise	Can perform	Use	Recognise	Can perform	Use
			Clinically			Clinically
Sharp Purser (Transverse ligament)	250 (68.68)	196 (54.14)	142 (39.34)	75 (38.66)	51 (26.29)	38 (19.79)
Anterior shear (Transverse ligament)	266 (73.28)	194 (54.19)	118 (32.69)	110 (56.70)	63 (32.47)	51 (26.56)
Lateral stability (Alar ligament and dens)	268 (73.83)	200 (56.18)	142 (39.34)	93 (47.94)	55 (28.35)	43 (22.40)
Side bending stress test (Alar ligament)	261 (71.90)	212 (59.05)	157 (43.49)	111 (57.22)	88 (45.36)	60 (31.25)
Rotation stress test (Alar ligament)	225 (61.81)	174 (48.47)	109 (30.19)	102 (52.58)	76 (39.18)	57 (29.69)
Distraction test (Tectorial membrane)	215 (59.39)	179 (49.58)	107 (29.64)	92 (47.42)	61 (31.44)	38 (19.79)
Passive upper cervical flexion (Tectorial membrane)	236 (65.37)	198 (55.46)	123 (34.07)	123 (63.40)	88 (45.36)	55 (28.65)
Distraction in craniovertebral flexion (Tectorial membrane)	170 (47.09)	142 (39.55)	85 (23.55)	53 (27.32)	34 (17.53)	22 (11.46)

Abbreviation: CVI = craniovertebral instability

#### 3.3.6 Attitudes toward testing, recommendations and guidelines.

Respondents indicated their opinion of when craniovertebral instability tests should be performed in clinical practice using a list of responses provided. It was permitted to nominate multiple responses. Again, the most common response was "whenever indicated" (55.6% of respondents with and 47.9% without post graduate qualifications), followed by "prior to upper cervical manipulation" (15.6% and 6.2%) or upper cervical mobilisation (10.2% and 20.1%). Responses are summarised in Figure 3.2.

To collect qualitative information, respondents were asked to offer open ended responses to elaborate on their response. Clinicians with post graduate qualifications were more likely to test based on clinical presentation than intended technique compared with their counterparts without further qualifications. A larger number of clinicians with post graduate qualifications also indicated that in their opinion these tests should not be used at all clinically. Reasons suggested revolved around two themes, an absence of validation of the individual tests and inherent risk in their performance due to provocation of symptoms.

When asked whether clinicians would support the use of CVI screening tests before applying manipulation or end-range techniques to the upper cervical spine if recommended by the Australian Physiotherapy Association, 76.9% of respondents indicated that they would comply with a recommendation. Respondents with post-graduate qualifications were less likely to state they would comply with guidelines  $(71.3\% \text{ versus } 87.4\%, \text{Chi}^2 = 18.36 \text{ p} < 0.001)$ . Respondents indicating in the negative

were asked to provide free comment. Ninety-nine comments were received. Comments included assessment should be based on individual presentation rather than general recommendations (32.3%), the absence of published evidence to support the validity and reliability of CVI screening (28.3%) and lack of knowledge of the tests and their performance and interpretation (14.1%).



Abbreviations: PG = post-graduate

**Figure 3.2.** Response to the question "When should CVI tests be used in clinical practice?"

Finally, participants responded to the item asking whether information and recommendations regarding CVI testing should be included in the current "Clinical guidelines for assessing vertebrobasilar insufficiency in the management of cervical spine disorders" (Rivett, Shirley, Magarey, & Refshauge, 2006). There was strong support from clinicians for inclusion of information in the guidelines with 82.5% of clinicians with and 97.8% without post-graduate qualifications indicating support (between-group comparison Chi<sup>2</sup>=26.47, p<0.001). Using open responses, 29.4% commented that patient safety and therapist knowledge would both be improved by inclusion of information and 15.6% commented that clinician awareness of the possible presence of CVI would be improved by inclusion.

Interestingly, 12.4% of respondents indicated that information regarding CVI would be a useful inclusion but recommendations for testing should not be made. Similarly, 10.6% of comments received from this group indicated that the decision to test should be based solely on the clinician's assessment of the individual patient. Comments from respondents who indicated they would not support inclusion of CVI information in the pre-manipulative guidelines included that the tests themselves lack the necessary reliability or validity for inclusion (23.7%), the current guidelines were only concerned with vertebrobasilar insufficiency, CVI being a separate issue (15.8%), testing should be based on patient presentation and examination alone (10.5%), and there are already too many guidelines and screening procedures which encumbered clinical practice (10.5%).

#### 3.4 Discussion of survey results

The response rate to the survey of 37.8% may be considered low. Respondents do, however, reflect the demographics of the membership of MPA suggesting that these findings may be indicative of the opinions and attitudes of the membership as a whole. It is also within the range reported by other published surveys that have attempted to gauge the opinions of Australian physiotherapists. Wajon and Ada (Wajon & Ada, 2003) achieved a response rate of 22.2% in their examination of thumb pain in MPA members and Grimmer et al (Grimmer, Kumar, Gilbert, & Milanese, 2002) achieved 38% response researching knowledge of non-steroidal anti-inflammatory medicine use in the same group. It is, however, considerably lower than the 65% response of Magery et al (Magery et al., 2004) examination of vertebrobasilar insufficiency testing. This probably reflects the comparatively lower level of pre-existing knowledge and understanding of the topic of CVI amongst the target group.

The variety of responses to the request to define craniovertebral instability highlights one of the greatest difficulties in examining this and other areas of spinal instability, namely the absence of a clear and accepted definition of spinal instability (White & Panjabi, 1990). Given the complexity of clinical instability, the anatomical, biomechanical and clinical aspects listed could all be considered basic elements of the problem. This gives rise to differing interpretations of the disorders classed as "instabilities" and apparent conflict within the literature. In responding to our question, there is a clear difference in

interpretation between clinicians with and without post graduate qualifications in manual therapy. Respondents without post graduate education more frequently classified craniovertebral instability as an anatomical disruption or abnormality, whereas a greater proportion of those with further education considered instability as a broader biomechanical disorder. This latter approach is more indicative of the model of stability proposed by Panjabi (1991) currently underpinning motor control approaches to spinal stability.

Given the absence of defined and agreed pathology constituting CVI, consensus regarding the clinical characteristics of patient presentation would not be expected. Following our review of the literature, 42 distinct signs and symptoms were extracted from published descriptions of patients with reported instability of the upper cervical spine. There are a number of possible reasons why more than 50% our sample only considered a small number of these signs and symptoms to be associated with CVI. Recognition of these disorders clinically may be low due both to their low prevalence in the clinical setting and poorly defined and varied (Swinkels et al., 1996; Swinkels & Oostendorp, 1996) presentation. Many of the signs and symptoms listed may be a component of other cervical spine presentations and not suggest CVI on their own. A clinical reasoning process will involve the processing of a set of clinical information inclusive of patient history in reaching a decision. Listing signs and symptoms as discrete criteria may not be suggestive of CVI to our respondents without being placed in a broader clinical context. Finally, CVI is described by some authors in terms of presenting cardinal neurological symptoms or signs caused by central nervous system disorders such as spinal cord compression or vertebrobasilar insufficiency (Hing & Reid, 2004; Meadows, 1998; Pettman, 1994; Sanchez-Martin, 1992; Swinkels & Oostendorp, 1996). Published reports would suggest such a severe presentation would be rare in CVI. Many patients will tolerate marked instability without exhibiting neurological symptoms (Uitvlugt & Indenbaum, 1988), instead presenting with a wide variety of less severe symptoms (BenEliyahu, 1995; Derrick & Chesworth, 1992; Niibayashi, 1998; Swinkels et al., 1996). When results were stratified by post graduate qualifications, some statistically significant differences were observed between groups. However, the direction of recognition of signs and symptoms of CVI did not tend to one group over the other. This suggests that, within the limitations of the questionnaire, knowledge of the presentation of CVI was not enhanced by post graduate study in manual therapy.

The item asking whether clinicians would perform a pre-manipulation test for CVI in the presence of certain disorders showed that there is an understanding that CVI may be associated with trauma, including motor vehicle accidents, and with rheumatoid arthritis. This would be understandable given the common types of problems that present clinically but is interesting given that no CVI stress test has ever been validated within a post-traumatic population. On the other hand, the finding that only 24% of clinicians would consider screening a headache patient for CVI is puzzling since two-thirds of respondents' nominated headache as symptom they associated with a CVI presentation. This most likely reflects that screening for CVI is not as routine as other pre-manipulative procedures such as vertebral artery insufficiency screening.

The low level of association with congenital disorders would once again indicate that clinicians do not encounter these disorders frequently and hence do not recognise the potential association. The non-recognition of inflammatory disorders as a potential predisposing factor to CVI represents a greater gap in therapist knowledge. The association with inflammatory conditions extends beyond rheumatoid arthritis as ankylosing spondylitis and systemtic lupus erythematosus have also been linked to these disorders (Swinkels et al., 1996; Swinkels & Oostendorp, 1996). Furthermore, atlanto-axial instability has been demonstrated following infections such as tonsillitis and pharyngitis (Gibb, 1969a; Locke, Gardner, & van Epps, 1966a; Sullivan, 1949a) where hyperaemia associated with inflammation may lead to local bone decalcification and softening of ligaments and their attachments (Hensinger, 1986; Roche, O'Malley, Dorgan, & Carty, 2001a; Yochum & Rowe, 1985).

Recognition and use of craniovertebral screening tests is associated in our sample with post graduate studies in manual therapy. This would indicate that screening for instability in the craniocervical region is not consistently taught in undergraduate curricula but rather is encountered through further study. Recognition of tests examining the integrity of the transverse and alar ligaments would be considered moderate-to-high in the post graduate study group. However, there was less awareness of tests for the tectorial membrane, perhaps indicating that the role of this structure in craniocervical stabilisation receives less consideration. Self reported rates of performance of these screening tests would indicate they are not in routine use with clinicians examining and treating the upper cervical spine. Of the tests listed, only the "sidebending stress test" for the alar ligament was used by more than 40% of respondents with and over 30% without further qualifications.

Self reported levels of CVI screening in our respondents are perplexing. Subgroups stratified by post graduate qualification reported screening rates "whenever indicated" as 56% and 48% respectively. However, the most commonly utilised described screening test, the side bending stress test for the alar ligament, was only used by 43.5% and 31.3% of respondents respectively. If these rates of assessment are accurate, clinicians must be relying on other forms of manual assessment rather than described tests to assess for this disorder. Given the lack of agreement on clinical presentation and recognition of predisposing conditions, it remains unclear upon what basis respondents are judging whether screening for instability in the upper cervical spine is indicated. It is possible that clinicians are relying on other forms of assessment such as passive intervertebral movement testing (PPIVM's) to assess for perceived excessive 'joint play' rather than the described tests for specific ligament integrity.

The use of the response option "whenever indicated" may need to be seen as a limitation in this study. Response options in this questionnaire were not exclusive. Therefore, this option did not limit choice of response. However, some respondents may have selected this response on the basis of an 'all covering' option, reducing the discriminative ability of these items. Acceptance of the statement "whenever indicated" is also difficult given the lack of agreement on clinical presentation and recognition of predisposing conditions by our respondents. This theme continues when our sample is asked to provide an opinion on when CVI screening tests should be used in clinical practice. By far the greatest response was to perform the tests "whenever indicated". Whilst this is an obvious response in the context of clinical examination and in the midst of a clinical reasoning process, the responses to the questions already discussed fail to show that we are clear about who is 'at risk' and how CVI might present clinically. Respondents were given the opportunity for free comments to support their response to this item. The single greatest response was that their decision to use any clinical tests was governed by each patients' individual presentation rather than using a wholesale screening approach. Other respondents linked their decision to test to either specific conditions such as trauma or to the use of end range techniques. A smaller number of respondents strongly indicated that the tests should not be used at all. Their reasons fell into one of two categories; either they point to the lack of support in the literature for the validity and reliability of these techniques or they express concern about the provocative nature of some of these techniques and their administration in such a perceived vulnerable area.

Whilst the majority of respondents indicated that they would support any recommendation made by their professional body in regard to clinical testing for CVI, there is clearly a sentiment, particularly among physiotherapists who have extended their academic qualifications in musculoskeletal physiotherapy, that a recommendation for routine screening tests is not warranted in the current environment. The responses provided as free comments provide an insight into the reasons why they are less likely to

support recommendations for testing in clinical guidelines. Concerns expressed about the value of clinical reasoning and testing in context, the limitations and validity of the tests themselves and the overall level of knowledge possessed by clinicians are reasons with considerable foundation and it is beyond doubt that the area of clinical diagnosis of CVI needs to be the subject of further research. It remains questionable whether there is real support by Australian physiotherapists for a move toward screening as we have seen emerge in the practice of some of our overseas colleagues.

There is, however, a much stronger sentiment requesting the provision of accessible information in guidelines documents from which clinicians may inform their clinical practice. Whilst this again garnered less support from those with higher qualifications, almost 90% of respondents indicated that they would support the inclusion of information on CVI in pre-manipulation clinical guidelines. Free comments provided reinforced this position as respondents expressed the desire for an accessible body of knowledge which would be used to improve clinician awareness and patient safety from within a clinical reasoning framework but would highlight both the benefits and limitations of this form of screening.

#### 3.5 Conclusions drawn from the survey

Instability is a term that has taken on a variety of meanings in the contemporary physical therapy vernacular. This is reflected in our findings that when physiotherapists' describe upper cervical instability, they appear to be considering differing aspects or interpretations of the term.

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Similarly, there appears to be no accepted or consensus set of diagnostic criteria used by Australian physiotherapists through which they are able to determine whether CVI is present in patients presenting to them for treatment.

There is clearly support for inclusion of information regarding CVI testing in the premanipulation guidelines but when we consider both the state of the existing evidence for the effectiveness of these clinical tests and responses of Australian physiotherapists in this study, we can at most state that this should include information on potential risk factors and aspects of potential presentation of CVI. There is not the current level of knowledge, education, evidence or will to be able to recommend guidelines for routine screening testing of patients with cervical spine disorders. These findings do, however, highlight the directions required to further understand the area of craniovertebral instability.

# 3.6 Implications for the validity of craniovertebral ligament testing

If we are to base consensual validation upon agreement amongst competent others that the description, interpretation and evaluation of the tests are correct, the results of this survey suggest that the consensual validity of craniovertebral ligament testing among physiotherapists appears to be poor. At the centre of this lack of agreement are several core issues. The most fundamental of these must be that there is a lack of agreement regarding what constitutes the disorder described as 'instability'. This survey clearly demonstrated that clinicians are using differing criteria to determine the presence of instability ranging from frank disruption of anatomical structures to perceived alterations in joint range and translation, and poorly defined sets of clinical signs and symptoms.

Similarly, consensus on the clinical aspects of presentation is lacking. Of the 42 listed signs and symptoms in this survey, all of which were extracted from previously published case reports of craniovertebral instabilities, only four features were considered by 60% or more of respondents to suggest the potential presence of any instability in this region. Of the listed disorders known to be associated with instability in the upper cervical spine, only trauma and rheumatoid arthritis were suggestive of the potential for instability to our respondents.

In regard to the use of standard clinical tests to assess intersegmental stability in the craniovertebral region, the majority of respondents indicated that they did not use these tests at all. Indeed, only three clinical tests were recognised and used clinically by more than 50% of respondents with post-graduate qualifications in musculoskeletal physiotherapy. A 50% level of recognition and use was not indicated by respondents without further qualifications for any named clinical test listed in the survey. Issues raised by some respondents in free comment illustrates reservations regarding the use of these

tests due to the perceived provocative nature of some tests and a lack of rigorously conducted validity studies published to date. From this, it appears that the question for some respondents revolved not around the concept of the tests but of potential harm or an intellectual position whereby clinical validity is required to be comprehensively demonstrated prior to adoption of the tests. This is an interesting stance in the context of rigorously evaluated clinical practice overall.

The differential in responses to these questions between the levels of post graduate education in musculoskeletal physiotherapy raise some interesting issues themselves in regard to the establishment of consensual validity. Clearly respondents with postgraduate qualifications had more exposure to both the concept and practical application of stability assessments of the craniovertebral region, bringing with them a potentially greater knowledge of the topic. Conversely, the level of exposure and knowledge at the pre-professional level appears considerably lower. Given that consensual validity is achieved through agreement amongst 'competent others', the assumption that all clinicians with an interest in musculoskeletal physiotherapy constitute a cohort of 'competent others' may be questioned as the level of knowledge about the topic itself was clearly stratified by level of education.

# **CHAPTER 4**

# LITERATURE REVIEW OF THE GROSS ANATOMY AND HISTOLOGY OF THE CRANIOVERTEBRAL LIGAMENTS

Stability within the craniocervical complex is achieved by a complex interaction between the osseoligamentous and neuromuscular systems of this region (Crisco, Oda et al., 1991). Central to this interaction is the role of the ligaments that span the O-C2 complex (Harris et al., 1993; Levine & Edwards, 1989).

At the O-C1 level, stability is reported to be due to the osseous configuration of the articular facets and to the joint capsules, along with the anterior and posterior atlanto-occipital membranes, the tectorial membrane and the two alar ligaments (Menezes, 2005; Wiesel et al., 1978).

At the lateral atlanto-axial joints, the articular surfaces are biconvex and the joint capsules relatively lax to allow for the large range of movement occurring at this level (Hohl & Baker, 1964; White, Johnson, Panjabi, & Southwick, 1975). As a result, these structures are reported to have a minimal contribution to stability at this level (Pettman, 1992b). The major contributing structures to atlantoaxial stability are the odontoid process, the anterior arch of the atlas, the transverse ligament posteriorly, and the alar ligaments and tectorial membrane (Levine & Edwards, 1989) with the ligamentous structures strongly associated with resisting excessive movement at the atlantoaxial joint (Rauschning, 1997).

The function of all ligaments is to provide stability to the joints, assist in maintaining joint position during motion and to absorb energy during trauma (Panjabi, Oxland, & Parks, 1991a). This is accomplished by the development of stress and strain within the ligaments. The ability of the tissue to achieve this is dependent on its physical properties including:

- histological composition of the ligament
- degree of hydration of the tissue
- age of the person
- cross-sectional area. A larger cross sectional area produces greater stiffness and hence more stability for the joint
- length of the ligament. Longer ligaments are more compliant and thus provide less stability
- location of the ligament with reference to the centre of rotation for each physiological movement
- relative proportion of collagen and elastin fibres within the ligament, and
- the structural orientation of these fibres (Panjabi, Oxland, & Parks, 1991b).

In order to understand how the craniovertebral ligaments fulfil their role, knowledge of the anatomical and physical properties of each ligament is required. Similarly, an understanding of structure and function of these ligaments is essential to an understanding of the consequences of their disruption. In a landmark paper, Werne (1957) described the data available on the anatomy and function of the intraspinal ligaments of the craniovertebral region as contradictory and vague. In the intervening 50 or so years, this situation has persisted with the few published reports that have emerged providing inconsistent and contradictory descriptions of the anatomy and biomechanics relating to these ligaments. As a result, this area remains poorly examined and poorly understood.

# 4.1 Tectorial membrane

The tectorial membrane is the least explored of the passive stabilising structures of the craniovertebral region. Also known as the posterior occipito-axial ligament (Wood Jones, 1953), the tectorial membrane is described as a broad sheet of collagenous tissue covering the atlanto-axial joint complex including the odontoid process and the alar and cruciate ligaments (Fick, 1904; Grant & Basmajian, 1965; Mercer, 2004; Oda, Panjabi, Crisco, Bueff et al., 1992) and anchoring the odontoid process directly to the base of the skull (Rauschning, 1997).

Most authors refer to the tectorial membrane as being continuous with, or an upward extension of the posterior longitudinal ligament (Driscoll, 1987; Last, 1978; Mercer, 2004; Oda, Panjabi, Crisco, Bueff et al., 1992; Romanes, 1972; White & Panjabi, 1990; Wiesel et al., 1978; Wood Jones, 1953; Woodburne & Burkel, 1988; Zuckerman, 1961). It is usually described as arising from the posterior surface of the vertebral body of the second cervical vertebra (Last, 1978; Mercer, 2004; Moore & Dalley, 2006; Oda, Panjabi, Crisco, Bueff et al., 1992; Werne, 1957; Wood Jones, 1953; Woodburne & Burkel, 1988), but has also been reported as having fibres originating in the posterior longitudinal ligament (Gardner, Gray, & O'Rahilly, 1975) or from the dorsal surface of the odontoid process (Wiesel et al., 1978). This variation led Fick (1904) to state that it remains unclear which vertebra is the true origin of the tectorial membrane.

The tectorial membrane expands and broadens as it passes upwards (Woodburne & Burkel, 1988), taking a 'funnel-shaped' appearance (Werne, 1957) as it passes over the posterior portion of the dens before angling anteriorly at approximately 45° toward its attachment (Driscoll, 1987; White & Panjabi, 1990).

The cephalad attachment of the tectorial membrane has been less consistently described. Insertions described in the literature include the anterior edge of the foramen magnum (Driscoll, 1987; Last, 1978; Mercer, 2004; White & Panjabi, 1990; Woodburne & Burkel, 1988), the clivus (Werne, 1957) or the base of the skull on the upper surface of the occipital bone (Gardner et al., 1975; Hollinshead, 1969; Moore & Dalley, 2006; Oda, Panjabi, Crisco, Bueff et al., 1992; Tubbs et al., 2006; Wood Jones, 1953; Woodburne & Burkel, 1988). Romanes (1972) describes an attachment onto the occipital bone but states that this insertion always lies medial to the hypoglossal canals. Additionally, the lateral margins of the ligament are said to overlie and blend with the accessory atlanto-axial ligaments (Romanes, 1972). Tubbs et al (2006) describes strong adherence of the tectorial membrane to the jugular tubercles and a semicircular occipital attachment to the level of the internal auditory meatus.

Several authors describe close physical relationships between the tectorial membrane and the spinal dura mater where they have been described as contacting (Tubbs et al., 2006) or as being firmly attached (Fick, 1904; Last, 1978).

The structure of the tectorial membrane itself has been the subject of widely varying description within the anatomical literature. Most descriptions and illustrations of this structure describe a broad ligamentous band of tissue running between two points of bony insertion. This can be clearly seen in texts including 'Anatomy Regional and Applied' (Last, 1978), 'Buchanan's Manual of Anatomy' (Wood Jones, 1953), 'Grant's Method of Anatomy' (Grant & Basmajian, 1965) and 'Clinically Oriented Anatomy' (Moore & Dalley, 2006) (Figure 4.1). However, various reports of dissections of the craniovertebral region have been published where the tectorial membrane is described as a multilayered structure consisting of distinct bands.

In their kinematic study on the transection of the tectorial membranes in five specimens, Oda et al (1992) describe the structure as having a superficial central portion extending from the posterior surface of the vertebral body of the axis to the upper surface of the occipital bone and deeper layers which ascend on the medial sides of the atlanto-occipital joints extending to the margins of the foramen magnum. However, much of their description is attributed to the previously published but unsupported description by Williams and Warwick (1980) rather than direct observation.



**Figure 4.1** Differing representations of the tectorial membrane in anatomical texts. A. Fick, R. (1904). *Hundbuch der Anatomie und Mechanik der Gelenke*. B. Poirier, P. J., Nicolas, A., & Charpy, A. (1911). *Traite d'Anatotomie Humaine*. C. Ross, L. M., & Lamperti, E. D. (Eds.). (2006). *Thieme atlas of anatomy. General anatomy and musculoskeletal system*. D. Zuckerman, S. (1961). *A new system of anatomy*.

Cave (1933/34) published an extensive examination of 85 cadavers in which he states agreement with the cited work of Quain from 1915 who described the tectorial membrane as having superficial and deep portions, with the deep portion consisting of distinct medial and lateral components. Cave notes an interesting division within the literature of the period where anatomists in continental Europe supported the existence of a divided structure for the tectorial membrane whereas British anatomists of the time did not recognize this subdivision, although the existence of equivalent structures such as the cervico-basilar ligament, the occipito-cervical ligament and ligamentum latum axiale were proposed by several British anatomists.

Fick (1904) draws a clear distinction between the two layers of the tectorial membrane. He describes the superficial layer as consisting of fibres continuous with the posterior longitudinal ligament whereas the deeper layer is composed of shorter fibres running between adjacent vertebrae. Fick reports the deep portion as being comprised of three bands. A middle band approximately one centimetre wide and composed of vertical fibres covers the dens whilst two lateral bands pass superiorly and laterally to it. Both layers are described to insert together approximately one centimetre above the foramen magnum.

Poirier, Nicholas and Charpy (1911) also described the tectorial membrane as having three distinct bundles, one central and two lateral. However, these authors considered that only the deeper layer truly comprised the tectorial membrane with the posterior layer belonging to the 'communal posterior vertebral ligament', another reference to the posterior longitudinal ligament.

The existence of layers and bands in the tectorial membrane has recently been challenged by Tubbs et al (2006). Following the dissection of a series of 13 formalin-fixed cadavers, these authors comment that they were unable to find any distinct parts to the tectorial membrane, either as deep or lateral components. One difference that sets this study apart from previous examinations is the approach taken during the dissection. Unlike previous studies including those by Fick (1904) and Dvorak and Panjabi (1987) who approached the cranio-cervical ligament complex from the posterior aspect, these researchers approached from the anterior direction transecting the structures anterior to the tectorial membrane. Whether this difference in approach and view can account for the difference in descriptions is unknown but should not be discounted.

Based on dissections published to date, the contribution of the tectorial membrane to the joint capsules of the lateral joints of the upper cervical spine also remains unclear. Cave (1933-34) clearly describes the deep lateral portion of the tectorial membrane as contributing to the O-C1 joint capsule, however subsequent authors have not mentioned this relationship. This notion is supported by the earlier work of Fick (1904) whose observations indicate that fibres of the tectorial membrane strengthen the medial side of the atlanto-occipital joint and the posterior and medial portions of the atlano-axial joint capsule. Fick also describes a grouping of fibres passing superolaterally from the body of the axis to the inner surface of the atlas which provides strong stabilisation to the atlanto-

axial joint, an observation also described by other early authors (Poirier, Nicolas, & Charpy, 1911; Testut & Latarjet, 1928). Oda et al (1992) describe the deep layers of the tectorial membrane ascending on the medial sides of the O-C1 joints as they pass to their attachment on the margin of the foramen magnum, but do not remark on any contribution to the atlanto-occipital joint along its course.

Likely areas of compromise of structure of the tectorial membrane following trauma have never been discussed as they have for the alar and transverse ligaments. One of the major reasons for this is the limited histological examination of this structure. As a consequence, there remains limited understanding of fibre composition and behaviour of the tectorial membrane. The only histological examination of the tectorial membrane to be published is the recent work of Tubbs et al (2006). Their brief description of parallel collagen fibres interposed by spindle shaped fibrocytes is typical of the structure of ligamentous tissue (Frank, Amiel, Woo, & Akeson, 1985). Tubbs et al note that near the attachment onto the axis, the collagen fibres became more homogeneous with larger nonspindled fibrocytes present, whilst near the cranial attachment there is an increase in the number of elastin fibres running parallel with the surrounding type III collagen fibres and calcified areas are present which interdigitate with the underlying bone. This gradual transition in cell type and matrix composition is reminiscent of the typical pattern of insertion for ligaments described by Cooper and Misol (1970).

Differences in published descriptions of this structure, particularly in regard to the existence of multiple layers and distinct medial and lateral components require

exploration prior to acceptance of the morphology of the tectorial membrane as a biological basis for clinical testing.

### 4.2 Alar ligaments

Symmetrically placed on both sides of the dens in the sagittal plane, the right and left alar ligaments remain inconsistently described (Dvorak & Panjabi, 1987; Dvorak, Schneider, Saldinger, & Rahn, 1988; Panjabi, Dvorak, Crisco, Oda, Wang et al., 1991). The classical textbook description is of two strong, 'cord-like' structures extending superiorly to the occiput (Last, 1978; Moore & Dalley, 2006; Wiesel et al., 1978; Wood Jones, 1953; Zuckerman, 1961).

The origin of the alar ligaments on the dens has been variously described as the lateral margins of the posterior surface of the upper one-third of the dens (Panjabi, Oxland et al., 1991b), the apex of the dens (Gardner et al., 1975; Romanes, 1972), the dorsolateral surface of the tip of the dens (Driscoll, 1987; Panjabi, Dvorak, Crisco, Oda, Wang et al., 1991; Wood Jones, 1953) or the sides of the dens (Moore & Dalley, 2006). It has been suggested that a small proportion of fibres do not have a medial attachment at all onto the dens, but pass behind or above the dens to be continuous with the contralateral alar ligament (Fick, 1904). This feature was also described by Testut and Latarjet (1928) who described an inconsistently present arc-like cord with superior concavity extending from occiput to occiput, also known as the 'transverse ligament of the occiput of Lauth'. More

recently, this was noted and described as a variant termed the transverse occipital ligament (Ackermann & Cooper, 2005).

Each ligament runs laterally from the dens in the direction of the occipital condyles, with the two ligaments tilting away from the sagittal plane by approximately 70° and creating an included angle between them estimated between 140° and 180° (Dvorak & Panjabi, 1987; Panjabi, Oxland et al., 1991b; White & Panjabi, 1990). The orientation of each ligament has often been described as superolateral (Last, 1978; Panjabi, Oxland et al., 1991b; Wood Jones, 1953), but has also been noted as closer to horizontal (Ludwig, 1952; Mercer, 2004; Testut & Latarjet, 1928). Dvorak and Panjabi (1987) list three types of fibre orientation which were dependent on the height of the dens relative to the level of the occipital condyles. These authors found in a series of 19 specimens, nine specimens displayed alar ligaments oriented craniocaudally, six specimens oriented horizontally and four specimens with a caudocranial orientation. A similar finding was reported by Okazaki (1995) in an examination of 44 cadavers. In this study, 19 ligaments were described as caudocranially oriented, 24 as horizontal and one ligament was reported to have a craniocaudal orientation (Okazaki, 1995). Although not frequently described in radiological studies, a variation in the orientation of the alar ligament was noted by Pfirrmann et al (2001) in a magnetic resonance imaging study of the normal morphology of the alar ligaments of 50 asymptomatic individuals. However, they do report that a craniocaudal orientation is rare.

The occipital insertion is frequently reported to be onto the medial surface of the occipital condyles (Driscoll, 1987; Dvorak et al., 1988; Fick, 1904; Gardner et al., 1975; Panjabi, Dvorak, Crisco, Oda, Wang et al., 1991; White & Panjabi, 1990; Wood Jones, 1953; Zuckerman, 1961) but has also been described as being to the lateral walls of the foramen magnum (Last, 1978; Moore & Dalley, 2006; Panjabi, Oxland et al., 1991b).

Cave (1933/34) reported distinct bundles of fibres extending from the dens in a similar plane to those fibres extending occipitally, attaching to the pretubercular recess of the atlas. He noted that these bundles served to separate the anterior from the posterior median atlanto-axial joint spaces. This would be consistent with the interpretation of Gardner et al (1975) of the description given by Poirier and Charpy (1911) which states that synovial cavities both in front and behind the dens each have their own capsular ligament and synovial membrane. Despite these early descriptions, no author revisited the possibility of an atlantal portion of the alar ligament until the work of Dvorak and Panjabi in 1987. Of 19 specimens examined by gross dissection, Dvorak and Panjabi reported a ligamentous connection between the dens and the lateral mass of the atlas in 12 cases. They described this as a distinct portion of the alar ligament of approximately three millimetres in length with fibres oriented obliquely craniocaudally from the dens to the lateral mass of the atlas. Based on these findings, it can be assumed that this structure is either not present or not identifiable in approximately one-third of people. More recent studies have not added strength to arguments for the consistent existence of an atlantal portion of the alar ligament. In a recent examination of the craniovertebral complex in twenty fresh cadavers, no atlantal portion of the alar ligament was observed in any

specimen (Cattrysse et al., 2007). Magnetic resonance imaging techniques used to examine this area have also cast doubt on the presence of this structure. Krakenes et al (2001) did not report an atlantal attachment in a series of 30 people. Whilst other studies have discussed these findings of Dvorak and Panjabi, they have not gone on to state whether they could visualise this in any of the participants in their studies (Kim et al., 2002; Pfirrmann, Binkert, Zanetti, Boos, & Hodler, 2001). Whether this is a limitation of magnetic resonance imaging or a reflection of the anatomical variance is unknown. Another explanation may be that the atlantal portion of the alar ligament described by Dvorak and Panjabi is actually the capsular thickening dividing the median atlanto-axial joints as described by earlier anatomists.

Predating the work of Cave, Fick (1904) described an inconsistently present doubled or accessory portion to the alar ligament. However, rather than having an atlantal attachment this band of tissue was reported to pass vertically toward the occiput.

The concept of contribution of fibres from the alar ligament reinforcing and strengthening joint capsules is raised by the descriptions of Cave (1933/34). Cave notes that substantial bands of the alar ligament often clothed the dorsal aspect of the cephalad portion of the dens, supporting the capsules of the atlanto-occipital joints with their lateral fibres. He also notes that the alar ligament provides reinforcement to the capsule of the lateral atlano-axial joints by the contribution of ligament fibres. If this description is accurate, then it would be possible for lesions of the alar ligament to impact directly on the stability and integrity of these joints.

The alar ligaments have been found to be comprised almost exclusively of collagen fibres which run parallel to each other through the entire ligament and are oriented along the direction of the ligament (Dvorak et al., 1988; Saldinger et al., 1990). The few elastic fibres observed appeared in the marginal areas of the ligament (Dvorak et al., 1988; Saldinger et al., 1990). The implication of this alignment is that a major elongation of the alar ligament is almost impossible (Mercer, 2004; Saldinger et al., 1990). Consequently, the ligaments may be irreversibly overstretched or ruptured when stressed in a vulnerable position.

In their examination of the histology of the transverse and alar ligaments in a series of fifteen specimens, Saldinger et al (1990) report marked differences in structure of the alar ligament between its ventral and dorsal aspects. Collagen fibres were more densely packed on the dorsal side compared with the ventral region of the ligament. Portions of both the left and right alar ligaments inserted at the upper part of the odontoid process, however a portion of the fibres on the dorsal aspect bypassed the dens completely instead attaching to the atlas at either end and spanning the dens without attachment. On the ventral aspect, the ligament is described as 'reaching' the median atlanto-axial joint capsule. Whether it contributes fibres to the joint capsule is not stated. In their introduction, the authors describe the alar ligament as having atlantal and occipital portions. However, nowhere in their description do they comment on which attachment their findings pertain to or report similarities or differences between the observed portions of the alar ligament.
The insertions of the ligament display a transition from connective to bony tissue (Saldinger et al., 1990). The description corresponds to the typical four zones of transition in ligament insertion from parallel collagen fibres through fibrocartilage, mineralised fibrocartilage and finally lamellar bone (Cooper & Misol, 1970).

## **4.3 Cruciform ligaments**

The cruciform ligaments consist of two components; the transverse ligament and the longitudinal promulgations known as the ascending and descending portions of the cruciate ligament (Dvorak et al., 1988). These structures lie in front of and in contact with the tectorial membrane (Last, 1978).

## 4.3.1 Transverse ligament

Of the ligaments of the craniocervical complex, the transverse ligament appears to be the most extensively studied and greater agreement exists on its course, function and composition.

The transverse ligament consists of a well defined band of connective tissue positioned across the atlas, serving to hold the dens against the anterior ring of the atlas (Dvorak et al., 1988; Panjabi, Oxland et al., 1991b). It arises from tubercles on the medial aspects of

each lateral mass of the atlas (Goel et al., 1990; Grant & Basmajian, 1965; Wood Jones, 1953) and extends posteriorly to pass around the posterior surface of the middle and upper thirds of the dens below the origins of the alar and apical ligaments (Panjabi, Oxland et al., 1991b). It thereby completes the osteoligamentous ring of the median atlantoaxial joint (Mercer, 2004). When viewed from above, the cranial fibres of the ligament run transversely whilst the basal fibres run semicircularly (Werne, 1957).

The function of the transverse ligament is accepted to be the restriction of forward translation of the atlas relative to the axis (Mercer, 2004), particularly during flexion of the head on the neck (Dvorak et al., 1988). This structure is thus integral to the stability of the atlantoaxial joints (Mercer, 2004). The importance of this relationship was questioned by Testut and Latarjet (1911) who comment that if the other craniovertebral ligaments are destroyed, the odontoid can be moved freely in and out of the atlantal ring even if the transverse ligament remains intact.

Panjabi, Oxland and Parks (1991) describe the transverse ligament as running approximately in the transverse plane and being angled at around 80 degrees to the sagittal plane. In their sample of six specimens, these authors describe two distinct layers to this ligament. The superficial layer lay posterior to the alar ligaments and was obscured in its inferior margins by the alar ligaments. The deeper layer was broadest at its centre and thinnest at its lateral attachments to the atlas. The thickness of the central portion of the ligament has been estimated at seven to eight millimetres (Driscoll, 1987; White & Panjabi, 1990). All the studies mentioned above report the transverse ligament as an extracapsular structure existing to limit anterior excursion of the atlas on the axis. In his detailed account of an examination of 85 cervical columns, Cave (1933/34) reported that the atlanto-occipital joint capsule descends to attach distal to the tubercle for the transverse ligament. Cave describes the capsule in this area as weak but reinforced by contributions from the transverse ligament and other ligamentous structures close by. If this is indeed the case, then this ligament will have a greater role than anticipated in assisting stabilisation of the atlanto-occipital joints.

The transverse ligament consists almost exclusively of collagen fibres with a small number of loose elastin fibres present in the outer zones of the ligament (Dvorak et al., 1988; Saldinger et al., 1990). In their sample of seven specimens, Dvorak et al (1988) described these elastin fibres as occurring within the ligament where the collagen fibres are less densely arranged and the fibre orientation more undulating. Following their examination of 15 specimens, Saldinger et al (1990) reported that the elastin fibres are found in the connective tissue surrounding the ligament's outer zones. The central part of the ligament was almost free of elastin fibres.

Most fibres in the transverse ligament are reported to be oriented in the direction of the ligament (Panjabi, Oxland et al., 1991b; Saldinger et al., 1990). Near the insertions of the ligament into the atlas and where it is close to the dens, the collagen bundles run parallel to each other. Between the insertions and the dens, the bundles branch out, crossing each

other at an angle of approximately 30 degrees (Panjabi, Oxland et al., 1991b; Saldinger et al., 1990). This crossed arrangement of fibres allows a modest elongation of the ligament prior to failure, thereby permitting a small displacement between atlas and dens estimated by Saldinger et al (1990) as being up to three millimetres.

On the ventral aspect of the ligament where it passes close to the dens, the collagenous fibres show a transition into fibrocartilage (Panjabi, Oxland et al., 1991b; Saldinger et al., 1990). In this area, the ligament appears thicker. This cartilaginous aspect of the ventral portion is compared by Saldinger et al (1990) to the structure of tendon where it passes over bone where a cartilaginous pressure zone exists to function as a pulley. On the dorsal aspect of the ligament, collagen fibres run directly from attachment to attachment on the atlas (Saldinger et al., 1990).

The insertions of the transverse ligament into the lateral masses of the atlas show a gradual transition from organised connective tissue into bone. Similar to the transition shown in attachment of the alar ligaments, this has been reported as a progression through the four zones originally described by Cooper and Misol (1970) (Panjabi, Oxland et al., 1991b; Saldinger et al., 1990).

#### 4.3.2 Ascending and descending cruciform ligaments

Triangular in shape (White & Panjabi, 1990), the ascending and descending portions of the cruciform ligament are promulgations extending orthogonally from the transverse ligament. Longitudinal fasciculi from these structures have also been suggested to blend into the tectorial membrane (Goel et al., 1990).

The ascending band extends upward from the posterior surface of the transverse ligament (Wood Jones, 1953). It is reported to lie in contact with the posterior surface of the apex of the dens and attaches to the occipital bone (Dvorak et al., 1988; Wood Jones, 1953). The point of attachment has been reported to be the anterior edge of the foramen magnum (Driscoll, 1987; White & Panjabi, 1990) or the posterior part of the basilar groove between the anterior margin of the foramen magnum and the superior attachment of the tectorial membrane (Wood Jones, 1953).

The descending band extends from the posterior surface of the transverse ligament to the posterior surface of the body of the axis, above the inferior attachment of the tectorial membrane (Driscoll, 1987; White & Panjabi, 1990; Wood Jones, 1953).

In his extensive series of dissections of the craniovertebral region, Cave (1933/34) noted that the superior 'crus' was always found however the inferior 'crus' may be absent in some specimens. Cave noted an inverse relationship between the presence or development of the inferior crus with the development of the atlanto-axial ligaments,

suggesting that the atlanto-axial ligaments are actually a component of the cruciate ligament complex.

The functional significance of these structures has not been demonstrated (Mercer, 2004) and some authors suggest that they may not have any function (Panjabi, Oxland et al., 1991b). Werne (1957) states that these bands do not have a function in guiding or resisting movement, but does suggest that the ascending band of the cruciform ligament may form a wall of a bursa interposed between the dens and the foramen magnum. This suggested lack of function is curious given that biomechanical studies have demonstrated that the ascending and descending cruciform ligaments display the greatest overall strength of all the craniovertebral ligaments when the isolated ligaments are tested to failure (Pintar, Myklebust, Yoganandan, Maiman, & Sances, 1986). Fick (1904) suggested that the ascending portion of the cruciform ligaments functions to prevent tearing of the transverse ligament, although the proposed mechanism for this is not described. Further, he noted that the descending portion prevented any upward movement of the transverse ligament.

Mercer (2004) questions whether these bands should be discussed as ligaments when the attachments sites are considered. A true ligament is defined as bands of fibrous connective tissue attaching bone to bone (Frank et al., 1985). Given the origin of these structures is reported to be the posterior portion of the transverse ligament, not a bony surface, these ascending and descending bands fail to comply with the basic definition of a ligament.

#### 4.4 Other ligaments in the craniovertebral complex

## 4.4.1 Apical ligament

Thin and tightly adherent to the overlying tectorial membrane, the apical, or dentate, ligament originates on the posterior superior aspect of the dens (Panjabi, Oxland et al., 1991b). In a series of six gross dissections, Panjabi et al (1991b) described the apical ligament as extending from this origin and tilting at approximately twenty degrees forward from the frontal plane to insert onto the anterior wall of the foramen magnum (Driscoll, 1987; Panjabi, Oxland et al., 1991b; Romanes, 1972). The ligament takes a characteristic 'V' shape as the width at the origin is only one-half to one-third of the width of its broad, fan-shaped insertion onto the foramen magnum (Panjabi, Oxland et al., 1991b).

The apical ligament is of no known importance and is estimated to be missing in approximately 20% of the population (Mercer, 2004). It is considered to be the fibrous remnant of the cranial end of the notochord (Last, 1978; Mercer, 2004).

## 4.4.2 Atlanto-occipital ligaments

There are two atlanto-occipital ligaments extending between the atlas and the occiput; the anterior and the posterior atlanto-occipital ligaments. They are also known as the anterior and the posterior atlanto-occipital membranes (Gardner et al., 1975; Hollinshead, 1969; Mercer, 2004; Zuckerman, 1961).

Whilst these structures are consistently mentioned in anatomical descriptions of the craniocervical region, debate exists as to whether they should be considered as true ligaments. Mercer (2004) notes that the membranes appear to consist of poorly organised dense areolar tissue and cites the examination of the posterior membrane by R.H. Ramsay (1966) who concluded that the membranes should be considered to be fascial curtains dividing the external space occupied by the deep cervical muscles from the internal epidural space. This lack of structural organisation is inconsistent with accepted descriptions of normal ligament properties (Frank et al., 1985).

## Anterior atlanto-occipital ligament

An upward continuation of the anterior longitudinal ligament, the anterior atlanto – occipital ligament arises from the superior margin of the anterior arch of the atlas (Driscoll, 1987; Romanes, 1972; White & Panjabi, 1990; Wiesel et al., 1978; Wood Jones, 1953; Zuckerman, 1961). Its insertion into the occiput has been reported as being into the tubercle of the occiput (Driscoll, 1987; White & Panjabi, 1990), the anterior margin of the foramen magnum (Romanes, 1972; Wiesel et al., 1978) or the inferior surface of the basilar portion of the occipital bone between the occipital condyles (Wood Jones, 1953). Described as thin and membranous (Wood Jones, 1953), the central portion of the ligament is reported to be thickened by the ascension of some fibres from the anterior longitudinal ligament (Hollinshead, 1969; Romanes, 1972; Wood Jones, 1953). The lateral margins of the ligament are reported to blend laterally with the anterior

capsules of atlanto-occipital synovial joints (Hollinshead, 1969; Romanes, 1972; Woodburne & Burkel, 1988).

### Posterior atlanto-occipital ligament

The posterior atlanto-occipital ligament consists of a broad sheet of tissue attaching superiorly to the posterior margin of the foramen magnum (Gardner et al., 1975; Romanes, 1972; Wiesel et al., 1978; Zuckerman, 1961). It is reported to attach below to the superior border of the posterior arch of the atlas (Gardner et al., 1975; Romanes, 1972; Wiesel et al., 1978; Wood Jones, 1953; Zuckerman, 1961). Romanes (1972) describes the lateral portions of the posterior atlanto-occipital ligament as arching over the vertebral artery and the first cervical nerve as they cross the posterior arch of the atlas. The ligament is then described as blending laterally with the capsules of the atlanto-occipital joints (Hollinshead, 1969; Romanes, 1972).

## 4.4.3 Accessory atlanto-axial ligaments

The accessory atlanto-axial ligaments are reported to arise bilaterally from the posterior surface of the body of the axis (Gardner et al., 1975; Wood Jones, 1953). Anatomical texts describe these ligaments as passing superolaterally, reinforcing the atlanto-axial joint capsules posteriorly, and inserting onto the medial and the posterior aspects of the lateral mass of the atlas (Gardner et al., 1975; Wood Jones, 1953).

In recent study involving the dissection of ten formalin-fixed adult cadavers, the notion of the termination of these ligaments onto the atlas was challenged (Tubbs, Salter, & Oakes, 2004). These authors reported an attachment onto the occipital bone in all ten cadavers which they described as approximately one centimetre inferior to the hypoglossal canal and just posterior to the attachment of the occipital portion of the alar ligament. Interestingly, these authors provide no description of the inferior attachment of the ligaments in their paper.

## 4.4.4 Anterior atlanto-dental ligament

The anterior atlanto-dental ligament is described by White and Panjabi (1990) as passing between the anterior portion of the dens and the caudal portion of the anterior ring of the atlas. This description is based on the gross dissections of nineteen specimens by Dvorak and Panjabi (1987). However, it should be noted that this ligament could only be detected in two out of the nineteen specimens in this study, raising questions as to the appropriateness of describing it as a distinct ligament as opposed to an anatomical variant.

## **CHAPTER 5**

# DESCRIPTIVE ANATOMY OF THE LIGAMENTS OF THE CRANIOVERTEBRAL REGION

Content from this chapter has been published as;

Osmotherly PG, Rivett DA, Mercer SR. (2013). Revisiting the clinical anatomy of the alar ligaments. *European Spine Journal*, 22(1):60-64.

## 5.1 Introduction and aims

The gross morphology of the craniovertebral ligaments was investigated by blunt dissection in the sequence determined by their layering. The main aims of this study were to:

(i) Describe the morphology of

a. the tectorial membrane

b. the transverse, ascending and descending portions of the cruciform ligaments

c. the alar ligaments.

 (ii) Describe points of attachment of these ligaments to evaluate the anatomical assumptions underlying clinical stress tests for craniovertebral instability as described in published literature.

Many of the tests for assessing craniovertebral stability are described with reference to the work of Dvorak and Panjabi published in the late 1980s. In her landmark paper, Aspinall (1990) drew heavily on the work of these authors in proposing methods to clinically examine the craniovertebral ligaments. The descriptions given by these authors differed notably to past anatomical descriptions and some of their biomechanical assertions should be questioned. If these tests are to be considered valid, they must accurately reflect the underlying anatomical structure.

## **5.2 Dissection material**

## 5.2.1 Cadaveric material

Eleven cervical spine and head specimens were obtained from embalmed human cadavers (5 female, 6 male, mean age 84.1 years (SD 6.5 years), range 69 to 91 years). No specimen was involved in trauma as a cause of death. All cadaveric material was supplied by the Department of Anatomy and Developmental Biology, School of Biomedical Sciences, The University of Queensland. All cadavers used in this study were donated in accordance with the Queensland Transplantation and Anatomy Act 1979 (as amended). Ethical approval for this study was obtained from the University of Queensland. Characteristics of the study specimens are provided in Table 5.1.

## 5.2.2 Other materials

Dissecting tools Dissecting microscope Log book and sketches Camera

Specimen	Gender	Age	Reported cause of death	Other medical conditions	Embalming fluid
number		at death			
3600	Female	89	Myocardial infarction	Ischaemic heart disease	Adelaide mix
					Formalin, Plastopake
3669	Male	81	Cryptogenic fibrosing alveolitis	Adenocarcinoma of the	Adelaide mix
				prostate Carcinoma of the lung	Plastopake
3716	Female	91	Pneumonia	Cerebro-vascular dementia	Adelaide mix
				Ischaemic heart disease	Plastopake
3674	Male	89	Myocardial infarction	Ischaemic heart disease	Adelaide mix
				Congestive cardiac failure	Plastopake
3690	Female	89	Myocardial infarction	Ischaemic heart disease	Adelaide mix
					Plastopake
3719	Male	69	Myocardial infarction	Ischaemic heart disease	Adelaide mix
					Plastopake
3605	Male	91	Myocardial infarction	-	Adelaide mix
					Formalin, Plastopake
3595	Female	85	Pneumonia	-	Adelaide mix
					Formalin, Plastopake
3593	Female	81	Bilateral pneumonia	-	Adelaide mix
					Formalin, Plastopake
3585	Male	83	Lobar pneumonia	Bronchitis	Adelaide mix
				Parkinson's disease	Formalin, Plastopake
3631	Male	77	Metastatic prostate carcinoma	-	Adelaide mix
					Formalin, Plastopake

## **Table 5.1**Characteristics of the cadaveric specimens

#### 5.3 Dissection methods

Cervical spine columns were removed from each cadaver by disarticulation through the C6-C7 intervertebral disc and zygoapophyseal joints. Each specimen was divested of all muscle tissues leaving an osteoligamentous arrangement. The skull was sectioned at a level through the superior portion of the occipital bone and brain tissue removed. In accordance with methods previously described by Dvorak and colleagues (Dvorak & Panjabi, 1987; Dvorak et al., 1988), a posterior wedge of approximately 140° was cut from the occipital bone. Anteriorly, the bone was sectioned by a midline cut in the coronal plane. The posterior arch of the atlas and the posterior elements C2-C6 were resected. Brainstem, spinal cord and dura were removed to expose the tectorial membrane (Figure 5.1). Using a dissecting microscope at x10 to x40 power, the tectorial membrane, ascending and descending cruciform ligaments, transverse ligament of the atlas and the alar ligaments were examined by fine dissection. Each structure was systematically dissected by resecting its collagen fibres in bundles small enough to be grasped with sharpened jeweller's forceps. As bundles were stripped and removed, the orientation, location and attachment sites were recorded descriptively, photographically and in sketches. Superficial layers were resected to reveal deep layers which were then resected in a similar manner.

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**Figure 5.1.** Exposed tectorial membrane ready for fine dissection following preparation of the specimen. Specimen is viewed from the posterior aspect. Posterior elements have been resected and the dura mater removed.

#### 5.4 Results of anatomical study

#### 5.4.1 Tectorial membrane

The tectorial membrane was defined by an intimate and often adherent association with the dura posteriorly and by fibres extending superiorly to a curved attachment onto the occiput. Each tectorial membrane comprised two distinct layers of fibres with differing patterns of attachment.

The first (superficial) layer consisted of fibres running longitudinally in variably three (nine specimens) or four (two specimens) bands. These bands emerged from a central layer of fibres which appeared to be an upward projection from the posterior longitudinal ligament. The majority of the banded arrangement was situated within the superior component of this structure and remained visible from the point of division to the occipital insertion. The point at which the division into bands typically occurred was where the tectorial membrane overlay the atlas. This division was directly over the atlas in six specimens. One specimen divided at the level of the lateral atlantoaxial joints and one specimen divided at the atlanto-occipital joint level. The remaining three specimens divided further inferiorly at a level over the vertebral body of the axis. Where a three band arrangement was present, the central band assumed a 'fan' shape as it ascended into the basiocciput expanding on its upward course to its semicircular attachment. The two lateral bands arched outward alongside the central band constituting the outer aspects of the semicircle (Figures 5.2 a & b). In the two specimens with a four band arrangement, this spread of fibres in the bands was less obvious, appearing to follow a straighter line toward the points of attachment.



Figure 5.2 a. The superficial layer of the tectorial membrane viewed from the posterior aspect. The arrangement of the central and lateral bands are indicated.



Figure 5.2 b. The division of bands of the superficial layer of the tectorial membrane.

Superiorly, fibres attached from 5mm to 20mm past the foramen magnum onto the anterior internal surface of the occiput (median distance 9mm). No pattern emerged as to either medial or lateral components extending further into the occiput. Inferiorly, fibres of all bands spanned over several segments, blending into the posterior longitudinal ligament overlying levels from C2 to C6. Some attachments were evident on some specimens onto the posterior aspects of the vertebral bodies of the axis and C3. Six specimens could be classified as having some attachment onto the vertebral body of the axis. Two specimens also displayed attachment onto the superior portion of the posterior aspect of C3. Present in most specimens this occurred via a central slip over the level of the axis. Less frequently, small slips could be discerned diving to the deeper layer from lateral bands.

The second (deeper) layer consisted of three clearly discernible bands of longitudinally running fibres in all specimens (Figures 5.3 a & b). This layer passed over the atlas in each specimen with minimal or no attachment to it as it traversed toward its attachment into the basiocciput. Inferiorly, each of the three bands consisted of a broad projection arising from strong attachment directly onto the posterior aspect of the vertebral body of the axis. Each band remained as separate bands along their course such that the left lateral band attached distinctly to the left side of the posterior aspect of the vertebra, the right band arising from the right side of the posterior aspect of the vertebra and the central band attaching in a broad area centrally.

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**Figures 5.3 a & b.** Three bands of the deep layer of the tectorial membrane viewed from the posterior aspect are indicated (a). The central band broadens as the ligament passes over the odontoid process (b).

As it ascended, the central band assumed a 'fan' shape, broadening as it passed over the atlas. As the band crossed the level of the odontoid process, the fibres angled and travelled anteriorly, broadening anterolaterally to extend beyond the foramen magnum and create a semicircular attachment onto the internal surface of the basiocciput, with fibres attaching from 4mm to 22mm anterior to the foramen magnum (median 12mm).

The lateral bands ascended partially covered by the central 'fan' such that the medial portion of the lateral bands lay beneath the lateral portions of the central band (Figure 5.4). Following removal of the central band, the geometry of the lateral bands could be more clearly discerned (Figures 5.5 a b & c). Each lateral band ascended along the posterolateral aspect of the axis. At the level of the upper one-third of the odontoid process the fibres diverged such that each lateral band arced both medially and laterally. Medially, the fibres from each side converged and formed an arch over the tip of the odontoid process. Laterally, the fibres continued to their attachment onto the lateral aspect of the basiocciput. The lateral attachment extended to encompass the internal occipital surface around the jugular foramen.

Whilst the lateral bands in the majority of specimens could be seen to pass over the medial aspects of the atlanto-occipital and lateral atlantoaxial joints, two specimens displayed identifiable attachments of some fibres into the medial aspects of the atlanto-occipital joints. Although the tectorial membrane was generally mobile over the atlas, three specimens were observed to provide some, although not extensive, direct

attachment onto the medial aspect of the lateral mass of the atlas from the lateral bands of the deep layer of the tectorial membrane.



**Figure 5.4**. The three bands of the deep layer of the tectorial membrane viewed from the posterior aspect are outlined. The lateral bands are partially covered by the fan-shaped central band.



Figures 5.5 a, b & c. Lateral bands of the deep layer of the tectorial membrane viewed from the posterior aspect.

- a. The central band of the tectorial membrane has been removed exposing both lateral bands running either side of the exposed odontoid process.
- b & c. The direction of fibres of the lateral bands are indicated by arrows. The fibres are shown to diverge at the cranial aspect, expanding both medially and laterally.



Figure 5.5 b





Feature	Specimen number										
	3600	3669	3716	3674	3690	3719	3605	3595	3593	3585	3631
Number of bands	4	4	3	3	3	3	3	3	3	3	3
Level of band division	C2	C2	C1	C1	C1/2	C1	0-C1	C1	C2	C1	C1
Distance of furthest attachment into occiput (mm)	15	11	22	8	6	9	13	9	8	4	12
Inferior attachments	PLL	PLL, CV2, CV3	PLL, CV2	PLL to level of C5, CV3	PLL to level of C5, CV2	PLL to level of C6, CV2	PLL	PLL, CV2	PLL to level of C7, CV2	PLL to level of C7	PLL to level of C4

Table 5.2	Features of the superficial layer of the	e tectorial membrane
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Legend: PLL = posterior longitudinal ligament. CV = posterior aspect cervical vertebral body.

Feature	Specimen number										
	3600	3669	3716	3674	3690	3719	3605	3595	3593	3585	3631
Number of bands	3	3	2	3	3	3	3	3	3	3	3
Distance of furthest attachment into occiput (mm)	20	10	22	8	8	13	20	13	8	11	12
Inferior attachments	CV2	CV2	CV2	CV2	CV2	CV2	CV2	CV2	CV2	CV2	CV2

Legend: CV = posterior aspect cervical vertebral body.

#### 5.4.2 Transverse, ascending and descending portions of the cruciform ligament

Each triangular in shape, the ascending and descending cruciform ligaments extended longitudinally orthogonal to the transverse ligament. The fibres were oriented along the longitudinal axis cephalad and caudad respectively. Both the ascending and descending cruciform ligaments were present in nine of the eleven specimens. In one specimen the ascending cruciform ligament was absent and in one specimen the descending cruciform ligament.

The fibres of the ascending cruciform ligament arose from the transverse ligament in all specimens (Figure 5.6). The majority of ligaments examined arose from the posterior half of the transverse ligament. However, two specimens were found to provide fibre attachments from the full thickness of the transverse ligament. The superior attachment of each ascending cruciform ligament was onto the clivus of the occiput. Attachment sites extended up to 10 millimetres beyond the foramen magnum, attaching into the clivus between the foramen magnum and the attachment points of the tectorial membrane. The median length of the ligament was 13.5 millimetres in the eleven specimens (range 10 to 15 mm). In two specimens, a deeper slip of the ascending cruciform ligament was noted. This slip inserted onto the posterior aspect of the superior portion of the odontoid process, attaching below its tip.



**Figure 5.6** The deep craniocervical ligaments viewed fom the posterior aspect. The tectorial membrane has been removed. The transverse and ascending cruciform ligaments are indicated. The alar ligaments are seen emerging above the transverse ligament beneath the ascending cruciform ligament.

The descending cruciform ligament appeared as an inverted triangle extending inferior to the transverse ligament. Its superior attachment was superficially to the posterior aspect of the transverse ligament but also and more substantially to the posterior aspect of the vertebral body of the axis in all specimens. The eleven specimens displayed inferior attachments onto the posterior surface of the body of the second cervical vertebra and the superior portion of posterior aspect of the vertebral body of the third cervical vertebra. The descending cruciform ligaments examined extended up to 10 mm below the inferior border of the transverse ligament (median length 9 mm).

The transverse ligament of each specimen formed an elliptical shape up to several millimetres thick in sagittal section passing behind the odontoid process at a level below the origins of the alar ligaments. Each transverse ligament arose on each side from a tubercule on the medial aspect of the atlantal ring positioned immediately medial to the lateral atlantoaxial joint. From its superior to inferior border, the ligament measured from 8 to 14 mm (median width 12 mm). Traversing between the atlantal attachments, it measured between 14 and 22 mm in length (median length 18.5 mm). Beneath the lateral aspects of each ligament, a triangular fat pad was located immediately beside the odontoid process. The prominence of the fat varied between specimens. Following removal of the majority of fibres of the ligament, from the posterior aspect progressing anteriorly, a fibrocartilaginous layer was encountered surfacing the anterior portion of the ligament and providing an interface of the transverse ligament with the posterior aspect of the odontoid process. This interface permitted motion of the transverse ligament against the odontoid process in a sliding manner.

Three of the eleven specimens displayed distinct attachment of a proportion of the lateral fibres of the transverse ligament onto the medial aspect of the lateral atlanto axial joint. These attachments proved continuous with the medial aspect of the lateral atlantoaxial joint (Figure 5.7). Movement of the residual lateral fibres of the transverse ligament

during the final stages of dissection could clearly be shown to cause movement of the entire atlantoaxial joint capsule in a medial direction.



**Figure 5.7** The transverse ligament shown to attach into the medial aspect of the lateral atlantoaxial joint. The atlantoaxial joint has been disarticulated and the inferior articular process of the atlas is viewed from its inferior aspect. The remainder of the transverse ligament is held by forceps and can be seen to be continuous with the joint capsule.

## 5.4.3 Alar ligaments

Situated bilaterally, the alar ligaments were observed to run laterally from the odontoid process to the occiput. Each ligament inspected consisted of a thick bundle of fibres, ovoid in cross-section, oriented along the direction of the ligament passing laterally to the occiput. (Figure 5.8) No bands of fibres were observed between the odontoid process and atlas.



**Figure 5.8** The alar ligaments arising from the odontoid process. The transverse and cruciform ligaments have been removed. View is from the posterior aspect.

The origin of the alar ligaments on the odontoid process was consistently seen to be approximately 2 mm below the tip of the process extending inferiorly. Attachment occurred variably on either the lateral or the posterolateral aspect of the process, typically extending down its superior one-third but encompassing one-half of the distance down the odontoid process in some specimens. Distance of the attachment extended between 5 and 8 mm inferior to its superior margin. The variation in attachment distance from the tip of the odontoid process and the extent of the attachment onto the process reflected differences in magnitude of the ligament in individual specimens.

The attachment of each ligament on to the occiput was observed to be a discrete area between 2 and 4 mm in diameter on the medial surface of the occipital condyles in ten specimens. The remaining specimen demonstrated a more diffuse attachment into this area. Each attachment site was located in close proximity to the atlanto-occipital joint.

In progressing toward their insertion onto the occiput, the bands of the alar ligaments were observed to be oriented horizontally in seven specimens, with the remainder assuming a slightly cranio-caudal orientation.

The length of the alar ligaments between bony insertions ranged between 11 and 15 mm (median length 12 mm). The superior-inferior width of the ligaments viewed from a coronal plane ranged from 4 to 5 mm.

In addition to the previously described bands comprising the alar ligaments, five of the eleven specimens exhibited substantial bands passing between the medial surfaces of each occipital condyle which spanned the dens posteriorly with either minimal or no attachment to it (Figure 5.9). Each band had a horizontal orientation with a width of up to 4mm. Fascia and capillaries could be observed passing through the space between the two bands of the ligament in some specimens. These posterior bands of ligament permitted a degree of mobility as they passed behind the posterior aspect of the dens. Each of the five ligaments with transverse bands displayed a large proportion of fibres traversing directly from occipital condyle to occipital condyle. Whilst the transverse band in one of these specimens displayed a weak but definite attachment to the posterior aspect of the superior portion of the odontoid process below the level of the tip. The thickest of these bands, displaying no attachment to the odontoid process, possessed a cartilaginous anterior surface similar to the under surface observed in the transverse ligament.

A summary of the features of the alar ligaments observed in each specimen is presented in Table 5.4.



**Figure 5.9** Viewed from the posterior aspect, a band of posterior fibres of the alar ligament can be seen traversing from occiput to occiput with minimal attachment to the odontoid process.



Figure 5.10 Transverse bands of the alar ligament viewed from the posterior aspect.

**a.** Alar ligament with no attachment to the odontoid process.



**b.** Non-attached alar ligament lifted away from odontoid process with probe.

## **Table 5.4**Features of the alar ligaments

Feature	Specimen number										
	3600	3669	3716	3674	3690	3719	3605	3595	3593	3585	3631
Occipital portion	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
Atlantal portion	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Ligament orientation	Ceph-caud	Horizontal	Ceph-caud	Horizontal	Ceph-caud	Horizontal	Ceph-caud	Horizontal	Horizontal	Horizontal	Horizontal
Aspect of attachment on odontoid	Lateral	Lateral & postero- lateral	Lateral	Postero- lateral	Lateral	Lateral		Lateral & postero- lateral	Postero- lateral	Lateral	
Transverse band	Not present	Not present	Thick & mobile. No attachment to odontoid	Mobile. Attaches to odontoid posteriorly	Not present	Mobile. Attaches to odontoid posteriorly	Not present	Thick & mobile. Attaches strongly to odontoid posteriorly	Thin & mobile. Attaches to odontoid posteriorly	Not present	Not present

#### 5.5 Discussion of the results of the anatomical study

## 5.5.1 Tectorial membrane

The results of this dissection study indicates that the structure of the tectorial membrane is more complex than has been described and illustrated in standard anatomical texts. Overall, this structure bears a strong similarity to the descriptions published by earlier European anatomists.

The notion that the tectorial membrane is simply a broad layer of tissue suspended between two points of bony adherence (Last, 1978; Moore & Dalley, 2006; Tubbs et al., 2007; Wood Jones, 1953) appears to be clearly incorrect. These dissections demonstrate that the tectorial membrane is a multilayered structure composed of longitudinally running fibres. Each specimen examined was composed of two distinct layers of dense tissue. The fibres comprising each layer gathered into clear bands. Typically, a three band arrangement was present in each layer although a four band arrangement was an observed variant in the superficial layer. The presence of a banded structure suggests that the tissue is capable of resisting forces from differing directions corresponding to the longitudinal axes of the bands themselves. This description of the tectorial membrane as a structure composed of superficial and deep layers with distinct elements within each layer bears a strong similarity to descriptions published in the early part of the twentieth century (Cave, 1933-34; Fick, 1904; Poirier et al., 1911) which have been discussed in Chapter 4 and is a departure from the explanations provided in currently accepted texts and atlases of anatomy.

The tectorial membrane has frequently been described as an upward extension of the posterior longitudinal ligament (Last, 1978; Romanes, 1972; White & Panjabi, 1990; Woodburne & Burkel, 1988; Zuckerman, 1961). Our results suggest that the superficial layer of the tectorial membrane is continuous with the posterior longitudinal ligament but the deeper layer has no connection with this structure inferiorly. Specimens in this study frequently contained numerous fibres which were observed to be continuous over several segments. These fibres were observed to blend into the posterior longitudinal ligament between the levels of the third and sixth cervical vertebra. Poirier et al (1911) provided a similar description of the relationship between the layers of the tectorial membrane and the posterior longitudinal ligament. The conclusion of these authors was that only the deep layer should be recognised as the tectorial membrane with the superficial layer considered being part of the posterior longitudinal ligament. Whilst it cannot be disputed that the fibres of the superficial layer of the tectorial membrane are continuous with the posterior longitudinal ligament, the marked differences in fibre orientation between these structures make considering them as one anatomical entity difficult. The posterior longitudinal ligament in the adult cervical spine has been demonstrated to consist of three distinct layers. The fibres of the deeper two layers span only one segment each in attaching vertebra to vertebra, whereas the superficial band contains central fibres passing longitudinally which span a variable number of segments and lateral extensions passing inferolaterally at each level to attach at the base of the pedicle one or two vertebral
segments below their origin (Mercer & Bogduk, 1999). This contrasts with the observed distribution of fibres in the superficial layer of the tectorial membrane. The findings from the current dissection series indicate that the fibres generally ascend centrally but rather than maintain a distinctly longitudinal orientation, diverge to form a 'fan-shaped' arrangement which continues toward its attachment into the occiput. No significant central bands of fibres were observed attaching unisegmentally onto the atlas. Extensive attachment between the atlas and axis would not be expected given accepted descriptions of the biomechanics occurring at these articulations. Penning (1978) highlights the independence of movement at the atlas with respect to the atlas to permit paradox motion between these adjacent segments. This is described in further detail in Chapter 9. At the level overlying the atlas, lateral components are evident. These pass superolaterally to a broad attachment into the basiocciput exactly reversing the fibre direction described for the lateral elements of the posterior longitudinal ligament by Mercer and Bogduk (1999).

The inferior attachments of the tectorial membrane have been described as the posterior surface of the vertebral body of the axis (Moore & Dalley, 2006; Oda, Panjabi, Crisco, Bueff et al., 1992; Werne, 1957), the posterior longitudinal ligament (Gardner et al., 1975) and the dorsal surface of the odontoid process (Wiesel et al., 1978). In accepting that the superficial layer is indeed a component of the tectorial membrane rather than the posterior longitudinal ligament, the current findings support the first two of these descriptions. The deeper layer has extensive and strong attachment onto the posterior aspect of the vertebral body of the axis from both its central and lateral components.

There was, however, no indication in any specimen of any attachment onto the posterior surface of the odontoid process as described by Weisal et al.

Fick (1904) described an attachment of a cluster of fibres extending superolaterally from the tectorial membrane to the inner surface of the atlas which functioned to provide strong stabilisation to the atlantoaxial joint. The existence of an extensive attachment onto the atlas was not supported by our findings. Attachments onto the atlas were not consistently present and were of insufficient magnitude to be ascribed any functional significance.

The occipital attachments of the tectorial membrane have variously been described in textbooks and published journal articles as the anterior edge of the foramen magnum (Driscoll, 1987; Last, 1978; Mercer, 2004; White & Panjabi, 1990; Woodburne & Burkel, 1988), the clivus (Werne, 1957) or the base of the skull on the upper surface of the occipital bone (Gardner et al., 1975; Hollinshead, 1969; Moore & Dalley, 2006; Oda, Panjabi, Crisco, Bueff et al., 1992; Tubbs et al., 2006; Wood Jones, 1953; Woodburne & Burkel, 1988). In each specimen examined in this series, the occipital attachment occurred beyond the foramen magnum. Attachments were diffuse and extensive, ranging between four and 22 mm beyond the foramen magnum. Lateral attachments onto the occiput frequently extended further than the hypoglossal canal, contradicting the statements of Romanes (1972) in Cunningham's textbook of anatomy. As previously indicated by Tubbs (2007) attachment around and even lateral to the jugular foramen was common to significant proportions of fibres originating in the lateral bands.

Both Cave (1933-34) and Fick (1904) provide descriptions of the lateral portions of the tectorial membrane contributing to the medial aspects of the atlanto-occipital joints and the lateral atlantoaxial joints. Only two specimens in this series were noted to have attachments into the atlanto-occipital joints from the lateral bands of the tectorial membrane. No specimen was observed to contribute to the lateral atlanto-axial joints. These findings indicate that attachments into these joints are inconsistent. When these connections are present, they are not considered to be of sufficient magnitude to be an important component in the stabilisation of the medial aspects of the atlanto-occipital joints.

The longitudinal orientation of the fibres of the tectorial membrane passing over the odontoid process and continuing anteriorly support its previously described function as a limiting structure during craniocervical flexion (Penning, 1998; White & Panjabi, 1990). Given the course of the fibres, flexion occurring at the atlanto-occipital joint would tension the longitudinally running tectorial membrane over the tip of the odontoid process creating a potentially limiting factor restricting the movement.

The curved nature of the structure strongly suggests that the tectorial membrane may play a role in limiting craniocervical axial rotation. As the structure passes over the odontoid process it angles anteriorly toward its insertion onto the internal surface of the occiput. This places both layers of the tectorial membrane into a more horizontal plane. The fibres of the superficial layer and the central band of the deeper layer diverge and arc laterally toward their broad semicircular insertion. The lateral bands of the deeper layer arc both medially, crossing the midline, and laterally. This potentially places all fibres in a position to resist rotation of the occiput with respect to the axis in either direction. These observations are consistent with the findings of the biomechanical study conducted by Oda and colleagues (1992) where changes in range of craniocervical motion were recorded before and after transection of the tectorial membrane. In this study, transection of the tectorial membrane increased craniocervical axial rotation in one direction by 3.9° or 11.75% with the majority of this increased range occurring at O-C1; 6.7° to 9.6° or an increase of 43.3%. Minimal change was recorded at the atlantoaxial joint as would be expected since there is minimal attachment of the tectorial membrane to the atlas. Panjabi et al (1991) reported an average increase in magnitude of craniocervical axial rotation following combined tectorial membrane and alar ligament transection of 9.5°. Together, these studies indicate a primary role for the tectorial membrane in resisting axial rotation in this region followed by a second stage role for the alar ligaments in checking excessive axial rotation, particularly following tectorial membrane injury.

## 5.5.2 Transverse, ascending and descending portions of the cruciform ligament

The findings of the dissection of these ligaments closely reflect the findings of previous studies of their structure. Each ligament displayed a consistent construction throughout the dissection series. The absence of one portion of the cruciform complex from two of the eleven specimens could be considered normal anatomical variation rather than any indication of consistent structural diversity as suggested by Cave (1933/34).

The ascending and descending cruciform ligaments provide a contrast in the manner of their attachments approximate to the transverse ligament. The ascending cruciform ligament arises directly from the transverse ligament before passing in a cephalad direction. The descending cruciform arises both from a superficial attachment into the transverse ligament but also from strong insertions onto the posterior aspects of the vertebral bodies of the second cervical vertebra. However, the points of attachment provide little clue as to the functional significance of these ligaments within the craniocervical complex. Previous authors have suggested that their role is to minimise upward or downward movement of the transverse ligament (Fick, 1904; Werne, 1957). The direct attachment of fibres of the ascending cruciform ligament into the transverse ligament could support this notion. However, the superior attachment of the descending cruciform ligament is more strongly into vertebral body rather than the transverse ligament, making it less suitable for this task.

The absence of a bony inferior attachment of the ascending cruciform ligament does support the argument of Mercer (2004) that it may not be considered a ligament in a true sense. Whilst certainly existing as a band of dense connective tissue, it does not meet the criteria for a ligament stipulated by Frank et al (1995) who state that a bone to bone attachment is essential for classification as a ligament. The case for the status of the descending cruciform ligament is, however, well supported according to this definition, countering the argument over classification of this structure. Each descending cruciform ligament originated from a distinct bony point of origin with fibres running bone to bone and must be considered to be a ligament according to this definition.

The existence of a discrete band of fibres from the ascending cruciform ligament attaching superiorly onto the posterior aspect of the odontoid process in two specimens should also be considered an example of normal anatomical variation. Their existence is not consistent and it is difficult to attach a functional significance to their presence in these specimens.

The magnitude and structure of the transverse ligament inserting onto the tubercles of medial aspects of the ring of the atlas and passing behind the odontoid process is consistent with previous descriptions supporting its function as a ligament placed to counteract anterior displacement of the atlas on the axis.

The existence of a smooth, mobile fibrocartilaginous layer on the anterior surface of the transverse ligament ensures that the ligament can move against the odontoid process with little impediment during rotation of the atlas upon the axis. The relationship between these structures is assisted by the location of the triangular fat pads located beneath the lateral aspects of the transverse ligament. These fat pads function to accommodate the vacant space either side of the odontoid process between the transverse ligament and the anterior ring of the atlas.

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The existence of a substantial contribution of fibres from the transverse ligament to the medial aspect of the lateral atlantoaxial joints in three specimens suggests that the transverse ligament may play a role in the stability of this joint in some individuals. The geometry of the lateral atlantoaxial joints with their biconvex articulation means that these joints have little inherent stability. The location of the insertion of the transverse ligament onto the tubercle immediately medial to the lateral atlantoaxial joint would permit a contribution of fibres to the joint readily. Reinforcement of the medial joint capsule by the transverse ligament would improve the stability of this articulation in limiting lateral movement of the atlas on the axis. Given that this feature was not apparent in all specimens, such an inference may not be generalised to all people. However, it might be considered that it may have clinical implications for some individuals following compromise of the transverse ligament.

## 5.5.3 Alar ligaments

The odontoid attachment of each alar ligament examined occurred below the level of the tip of the process, with attachment continuing caudally down the odontoid process as far as 8 millimetres below the most superior point of the ligament. This contradicts the reports in some standard texts such as Gardiner et al (1975) and Romanes (1972) stating that the site of attachment is the apex of the odontoid process.

The occipital attachments observed in this series were consistent with reports of most previous authors, being into the medial surface of the occipital condyles but not consistent with the descriptions of Moore and Dalley (2006) and Panjabi et al (1991b) as inserting onto the lateral walls of the foramen magnum. Most specimens were observed to insert in close proximity to the occipito-atlantal joints. However, no obvious contribution to the capsules of these joints was noted in these specimens as had been suggested by Cave (1933-34).

The classical description of the alar ligaments is of two cords of tissue running caudocranially from the odontoid process. In this dissection series, the majority of alar ligaments were observed to be oriented horizontally, with four ligaments observed to run slightly cranio-caudally. This finding suggests that the orientation of the ligaments may be more horizontal than has previously been described. This would be more in keeping with the described role of these structures which is to restrict the movement of rotation of the occiput on the occipito-atalantoaxial complex in the horizontal plane.

No atlantal portion of the alar ligament was noted in any specimen examined. This is a significant departure from the findings of Dvorak and Panjabi (1987) who reported a distinct ligamentous connection between the odontoid process and the lateral mass of the atlas in 12 of 19 specimens examined by gross dissection. Whilst the existence of these bands would not be expected in all specimens given Dvorak and Panjabi's report, it would seem unexpected that if these structures were commonly existing anatomical features they would not be apparent in any of the eleven specimens examined in this series. Two possible explanations may exist for this anomaly. Variation is common within normal anatomy and specific populations may exhibit some variations which may

not be widely present beyond that population. One explanation could be that the ligamentous bands described by these authors were specific to a population present within their study sample and hence may not be commonly present in other individuals. It is also possible that the structures reported were not, in fact, elements of the alar ligaments. Previous authors have noted bundles of connective tissue arising from the axis and passing to the atlas. These reports have attributed this tissue to elements of the median atlantoaxial joint capsule rather than the alar ligaments (Cave, 1933-34; Gardner et al., 1975; Poirier et al., 1911). It was also noted in the present dissection series that elements of loose connective tissue associated with small vessels were present in this region. This could also be a possible source for the observations of Dvorak and Panjabi.

The presence of transverse bands in nearly one-half of the specimens examined suggests that this is a common variant of the alar ligament. Complete overarching or minimal attachments to the odontoid process suggest that these bands, when present, may have a role assisting in maintenance of the relationship between occiput, atlas and odontoid process in the sagittal plane. Such a role has been previously described for the alar ligaments in the absence of an intact transverse ligament (Poirier et al 1911) and the similarity in orientation to the transverse ligament would make this a logical inference. Their mobile nature in relation to the odontoid process suggests that they do not encumber the dens during craniovertebral rotation. In this case, these bands will not contribute to the coupling of lateral flexion and rotation occurring at the craniovertebral segments that has been attributed to tension developed within the alar ligaments.

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#### 5.6 Implications for the validity of clinical stress testing

## 5.6.1 Tectorial membrane

The tectorial membrane is a complex and substantial structure containing a far greater tissue volume than the deeper ligaments of the craniocervical complex. Given its potential for restricting movement in this region, it should be considered to play a greater role in passive stability of the occipito-atlantoaxial region than has been previously attributed to it. Routine examination of the stability of this region should reflect this potential role.

Current tests for the integrity of the tectorial membrane are based on descriptions of a structure traversing longitudinally between the axis and the occiput and coursing anteriorly over the tip of the odontoid process. Hence, testing is based on examining a combination of movement involving craniocervical flexion and longitudinal distraction. These features are supported in the current dissection series of the tectorial membrane. However, the wider than previously described lateral insertions onto the occiput and curved nature of the fibres constituting this structure, particularly the deeper bands, provide support for the tectorial membrane also being a passive restraint opposing occipito-atlantoaxial rotation. The role of the tectorial membrane as a first line of restraint in this direction is supported by the past work of Oda et al (1992) and Panjabi et al (1991). Currently, clinical stress testing of the tectorial membrane does not consider a role in limiting axial rotation and does not provide a reflection of what is very likely to be a primary function of the structure. Further examination of the role of the tectorial

membrane in limiting craniocervical rotation is required which may result in further refinement of the stress tests for this structure to incorporate a rotation component.

## 5.6.2 Cruciform and transverse ligaments

The current stress tests for the transverse ligament all involve attempted displacement of the atlas anteriorly with respect to the axis. The findings of the dissection of these specimens reinforce previous descriptions of the transverse ligament passing broadly behind the odontoid process in a position capable of resisting this displacement. Hence, these findings in regard to the transverse ligament support the tests currently described providing an additional measure of biological plausibility and face validity.

## 5.6.3 Alar ligaments

The consistent existence of a strong cord-like structure between the odontoid process and the medial aspect of the occiput suggests that this structure plays a role in resisting both side bending and axial rotation of the occipito-atlantoaxial complex. Descriptions of this component of the alar ligaments are similar to previous anatomical descriptions used to model the biomechanics of the region upon which the clinical stress tests have been based. Hence, these findings provide face validity to the existing tests.

It should, however, be noted that since a minority of people exhibit an alar ligament displaying no attachment onto the odontoid process, that instances exist in which any

attempt to make conclusions about its integrity on the basis of assessment of rotation or side bending will be potentially errant. Hence, normal anatomical variation builds in an inherent potential for false findings in these individuals. From a passive testing perspective, this elevates the importance of testing the tectorial membrane in addition to the other ligaments of the craniocervical complex when assessing for stability of this region prior to manual therapy interventions.

The absence of findings with respect to the previously described atlantal portion of the alar ligament makes any attempt to describe or differentiate test findings based on the integrity of this presumed structure invalid. The presence of an atlantal portion of an alar ligament in any individual should be considered an anatomical variant, not an essential component of stability of the craniocervical complex. Although clearly described by Dvorak and Panjabi (1987) and ascribed functional significance in their descriptions of the biomechanics of this region (Dvorak et al., 1988), the inconsistency of findings in regard to their presence in this current and previous studies described in Chapter 4 should lead the clinician to conclude that no weight should be attributed to any test finding regarding its integrity.

Stress testing for the alar ligaments has been suggested to be performed in all of three planes; horizontal, upper cervical spine flexion and upper cervical spine extension, due to variation in ligament orientation (Aspinall, 1990). The findings of the current study suggest that the orientation of the alar ligaments is more horizontal than previously described. Whilst some variation in ligament orientation does exist, the magnitude of this

variation is less than has been depicted in standard texts. Testing in a variety of positions may still be argued because of the existence of this variation although it is likely that testing in the horizontal plane will be the most informative.

The rationale for this variation in alar ligament orientation is given by Dvorak (2008) as being due to variation in height of the odontoid process. This presupposes that the alar ligaments are attached to the tip of the odontoid process. This is not supported by the findings of this study. No alar ligament was observed to arise from the tip of the odontoid process in any specimen examined with the mean distance being 2 millimetres from this bony landmark and the extent of attachment onto the process was measured as being up to 8 millimetres inferior to this. Hence, this explanation does not provide an adequate rationale for ligament orientation. It is more likely to simply be a function of normal variation between individuals.

# **CHAPTER 6**

## LITERATURE REVIEW OF THE RADIOLOGICAL ANATOMY OF THE CRANIOVERTEBRAL LIGAMENTS

## 6.1 General radiographic approach

Conventional radiography is incapable of imaging soft tissue structures such as ligaments (Volle, 2000), particularly in the absence of fracture. Hence, approaches to assessing stability of the craniovertebral region by conventional X-rays rely on alterations in reliable skeletal landmarks (Deliganis et al., 2000).

Methods relying on alterations in craniovertebral skeletal landmarks are interpreted as indications of ligamentous disruption since the ligaments provide stability to the area (Harris, Carson, & Wagner, 1994). They do not generally allow specific identification of the affected ligament structure.

One method used to make inference on the ligamentous integrity of the craniovertebral region allows for measurement of intervals using lateral x-ray films. Developed from measurements on 400 radiographs of people with no craniovertebral abnormalities, a posterior axial line is projected as the rostral extension of the posterior cortex of the body of the axis. The distance of this line from the basion (the midsagittal point of the anterior margin of the foramen magnum) is measured. This measurement is defined as the 'basion axial interval' (Figure 6.1 (a)). Similarly, the distance from the basion to the closest point of the tip of the dens, the 'basion-dental interval' is also measured (Harris, Carson, & Wagner, 1994)(Figure 6.1 (b)). For the craniovertebral junction to be considered normal,

neither of these intervals should exceed 12mm (Harris, Carson, Wagner, & Kerr, 1994). An excessive measurement does not identify disruption of a particular ligamentous structure.



a.

b.

## Figure 6.1

**a**. Basion-axial interval. The posterior axial line (PAL) coincides with the posterior cortex of the body of the axis. The distance between the upper extension of the PAL and the short solid line is the normal basion-axial interval of 12mm. The basion, indicated by the arrow should be situated within this interval.

**b**. Basion dental interval. The distance between the basion (arrow) and the rostral cortex of the dens (arrowhead) should not exceed 12mm. Reproduced from Harris, et al. (1994). p 882.

#### 6.2 Imaging of the alar ligaments

## 6.2.1 Conventional radiography

The use of functional x-rays in sidebending has been proposed as one method of evaluating the integrity of the alar ligaments (Reich & Dvorak, 1986). This method is based on a theoretical mechanism describing the role of the alar ligaments in coupled lateral flexion and rotation in the craniocervical segments. Reich and Dvorak postulated that lateral displacement of the atlas is induced by the anterior portion of the contralateral alar ligament while rolled onto the dens. There are two main assumptions in this model. The first assumption is that forced rotation of the axis is primary to the lateral displacement of the atlas. The second assumption is that the anatomical arrangement suggested by Ludwig (1952) is accurate and that the anterior fibres of the alar ligaments attach via their inferior fibres to the lateral masses of the atlas. Films are taken in the anterior-posterior (A-P) projection both in neutral and in maximal lateral flexion to each side, and the distance between the dens and each lateral mass is measured.

Reich and Dvorak (1986) sought to provide evidence for this approach by performing functional x-rays on 26 people with rheumatoid arthritis and 31 control subjects. They found that although lateral displacement of the atlas occurred in both groups, measured lateral displacement was greater in the rheumatoid arthritis group, although the amplitude of the displacement was not large in either group (1.71mm compared to 0.97mm). Their conclusions, whilst guarded, were based on the assumption that rheumatoid arthritis will

affect the craniocervical ligaments due to ongoing inflammatory reactions. Whilst the prevalence of transverse ligament compromise is well documented in rheumatoid arthritis, the effects on the alar ligaments have not been the subject of extensive investigation. Furthermore, the authors did not provide any other clinical evidence for the existence of any lesion of the alar ligaments in anyone in the sample.

## 6.2.2 Computed tomography

CT has been proposed as a method for examining the alar ligaments in both cadaveric and patient based studies (Dvorak, Hayek, & Zehnder, 1987a; Dvorak, Panjabi et al., 1987). The primary reason for this is the estimation of range of craniovetebral rotation which may be taken as a sign of alar ligament insufficiency (Dvorak, Panjabi et al., 1987). The use of functional CT has been challenged as unreliable due to standardisation issues and patient compliance, particularly given the emerging use of MRI to visualise the ligaments (Krakenes & Kaale, 2006; Patijn, Wilmink, ter Linden, & Kingma, 2001).

The alar ligaments themselves can be identified on CT. In axial section near the apex of the dens, they appear as small paramidline, quadrangular soft tissue masses separated by epidural fat (Figure 6.2A). In coronal section, they are clearly identified as soft tissue bands (Figure 6.2B) (Daniels et al., 1983).



Α

B

Figure 6.2. Appearance of the alar ligaments on CT imaging

- **A.** Axial section CT at the level of the dens. The alar ligaments are indicated by black arrows.
- **B**. Coronal section CT. The alar ligaments are indicated by arrows.

Reproduced from Daniels et al. (1983).

## 6.2.3 Magnetic resonance imaging

The limitations of computerised tomography in terms of poor soft tissue contrasts and frequent failure to detail the alar ligaments in vivo (Kim et al., 2002) has led to evaluation of the use of MRI in detailing the ligaments and describing lesions in the ligament complex.

Commencing imaging cadaveric specimens, Schweitzer et al., 1992 were able to able demonstrate the alar ligaments as short, broad structures of intermediate signal, extending outward from the superior and lateral portions of the dens to the medial aspect of the occipital condyles.

Willauschus et al., 1995 examined the alar ligaments in both normal volunteers and cadavers. The ligaments could be identified in all eight volunteers and 14 of 15 cadaveric specimens as a low to intermediate signal intensity, with clearly defined borders and orientation.

A more complete description of the imaged anatomy of the alar ligaments was provided by Pfirrmann and colleagues in two papers describing their findings using a sample of 50 asymptomatic individuals with no history of trauma (Pfirrmann, Binkert, Zanetti, Boos, & Hodler, 2000; Pfirrmann et al., 2001). These authors were able to define 80 of the 100 ligaments imaged, passing from the lateral aspect of the dens to the medial inferior aspect of the occipital condyles. The ligaments that were not able to be identified were considered to be obscured by epidural fat surrounding the ligaments which has similar signal intensity to the ligaments themselves making interpretation difficult. Forty of the observed ligaments had a horizontal orientation, while thirty-five coursed caudocranially and five craniocaudally. Left to right asymmetry of the ligaments was common with 88% of all observed ligaments, indicating that this would not be considered an anomaly in the broader population (Figures 6.3 and 6.4). The cranial and caudal borders of the ligaments converged toward the occipital attachment in 58 cases. Twenty-two remained parallel.

Similar rates for demonstrating reliability in identifying the ligaments in various imaged planes have been published by other researchers. Kim et al., (2002) could clearly identify 70% of ligaments in neutral images in the axial plane and 98% using coronal images in a sample of 22 individuals with no predisposing factors to neck pain. Roy, Hol, Laerum, & Tillung, (2004) identified alar ligaments in 14 of 15 subjects in coronal scans and 13 of 15 subjects in sagittal scans. Greater difficulty was encountered on images in the sagittal plane due to the inability to differentiate the ligament easily from epidural fat. High rates of recognition of the alar ligaments in the coronal plane and frequent asymmetries in their structure were also noted by Wilmink and Patijn (2001).





## Figure 6.3

Figure 6.4

- **Figure 6.3** Coronal T1-weighted spin-echo MR image with arrows showing delineated and symmetrical alar ligaments oriented caudocranially. Reproduced from Pfirrmann et al. (2001). p. 136.
- **Figure 6.4** Coronal T1-weighted spin-echo MR image showing delineated asymmetrical alar ligaments oriented craniocaudally on the right and caudocranially on the left. Reproduced from Pfirrmann et al. (2001). p. 136.

Krakenes et al. (2001) reported similar results to Pfirrmann et al., describing the alar ligaments in 30 people with no history of cervical spine problems (Figure 6.5). They were able to clearly identify the ligaments in all 30 cases in both sagittal and coronal planes, describing attachments to the posterolateral aspect of the dens and passing laterally to insert on a roughened area of the occipital condyles. Ligament orientation was observed to be variable, with 22 described as horizontal, five caudocranial and three craniocaudal (Krakenes et al., 2001). No comment was made regarding asymmetry between ligaments in their sample. In cross-section, three main variants could be described; these being round, ovoid and 'wing-like'.

None of the cited studies describe more than one portion of the alar ligament linking between dens and occiput. This supports the finding of the anatomical studies described in chapter 5 disputing the reliable existence and importance of the atlantal portion of the alar ligament.

Table 6.1 provides a summary of these findings including the imaging parameters used.





A. Densely packed ligament fibres showing low signal intensity (black arrowheads). **B.** Thick ligaments with loose fibre structure showing intermediate signal (white arrows).

Reproduced from Krakenes et al. (2001). p. 1091.

<b>Table 6.1</b> .	Summary of published	MRI descriptions	of the alar ligaments.
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Author	Sample	MRI equipment and sequences	Description	Other findings
Schweitzer et al., 1992	3 cadavers	1.5T scanner	Short and broad and of intermediate signal	
		Sagittal, coronal and		
		axial planes FOV=10cm	Extend outward from the superior and lateral	
		256x192 matrix	portion of the dens to the medial aspect of the	
		Spin echo sequences 3000/35 TR/TE	occipital condyle	
		Slice thickness 4mm and		
Willauschus et al 1995	8 volunteers	1 5T scanner and head	Ligaments identified in	
ti induserius et di., 1995	15 cadavers	coil	all 8 volunteers as low to	
		FOV 120-250mm	intensity in spin echo	
		3D gradient-echo fast	sequences with clearly	
		imaging with steady precision or fast low angle shot.	determined borders and orientation	
		0	Optimal contrast using	
		Repetition time 24-	T1-weighted sequence	
		18msec, flip angle 10-70 degrees	axial or coronal orientation	

			Ligaments identified in all but one cadaveric specimen. Signal same as for volunteers	
Kim et al., 2002	22 people (16 male and 6 female) 22-33 years (mean = 27) No history of neck pain, head or neck trauma or inflammatory disease. Unrestricted cervical range of motion	<ul> <li>1.5T scanner with head coil</li> <li>FOV = 16x16cm 512x256 matrix</li> <li>Fast spin echo proton density imaging</li> <li>Contiguous axial and coronal images (TR/TEeff/NEX = 4000 ms/ 15ms/4) with 2mm slice thickness</li> </ul>	Out of 22 subjects, right and left alar ligaments could be demonstrated in 15 and 16 on axials in neutral, 21 and 22 coronal image planes in neutral, 22 and 22 in right rotation and 21 and 22 in left rotation of the head on neck Ligament lengths measured in coronal plane with head in neutral; 6-14mm on right side and 7-12mm on left	Alar ligament could be seen reliably on MR, particularly on coronal scans
Wilmink & Patijn, 2001	12 patients diagnosed with whiplash associated disorders (age 17-55 years, mean = 40) and 6 asymptomatic controls (age 22-55 years, mean = 35)	0.5T scanner with quadrupture neck coil Proton-density T2- weighted coronal slices acquired TR/TE/ETL 2,500msec/18msec/16 FOV = 140mm Matrix 200x256	Alar ligaments could be identified in all 18 subjects	

Pfirrmann et al., 2000, 2001	50 people (31 male, 10 female)	1.0T scanner	80 of 100 ligaments identified: 84% of left	Dens deviated left 14%, right 12% with respect
2001	19-47 years (mean 29.8)	FOV = 26x13cm, imaging matrix 512x180,	side and 76% of right.	to lateral mass of atlas
	No history of trauma, no neck pain	3 and 4 acquisitions were averaged	Orientation; 40 horizontal, 35	Small number of ligaments not identified
		Axial T1-weighted images (640/12 repetition time	caudocranial and 5 craniocaudal	most likely due to epidural fat which is closely related to the ligaments and has
		msec/echo time msec). Slice thickness 3mm or 4mm	58 cranial and caudal borders converged toward the occipital attachment 22 were	similar MR signal intensity
		Coronal T1-weighted (350/15) and T2-	parallel	Hyperintense signal 21%, hypointense signal
		weighted (4000/130) turbo spin echo images with slice thickness 3mm	88% assymetrical left to right	14% and 21% left and right ligaments
		and 4mm	Passing from lateral aspect of the dens to medial inferior aspect of occipital condyles	Heterogeneous signal in an asymptomatic population. This makes signal intensity criteria difficult to use for
			Mean length 11mm cranially and 13mm caudally	diagnosis of alar ligament alterations
			Included angle between ligaments 140°-180°	

Krakenes et al., 2001	30 people 11 male (age 28-66 years, mean = 46) and 19 female (age 29-62 years, mean = 45) No history of motor vehicle accident Unable to recall head or neck trauma	<ul> <li>1.5T scanner with standard head coil</li> <li>Proton density weighted fast SE obtained in 3 orthogonal planes</li> </ul>	Ligaments well defined in coronal and sagittal planes in all 30 cases Attach to posterolateral aspect of dens and run laterally to roughened area of the occipital condyles. Axial views: posterolateral orientation in 23/30 cases, straight lateral in 5/30 and anterolateral in 2/30 Ligament orientation: horizontal in 22, caudocranial in 5, craniocaudal in 3 Cross section: 3 main variants; round, ovoid, wing-like	Upper rim of ligament well defined toward epidural fat in all cases Atlanto-dental portions could not be identified in any cases Signal intensity; Low all through ligament in 6/30 giving dark appearance. 7 had slightly higher giving grey appearance 17 had low signal laterally and higher signal medially
Roy et al., 2004	15 people Age 21-27 years No history of neck injury	<ul><li>0.5T scanner with vertically open bore.</li><li>Surface coil</li><li>11 contiguous cross-</li></ul>	Alar ligaments visible in coronal scans in 14/15 subjects and in sagittal scans in 13/15 subjects	In sagittal plane, ligament difficult to distinguish from surrounding tissue if it is not predominantly

sectional proton density images at 3mm intervals in 3 planes Fast spin echo pulse sequence	hypointense as it courses within epidural fat and is not separated from it by any anatomical structure with a distinctive appearance on MRI
	On coronal scans, 8 ligaments judged to be grade 2 (areas of hyperintensity not encompassing more than half the CSA of the ligament) and 1 judged as grade 3 (high intensity encompassing more than half CSA)

Legend: T = tesla, FOV = field of view, TR/TE, TR/TEeff/NEX, ETL, SE = spin echo, MVA = motor vehicle accident, CSA = cross sectional area

#### 6.3 Imaging of the transverse ligament of the atlas

## 6.3.1 Conventional radiography

As with all ligament structures, the craniocervical ligaments cannot be seen using conventional X-ray techniques (Volle, 2000). However, integrity of the transverse ligament has been judged on the basis of functional lateral x-rays. First described by Coutts (1934), forward subluxation of the atlas as a consequence of transverse ligament compromise is gauged by measuring the distance between the anterior border of the dens and the posterior inferior margin of the anterior arch of the atlas (Coutts, 1934; Douglas, Sanders, Machers, Pitcher, & van As, 2007; Hinck & Hopkins, 1960). This span is known as the anterior atlanto-dental interval (ADI) (Coutts, 1934). A lateral film taken in extension provides a baseline ADI. A second film, in a forward flexed position, may illustrate an anterior movement of the atlas in the presence of ligamentous compromise. This is seen as an increased ADI and results in a decrease in the space available for the spinal cord (Rana et al., 1973; Sharp & Purser, 1961; Uitvlugt & Indenbaum, 1988; Volle, 2000). Estimates of the normal values of ADI in flexion vary from one millimetre (Coutts, 1934) to three millimetres (Stevens et al., 1971), although four millimetres has also been suggested as normal in a rheumatoid arthritis population (Uitvlugt & Indenbaum, 1988). In children, the ADI can be up to five millimetres and quite mobile (Dickman, Mamourian, Sonntag, & Drayer, 1991).

## 6.3.2 Computed tomography (CT)

The transverse ligament may be defined in axial sections as a curvilinear soft tissue structure extending between the medial edges of the lateral masses of the atlas (Daniels, Williams, & Haughton, 1983) (Figure 6.6). Sectioning in the coronal plane is less reliable as it is difficult to distinguish the transverse ligament from the dural sac and the tectorial membrane.

Whilst visualisation of the ligament itself is possible with CT, it has been suggested that it has limited diagnostic value as an imaging tool due the high rate of both false positive and negative results yielded because of poor soft tissue contrast (Willauschus et al., 1995).



Figure 6.6Axial CT section demonstrating the appearance of the transverse ligament.<br/>The transverse ligament is indicated by arrows.<br/>Reproduced from Daniels et al. (1983). p 714.

## 6.3.3 Magnetic resonance imaging (MRI)

The transverse ligament is discernable in nearly all cases using MRI (Dickman et al., 1991; Krakenes, Kaale, Nordli et al., 2003). It can be visualised on images in both the coronal and axial planes (Krakenes, Kaale, Rorvik, & Gilhus, 2001) as a low to intermediate signal intensity structure (Dickman et al., 1991; Schweitzer, Hodler, Cervilla, & Resnick, 1992). Dickman et al. (1991) described the transverse ligament in twenty asymptomatic subjects using axial gradient echo MR images angled parallel to the atlas (1.5 tesla scanner. gradient echo technique; TR 733msec, TE 18msec, flip angle 20°, three millimetres slice thickness). These authors reported that as a relatively homogenous low signal intensity structure, the anterior margin of the ligament could be contrasted with the area of high signal intensity produced by the synovial joint interposed between the posterior cortex of the dens and the transverse ligament. Posteriorly, they report that the ligament was adjacent to the high signal intensity from the cerebrospinal fluid (Dickman et al., 1991). The reporting of this relationship suggests that these researchers were unable to distinguish the transverse ligament from the tectorial membrane or dura mater as both of these structures lie posterior to the transverse ligament and are interposed between it and the spinal canal containing the cerebrospinal fluid.

More recently, Krakenes et al (2001) were able to provide a more detailed description of the transverse ligament following imaging of thirty people with no history of neck trauma. Proton-density-weighted fast spin echo images were acquired in three orthogonal planes with a 1.5 tesla scanner and standard head coil. Transverse ligaments were well demarcated, arching across the atlantal ring in twenty cases. Definition of margins was less clear in ten cases, primarily due to the obscuring effects of other low signal intensity tissue in the soft tissues surrounding the dens (Figure 6.7). They described a flattened median portion of the ligament in all thirty cases with a mean mid-portion thickness of 2.5millimetres and mean craniocaudal height of 7 millimetres. Between the dens and the atlas, the transverse ligament twisted, taking on an oblique horizontal orientation, before inserting into the atlantal ring in a shape described as a "crescent shaped in cross section" (p. 1092).



Figure 6.7 Transverse ligament (indicated by black arrows) arching around the dens showing low signal intensity and delineated borders. Reproduced from Krakenes, et al. (2001). p. 1093.

## 6.4 Imaging of the tectorial membrane

## 6.4.1 Computed tomography

The tectorial membrane has not been the subject of extensive study radiologically. On axial CT images, it has been described as a broad band behind the dens, consisting of two layers, superficial and deep (Daniels et al., 1983). It has not been possible to distinguish the tectorial membrane from the dura. Instead, both are described as one rim of tissue posterior to the dens and lateral masses of the atlas.

## 6.4.2 Magnetic resonance imaging

The tectorial membrane may be routinely seen on MRI as a low signal intensity band that may be visualised in sagittal and axial plane images (Benedetti, Fahr, Kuhns, & Hayman, 2000; Schweitzer et al., 1992).

In their MRI series, Krakenes et al (2001) described the tectorial membrane as originating from the posterior surface of the vertebral body of the axis and ascending to insert onto the clivus, slightly above the foramen magnum. They were able to identify the median portion of the tectorial membrane in 26 of their 30 cases but could not distinguish it from the anterior dura. The lateral portions of the tectorial membrane could be distinguished in all 30 cases, attaching to the posterior edge of the upper part of the body of the axis.

From the mid dens level caudally, the tectorial membrane could be distinguished from the transverse ligament on axial images in all cases as it appeared as a slightly darker,

sinuous structure (Krakenes et al., 2001). Cranially, the membrane was indistinguishable from the dura above the level of the alar ligaments. However, in fourteen cases, a tiny fat layer was observable between the membrane and the dura on axial section. (Krakenes et al., 2001).

Dimensions estimated from MRI images indicated a mean width between dens and clivus of 15 millimetres (range 12 to 16 millimetres) and a mean thickness measured in the lateral one-third of the membrane of 1.4 millimetres (range 1.0 to 1.8 millimetres).

# **CHAPTER 7**

# AN EXAMINATION OF THE DEEP CRANIOVERTEBRAL LIGAMENTS USING HIGH RESOLUTION AND CLINICAL RESOLUTION MAGNETIC RESONANCE IMAGING

## 7.1 Introduction and aims

Diagnosis of irregularities of the craniovertebral ligaments by medical imaging is predicated by a presumed understanding of the normal radiological appearance of these ligaments. As discussed in Chapter 6, descriptions of the radiological appearance of these ligaments often lack detail and are, at times, contradictory. As a consequence, the radiological clinical assessment of pathological changes in these structures may be lacking in certainty, or even be completely absent because there is not a systematic description of the morphology from which to work.

MRI is currently accepted as the most accurate method of depicting the craniocervical ligaments (Baumert et al., 2009). In all clinical MRI, a contrast between areas of high signal intensity and areas of low signal intensity must be present to demonstrate both normal anatomical features and abnormalities (Westbrook, Kaut Roth, & Talbot, 2011). However, debate remains ongoing regarding the reliability of MRI in detecting the craniocervical ligaments and which pulse sequences and protocols may be best suited to this purpose (Baumert et al., 2009).

Following an examination of 50 healthy individuals, Pfirrmann and colleagues (2001) suggested the use of both T1-weighted and T2-weighted imaging for the identification of the ligaments of this region. These authors found little difference in signal intensity with respect to the surrounding muscle tissue between these acquisitions but noted that the incorporation of a spin-echo series resulted in better image quality.

The most frequently cited acquisition sequence for the examination of these ligaments involves the proton density-weighted imaging protocol developed by Krakenes et al. (2001). These authors compared the image quality and the ability to accurately delineate the craniocervical ligaments using several acquisition strategies including T1-weighted spin echo, T2-weighted fast spin echo and proton density-weighted fast spin echo, concluding that the proton density-weighted fast spin echo was superior in discriminating these ligaments from surrounding tissue.

In contrast, recent publications have recommended the use of T2-weighted imaging to detect ligamentous injuries in the cervical spine (Bagley, 2006). Baumert and colleagues (2009) examined the craniocervical ligaments in 52 healthy individuals using a T2-weighted three-dimensional turbo spin echo sequence to evaluate their visibility and morphology. Using image data reconstruction allowing visualisation in planes oblique to the imaging planes, these authors reported good to excellent depiction of the alar ligaments in all 52 subjects (Baumert et al., 2009).
The current study aims to provide greater detail regarding the radiological appearance of these ligaments. By examining these structures under high definition MRI, a more accurate description of their morphology and radiological appearance may be achieved. Comparing the observations from the high definition images to images of the same specimens comparable to clinical acquisition may provide systematic methods for the clinical examination of these structures. Confirmation of radiological observations by fine dissection will provide an added measure of validity to the findings evinced by the high resolution imaging of these ligamentous structures.

Clinically, MRI remains the diagnostic gold standard for lesions of the craniocervical ligaments. As such, an understanding of the strengths and weaknesses of MRI in accurately detailing the structures contained in the craniocervical region are essential prior to the assessment of clinical stress tests against this gold standard in subsequent studies. A second aim of this study was to establish which MRI acquisition parameters could be used to optimally and accurately assess the craniocervical ligaments in order to reflect their morphology and to detect any changes occurring during the application of described clinical stress tests during subsequent studies.

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#### 7.2 Methods

#### 7.2.1 Cadaveric material

Six cervical spine and head specimens were obtained from embalmed human cadavers (2 female, 4 male, mean age 81.2 years (SD 12.6 years), range 58 to 94 years). No cadaveric material had a listed cause of death due to trauma. All cadaveric material was supplied by the Department of Anatomy and Developmental Biology, School of Biomedical Sciences, The University of Queensland. All cadavers used in this study were donated in accordance with the Queensland Transplantation and Anatomy Act 1979 (as amended). Ethical approval for this study was obtained from the University of Queensland. Characteristics of the study specimens are provided in Table 7.1.

## 7.2.2 Preparation of cadaveric material

Specimens were reduced to a section spanning the interval of the occiput to the level of the C2/3 intervertebral disc. Specimens were then divested of all muscle tissue, leaving an osteoligamentous arrangement of a size which could be encased in the bore of the 4.6T MRI scanner.

Each specimen was prepared using an approach based upon the dissection technique described by Dvorak et al (1988). A posterior wedge of approximately 140° was removed from the occipital bone. The posterior arch of the atlas was then resected and a wide laminectomy performed to remove the posterior elements of the axis, thereby exposing the internal soft tissue elements of the vertebral canal.

The dura mater was not removed for this study due to its previously described intimate relationship with the tectorial membrane. It was considered that removal of the dura mater risked unnecessary disruption of fibres of the tectorial membrane and its presence would more closely replicate imaging taken in the clinical setting.

Prior to imaging, each specimen was hydrated for twenty-four hours in a 20% propylene glycol solution to enhance response to the MRI signal. Specimens were then encased in 65mm diameter plastic cylinders. The space surrounding the specimens was filled with Fomblin oil, a high density perfluropolyether derivative, to minimise vibration movement of the specimen during scanning. The use of Fomblin also provides improved image contrast as it provides a completely dark background on the MR image since it does not contain hydrogen protons (Magnitsky et al., 2005).

## 7.2.3 Imaging of specimens

High resolution images were acquired on a Bruker (Ettlingen, Germany) animal magnetic resonance imaging system consisting of a 4.6T magnet interfaced to an AVANCE spectrometer running ParaVision 4.0. A 3D RARE multiple spin echo sequence was used with the following parameters: TR = 2 sec, echo train length = 8, effective TE = 56, SW = 100000Hz, field-of-view (FOV) = 80 x 80 x 45 mm, acquisition matrix = 512 x 512 x 256, image resolution = 0.156 x 0.156 x 0.176 mm. The total acquisition time for each specimen was 18 hours, 24 minutes.

Clinical definition images were acquired using a 3T Siemens TRIO MRI system (Siemens AG, Erlagen, Germany) using a 12 channel head coil. Three sequences were acquired to see which sequence gave the best anatomic detail. SPACE 3D spine echo images were acquired with the following parameters: TR = 500 ms, TE = 29 ms, FOV =  $220 \times 220 \times 72$  mm, acquisition matrix =  $256 \times 256 \times 80$ , image resolution =  $0.9 \times 0.9 \times 0.9 \times 0.9$  mm, number of averages = 4, imaging time = 6.5 minutes. Turbo spin echo 2D coronal slices with the following parameters: TR = 1000 ms, TE = 39 ms, FOV =  $150 \times 112.5$  mm, acquisition matrix =  $320 \times 240$ , image resolution =  $0.5 \times 0.5$  mm, slice thickness = 1.5 mm, number of slices = 50, turbo factor = 3, number of averages = 2, imaging time = 8 min. Turbo spin echo 2D axial slices were acquired with the following parameters: TR = 2200 ms, TE =10 ms, FOV =  $120 \times 120$  mm, acquisition matrix =  $256 \times 256$ , image resolution 0.5 mm x 0.5 mm, slice thickness = 2 mm, number of slices = 40, turbo factor = 21, number of slices = 40, turbo factor = 21, number of slices = 3, acquisition time = 7.5 min.

Images from each acquisition were exported in DICOM format for analysis and stored on compact disc. Viewing and analysis of images was performed using OsiriX 3.5 image processing software (Osirix Foundation, Geneva, Switzerland). Examination and measurement of each of the ligaments was undertaken using a multiplanar reconstruction of the acquired data.

The clarity of the craniocervical ligaments viewed in images acquired at clinical definition was assessed according to the classification system previously used by

Pfirrmann et al. (2001), whereby ligament structure is categorised on a three point scale as;

- a. Well defined with regular contours
- b. Defined with irregular contours, or
- c. Unable to be differentiated from surrounding tissue.

Data were collected from all images acquired in both 4.6-T and 3-T upon viewing in three orthogonal planes; sagittal, coronal and axial. Detailed descriptions of the structure and the attachment sites of each ligament were recorded.

Morphometric measurements were made for each ligament. For the alar ligaments, measures included length, cephalo-caudal height, antero-posterior width, attachment distance in relation to the tip of the odontoid process, and angle of orientation of the ligaments in both coronal and axial planes. Transverse ligament measures included cephalo-caudal height, antero-posterior thickness, and length of both anterior and posterior margins of the ligament in axial section. Measurements of the tectorial membrane included antero-posterior thickness, and distance of attachment onto the internal surface of the occiput.

All observations and measurements were recorded independently of previous observations and acquisitions. Through blinding to reports from examinations of the specimens at other resolutions and acquisition sequences, a non-biased appraisal of the structure and dimensions of the ligaments could be ensured.

#### 7.2.4 Analysis of quantitative morphometric data

Morphometric measurements were summarised using descriptive statistics to represent the values obtained from each specimen using each acquisition sequence.

The equivalence of measurements was obtained using the four different acquisitions examined. Each morphometric measurement obtained from each acquisition sequence was considered to be a distinct variable. Differences in central tendency of the four groups were initially assessed using the Kruskel-Wallis test for equality of group median values. A p-value of less than 0.05 was taken to indicate statistical significance. Where a statistically significant finding was elicited indicating that at least one of the group medians differed from the measurements obtained from other acquisitions, comparison was performed between the measurements obtained from each 3-T acquisition and the measurements from the 4.6-T derived images using the Wilcoxon sign rank test to assess dependent variables. Again, a p-value on this test of less than 0.05 was taken to indicate statistical significance.

#### 7.2.5 Confirmatory dissection

Following imaging, each specimen was dissected in a manner consistent with the methods previously given in descriptive anatomical studies. The tectorial membrane, ascending and descending cruciform ligaments, the transverse ligament of the atlas and the alar ligaments were examined by fine dissection. Each structure was systematically dissected by resection of collagen bundles small enough to be grasped with sharpened

jeweller's forceps. As bundles were stripped and removed, the orientation, location and attachment sites were recorded descriptively and photographically. Superficial layers were resected to reveal deep layers which were then resected in a similar manner.

Descriptions derived from dissection of each specimen were then compared to the descriptions derived from examination of each specimen at high resolution. Direct comparison of these findings was used to confirm that the high resolution images were reflective of the actual anatomical structure of the specimens and hence, suitable reference studies against which the clinical definition images could be accurately compared.

Specimen number	Gender	Age at death	Reported cause of death	Other medical conditions	Embalming fluid
3756	Female	58	Acute coronary occlusion	Marfan's syndrome	Adelaide mix Plasdopake
3714	Male	92	Hydrostatic pneumonia	Carcinoma of the lung	Adelaide mix Plasdopake, Mold X
3753	Male	90	Bronchopneumonia	Coronary atherosclerosis	Adelaide mix Plasdopake
3750	Female	94	Cerebrovascular accident	-	Adelaide mix Plasdopake
3739	Male	74	Renal failure	Type 2 diabetes Ischaemic heart disease	Adelaide mix Plasdopake
3665	Male	79	Hydrostatic pneumonia	Metastatic carcinoma Prostate carcinoma	Adelaide mix Plasdopake, Mold X

## 7.3 Results

## 7.3.1 Study specimens

The six specimens examined in this study consisted of two female and four male cadavers ranging in age from 58 to 94 years (mean age 81.2 years). No specimen included in this study had a cause of death due to trauma.

# 7.3.2 High resolution imaging – 4.6 T

## Alar ligaments

The structure, borders and attachments of the alar ligaments could be reliably viewed in all six specimens passing from odontoid process to occiput. Each alar ligament consisted of fibres running longitudinally between two definable regions of bony attachment.

On coronal view, each alar ligament could be seen to be substantially originating from the lateral and posterolateral aspect of the superior portion of the odontoid process. The length of attachment down the odontoid process was substantial, often encompassing the majority of its length (Figure 7.1). The origin was always below the tip of the odontoid process, attaching on average 1.8mm inferior to it (Figure 7.2).

The alar ligaments passed laterally toward their attachments onto the occipital condyles. The average length of the ligaments was 9.5mm (range 6.9 to 11.1mm). On their path laterally, the ligaments reduced in measured superior-inferior height, producing a tapered appearance from an average height medially of 7mm down to 3.5mm laterally.



**Figure 7.1** The alar ligaments (indicated by arrows) in coronal section acquired using imaging at 4.6T. The fibres of the ligament can be seen passing in a lateral direction between the odontoid process and the occiput.



**Figure 7.2** The alar ligaments in coronal section acquired using imaging at 4.6T. Attachment to the odontoid process is below the level of the tip as indicated by the arrow.

Insertion could be clearly visualised occurring into the medial aspect of the inferior portion of the occipital condyles, slightly superior and anterior to the atlanto-occipital joints. In all six specimens, inferior fibres of the alar ligaments could also be seen to blend with the medial aspect of the atlanto-occipital joints providing the appearance of a distinct contribution of the alar ligaments to the medial aspect of the joint itself (Figure 7.3).

The orientation of each alar ligament was measured with respect to the midline of the odontoid process. The method of calculating this angle is indicated in Figure 7.4. The orientation appeared to be primarily horizontal in five of the six specimens, with angles measured between 81° and 94°. One specimen was observed to have a distinctly shorter odontoid process relative to the occipital condyles. The alar ligaments in this specimen assumed a more cranial orientation measured as 114° and 111°. Side to side asymmetry was common with variation in the direction of ligament orientation observed within individual specimens. A detailed description of individual ligament characteristics in coronal view in each specimen is provided in Table 7.2.



**Figure 7.3** Alar ligaments in coronal view acquired using imaging at 4.6T. Attachment onto the occiput is indicated by the arrow. Blending of the inferior fibres of the alar ligament into the medial aspect of the atlantooccipital joint is indicated by the circled area.



**Figure 7.4** Calculation of the angle of orientation of the alar ligaments with respect to the midline of the odontoid process. The measured angle is indicated by the symbol  $\theta$ . Image acquired at 4.6T.

# **Table 7.2**Measurements and observations obtained from 4.6 tesla MRI examination<br/>of the alar ligaments in coronal view.

Specimen number	Length - medial to lateral (mm)	Height – medial (mm)	Height – lateral (mm)	Distance of attachment below tip of odontoid process (mm)	Orientation with respect to vertical axis of odontoid process (degrees)	Attachment into O-C1 medial joint capsule
3756	Left 11.1 Right 11.1	Left 6.7 Right 6.7	Left 3.2 Right 3.8	0.0	Left 91.8° Right 94.0°	Visible
3714	Left 10.0 Right 10.7	Left 7.4 Right 8.7	Left 3.5 Right 4.4	2.9	Left 88.3° Right 91.7°	Visible
3753	Left 8.2 Right 9.0	Left 7.8 Right 8.1	Left 2.6 Right 4.5	2.7	Left 85.6° Right 88.3°	Visible
3750	Left 8.8 Right 10.6	Left 5.3 Right 4.6	Left 3.0 Right 2.3	2.6	Left 87.2° Right 81.0°	Visible
3739	Left 7.7 Right 6.9	Left 4.8 Right 5.9	Left 3.7 Right 4.1	0.7	Left 114.3° Right 111.3°	Visible
3665	Left 8.4 Right 11.0	Left 9.4 Right 8.7	Left 3.5 Right 3.6	2.1	Left 87.4° Right 89.8°	Visible

On sagittal view, the alar ligaments were examined in cross-section along their course. Medially, the cross-sectional shape was primarily round with a mean diameter in these specimens of 5.1 mm. Viewed in cross-section toward their insertion, five ligaments had become more ovoid in shape due to a reduction in height. One had assumed a crescent shape with the convex surface facing postero-superiorly. Mean dimensions of the alar ligaments in cross section were 6.3 mm in the antero-posterior direction and 2.9 mm in the superior-inferior direction. The cross sectional shape of the alar ligaments is indicated in Figures 7.5 a and b.

In axial view, the alar ligaments could be very clearly delineated along their entire path from dens to occiput (Figure 7.6). The fibres of each alar ligament were oriented in a medial-lateral direction between these points of bony attachment. The length of each ligament was measured in this plane, averaging 10.2 mm, with a mean width immediately distal to the odontoid process of 4.3 mm. The ligaments each passed in an obliquely posterior direction creating an average included angle between the ligaments of 137.4 degrees. A detailed description of individual ligament characteristics in axial view in each specimen is provided in Table 7.3.

As noted in the coronal examination, an element of the anterior fibres of the alar ligaments could be traced back to a communication with the medial aspect of the atlantooccipital joint when viewed in horizontal section. However, unlike the coronal view, this could not be clearly visualised in all specimens. Of the 12 alar ligaments examined, only six could be clearly seen to provide a contribution to the medial aspect of the atlantooccipital joint (Figure 7.7).

Five of the six pairs of alar ligaments also contained a proportion of fibres that completely traversed the dens without attachment (Figure 7.8). The breadth of these bands varied between specimens with a mean thickness over six specimens of 1.0mm. In the five specimens where this was evident this band comprised approximately 27% of the antero-posterior width of the ligament.

No atlantal portion of the alar ligament was noted in any viewed plane in any specimen examined.





**Figure 7.5.** Sagital views demonstrating the alar ligaments in cross section (indicated by arrows) acquired using imaging at 4.6T. a. Medial aspect. b. Lateral aspect.



**Figure 7.6** The alar ligaments viewed in axial section acquired using imaging at 4.6T. Fibre orientation is visible medial to lateral between the odontoid process and the occipital condyle attachments.



**Figure 7.7** The alar ligaments viewed in axial section acquired using imaging at 4.6T. Fibres of the alar ligament blending into the medial aspect of the atlant-occipital joint indicated by circled region.



**Figure 7.8** The alar ligaments viewed in axial section acquired using imaging at 4.6T. Fibres of the alar ligaments traversing the odontoid process indicated by the arrow.

**Table 7.3**Measurements and observations obtained from 4.6 tesla MRI examination<br/>of the alar ligaments in axial view.

Specimen number	Length (mm)	Width immediately distal to odontoid process (mm)	Included angle between alar ligaments	Attachment into O-C1 medial joint capsule	Depth of fibres traversing odontoid process (mm)
3756	Left 10.7 Right 10.9	Left 3.6 Right 3.4	Posterior 172.9°	Left visible Right visible	0.3
3714	Left 11.7 Right 9.5	Left 4.8 Right 4.1	Posterior 147.7°	Left visible Right visible	0
3753	Left 10.6 Right 10.2	Left 4.3 Right 4.2	Posterior 120.9°	Left not visible Right not visible	0.8
3750	Left 10.7 Right 10.9	Left 4.9 Right 5.3	Posterior 119.4°	Left not visible Right not visible	2.2
3739	Left 7.9 Right 8.4	Left 3.6 Right 3.5	Posterior 126.2°	Left not visible Right visible	1.0
3665	Left 10.1 Right 10.3	Left 5.6 Right 4.4	Posterior 137.3°	Left visible Right not visible	1.5

#### Ascending and descending cruciform ligaments

Ascending and descending cruciform ligaments were assessed using a sagittal section. This section was obtained by selecting a midline plane in coronal section passing through the centre of the odontoid process (Figure 7.9).

Ascending cruciform ligaments could be viewed in four of the six specimens examined. They consisted of an upward projection from the superior portion of the transverse ligament. The points of attachment of each ligament, as well as their anterior and posterior borders were poorly defined in this view. Where present, ascending cruciform ligament length ranged from measured lengths of 7.6 mm to 14.7 mm, with an average length of 11.0 mm.

No descending cruciform ligaments could be clearly identified or meaningfully measured in any sequence examined.

## Transverse ligament

The transverse ligament could be clearly defined on both axial and sagittal plane images. All end points and borders of this structure could be accurately marked for description and measurement purposes.

In midline sagittal view, the transverse ligament appears in cross section as a dense elliptical structure located posteriorly against the dens (Figure 7.10). Measured anteroposteriorly, the transverse ligaments examined had a mean thickness of 2.4mm.



**Figure 7.9** Ascending cruciform ligament in sagittal view indicated by the arrow. Image acquired at 4.6T. The vertical height of the ligaments ranged from 7.1mm to 12.4mm with a mean height of 9.8mm. A detailed summary of the characteristics of individual transverse ligaments examined in provided in Table 7.4.

In horizontal section, the transverse ligament is seen as a broad, clearly distinguishable band arcing around the posterior aspect of the odontoid process. Concave anteriorly, it consists of parallel fibres running between tubercles situated on either side of the medial aspect of the lateral masses of the atlas (Figure 7.11).

Measured in the midline, the specimens examined had a mean anterior to posterior thickness of 3.44mm. As the ligaments progressed toward their insertion onto the atlantal tubercles, a broadening of the ligament was observed in all specimens which served to increase the surface area of attachment of each end of the ligament. Immediately proximal to the attachments, the mean thickness of the transverse ligaments examined increased to 4.7mm. This was achieved through a flattening of the posterior margin of the ligament such that it the curve formed by this margin followed a greater radius than the anterior margin. The mean length of the posterior margin of the transverse ligament, measured tubercle to tubercle, was 26.7mm. The anterior margins examined in this series had a mean length of 21.8mm. A summary of the characteristics of individual transverse ligaments is provided in Table 7.4.



**Figure 7.10** Midline sagittal view acquired using imaging at 4.6T. The transverse ligament is viewed in cross section.



**Figure 7.11** The transverse ligament in axial view acquired using imaging at 4.6T. The atlantal tubercles for attachment of the transverse ligament are indicated by white arrows. The transverse ligament is indicated by the blue arrow.

Table 7.4	Measurements and observations obtained from 4.6 tesla MRI examination
	of the transverse ligaments in sagittal and axial views.

- ·	Sagitta	al view	Horizontal view						
Specimen number	Midline antero- posterior thickness (mm)	Vertical height (mm)	Midline antero- posterior thickness (mm)	Length of anterior margin (mm)	Length of posterior margin (mm)	Antero-posterior thickness by atlantal tubercle (mm)			
3756	1.2	7.1	2.1	24.6	31.9	Left 5.2 Right 5.7			
3714	3.0	12.4	5.2	16.9	25.9	Left 4.9 Right 5.7			
3753	2.6	9.6	2.7	23.5	26.8	Left 4.8 Right 4.6			
3750	3.2	10.2	3.7	20.2	24.2	Left 4.5 Right 4.7			
3739	2.0	9.5	4.2	21.1	23.8	Left 3.4 Right 3.7			
3665	2.6	9.8	2.8	24.4	27.7	Left 5.2 Right 4.7			

#### **Tectorial membrane**

The tectorial membrane could be identified on each specimen in both sagittal and horizontal sections. Compared to the other ligaments examined, points of attachment were less clearly discernible. This was due to the more diffuse attachments of this structure.

In midline sagittal section, the tectorial membrane was intimately related to the dura. Below the level of the transverse ligament, it could be seen to consist of two distinct layers (Figure 7.12a). The deeper layer could be seen to attach into the posterior aspect of the body of the axis. The superficial layer extended beyond the inferior limit of the dissection. This was evident in five of the six specimens examined. As the tectorial membrane passed over the superior third of the odontoid process, its antero-posterior thickness reduced. At this point, distinct layers of the structure could not be discerned and a clear distinction between the dura and the tectorial membrane could not be made in three of the six specimens. Above the level of the odontoid process, layering of the structure could be seen in only two of the six specimens in midline section (Figure 7.12b). Attachment onto the occiput occurred above the level of the basion in all six specimens. Whilst insertion into the occiput was diffuse, the attachment distance above the basion was measured as ranging from 2.5mm to 8.7mm. For the six specimens, the mean of the measured attachment distances onto the occiput were from 5.8mm caudally to 12.8mm cranially.

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a.

b.

**Figure 7.12** a. The two layers of the tectorial membrane visible below the level of the transverse ligament (A) indicated by the arrows. Attachment can be seen onto the posterior aspect of the axis (B).

b. Layering of the tectorial membrane above the level of the transverse ligament (A) and odontoid process (B) indicated by the arrow. The basion is also indicated (C). Images acquired at 4.6T.

As the sagittal section was panned laterally, the tectorial membrane increased in anteroposterior thickness. Separation of the structure into two layers could again be seen both above and below the level of the transverse ligament in four of the six specimens.

In axial section, the tectorial membrane could be traced along its path from axis to occiput. A substantial insertion into the posterior aspect of the body of the axis could be seen in four of the six specimens (Figure 7.13). Examining inferiorly to superiorly, the tectorial membrane thinned substantially in its anteroposterior dimension centrally as it passed over the superior aspect of the odontoid process. The lateral aspects of the structure could be seen to comparatively maintain a greater cross sectional area (Figure 7.14). The mean anteroposterior thickness of the tectorial membrane overlying the transverse ligament was 1.1mm centrally and 1.7mm laterally. These dimensions increased at the level of the alar ligaments to 1.3mm centrally and 1.9mm laterally.



**Figure 7.13** Axial view acquired at 4.6T demonstrating the attachment of the tectorial membrane onto the posterior aspect of the vertebral body of the axis.



**Figure 7.14** The lateral aspects of the tectorial membrane demonstrating increased thickness in the antero-posterior dimension either side of the midline. Viewed in axial section. Image acquired at 4.6T.

#### 7.3.3 Clinical resolution imaging

The quality of image used in the analysis was affected by both the sequence used to acquire the image and by the plane in which the image was acquired. The image quality was highest when viewed in the plane of acquisition. Accurately defining borders and attachments of the ligaments was more problematic in reconstructions in other planes.

# Alar ligaments

# *i.* T2 space 3D spin echo sequence

The structure of the alar ligaments was poorly defined in coronal view using this acquisition sequence. Of the 12 alar ligaments under examination, only four could be described as defined with irregular contours, while the remaining eight ligaments could not be clearly defined at all.

Where the alar ligaments were discernible for examination, they consisted of a single band of tissue extending laterally from the superior aspect of the odontoid process to the occiput (Figure 7.15). The mean length of the ligaments between points of bony attachment was 9.3mm. Attachment to the odontoid process was below the level of its tip. Clearly discernible in three of the six specimens, the odontoid attachment commenced at a mean distance of 0.8mm below the tip of the process. The ligaments tapered as they progressed laterally. Measured immediately adjacent to the odontoid process, the mean superior-inferior height was 6.2mm. This reduced to a mean height of 3.5mm proximal to the attachment onto the occiput. The orientation of the individual alar ligaments was primarily horizontal with a mean angle of 93.8° measured with respect to the midline of the odontoid process. Occipital attachment could be seen onto the internal surface of the condyles. However, no contribution of any proportion of fibres was visible blending into the medial aspect of the joint capsule of the atlanto-occiptal joints at this resolution.

In axial view, the alar ligaments could be more distinctly defined (Figure 7.16). Nine of the twelve ligaments were categorised at discernible, while three could not be clearly distinguished from the surrounding tissue to be accurately described and measured. Measured medially to laterally, the mean length of the ligaments in this plane was 9.4mm (range 8.1 to 10.1mm) and their mean width was calculated as 4.4mm (range 3.3 to 5.4mm). Each alar ligament passed posterolaterally from the odontoid attachment to create a mean included angle between ligaments of 135.4°. Individual angles measured ranged from 117.9° to 172.2° posteriorly. At this resolution, a proportion of fibres could be discerned passing posterior to the odontoid process without attachment to it in two specimens. The mean thickness of these fibres overlying the odontoid process was 1.1mm. Communication with the medial aspect of the atlanto-occipital joints was not visible in any specimen examined using these imaging parameters. Cross sections of the alar ligaments could be determined in three specimens on viewing in the sagittal plane. Medially, each ligament was rounded in shape, flattening in superior to inferior dimension to a more ovoid shape as the cross section was viewed laterally. The individual measurements and observations for each specimen using this acquisition are provided in Table 7.5.

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Figure 7.15 Coronal view of alar ligaments with T2-weighted space spin echo sequence.



Figure 7.16 Axial view of alar ligaments with T2-weighted space spin echo sequence.

Table 7.5	Measurements and	observations	of the alar ligaments	s obtained at 3-Tesla	using T2 s	pace 3D s	pin echo acq	uisition
			4 /		4 /			

T2 space 3D spin echo	Coronal view							Axial view					
Specimen number	Rating of clarity	Length - medial to lateral (mm)	Height – medial (mm)	Height – lateral (mm)	Distance of attachment below tip of odontoid	process (mm) Orientation with respect to vertical axis of odontoid process (degrees)	Attachment into O-C1 medial joint capsule	Rating of clarity	Length (mm)	Width immediately distal to odontoid process (mm)	Included angle between alar ligaments (degrees)	Attachment into O-C1 medial joint capsule	Depth of fibres traversing odontoid process (mm)
3756	Left B Right B	Left 10.0 Right 9.3	Left 6.8 Right 6.6	Left Right	3.4 0.4 3.9	Left 90.0° Right 93.4°	Not visible	Left B Right B	Left 9.7 Right 9.5	Left 3.5 Right 3.3	Posterior 172.2°	Left not visible Right not visible	Not visible
3714	Left B Right C	Left 9.8 Right NA	Left 5.6 Right NA	Left Right	4.2 2.1 NA	Left 94.0° Right NA	Not visible	Left B Right C	Left 9.5 Right 9.5	Left 4.5 Right 4.0	Posterior 145.1°	Left not visible Right not visible	Not visible
3753	Left B Right C	Left 8.2 Right NA	Left 5.7 Right NA	Left Right	2.6 0 NA	Left 97.8° Right NA	Not visible	Left C Right C	Left NA Right NA	Left NA Right NA	NA	NA	Not visible
3750	Left C Right C	Left NA Right NA	Left NA Right NA	Left Right	NA NA NA	Left NA Right NA	Not visible	Left B Right B	Left 9.7 Right 8.9	Left 4.8 Right 4.6	Posterior 117.9°	Left not visible Right not visible	Not visible
3739	Left C Right C	Left NA Right NA	Left NA Right NA	Left Right	NA NA NA	Left NA Right NA	Not visible	Left B Right B	Left 8.7 Right 8.2	Left 4.7 Right 4.6	Posterior 119.2°	Left not visible Right not visible	1.2
3665	Left C Right C	Left NA Right NA	Left NA Right NA	Left Right	NA NA NA	Left NA Right NA	Not visible	Left B Right B	Left 10.1 Right 10.1	Left 5.4 Right 4.7	Posterior 122.4°	Left visible Right not visible	1.0

Legend: A = well defined with regular contours, B = defined with irregular contours, C = unable to differentiate from surrounding tissue
# *ii. T1 turbo spin echo sequence*

The coronal plane acquisition of this sequence yielded improved definition of the alar ligaments in coronal view. Of the 12 ligaments examined, ten were classified as defined with irregular contours. Only two ligaments, both ligaments from specimen 3750, were unable to be differentiated from the surrounding tissue.

Each alar ligament was viewed as a single band of tissue extending from the superior portion of the odontoid process and passing laterally to attach onto the occipital condyle. The mean length of the ligaments was estimated as 9.1 mm (range 7.1 to 10.6 mm). The odontoid attachment could clearly be distinguished as forming below the level of the tip of the odontoid process in five of the six specimens. The mean distance of attachment of the alar ligaments inferior to the odontoid tip was 1.3 mm (range 0 to 2.5 mm). The alar ligaments assumed a tapered appearance as they progressed laterally reducing from a mean height of 7.2 mm adjacent to the odontoid process to 3.8 mm adjacent to their lateral attachment. The orientation of the ten discernible ligaments with respect to the midline of the odontoid process ranged from horizontal to slightly cephalad with a mean angle estimate of 98.2°. A contribution of fibres reinforcing the medial aspect of the atlanto-occipital joint was observed in three of the ten ligaments assessed (Figure 7.17).

In axial view, the ability to accurately discern the alar ligaments was poor. Only two ligaments were classified as defined with the remaining ten ligaments unable to be discerned from the surrounding tissue in sufficient detail to accurately report on the borders of the ligaments or their attachment onto the dens or occiput. All measurements in the axial plane were recorded from images of specimen 3714.

Measurements and observations recorded from this acquisition sequence in both coronal and axial views are provided in Table 7.6.



**Figure 7.17** The alar ligaments in coronal view using a T1-weighted turbo spin echo sequence. Inferolaterally, the alar ligaments can be seen passing to the medial aspect of the atlanto-occipital joint.

Table 7.6	Measurements and	observations	of the alar	ligaments	obtained at 3-7	Fesla using	T1 turbo s	pin echo ac	quisition.
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T1 turbo spin echo		Coronal view								Axi	al view		
Specimen number	Rating of clarity	Length - medial to lateral (mm)	Height – medial (mm)	Height – lateral (mm)	Distance of attachment below tip of odontoid process (mm)	Orientation with respect to vertical axis of odontoid process (degrees)	Attachment into O-C1 medial joint capsule	Rating of clarity	Length (mm)	Width immediately distal to odontoid process (mm)	Included angle between alar ligaments (degrees)	Attachment into O-C1 medial joint capsule	Depth of fibres traversing odontoid process (mm)
3756	Left B Right B	Left 9.3 Right 10.1	Left 6.7 Right 6.5	Left 3.5 Right 3.6	0.6	Left 90.0° Right 93.2°	Not visible	Left C Right C	Left NA Right NA	Left NA Right NA	NA	Left not visible Right not visible	Not visible
3714	Left B Right B	Left 9.3 Right 10.6	Left 7.6 Right 7.1	Left 3.9 Right 4.0	2.5	Left 94.1° Right 89.8°	Visible	Left B Right B	Left 10.2 Right 10.1	Left 3.9 Right 4.3	Posterior 141.1°	Left not visible Right not visible	Not visible
3753	Left B Right B	Left 8.1 Right 9.2	Left 8.0 Right 8.1	Left 3.0 Right 3.9	1.9	Left 97.8° Right 90.0°	Visible right	Left C Right C	Left NA Right NA	Left NA Right NA	NA	NA	Not visible
3750	Left C Right C	Left NA Right NA	Left NA Right NA	Left NA Right NA	NA	Left NA Right NA	Not visible	Left C Right C	Left NA Right NA	Left NA Right NA	NA	Left not visible Right not visible	Not visible
3739	Left B Right B	Left 7.7 Right 7.1	Left 5.0 Right 5.7	Left 3.5 Right 3.8	0	Left 116.3° Right 114.4°	Not visible	Left C Right C	Left NA Right NA	Left NA Right NA	NA	Left not visible Right not visible	Not visible
3665	Left B Right B	Left 9.3 Right 10.0	Left 9.0 Right 8.0	Left 4.0 Right 4.4	2.0	Left 102.3° Right 94.1°	Not visible	Left C Right C	Left NA Right NA	Left NA Right NA	NA	Left not visible Right not visible	Not visible

Legend: A = well defined with regular contours, B = defined with irregular contours, C = unable to differentiate from surrounding tissue

# *iii.* Proton density-weighted 2D turbo spin echo sequence

In coronal section, seven alar ligaments were classified as defined with irregular contours, while five ligaments were not able to be differentiated from the surrounding tissue using the proton density-weighted axially acquired sequence.

Consistent with previous observations, only occipital bands of the alar ligaments were visible in each specimen extending from the superior aspect of the odontoid process to the occipital condyles. The mean length of the seven assessable ligaments was 7.9 mm (range 6.9 to 9.3 mm). An estimation of the distance of the superior attachment of the alar ligaments from the tip of the odontoid process was only possible in two specimens due to image quality. The mean distance calculated for this interval was 1.6 mm. Tapering of the alar ligaments was clearly evident as the structure passed laterally, reducing from a mean height of 6.1 mm adjacent to the odontoid process to a mean height of 3.5 mm laterally as it approached the occipital insertion. The oriention of the alar ligaments with respect to the midline of the odontoid process was estimated in five ligaments only. The angles measured ranged from 87.6° to 119.6° (mean angle 101.3°). No contribution of the alar ligaments to the medial aspect of the atlanto-occipital joints was observed in any specimen in images acquired using this sequence.

In axial view, 11 of the 12 ligaments could be defined on images obtained using this sequence (Figure 7.18). The mean ligament length in this plane was 9.1 mm (range 7.2 to 10.8 mm) and the mean ligament width adjacent to the odontoid process was 4.4 mm

(range 3.6 to 5.3 mm). The included angle between alar ligaments was oriented posteriorly and ranged from 120.4° to 167.2° (mean angle 135.9°). A proportion of fibres of the alar ligaments traversing the odontoid process was recorded in two specimens, with a mean depth of these traversing bands of 1.1 mm. Attachment of a portion of the alar ligaments into the medial aspect of the atlanto-occipital joint capsule was visible on one side in one specimen only on axial view.



**Figure 7.18** The alar ligaments in axial view as seen using a proton density-weighted 2D turbo spin echo sequence.

Table 7.7	Measurements and observations of the alar ligaments obtained at 3-Tesla acquired using a proton density-weighted 2D
	turbo spin echo sequence.

Proton density weighted 2D turbo spin echo	Coronal view							Axial view					
Specimen number	Rating of clarity	Length - medial to lateral (mm)	Height – medial (mm)	Height – lateral (mm)	Distance of attachment below tip of odontoid process (mm)	Orientation with respect to vertical axis of odontoid process (degrees)	Attachment into O-C1 medial joint capsule	Rating of clarity	Length (mm)	Width immediately distal to odontoid process (mm)	Included angle between alar ligaments (degrees)	Attachment into O-Cl medial joint capsule	Depth of fibres traversing odontoid process (mm)
3756	Left B Right B	Left 8.1 Right 8.1	Left 6.1 Right 6.3	Left 2.7 Right 3.9	0.9	Left NA Right NA	Not visible	Left B Right B	Left 7.2 Right 7.3	Left 3.7 Right 3.6	Posterior 167.2°	Left not visible Right not visible	Not visible
3714	Left B Right B	Left 9.3 Right 8.3	Left 7.6 Right 7.8	Left 3.7 Right 3.7	2.3	Left 92.3° Right 93.1	Not visible	Left C Right B	Left NA Right 9.4	Left NA Right 4.7	NA	Left not visible Right not visible	Not visible
3753	Left C Right C	Left NA Right NA	Left NA Right NA	Left NA Right NA	NA	Left NA Right NA	Not visible	Left B Right B	Left 10.8 Right 10.3	Left 3.9 Right 4.0	Posterior 120.4°	Left not visible Right not visible	0.8
3750	Left B Right C	Left 7.3 Right NA	Left 5.1 Right NA	Left 3.8 Right NA	Not visible	Left 87.6° Right NA	Not visible	Left B Right B	Left 10.0 Right 9.2	Left 5.0 Right 4.0	Posterior 122.7°	Left not visible Right not visible	1.3
3739	Left B Right B	Left 7.2 Right 6.9	Left 5.1 Right 5.0	Left 3.1 Right 4.0	Not visible	Left 119.6° Right113.8°	Not visible	Left B Right B	Left 8.3 Right 8.5	Left 4.6 Right 4.0	Posterior 129.8°	Left not visible Right not visible	Not visible
3665	Left C Right C	Left NA Right NA	Left NA Right NA	Left NA Right NA	NA	Left NA Right NA	Not visible	Left B Right B	Left 9.3 Right 10.1	Left 5.3 Right 5.0	Posterior 139.4°	Left visible Right not visible	Not visible

Legend: A = well defined with regular contours, B = defined with irregular contours, C = unable to differentiate from surrounding tissue

# Transverse and cruciform ligaments

#### *i.* T2 space 3D spin echo sequence

In sagittal view, the transverse ligaments of five of the six specimens could be discerned. One specimen was classified as well defined with regular contours, whilst four were classified as defined with irregular contours.

In midline section, the transverse ligament was viewed in cross section as an elliptical structure (Figure 7.19). No ascending or descending cruciform ligaments could be distinguished in any specimen using this acquisition. The mean midline antero-posterior thickness of the ligament in this plane was estimated to be 2.4 mm and the mean height measured superior to inferior was 9.6 mm. Measurements and observations from images assessed in the sagittal plane are provided in Table 7.8.

In axial view, the image quality of five of the six specimens was classified as defined with irregular contours. The transverse ligament of the remaining specimen was unable to be clearly distinguished from the surrounding tissue for the purposes of description and measurement.

Observations of the borders of the transverse ligament were consistent with previous descriptions at higher resolution, with attachment onto the transverse tubercles of the atlas either side of the odontoid process (Figure 7.20). The mean antero-posterior thickness of the ligament was calculated as 2.8 mm centrally, expanding to 3.4 mm lateral

to the point of bony attachment. The mean lengths of the margins of the ligament were calculated as 22.8 mm posteriorly and 20.4 mm anteriorly. The measurements from individual specimens are provided in Table 7.9.



**Figure 7.19** The transverse ligament in sagittal view using a T2 space 3D spin echo sequence. The ligament appears as an elliptical structure located posteriorly adjacent to the odontoid process.



**Figure 7.20** The transverse ligament in axial view using a T2 space 3D spin echo sequence

# *ii. T1 turbo spin echo sequence*

The structure of the transverse ligament was poorly defined when examined in sagittal view using this acquisition sequence. Of the six specimens analysed, four were unable to be adequately differentiated from surrounding tissue for either description or measurement. The transverse ligament of one specimen was defined with irregular contours and the transverse ligament of another specimen could be clearly defined and measured (Figure 7.21).

Based upon observations from the two transverse ligaments deemed suitable for measurement, the mean midline antero-posterior thickness of the ligaments was 2.6 mm and the mean inferior to superior height was calculated as 10.1 mm. No ascending or descending cruciform ligaments were noted in any specimen examined. A summary of measurements is provided in Table 7.8.



**Figure 7.21** The transverse ligament in sagital view using a T1-weighted turbo spin echo sequence

In axial view, the transverse ligament of only one specimen could be differentiated from surrounding tissue and in this case, the borders were classified as irregular and not clearly defined (Figure 7.22). The single specimen measured had an antero-posterior thickness of 2.5 mm in the midline, expanding to a mean thickness of 3.6 mm adjacent to the attachments onto the atlantal tubercles. In contrast to measurements of the length of the margins of this ligament using other acquisition sequences, there was little difference in the measured lengths between the anterior and posterior aspects of the ligament. Anteriorly, the ligament length was measured as 19.7 mm and the posterior aspect of the ligament was measured as 19.9 mm. All measurements for the specimen are provided in Table 7.9.



**Figure 7.22** The transverse ligament of the atlas in axial view using a T1-weighted turbo spin echo sequence.

## *iii.* Proton density-weighted 2D turbo spin echo sequence

In sagittal view, the transverse ligaments of five specimens could be discerned using a proton density-weighted acquisition. One specimen was classified as defined with regular contours, whilst another four were classified as defined with irregular contours.

Elliptical in cross-section when viewed in the midline, the transverse ligaments had a mean antero-posterior thickness of 2.9 mm and a mean inferior to superior height calculated as 13.2 mm (Figure 7.23). An ascending cruciform ligament was noted in one specimen only. No descending cruciform ligaments were observed in any specimen in this view of this acquisition. A summary of measurements for each specimen is given in Table 7.8.

In axial view, the transverse ligament could be discerned in all six specimens passing around the posterior surface of the odontoid process between the two tubercular atlantal attachments (Figure 7.24). Two ligaments were classified as defined with regular contours, whilst the remaining four were classified as defined with irregular contours. The mean antero-posterior thickness of the ligament in midline was 2.6 mm. Adjacent to the insertions onto the atlas, the mean antero-posterior thickness of the ligaments was calculated as 3.8 mm. The mean length of the anterior margin of the ligament was 20.1 mm and the mean length of the posterior margin was 23.1 mm. Measurements for each specimen are provided in Table 7.9.

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**Figure 7.23** The transverse ligament in sagital view using a proton density-weighted 2D turbo spin echo sequence. The transverse ligament appears as an elliptical structure posterior to the odontoid process. The ascending cruciform ligament is visible arising from the superior margin of the transverse ligament.



**Figure 7.24** The transverse ligament in axial view extending between the atlantal tubercles seen using a proton density-weighted 2D turbo spin echo sequence.

# **Table 7.8**Measurements and observations for the transverse ligaments of eachspecimen obtained in sagittal section using all three acquisition sequences.

Specimen number	T S	2-weighte PACE 3D S	d E	T1	-weighted	TSE	Proton d	ensity-wei TSE	ghted 2D
	Image clarity	Midline antero- posterior thickness (mm)	Vertical height (mm)	Image clarity	Midline antero- posterior thickness (mm)	Vertical height (mm)	Image clarity	Midline antero- posterior thickness (mm)	Vertical height (mm)
3756	С	NA	NA	С	NA	NA	В	1.7	12.4
3714	A	3.0	10.8	В	4.0	12.0	A	5.1	16.4
3753	В	2.1	8.8	С	NA	NA	В	2.8	15.0
3750	В	2.7	8.6	A	1.2	8.1	С	NA	NA
3739	В	1.9	8.6	С	NA	NA	В	2.4	11.6
3665	В	2.5	11.1	С	NA	NA	В	2.5	10.8

Legend: SE = spin echo, TSE = turbo spin echo, A = well defined with regular contours, B = defined with irregular contours, C = unable to be difined, NA = not available

# Table 7.9 Measurements and observations for the transverse ligaments of each specimen obtained in axial section using all three

# acquisition sequences.

Specimen number		T2-weig	hted SPA	CE 3D SE			T1-	weighted	TSE		I	Proton den	sity-weig	hted 2D TS	SE .
	Image clarity	Midline antero- posterior thickness (mm)	Length of anterior margin (mm)	Length of posterior margin (mm)	Antero-posterior thickness by atlantal tubercle (mm)	Image clarity	Midline antero- posterior thickness (mm)	Length of anterior margin (mm)	Length of posterior margin (mm)	Antero-posterior thickness by atlantal tubercle (mm)	Image clarity	Midline antero- posterior thickness (mm)	Length of anterior margin (mm)	Length of posterior margin (mm)	Antero-posterior thickness by atlantal tubercle (mm)
3756	В	1.5	23.6	27.6	L 2.8 R 2.9	С	NA	NA	NA	NA	В	1.6	24.2	27.5	L 2.9 R 2.9
3714	В	2.9	19.4	20.1	L 3.5 R 4.7	С	NA	NA	NA	NA	В	2.2	17.3	20.0	L 2.9 R 2.9
3753	В	2.8	21.3	22.9	L 3.0 R 2.8	С	NA	NA	NA	NA	В	1.9	20.7	24.5	L 3.4 R 3.7
3750	В	3.8	20.2	24.5	L 3.9 R 2.7	В	2.5	19.7	19.9	L 3.5 R 3.6	А	2.8	19.8	23.4	L 4.1 R 3.9
3739	В	3.0	17.4	18.7	L 3.8 R 4.1	С	NA	NA	NA	NA	А	3.6	18.5	20.9	L 4.1 R 3.7
3665	С	NA	NA	NA	NA	С	NA	NA	NA	NA	В	3.7	19.8	22.0	L 5.4 R 5.7

Legend: SE = spin echo, TSE = turbo spin echo, A = well defined with regular contours, B = defined with irregular contours, C = unable to be difined, NA = not available

# **Tectorial membrane**

# *i.* T2 space 3D spin echo sequence

In sagittal view, the tectorial membrane could be discerned from the surrounding tissue in only one specimen. The contours of the tectorial membrane in this specimen were considered poorly defined. Where it was visible, the tectorial membrane appeared as a single layer of tissue present from the level of the second cervical vertebra and extending to the occiput, 10.7mm past the basion. No tectorial membrane could be clearly or partially identified in axial section in any specimen when examined using this acquisition.

# *ii. T1 turbo spin echo sequence*

The tectorial membrane was classified as defined with irregular contours in three of the six specimens in sagittal view using the T1-weighted acquisition sequence. In each specimen, the structure was viewed as a single layer visible from the axis to the occiput. The extent of the attachment onto the occiput could be discerned in two specimens, passing on average 16.3mm superior to the inferior point of the basion.

In axial view, the tectorial membrane appeared as a single black layer in three specimens. The structure could be more readily discerned in its superior portion above the level of the transverse ligament. When examined at the level of the alar ligaments, the midline thickness could be measured in each of the three specimens in which it was discernible, averaging 1.7mm in an antero-posterior direction. Lateral to the midline the tectorial membrane appeared to be of a greater thickness. In this lateral position, a measurement of antero-posterior thickness could be clearly made in two specimens only, averaging 2.3 mm. A summary of measurements for each specimen is provided in Table 7.10.

## *iii.* Proton density-weighted 2D turbo spin echo sequence

In sagittal view, the tectorial membrane could be discerned from the surrounding tissue in all six specimens when examined using this acquisition sequence. In all specimens, it was noted as a single layer of dark appearance extending from the axis to the occiput. In one specimen, however, this was only visible when viewed in a parasagittal section lateral to the midline. In one specimen only, a two layered appearance was noted in the region immediately inferior to the transverse ligament. The path of each tectorial membrane could be traced superiorly to the basion, extending a mean distance of 15.1 mm superior to this bony landmark.

In axial view, the tectorial membrane was identified as a single layered structure along its course in all six specimens. The structure could not be identified centrally in one specimen. However, lateral to the midline the tectorial membrane was evident in this specimen. In one specimen, a second layer could be identified on the left side only of the specimen at the level of the alar ligaments. In five specimens, the tectorial membrane appeared to have a greater antero-posterior thickness laterally than centrally. The mean antero-posterior thickness of the structure was estimated to be 1.4mm centrally and 1.88mm laterally when measured at the level of the alar ligaments. The measurements from individual specimens are provided in Table 7.10.

**Table 7.10** Measurements and observations for the tectorial membrane of each specimen obtained using all three acquisition sequences.

Specimen number		T2-weighted SPACE 3D SE		T1-weighted TSE	Pro	ton density-weighted 2D TSE
	Image clarity	Description	Image clarity	Description	Image clarity	Description
3756						
Sagittal view	С	Unable to be discerned from surrounding tissue	С	Unable to be discerned from surrounding tissue	В	Visible as a dark single layer lateral to the midline only.
Axial view	С	Unable to be discerned from surrounding tissue	С	Unable to be discerned from surrounding tissue	В	Extending 16.8mm into occiput Visible single layer lateral to the midline only. AP thickness at level of alar ligaments=2.0mm
3714						
Sagittal view	С	Unable to be discerned from surrounding tissue	В	Visible as a single layer extending 14.6mm into occiput	В	Visible as a single layer extending 16.1mm into occiput
Axial view	С	Unable to be discerned from surrounding tissue	В	Seen as a black layer present from the level of the alar ligaments extending superiorly. Midline AP thickness at level of alar ligaments=2.0mm. Lateral measurement not possible	В	Clearly seen at level of the alar ligaments. AP thickness = 2.2mm centrally and 2.9mm laterally

Sagittal view	C	Unable to be discerned from surrounding tissue	В	Visible as a single layer extending 18.1mm into occiput	В	Visible as a single layer extending 16.9mm into occiput
Axial view	С	Unable to be discerned from surrounding tissue	С	Unable to be discerned from surrounding tissue	В	Discernible at level of alar ligaments. AP thickness = 1.1mm centrally and 1.6mm laterally
3750						
Sagittal view	В	Visible as a single layer only. Thicker above and below transverse ligament. Extends 10.7mm into occiput	С	Unable to be discerned from surrounding tissue	В	Visible as a single layer extending from axis to occiput. Extends 12.96mm into occiput
Axial view	С	Unable to be discerned from surrounding tissue	В	Visible as a single layer only. AP thickness = 1.5mm centrally and 2.7mm measured laterally at level of alar ligaments	В	Visible from level of inferior portion of transverse ligament extending cephalad to the occiput. Layering visible on left side at level of alar ligaments. AP thickness centrally = 1.0mm, laterally = 1.5mm.
3739						
Sagittal view	С	Unable to be discerned from surrounding tissue	В	Visible as a single layer. Unable to define or measure the extent of attachment into occiput	В	Visible as a single layer. Extends 133mm into occiput
Axial view	С	Unable to be discerned from surrounding tissue	В	Midline AP thickness=1.6mm. Thickness laterally = 1.9mm. More visible superiorly	В	Visible as a single layer. Appears more substantial in the midline than laterally. AP thickness midline =1.8mm. Lateral AP thickness = 1.5mm

3665						
Sagittal view	С	Unable to be discerned from surrounding tissue	С	Unable to be discerned from surrounding tissue	В	Visible as a single layer for the majority of its course. Two layers are seen in the region immediately below the transverse ligament. Extends 14.6mm into occiput
Axial view	С	Unable to be discerned from surrounding tissue	С	Unable to be discerned from surrounding tissue	В	Seen as a single layer. More prominent either side of midline. AP thickness centrally = 1.0mm and laterally =1.7mm

Legend: SE = spin echo, TSE = turbo spin echo, A = well defined with regular contours, B = defined with irregular contours, C = unable to be difined, AP = antero-posterior

# 7.3.4 Consistency of measured anatomical features

A comparison of the measurements of the dimensions of the alar ligaments taken from each specimen using each acquisition sequence is given in Table 7.11. Analysis using the Kruskel-Wallis test for the equality of medians indicates that for measurements of alar ligament length in axial view, at least one set of measurements statistically significantly differed between the sequences assessed (p=0.03). Subsequent comparison of the median measurements of each of the 3-Tesla acquisitions against the equivalent 4.6-Tesla measurements of alar ligament length in axial view using the Wilcoxon sign rank test revealed that only measurements obtained from the T2-weighted images were statistically significantly different to the 4.6-Tesla measurements (p=0.02). Measurements obtained from T1-weighted and proton density-weighted images could be considered to be derived from the same distribution as the 4.6-Tesla measurements. No other alar ligament measurements were considered to statistically significantly differ between any acquisition sequences examined.

Measurements of the dimensions of the transverse ligaments using each acquisition sequence are summarised in Table 7.12. Following testing for the equivalence of medians, no statistically significant difference was apparent between measurements obtained from different acquisitions in the majority of measurements analysed. One exception was assessment of antero-posterior thickness of the ligament measured adjacent to the attachments to the tubercles of the atlas (p=0.01). Further analysis using the Wilcoxon sign rank test revealed that the medians of both the T2-weighted and proton density weighted images differed from the measurements obtained from the 4.6-Tesla images (p=0.01 and p=0.05 respectively). Measurements from each of these sequences underestimated the thickness of the structure at this point in comparison to the higher resolution image.

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Table 7.11	Comparison of	the measurements of	of the alar l	igaments taken	from each s	pecimen for	each acquisition	sequence
				0				

Measurement	4.6 Te	sla image	3 Tesla T	2 –weighted	3 Tesla T	1-weighted	3 Tesla P	D-weighted	p-value for
		Interquartile		Interquartile		Interquartile		Interquartile	equality of
	Median	range	Median	range	Median	range	Median	range	medians
Alar ligament length in coronal view	9.5	8.3-10.9	9.5	8.7-9.9	9.3	8.1-10.0	8.1	7.2-8.3	0.07
Alar ligament medial height in coronal view	7.1	5.6-8.4	6.2	5.7-6.7	7.3	6.5-8.0	6.1	4.0-7.6	0.22
Alar ligament lateral height in coronal view	3.5	3.1-3.9	3.6	3.0-4.0	3.8	3.5-4.0	3.7	3.1-3.9	0.75
Alar ligament attachment distance below tip of odontoid process in coronal view	2.4	0.7-2.7	0.4	0.0-2.1	1.9	0.6-2.0	1.6	0.9-2.3	0.44
Alar ligament orientation relative to odontoid process in coronal view	89.1	87.3-92.9	93.7	91.7-95.9	94.1	90-102.3	93.1	92.3-113.8	0.11
Alar ligament length in axial view	10.5	9.8-10.8	9.5	8.9-9.7	10.1	10.1-10.2	9.3	8.3-10.1	0.03
Alar ligament medial width in axial view	4.2	3.6-4.8	4.6	4.0-4.7	4.1	3.9-4.3	4.0	3.9-5.0	0.91
Alar ligament included angle in axial view	131.8	120.9-147.7	122.4	119.2-145.1	141.1		129.8	122.7-139.4	0.85
Alar ligament thickness of traversing fibres in axial view	0.9	0.3-1.5	1.1	1.0-1.2			1.1	0.8-1.3	0.86

<b>Table 7.12</b> Comparison of the measurements of the transverse ligaments taken from each specimen for each acquisition
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Measurement	4.6 Tesla image Interguartile		3 Tesla T2 –weighted Interguartile		3 Tesla T1-weighted Interguartile		3 Tesla PD-weighted Interguartile		p-value for equality of
	Median	range	Median	range	Median	range	Median	range	medians
Transverse ligament midline AP thickness in sagittal view	2.6	2.0-3.0	2.5	2.1-2.7	2.6	1.2-4.0	2.5	2.4-2.8	0.99
Transverse ligament vertical height in sagittal view	9.7	9.5-10.2	8.8	8.6-10.8	10.1	8.1-12.0	12.4	11.6-15.0	0.09
Transverse ligament midline AP thickness in axial view	3.3	2.7-4.2	2.9	2.8-3.0	2.5	2.5-2.5	2.5	1.9-3.6	0.52
Transverse ligament anterior margin length in axial view	22.3	20.2-24.4	20.2	19.4-21.3	19.7	19.7-19.7	19.8	18.5-20.7	0.52
Transverse ligament posterior margin length in axial view	26.4	24.2-27.7	22.9	20.1-24.5	19.9	19.9-19.9	22.7	20.9-24.5	0.10
Transverse ligament AP thickness by atlantal tubercle in axial view	4.7	4.6-5.2	3.2	2.8-3.9	3.6	3.5-3.6	3.7	2.9-4.1	0.01

Legend: AP = antero-posterior

Analysis of the measurements obtained from the tectorial membrane was not possible due to inadequate measureable observations at rigidly defined points along the course of the structure in the images obtained using 3-Tesla sequences.

# 7.3.5 Dissection of imaged specimens

# Alar ligaments

The alar ligaments of the six specimens imaged each consisted of a single band of dense connective tissue extending from either the lateral or posterolateral aspect of the odontoid process to the occiput. The orientation of these bands appeared primarily horizontal when examined in the coronal plane. One specimen exhibited a single ligament oriented in a cephalad directed manner and one specimen had a single ligament oriented in a caudal direction as they passed toward their occipital attachment. No atlantal portion of the alar ligaments was observed in any specimen.

When examined from above, all alar ligaments were oriented posteriorly. The actual angle of orientation differed between and within specimens such that the angle with respect to the sagittal plane displayed considerable variation.

Medially, attachment onto the odontoid process occurred over a broad area. The alar ligaments of two specimens were observed to extend as far cephalad as the tip of the odontoid process, whilst the superior margin of other alar ligaments was measured up to 5mm below this tip. The mean distance of attachment below the tip of the odontoid process was 2.3mm. The length and height of each alar ligament was measured in situ prior to blunt dissection of these structures. The mean length of the ligaments was 11.1mm (range 8mm to 13mm). Height of the ligament was ascertained immediately adjacent to the odontoid process. Mean height at this point was calculated as 7.0mm (range 4mm to 10mm).

Four of the six specimens exhibited transverse elements of their alar ligaments composed of a group of fibres traversing between the occipital condyles without attachment to the odontoid process. When present, the thickness of these transverse elements varied from approximately 1mm to several millimetres. Unlike the previous dissection series, all specimens exhibited the majority of the fibres of the alar ligaments attaching onto the odontoid process. No example of an alar ligament without an odontoid process attachment was observed in this series.

Observations on the contribution of the alar ligaments to the area immediately surrounding the atlanto-occipital joint varied. In three specimens, some fibres from the alar ligaments appeared to communicate with the medial aspect of both the left and right atlanto-occipital joints. In one specimen, this observation was reported on the right side only. In the remaining two specimens the alar ligaments were described as attaching adjacent to the atlanto-occipital joints but could not be observed to communicate or interdigitate directly with the joint capsule itself.

The characteristics of individual alar ligaments noted during dissection are provided in Table 7.13.

# **Table 7.13**Observations of the alar ligaments from dissection of the previously imaged specimens

Feature			Specime			
	3756	3714	3753	3750	3739	3665
Occipital portion	Present	Present	Present	Present	Present	Present
Length (mm)						
Left Right	12 9	10 10	13 11	12 12	11 8	13 12
Height medial (mm)						
Left	4	6	7	6	7	9
Right	6	8.5	7	7	6	10
Atlantal portion	Absent	Absent	Absent	Absent	Absent	Absent
Ligament orientation	Horizontal	Left caud-ceph Right horizontal	Horizontal	Horizontal	Left horizontal Right ceph-caud	Horizontal
Aspect of attachment on odontoid	Lateral & postero- lateral	Lateral & postero- lateral	Primarily postero- lateral	Not observed	Not observed	Not observed
Attachment distance (mm) below odontoid tip	0	5	3.5	3	0	Not reported
Transverse band	Present. Approx 1mm thick	Not present	Present. Approx 1mm thick	Substantial band several mm in thickness	Not present	Present and substantial
Attachment to	Present left and	Attachments	Attachment of	Attachment of fibres	Attachments	Visible attachment
atlanto-occipital joints	right	adjacent but not visibly into O-C1	fibres into left and right joints	into left and right joints	adjacent but not visibly into O-C1	into right O-C1 joint

# Cruciform and transverse ligaments

Both ascending and descending cruciform ligaments were observed in each of the six specimens examined. The ascending cruciform ligaments arose from the superior surface of the transverse ligament, passing in a cephalad direction and inserting onto the clivus. Ascending cruciform ligament length ranged from 12mm to 17mm (mean length 14mm, standard deviation 2mm). The triangular descending cruciform ligaments extended from the inferior aspects of the transverse ligament, attaching onto the posterior aspect of the body of the axis. Descending cruciform ligament length ranged from 6mm to 11mm (mean length 9.2mm, standard deviation 1.9mm).

Observations of the structure of the transverse ligaments were consistent with dissections described in Chapter 5. The transverse ligament was present in all six specimens examined. Elliptical in shape and attaching to the tubercles on the medial aspects of the atlantal ring adjacent to the lateral atlantoaxial joints, measurements of transverse ligament length ranged from 16mm to 28mm (mean length 21mm, standard deviation 4.1mm). The midline height, superior to inferior, measured from the posterior aspect of the ligament ranged from 9mm to 15mm (mean height 11.7mm, standard deviation 2.3mm).

# **Tectorial membrane**

Each of the six tectorial membranes examined consisted of a two layered arrangement of a superficial or posterior and a deep or anterior layer. Again, the structure observed was consistent with observations presented in the results of the previous dissection study detailed in Chapter 5.

Superficial layers each consisted of a three band appearance with a central fan-shaped component and two lateral components. Inferiorly, fibres from this layer extended beyond the limit of the specimens which were sectioned at the level of the C2/3 intervertebral disc. Superiorly, fibres from this band extended past the foramen magnum to the internal surface of the clivus, attaching over a diffuse area.

The deeper, or anterior, layer of each specimen was also composed of three bands with a predominant central fan-shaped band and two smaller lateral components. The central band arose from a strong attachment on the posterior surface of the body of the atlas and ascended to attach over a diffuse area onto the internal surface of the clivus. Each lateral band arose from the lateral aspects of the posterior surface of the body of the axis and passed superiorly. The majority of these fibres remained lateral to the central band and attached anterolaterally onto the clivus.

## 7.4 Discussion

These imaging results may be considered in terms of their consistency with the macrosostructure of the ligaments observed during dissection and the relative quality of different imaging parameters.

# 7.4.1 Comparison of the findings of high resolution imaging of the craniocervical ligaments with their macrostructure described during fine dissection

# Alar ligaments

Each alar ligament described from MRI analysis and upon confirmatory dissection consisted of a single defined band of tissue extending from the odontoid process to the occiput. No atlantal or anterior portions of the ligament were noted on either method of assessment in any specimen.

Both methods of analysis detailed the medial attachment of the ligaments to the lateral and posterolateral aspect of the odontoid process in all specimens. One specimen on imaging, and two specimens on dissection, were described as having superior attachments to the tip of the odontoid process. Specimen 3756 was observed and measured as attaching to the odontoid tip in both analyses whilst specimen 3739 was described as attaching to the tip on dissection but measured as attaching 0.7mm below the tip on imaging. This demonstrated consistency in identifying similar characteristics between specimens examined by both dissection and high resolution imaging. The difference in observation of 0.7mm in regard to specimen 3739 is accounted for by not only the small magnitude of the distance measured, but also the fact that the measurements created using MRI are taken at cross-sections of the specimen, whereas the specimen prior to dissection is viewed complete. Additionally, being processed digital data, images are viewed at considerable magnification making measurement of intervals possible which may be too small to assess under conditions of gross observation of the specimen.

When viewed in the frontal plane, the assessed orientation of the alar ligaments was primarily horizontal in ten of the twelve ligaments using both imaging and dissection methods. Due to the concave nature of the specimens, it was not possible to precisely measure the angles created by the ligaments using a protractor, hence only the subjective observation is reported. The observations again are consistent with the measurements taken of the imaged specimens, with ten of the twelve alar ligaments measured reported to be within 10° of horizontal. In horizontal plane examination, all alar ligaments were reported to be oriented obliquely posteriorly both on imaging and gross examinations, with included angles ranging from 119° to 173° on MRI assessment.

Assessment of alar ligament length was less when measured in the images of the specimens (mean length 9.5mm, range 6.9 to 11.1mm) than in the specimens during dissection (mean length 11.1mm, range 8 to 13mm). This may be due to the inability to use a straight ruler within a concave bony arrangement, potentially introducing measurement error into this estimate. Superior-inferior height of the ligament adjacent to the odontoid process was more easily measured in the specimens during dissection and

this is reflected in the consistency of measurements taken using both assessment methods. The mean ligament height measured using coronal plane section images was 7.0mm (range 4.6 to 9.4mm) and the mean height measured during dissection was 7mm (range 4 to 10mm).

Each of the specimens examined had their medial attachment onto the odontoid process. However, there was also evidence of the presence of traversing fibres which extended between occipital attachments without an odontoid process attachment. Five specimens were identified as having this band of traversing fibres present on MRI examination. The existence of four of these bands could be confirmed upon subsequent dissection. Specimen 3714 was correctly identified as not containing a traversing band on both examinations. Specimen 3739 was reported as having a traversing band on MRI examination which could not be confirmed on dissection. The reason for this inconsistency is uncertain given that the observations from the other five specimens are consistent not only in reporting the presence of this element of the alar ligaments, but also in their descriptions of the magnitude of each of the traversing bands themselves.

The contribution of fibres from alar ligaments into the medial aspects of the atlantooccipital joints was confirmed using both methods of examination. Using MRI, six of twelve assessed alar ligaments were noted to contribute fibres to the medial aspect of the joints when viewed in coronal section and all twelve alar ligaments appeared to provide fibres to the medial aspect of the joints when viewed in axial section. Seven alar ligaments were clearly identified as contributing to the atlanto-occipital joints on dissection of the specimens whilst the remaining five were all reported as attaching immediately adjacent to the joint.

# Cruciform and transverse ligaments

Compared to other ligamentous structures assessed using MRI, the cruciform ligaments were poorly defined. The ascending cruciform ligament was observed and measured in four of the six imaged specimens. The descending cruciform ligament was not clearly differentiated from surrounding tissue in any specimen. On dissection, both ligaments were noted to be present in all six specimens. The cruciform ligaments are best viewed on MRI in sagittal section where they can be recognised in cross section. The descending cruciform ligaments are both shorter and thinner than their ascending counterparts making differentiation of the descending cruciform ligaments from the tectorial membrane and the dura mater more difficult.

Description of the structure of the transverse ligaments was consistent between the high resolution images and the dissection reports. On both forms of reporting, the transverse ligament was noted to be an anteriorly concave structure located against the odontoid process. Attachment to the medial tubercles of the atlantal ring was noted in both assessments. Assessment of the dimensions of the structure was not consistent between methods of examination. Measurements of length of the ligament on dissection were consistently less than lengths measured using MRI. Again, this is most likely related to

the transverse measurement of a curved structure within a concave bony arrangement. Measurements of superior-inferior height of the transverse ligament on dissection were more similar to measurements obtained from the images, with measurements from the dissection being slightly larger for each specimen.

# Tectorial membrane

Assessment of the tectorial membrane was most informative when the structure was viewed in sagittal or parasagittal section. The overall structure of the tectorial membrane was not as accurately reflected using imaging in comparison to the results obtained on examination of the alar and transverse ligaments. One possible explanation for this variation is that the tectorial membrane is a much more complex structure than the transverse or alar ligaments spanning several vertebral segments and with diffuse bony attachments onto both the internal surface of the vertebral column and the internal surface of the occiput.

Dissection of the specimens revealed that the tectorial membrane of each of the six specimens was composed of two discernible layers, each consisting of three distinct bands of tissue. This dual layer arrangement was visible in all imaged specimens inferior to the level of the transverse ligament. Superior to the transverse ligament and overlying the odontoid process, the dual layers were recognised in only three specimens in sagittal section. Parasagittally, two layers could be identified in four specimens. The improvement in visibility when the plane of image was moved laterally was due to the increase in the antero-posterior dimension of the tectorial membrane laterally compared to its thickness centrally. Above the level of the odontoid process, layering of the tectorial ligament could be seen in only two specimens. This is because the structure itself becomes thinner and more diffuse in its superior aspect making differentiation of individual layers difficult, even at higher imaging resolutions. In no view obtained from any specimen could the band structure of the tectorial membrane be recognised. Given the lack of antero-posterior thickness of the tectorial membrane and its curved nature within the spinal canal, it is difficult to view the tectorial membrane in its entirety in coronal section, thus making recognition of any individual bands impossible.

Descriptions of the bony attachments of the tectorial membrane were consistent between examination methods. Inferiorly, the deep or anterior layer of the tectorial membrane was observed to attach strongly onto the posterior aspect of the body of the axis whilst the superficial or posterior layer was noted to extend inferiorly beyond the length of the specimen in all cases. Superiorly, attachment of the structure into the clivus was noted both during analysis of imaging and upon dissection of the specimens.

In summary, the images obtained from high resolution MRI generally reflected the macrostructure of the craniocervical ligaments detailed on the subsequent dissection of the specimens. Whilst limitations are apparent in measurement of specific ligament dimensions, error may be equally attributed to limitations of measurement during dissection as to measurement error of imaged specimens alone. Although accurate measurement of imaged structures will always be dependent upon ensuring that the image slice is orthogonal to the structure being examined, the consistency of findings between

the images and the dissection of the same specimens indicate that the 4.6-Tesla MRI studies are an appropriate reference by which the quality of the data collected from imaging of these same specimens using a 3-Tesla MRI system and various acquisition sequences may be judged.

# 7.4.2 Clinical resolution imaging

# Assessed clarity of images

Assessment of the clarity of the ligament structures, their borders and sites of attachment indicated substantial variation in the capacity of the commonly utilised acquisition sequences to produce an image of the craniocervical ligaments from which confident observations and measurements can be drawn.

Of the three acquisition sequences trialled, no sequence produced images of the alar ligaments or the tectorial membrane which were classified as clear with defined borders and attachment sites visualised. The proton density-weighted sequences did yield images with higher overall clarity scores, indicating that this sequence more frequently produced images where the ligament structures were defined despite some contours being irregular or less clearly delineated.

Overall, proton density-weighted sequences permitted identification of the alar ligaments of a quality from which measurements could be obtained in 75% of the ligaments examined. In comparison, T2-weighted sequences produced a measureable image of the
alar ligaments in 54% and T1-weighted sequences produced measureable images in 50% of alar ligaments in these specimens.

The tectorial membrane was identifiable using a proton density-weighted sequence in all specimens examined. As previously noted, the diverse sites of attachment of this structure make defining all borders and attachments problematic. T1-weighted sequences yielded only a 50% overall identification rate for this structure and T2-weighted only 8%.

Identification and clarity of the transverse ligament received a higher overall score compared to the alar ligaments and tectorial membrane. This was most likely due to the defined points of attachment of this ligament, its orientation in the axial plane rather than across acquisition planes, and the substantial volume and morphological simplicity of its arrangement. Only the transverse ligament received clarity ratings classified as well defined with regular contours. This occurred in 25% of proton density-weighted images and 8% of both T2-weighted and T1-weighted images. Overall, the transverse ligaments were defined in 93% of proton density-weighted images, 83% of T2-weighted images and only 25% of T1-weighted images.

These findings in regard to clarity of images of the craniocervical ligaments strongly suggest that proton density-weighted acquisitions produce more easily identifiable images of these ligaments than acquisitions utilising either T1 or T2-weighting. The most likely reason for this relates to the need to compromise slice thickness to accommodate practical acquisition times in the clinical setting.

Baumert et al (2009) suggest that a T2 contrast is the sequence best suited to distinguish ligamentous structures of the spine from surrounding fatty tissue, muscle and cerebrospinal fluid. However, the acquisition time required to achieve images of adequate quality using this sequence is in excess of eight minutes, making its use difficult clinically where a patient is required to be stationary for this period. Reduction in acquisition time is achieved clinically by increasing the slice thickness, resulting in a loss of signal to noise and altered contrast behaviour (Baumert et al., 2009). In order to achieve imaging within a clinically acceptable acquisition time, the slice thickness required using the T2-weighted imaging parameters in this study was 4mm.

Proton density-weighted sequences proposed for imaging of the craniocervical ligaments by Krakenes et al (2001, 2002) are suggested to provide good discrimination between ligament, bone and soft tissue because of a higher signal to noise ratio achieved by low echo time, thus permitting smaller pixels and thinner slice sections to be obtained. In this study, a slice thickness of 2mm was achieved within the clinical acquisition timeframe.

Achievable slice thickness is most likely to be the predominant factor in producing images in this study from which identification of the craniocervical ligaments, their borders and points of attachment could be made. Acquisition of MRI data is obtained in a selected anatomical plane. This limits the ability to visualise structures oriented across the acquisition plane and may result in partial volume effects which may obscure anatomically closely related structures (Baumert et al., 2009; Krakenes et al., 2001). The alar ligaments in particular are never oriented in a pure anatomical plane. Hence, it is not possible to visualise them in one image slice. Reconstruction of these ligaments is thus fraught with problems due to partial volume artefact. The 2mm slice thickness achieved using proton density-weighting allowed the greatest possibility of reconstructing the ligaments with a minimum of partial volume artefact present.

Further effects on the quality of imaging were produced as a result of using dissected anatomical specimens. The specimens imaged contained only selected osteoligamentous components of the craniocervical region. All muscle and fat tissue was removed from each specimen. Removal of this tissue results in signal reduction since the MRI signal is primarily derived from muscle and fat tissue (Westbrook et al., 2011). Furthermore, bone in cadaveric specimens becomes dehydrated and ligament, having inherently lower water content, will produce limited MRI signal. Hence, each specimen is constituted of tissue which has an inherently low spin density, limiting the quality of the images derived.

In an attempt to reproduce a clinical situation, imaging at 3-Tesla was performed in a standard clinical MRI unit using a standard head coil. This decision resulted in compromised image quality due to inadequate coil loading. Unlike an intact human head and neck, the dissected specimens occupied a very small proportion of the available volume within the coil. This resulted in a lower signal to noise ratio since the signal originated from a limited volume within the coil having a small field of view, whereas the noise originates from the entire volume of the coil (Westbrook et al., 2011).

#### Comparison of ligament structure between acquisition sequences

Consistent with observations from the dissection and the 4.6-Tesla investigations, each acquisition sequence examined revealed the alar ligament as a single band of tissue extending from lateral and posterolateral aspects of the odontoid process to the medial aspect of the inferior part of the occiput. No atlantal bands were observed in any specimen at any acquisition sequence used.

In coronal section, the orientation of the alar ligaments was judged to be primarily horizontal in five of the six specimens from the high resolution images. One specimen (specimen number 3739) was oriented in a cephalad direction. Where visible, the judgements of ligament orientation from the lower resolution sequences were consistent with the higher resolution images. Similarly, descriptions of alar ligament shape were consistent with these reference descriptions of the specimens demonstrating a tapering in height toward the lateral end of the ligament. No clinical resolution imaging appeared sufficient to consistently demonstrate any contribution of the alar ligaments to the atlanto-occipital joints in coronal plane view. Whilst three alar ligaments were observed to blend with the joint on examination of T1-weighted images, all twelve ligaments could be seen providing some contribution to the medial aspect of the atlanto-occipital joints at higher resolution acquisitions. As a result, no recommendation can be made as to a preferable acquisition sequence for identification of this anatomical aspect or its integrity in clinical examination.

T1-weighted sequences proved inadequate for alar ligament examination in these studies in the axial plane. Whilst the images from the remaining acquisition sequences contained data which could not be considered clear or complete, both the T2-weighted and the proton density-weighted images provided a consistent indication of alar ligament structure with each ligament demonstrated extending posterolaterally from the odontoid process. Both of these sequences also resulted in images inconsistently capable of illustrating the small bands of traversing fibres described and measured on these specimens using higher resolution images.

None of the imaging sequences examined was capable of clearly demonstrating the structure of the ascending and descending cruciform ligaments. Of all the specimens examined, only one ascending cruciform ligament was identified using proton density-weighted imaging, whilst identification of other cruciform ligaments could not be made using other weighted acquisitions. From these data, it appears that no sequence trialled is adequate to reproduce the structure of these ligaments as they are observed either by higher resolution imaging or by dissection.

The reported structure of the transverse ligament using T2 and proton density-weighted sequences was consistent with descriptions obtained from high resolution images. A midline sagittal section permitted visualisation of the elliptical cross-section of the ligament located against the odontoid process. In axial view, both of these sequences permitted description of the transverse ligament as it passed posteriorly around the

odontoid process to attach onto the atlantal tubercles, as noted at higher resolution images.

T1-weighted acquisition of images of the transverse ligament resulted in poorly defined images in both axial and sagittal plane viewing. The lack of ability to accurately define the ligament structure suggests that this form of image acquisition is not suitable for viewing or measuring the transverse ligament for either clinical or research purposes.

Of the clinical resolution sequences, the images acquired using a proton densityweighting were most likely to provide a visible and measureable representation of the tectorial membrane. The images obtained using each sequence at 3-Tesla displayed the tectorial membrane as a single layered structure extending superiorly from the posterior aspect of the vertebral body of the axis to a poorly defined attachment above the level of the basion. Neither the T1 nor the T2-weighted images could discern any layering of the tectorial membrane as visualised at higher resolution imaging and confirmed upon dissection of the individual specimens. A second layer of the tectorial membrane was discerned in one specimen using proton density-weighted sequences, however this is insufficient to suggest this acquisition sequence is superior for the purpose of detecting layering of the tectorial membrane given this layering was present in all six specimens at 4.6-Tesla imaging and upon dissection.

Variations in antero-posterior thickness of the tectorial membrane reported in axial section were consistent between the higher resolution imaging and both the T1-weighted

and the proton density-weighted images acquired at 3-Tesla. This confirmed that the thickness of the tectorial membrane reduced centrally where it overlay the odontoid process, remaining thicker in its lateral aspects. This is consistent with the reports from the dissection of these specimens where the lateral bands of the deeper layer of the tectorial membrane were substantial, ascending either side of the odontoid process.

#### 7.4.3 Implications for the validity of clinical stress testing

The consistency of findings between the current study and the previous anatomical studies described in this thesis strengthen the conclusions derived from the original dissection studies in regard to the implications of the observed structure of the craniocervical ligaments on the clinical stress tests described for testing their integrity.

Observations of the alar ligaments using MRI consistently reported these structures as substantial bands of tissue extending from the odontoid process to the occiput. Being primarily horizontally oriented when viewed in the coronal plane and posterolaterally oriented when viewed in the axial plane, their structure is consistent with their proposed role as resisting excessive occipito-atlantoaxial movement in the directions of lateral flexion and rotation, providing face validity for the existing clinical stress tests. The absence of any report of either an atlantal or an anterior portion of the alar ligaments was also consistent with previously noted anatomical study findings (Chapter 5). The absence of any secondary component of the alar ligaments, either inferiorly or anteriorly, suggests that in any individual where such bands of tissue may be present, they should be

interpreted as normal anatomical variation with no functional or clinical significance. Hence, the notion of clinically testing for the integrity of these ancillary components of the alar ligaments is not based upon the anatomical evidence or sound clinical reasoning.

Observations of the transverse ligament were consistent with our previous descriptions and did not produce any additional information which could be interpreted as not supporting the existing rationale for clinical testing of its integrity. The transverse ligament was described in all images obtained from all acquisition sequences as a broad, anteriorly concave structure located behind the odontoid process. This description is consistent with its ascribed role as preventing anterior displacement of the atlas on the axis, thus supporting both the biomechanical rationale and the face validity of the Sharp-Purser and the anterior shear tests.

The longitudinal course of the tectorial membrane, tending antero-superiorly as it passes over the superior aspect of the odontoid process, is consistent with the mechanisms described for the tectorial membrane clinical stress tests which incorporate both elements of distraction and upper cervical spine flexion. The visualised points of attachment onto the posterior aspect of the body of the axis and onto the clivus provide support for the necessity to stabilise the axis while distracting the occiput during the performance of these clinical tests.

# 7.4.4 Implications for further studies assessing the validity of clinical stress tests of the craniocervical ligaments using MRI

The second stated aim of this study was to establish which MRI acquisition parameters at clinical resolution were optimal for use in subsequent studies to assess the morphology and dimensions of the craniocervical ligaments during the performance of selected clinical stress tests. None of the acquisitions examined produced images from which the presence and structure of the craniocervical ligaments could be ascertained with certainty on each occasion. However, from the assessment of the clarity of each of the images created from the acquisitions obtained at 3-Tesla, the proton density-weighted acquisitions did consistently yield more identifiable images of the ligaments of this region than other acquisitions trialled. This finding was repeated for each ligament examined, indicating that a proton density-weighted acquisition sequence is a superior selection for the examination of these ligaments in subsequent studies. Overall, estimates of clarity would be expected to improve in images acquired from living people in a clinical situation compared to the cadaveric specimens used in the current study since the presence of muscle and fat tissue in participants would improve the MRI signal and the capacity of the head to fill a standard head and neck coil would result in improved coil loading.

Whilst the proton density-weighted acquisitions may be superior to other sequences trialled, limitations persist in regard to the identification of the borders and exact attachment points of the ligaments. This results in the introduction of error in the estimation of attachment sites and consequently potential error in measurement of the deformation of the ligaments themselves under the load of clinical testing. To accommodate this weakness in methodology in the next stage of study, each ligament in each image will need to be assessed and classified for quality according to the system described by Pfirrmann et al (2001). Furthermore, measurements taken of the ligaments, both in loaded and unloaded positions will be repeated and calculations of the reliability of measurement performed.

Measurements made on each specimen using the high resolution images were repeated using images created from each 3-Tesla derived acquisition. Analysis of these measurements using robust statistical methods indicates that where measurement was possible, little statistically significant difference was evident in the measurements between the sequences. Where differences did emerge, T2-weighted images emerged as the most frequent variable to differ from measurements made from the same specimen at high resolution. Measurements obtained from proton density-weighted images appear to acceptably represent the specimens examined since they do not appear to systematically differ from measurements of the specimens obtained at high resolution.

The inability to measure the tectorial membrane appropriately due to the inability to define the end points of the ligament with certainty would indicate that a corroborating form of measurement would be of assistance in defining the effect of the clinical tests. The most appropriate form of corroborating measurement would be obtained from measuring displacement of the bony landmarks which constitute the documented attachment sites of the ligaments. In addition to providing an indication of the separation

of points of attachment of the ligaments in relation to each other during clinical testing, these proxy measurements of effectiveness of the clinical tests may be analysed for their consistency of association with measurements derived from direct measurement of the craniocervical ligaments.

### **CHAPTER 8**

## REVIEW OF THE BIOMECHANICS OF THE CRANIOVERTEBRAL SEGMENTS IN RELATION TO LIGAMENTOUS FUNCTION

The clinical stress tests recommended for use when assessing ligamentous stability of the craniovertebral region have been based on descriptions of anatomical structure and biomechanics as interpreted by the authors proposing the examination techniques. Whilst some biomechanical descriptions have been provided in the literature as justification for the clinical tests, the actual biomechanics of the craniovertebral region and role of the ligaments in limiting movement in this region is subject to varying descriptions in the biomechanics literature and remains a subject of some disagreement (White & Panjabi, 1990).

#### 8.1 Descriptions of occipito-atlanto-axial biomechanics

#### 8.1.1 Occipito-atlantal movement

The concavity of the superior articular facet of the atlas is oriented both longitudinally and transversely. The inherent joint shape promotes sagittal plane movement but limits independent movement between the occiput and atlas in the other planes (Bogduk & Mercer, 2000; Singh, 1965). The role of the craniovertebral ligaments in directing movement at this joint is questionable given the limitations imposed by the shape of the joint itself and the fact that the axes of motion cross one another at right-angles (Werne, 1959). Flexion occurs when the occipital condyles roll forward and translate posteriorly across the anterior wall of the socket formed by the atlantal component of the joint (Figure 8.1) (Bogduk & Mercer, 2000). Flexion at the atlanto-occipital joint is usually considered to not be directly limited by any ligament in the region (Werne, 1959). Published anatomical and biomechanical descriptions of flexion at this level usually rely on the findings of dissections and examination of the craniovertebral segments by Werne (1957). Werne reported that flexion results in a slackening of the tectorial membrane at this level, the movement being limited by skeletal contact between the anterior portion of the foramen magnum and the dens with the bursa apicis dentis interposed between the skeletal elements (Werne, 1957, 1959). This finding has been confirmed by x-ray examination using six cadaveric specimens (Harris et al., 1993). Limitation of flexion has also been attributed to impaction of the occiput against the rim of the atlantal sockets (Mercer & Bogduk, 2001). However, under normal physiological load other factors may limit the motion before impaction occurs. These include tension created in the posterior neck muscles and impaction of the submandibular tissue against the throat (Mercer & Bogduk, 2001).

The motion of extension is the converse of flexion with the occiput rotating backwards and translating anteriorly within the atlantal socket (Mercer & Bogduk, 2001). This is illustrated in Figure 8.1. The factors limiting extension at this level have been variously described in cadaveric studies as tension developed in the tectorial membrane as its attachment moves away from the point where the structure rides over the tip of the dens (Werne, 1957, 1959) or by impaction of the posterior arch of the atlas against the occiput (Bogduk & Mercer, 2000). This divergence of opinion has centred on the nature of the membranous tissue surrounding the joint which has been described by some authors as fascial in nature and unlikely to constitute ligamentous restraint to extension (Bogduk & Mercer, 2000) and has been addressed in previous descriptions of the anatomy of this region in Chapters 4 and 5. Under normal loads and physiological movement, extension is likely to be limited by compression of the suboccipital muscles against the occiput (Mercer & Bogduk, 2001).



Figure 8.1. Right lateral views of flexion and extension of the atlanto-occipital joints. The centre figure depicts the occipital condyle in a neutral position. The dots provide reference points. Reproduced from Bogduk, N., & Mercer, S. (2000). p.634

The centre of rotation for flexion and extension has been estimated to be in the centre of a circle ecompassing the outline of both occipital condyles (Penning, 1998) (Figure 8.2). The range of sagittal plane motion at the occipito-atlantal joint has been estimated to have a mean value of approximately 13° based on cadaveric studies (Bogduk & Mercer, 2000). Estimates based upon radiographic studies have been considerably greater. Fielding (1957) utilised cineroentgenographic techniques to assess segmental movement in a normal population and estimated the range of flexion to be 10° and extension to be 25° (Fielding, 1957). In an X-ray examination of ten asymptomatic adults, van Memeren et al (1990) estimated a greater range of segmental flexion of 16.7°, with extension estimated as 11.3°. The estimates of van Memeren and colleagues are most likely greater since these authors assessed for the greatest visualised range of intersegmental movement rather simply measuring displacement at the end-range position. This method accounts for paradox motion between the vertebrae whereby segments can move in the opposite direction to the gross physiological direction and may not reach their extreme position in the extreme position of the whole spine, implying that measured range of motion at endrange may not be the same as maximal range obtained at intermediate points along the path of motion (Penning, 1998; van Memeren, Drukker, Sanches, & Beursgens, 1990). As noted by Guttman (1960) as cited by Penning (1998), atlanto-occipital extension is seen to occur during the end stage of flexion of the cervical spine.



Figure 8.2. Instantaneous centre of motion of atlanto-occipital motion in the sagittal plane. Lateral projection of the fixed basiocciput with an outline of superimposed occipital condyles in flexion (solid lines) and extension (dashed lines). The instantaneous centre of motion is denoted by the star. Reproduced from Penning, L. (1998). p.58.

Lateral flexion is described as a very small movement at the atlanto-occipital joint (Krag, 1997). Given the morphology of the joint, it requires either the contralateral condyle of the occiput to rise out of the atlantal socket while pivoting in the ipsilateral socket, or for both condyles to slide in parallel to tilt on the atlas (Mercer & Bogduk, 2001). The observed lateral shifting of the atlantal ring (Krag, 1997) suggests that the latter description may more accurately reflect the actual physiological movement. The limitation of the movement has been described as due to tension developed in the alar ligaments (Driscoll, 1987; Werne, 1957), despite the lack of any regular and distinct direct anatomical connection of these ligaments between the occiput and atlas. Estimates of the available range of lateral flexion at this level have been 5° estimated on cadaveric observation and between 0° (Hohl & Baker, 1964) and 3.9° measured radiographically (Bogduk & Mercer, 2000).

Axial rotation at the occipito-atlantal joint is not considered a true physiological rotation about a vertical axis (Mercer & Bogduk, 2001) but rather a small translation movement whereby one occipital condyle slides anteriorly on the atlas whilst the contralateral condyle slides posteriorly (Krag, 1997; Penning, 1998). This motion is illustrated in Figure 8.3. During normal occiput to C7 rotation, counter rotation of up to 4° has been commonly noted at the occipito-atlantal joint on X-ray examination (Iai et al., 1993). Also during rotation of the cervical spine, the occiput has been observed to displace laterally on the atlas a distance up to 4.4mm (Penning & Wilmink, 1987). The translation movements comprising rotation at this level are essentially limited by the deep concavity of the upper articular processes of the atlas (Krag, 1997; Mercer & Bogduk, 2001; Penning & Wilmink, 1987) and the capsules of the lateral atlanto-occipital joints (Bogduk & Mercer, 2000), although White and Panjabi (1990) have suggested that the alar ligaments also provide a check to this movement through the inconsistently observed atlantal connection of the alar ligaments described by Dvorak et al (1988). Estimates of atlanto-occipital rotation have ranged from 0° to 8° during forced cadaveric motion and 3.4° on x-ray examination (Bogduk & Mercer, 2000), and 1° on CT examination of normal subjects (Penning & Wilmink, 1987).



**Figure 8.3** Right lateral views of axial rotation of the atlanto-occipital joint. Reproduced from Bogduk, N., & Mercer, S. (2000). p.634

#### 8.1.2 Atlanto-axial movement

The unique configuration of the atantoaxial joint permits considerable range of movement as well as transmitting the axial load of the head and atlas to the remainder of the cervical spine (Fielding, 1957; Mercer & Bogduk, 2001). The articular cartilage on both the atlantal and the axial facets of the joint are convex, producing biconvex lateral articulations with divergent joint surfaces filled with intra-articular meniscoids (Bogduk & Mercer, 2000).

Flexion at the atlantoaxial joint follows on from flexion of the atlanto-occipital joint (Driscoll, 1987). It involves an anterior translation of the atlas, with the anterior arch of the atlas separating from the odontoid process as the atlantal component of the joint slides down the slope of the cartilage of the axial component (Mercer & Bogduk, 2001). This is illustrated in Figure 8.4.

The movement of extension is the converse of flexion with a posterior translation of the inferior articular processes of the atlas (Bogduk & Mercer, 2000). The odontoid process is curved slightly posterior. This permits the anterior arch of the atlas to slide upwards and slightly backwards, allowing the atlantoaxial joint to extend (Mercer & Bogduk, 2001).

Limitation of flexion at the atlantoaxial joint is suggested by Mercer and Bogduk (2001) to be a function of the transverse and alar ligaments. Posterior translation of the atlas

during extension is limited by bony impaction as the anterior arch of the atlas abuts against the dens (Mercer & Bogduk, 2001). In contrast, Werne (1957, 1959) states that the tectorial membrane limits both flexion and extension at this level, tightening as it passes over the dens during flexion and uses the pretensioning occurring at the atlantooccipital level during extension to tension in concert with the alar ligaments to prevent further extension.



**Figure 8.4** Lateral view of the right lateral atlantoaxial joint illustrating forward and backward displacement.

Reproduced from Bogduk, N., & Mercer, S. (2000). p.635.

The instantaneous centre of motion of flexion and extension is estimated to be located in the dorsal half of the dens (Penning, 1998; van Memeren, Drukker, Sanches, & Beursgens, 1990). Estimates of available sagittal plane motion have varied widely. Using lateral radiographic images, Fielding (1957) estimated a total sagittal range of motion of 15° with up to 10° of extension being available and only 5° of flexion. Penning (1998) provides a similar estimate based on x-ray examination with 16° being a mean measurement. However, van Memeren et al (1990) estimate mean ranges of 16.1° of flexion and 15.6° of extension using lateral x-rays of ten asymptomatic subjects between the ages of 19 and 22. Werne (1959) quotes a mean range of motion in this plane of 23° on the basis of cadaveric investigation.

Side bending at this level is primarily a result of lateral translation of the atlas upon the axis (Mercer & Bogduk, 2001). This involves the ipsilateral lateral mass of the atlas sliding down the slope of its supporting superior articular process whilst the contralateral lateral mass slides upward (Bogduk & Mercer, 2000). This is illustrated in Figure 8.5. The inferior and lateral slope of the articular facets of the axis ensure that ipsilateral side bending accompanies the lateral translation (Mercer & Bogduk, 2001). This movement is primarily limited by tension developed in the contralateral alar ligament but the absolute bony block caused by impaction of the lateral mass of the atlas against the side of the odontoid process will ultimately limit this movement (Bogduk & Mercer, 2000). Estimates of the range of side bending available are infrequent but cadaveric studies have suggested an available movement of approximately 5° (Dankmeijer & Rethmeier, 1943).

During atlantoaxial rotation, the occiput and atlas move together as one unit on the axis around the dens (Dvorak et al., 2008; Fielding, 1957; Mercer & Bogduk, 2001). This requires the anterior arch of the atlas to pivot on the odontoid process at the median atlantoaxial joint. At the lateral atlantoaxial joints, the ipsilateral lateral mass of the atlas will pass backward and medially, sliding down the posterior slope of its axial facet whilst the contralateral lateral mass will pass forward and medially, sliding down the anterior slope of its facet (Bogduk & Mercer, 2000). This is illustrated in Figure 8.5. The instantaneous centre of rotation for this movement is estimated to remain around the central portion of the dens (Iai et al., 1993).



**Figure 8.5** Atlantoaxial left rotation. A: Top view. B: Right lateral view demonstrating the lateral mass of the atlas passing forward across the superior articular process of the axis.

Reproduced from Bogduk, N., & Mercer, S. (2000). p.634.

The total range of atlantoaxial rotation to each direction has been estimated between 38.9° and 47° in cadaveric examinations (Bogduk & Mercer, 2000; Panjabi et al., 1988;

Werne, 1959) and 31.4° and 46° radiologically (Dvorak, Hayek et al., 1987b; Dvorak, Panjabi et al., 1987; Penning, 1998; Wilmink & Patijn, 2001). This comprises an estimated 55% of the total axial rotation available in the cervical spine (Penning & Wilmink, 1987). Axial rotation is usually described as limited by the alar ligaments with the lateral altantoaxial joint capsules also contributing to this restraining function (Mercer & Bogduk, 2001; Werne, 1957, 1959).

#### 8.1.3 Coupling during occipito-atlanto-axial motion

#### Coupling of movement between lateral flexion and axial rotation

During lateral flexion of the head and atlas on the axis, the odontoid process is moved toward the occipital condyle on the side to which lateral flexion is directed (Penning, 1978). The head translates upon the atlas away from the direction of lateral flexion as the triangular lateral masses of the atlas are wedged laterally during approximation of the occipital condyle and the axis on that side (Penning, 1998).

Lateral flexion exerts a compression force axially along the side of the vertebral column to which the movement is directed. The ipsilateral lateral mass of the atlas is compressed and transmits this force caudally to the axis. Under this load, the inferior articular process of the axis is theorised to be forced down and slides backward on the superior articular process of C3, causing the axis to rotate in the direction of side bending (Bogduk & Mercer, 2000). This movement is illustrated in Figure 8.6. However, guidance of this rotation has also been attributed to the posterior attachments of the alar ligaments onto the dens (Penning, 1978; Werne, 1959). The net result is that tilting of the head results in rotation of the axis in the same direction as indicated by a radiologically visible and palpable deviation of the spinous process of the axis to the opposite side (Bogduk & Mercer, 2000; Fielding, 1957).



**Figure 8.6** Lateral bending from occiput to axis. With respect to the head, the atlas has moved ipsilaterally. With respect to the head and atlas, the axis has rotated to the side of lateral bending.

Reproduced from Penning, L. (1998). p. 61.

Rotation of the head is attended by rotation of the atlas and axis in the same direction (Penning, 1998). As the axis tilts toward the side of rotation, the space between the occipital condyle and the lateral joint facet increases on the ipsilateral side and is lessened on the opposite side. As a result, the triangular lateral mass of the atlas is drawn back toward the midline on the side of rotation and pushed laterally on the contralateral side (Penning & Wilmink, 1987). This mechanism explains the observed displacement of the atlas relative to the occiput reported by several authors (Penning, 1978; Penning & Wilmink, 1987; Reich & Dvorak, 1986). This motion is illustrated in Figure 8.7. Penning and Wilminck (1987) estimated an average lateral displacement of 4.4 millimetres in each direction. The relative shift of the odontoid process laterally results in a concomitant lateral shift of the atlas producing lateral bending in the opposite direction to the rotation (Penning, 1978).



**Figure 8.7**. Rotation from occiput to axis. With respect to the head and atlas, the axis has rotated contralaterally. The occiput to axis is laterally bent contralaterally to the direction of rotation.

Reproduced from Penning, L. (1998). p. 60.

*Coupling of movements between axial rotation and movements in the sagittal plane* In addition to coupling in the coronal plane, biplanar radiography has also revealed that axial rotation at the atlantoaxial joint is also coupled with sagittal plane movements. Using seated participants with their head held in one position and the trunk rotated beneath it, Iai and colleagues (1993) demonstrated that either flexion or extension may occur during the performance of atlantoaxial rotation. In their sample of 20 males, extension was more commonly produced during rotation than flexion with a mean measured range of 10° This confirms the previous work of Mimura and colleagues (1989) also based on biplanar radiography. These authors found that axial rotation was accompanied by an average of 14° of extension and 24° of contralateral lateral flexion (Mimura et al., 1989). This coupling occurs because of the essentially passive movement of the atlas under the load of the head. The occurrence of flexion or extension during axial rotation is considered to be a product of the individuals atlantoaxial joint shape and the exact line of longitudinal forces acting on the atlas from the head (Bogduk & Mercer, 2000).

#### 8.2 Transverse ligament related biomechanics

The function of the transverse ligament is the least disputed of any of the craniovertebral ligaments. With the absence of an intervertebral disc and the horizontal orientation of the facet joints, stability at the atlantoaxial joint is generally seen as dependant on the surrounding soft tissues (Oda, Panjabi, Crisco, & Oxland, 1992). Tests for the integrity of

the transverse ligament are based on descriptions of the ligament as the principle stabilising element of the atlantoaxial articulation (Torres-Cueco, 2008), acting to prevent excessive anterior displacement of the atlas on the axis during flexion of the craniovertebral region (Aspinall, 1990; Meadows, 1998; Meadows, 1999b; Mercer, 2004).

The role of the transverse ligament in restraining anterior translation of the atlas on the axis was demonstrated experimentally by Fielding and colleagues (1974) with a sample of 20 fresh adult cadavers. Using slings of braided wire to loop the posterior ring of the atlas and draw it anteriorly, the transverse ligament was ruptured in all 20 specimens at varying loads. The rupture of these ligaments occurred prior to any fracture of the dens or rupture of other ligaments leading the authors to conclude that the transverse ligament is the primary stabiliser acting against any horizontal displacement force applied to the atlas (Fielding et al., 1974).

Positioned across the arch of the atlas (Dvorak et al., 1988), the transverse ligament is suggested to play an important role in controlling and restraining antlanto-axial-occipital flexion in addition to anterior translation of the atlas (Bogduk & Mercer, 2000; Dvorak & Panjabi, 1987; Dvorak et al., 1988; Panjabi, Crisco et al., 1998). This viewpoint assumes that the occiput and atlas move together as a composite unit toward the end range flexion position (Mercer & Bogduk, 2001). This view is contrary to observations suggesting that the position of the atlas is relatively independent of the relationship between the occiput and the axis where the atlas may move with respect to the occiput without moving with

respect to the axis (Penning, 1978), paradox motion being common between segments in the cervical spine (Penning, 1998; van Memeren et al., 1990).

The suggestion that flexion may result in atlantoaxial subluxation in the absence of transverse ligament integrity has been supported by finite-element modelling techniques. Puttlitz and colleagues (2000) modelled the effect of flexion of the craniovertebral junction with various stiffness values applied to the resistance properties of the transverse, alar and capsular ligaments. Findings based on this modelling calculated that of all passive structures exerting influence in this region, an intact transverse ligament provided the smallest change in atlantodental interval. The conclusion drawn from this is that the transverse ligament is a primary stabiliser during craniovertebral flexion (Puttlitz et al., 2000). Whilst this model provides some interesting information with regard to ligamentous stability and a more three-dimension method of analysis than conventional radiographic studies, it does not consider the possibility of paradox motion during physiological flexion. Nor does it consider the effect of position with respect to gravity. This is because the model is mathematical and the kinematic data used to derive the model were drawn from an earlier cadaveric study by Goel et al (1988) in which static measures were recorded at varying positions of displacement determined by the stepwise application of 'dead-weight', paradox rotation being neither observed or recorded (Goel, Clark, Gallaes, & King Liu, 1988).

Additionally, the magnitude of yield in the cranial portion of the ligament which permits atlantoaxial flexion to occur has suggested to some authors that the transverse ligament

plays no role in checking normal movement such as rotation in the sagittal plane (Werne, 1957). Panjabi et al (1991) have described the stabilising role of the transverse ligament as "unknown".

It would appear that stress testing of the transverse ligament based on anterior translation of the atlas is supported by the available biomechanical literature. Considering flexion as a component of this examination is given less support, although, considering the biconvex nature of the lateral atlantoaxial articulations, load due to the effects of gravity on the head could feasibly increase the horizontal displacement force providing support for the use of flexion in the application of the Sharp-Purser test. Incorporating flexion into this examination in other positions, such as the 'palate sign' which is described in supine lying (Beeton, 1995; Mathews, 1969), remains questionable.

#### 8.3 Alar ligament related biomechanics

The alar ligaments have been described as potential limiting structures for all anatomical plane movements in the occipito-atlanto-axial complex. Whilst most commonly described as limiting contralateral rotation and lateral flexion (Dvorak, Hayek et al., 1987a; Harris et al., 1993; Kim et al., 2002; Poirier et al., 1911; White & Panjabi, 1990), they have also been attributed to limiting bilateral rotation (Krag, 1997; Panjabi, Dvorak, Crisco, Oda, Wang et al., 1991; Werne, 1957; Williams & Warwick, 1980), flexion (Bogduk & Mercer, 2000; Dvorak et al., 2008; Mercer & Bogduk, 1999; Panjabi, Dvorak, Crisco,

Oda, Hilibrand et al., 1991; Puttlitz et al., 2000; Steel, 1968) and extension (Brolin & Halldin, 2004; Dvorak & Panjabi, 1987; Panjabi, Dvorak, Crisco, Oda, Hilibrand et al., 1991). Alternatively, they have been described as acting with the tectorial membrane to provide a mechanism for maintaining firm contact between joint surfaces and ensuring joint congruity (Penning, 1998).

Both the rotation and the side-bending stress tests for the alar ligaments are based on the inherent coupling of rotation and lateral flexion within the O-C2 complex. This coupling action has been reported in numerous studies, most notably in the landmark work of Fielding (1957). In this early study using dynamic fluoroscopic images in asymptomatic individuals, Fielding noted that when the head was tilted to one side, the spinous process of C2 deviated to the opposite side indicating ipsilateral rotation of this segment (Fielding, 1957). A further demonstration of the consistent existence of this action was provided by X-ray examination of both asymptomatic individuals and cadavers whereby side-bending of the head to 15 degrees without rotation resulted in ipsilateral atlantoaxial rotation in nine out of ten subjects (Hohl & Baker, 1964). This coupling action at the occipito-atlanto-axial segments is considered essential to the maintenance of equilibrium of the head on the cervical spine since lateral flexion at the segments C3 to T1 will be ipsilaterally coupled with rotation at these levels (Penning, 1998). Thus, a de-rotation is required to maintain the head in an upright and forward facing position (Mercer & Bogduk, 2001). It is postulated that because of the tension developed in the alar ligaments connecting the occiput and axis, lateral flexion and rotation of the axis will be

consistently and immediately induced in the same direction (Hing & Reid, 2004; Meadows, 1999b; Westerhuis, 2007).

#### 8.3.1 Side-bending stress test for the alar ligaments

The frequently cited mechanism for the side-bending stress test uses the description by Dvorak and Panjabi (1987). In describing the function of the alar ligaments, these authors state that during sidebending the occipital portion of the ipsilateral alar ligament is relaxed while the atlantal portion is stretched causing the atlas to translate in the direction of side-bending without concomitant rotation. With increasing side-bending, the occipital portion of the contralateral alar ligament is stretched, limiting the side-bending. The stretched portion of the occipital ligament together with the atlantal portion on the ipsilateral side induces a forced rotation of the axis in the direction of side-bending (Dvorak et al., 2008; Dvorak & Panjabi, 1987).

Although providing a plausible mechanical description for the coupling of rotation and lateral flexion in the upper cervical spine, the investigation by Dvorak and Panjabi (1987) was a descriptive anatomical study of the alar ligaments using nineteen fresh cadavers. No biomechanical experimentation was described in this paper. Descriptions of function were based entirely on observation of the origin, direction and insertion of fibres of the alar ligaments rather than direct observation or quantification of the mechanics of the craniovertebral segments. The role of the so called atlantal portion of the alar ligament features extensively in the descriptions emanating from this group of researchers (Dvorak et al., 2008; Dvorak & Panjabi, 1987; Dvorak et al., 1988). However, as discussed in the literature reviewed in Chapters 4 and 6, and in our own anatomical investigations described in Chapters 5 and 7, the existence and function of this portion of ligament remains in dispute. Given that the original study by Dvorak and Panjabi (1987) identified this tissue as being present in only twelve of nineteen specimens, it should not be considered to perform an essential role in the mechanics of this region since its existence can, at best, be described as inconsistent and function appears not to be compromised in individuals not possessing the structure. Furthermore, described as only up to three millimetres in length with fibres oriented obliquely from dens to atlas (Dvorak & Panjabi, 1987), its ability to transmit force or direct movement under the load of the head is questionable. Indeed, in assessing the tensile strength of the alar ligaments, these authors note that they were unable to assess the strength of the tissue identified as the atlantal portion of the alar ligament due to its "small size" (Dvorak et al., 1988).

It is generally accepted that the contralateral alar ligament plays a role in limiting lateral translation of the head (Bogduk & Mercer, 2000; Mercer & Bogduk, 2001; Werne, 1957; White & Panjabi, 1990), however, it has also been suggested that the movement is limited ultimately by bony impaction of the contralateral lateral mass of the atlas on the lateral aspect of the odontoid process (Mercer & Bogduk, 2001).

One mechanism proposed for producing the coupling of movement in this region is related to alar ligament attachments onto the dens. Using descriptive anatomical methods, Werne (1957) examined 24 cadaveric specimens and described a mechanism whereby the contralateral alar ligament was tensioned through moderate lateral flexion. As lateral flexion is increased toward end range, the contralateral alar ligament pulls on its attachment to the posterior surface of the dens, causing a rotation in the same direction as the head is tilted. This rotation is suggested to result in a tightening of both alar ligaments which, will inhibit further movement into lateral flexion or rotation. This is illustrated in Figure 8.8.

Alternative biomechanical rationales for the cause of the coupling of atlanto-occipital lateral flexion and ipsilateral rotation of the second cervical vertebra that do not emphasise the role of the alar ligaments have been proposed. One mechanism presented is that the coupling is a function of the geometry of the articulations under the influence of gravitational load. In an upright position, lateral flexion of the head will exert an axial compression load along the ipsilateral side of the vertebral column. The ipsilateral lateral mass of the atlas is compressed and transmits this force caudally. Under this load, the ipsilateral articular process of the axis is forced to move downward and backward along the slope of the superior articular process of C3. This backward displacement causes the axis to rotate in the direction of sidebending (Mercer & Bogduk, 2001).

Following an x-ray examination of 372 asymptomatic people, Jirout (1973) suggested that this rotation of the axis may be a product of the muscle action of rectus capitus

posterior major acting on the spinous process of the axis. Running from the spine of the axis to and beneath the lateral aspect of the inferior nuchal line on the occipital bone (Gardner et al., 1975), the line of pull of this muscle could be considered consistent with this proposed mechanism. Whilst suggested as a mechanism by Jirout, the methods of the study involved only x-ray examination and resultant changes in position of the articular processes. Therefore, no direct assessment could be made of the action or recruitment of rectus capitus posterior major during or following the lateral flexion movement. No further research has been published to explore the role of this muscle in the coupling mechanism which could either support or refute Jirout's proposed mechanism.



Figure 8.8. Alar ligaments during occipito-atlanto-axial lateral flexion.
A: In the mid position the alar ligaments are not tensioned.
B: On moderate lateral flexion, the contralateral alar ligament tightens.
C: On extreme lateral flexion the dens rotates causing the ipsilateral alar ligament to tighten.

Reproduced from Werne (1957). p.46.
In a cadaveric examination of one specimen, Hohl and Baker (1964) observed that imposing craniocervical lateral flexion whilst preventing atlantoaxial rotation produced no appreciable lateral displacement of the atlas on the axis or any asymmetry of the position of the odontoid process. When as little as 10° of atlantoaxial rotation was permitted, the atlas deviated laterally on the axis producing an offset of the articular facets and an asymmetrical position of the odontoid process (Hohl & Baker, 1964). This observation underlies the importance of stabilisation of the posterior elements of the axis to prevent rotation during the side-bending stress test for the alar ligaments.

#### 8.3.2 Rotation stress test for the alar ligaments

The alar ligaments are the main restraint against rotation of the upper cervical complex with the lateral atlanto-occipital joint capsules playing a minor role (Dvorak et al., 1988; Mercer & Bogduk, 2001). The rotation stress test for the alar ligaments is based on preventing the coupling of rotation with lateral flexion during the application of a physiological rotation of the head on a fixed axis (Hing & Reid, 2004).

During rotation of the occiput, the contralateral alar ligament is suggested to wind around the odontoid process due to its posterior attachment, and the ipsilateral alar ligament remains free of tension (Dvorak et al., 2008; Dvorak et al., 1988; Mercer, 2004). The odontoid process will then shift laterally in the same direction as the rotation since the tensioned alar ligament prevents the posterior odontoid from moving and thus becomes the centre of rotation (Penning, 1998). This lateral displacement is secondary to the forced rotation of the axis (Dvorak et al., 2008). The landmark study of Werne (1957) provides a clear explanation for the coupling of movement during rotation, describing movement in relation to C2 rotation with an initially stationary occiput. According to Werne, upon rotation of C2, the ipsilateral alar ligament is tensioned. On an increased range of rotation, the ipsilateral alar ligament is shortened by winding around the dens. This shortening is suggested to to draw the ipsilateral occipital condyle toward the dens, resulting in O-C1 lateral flexion in the same direction as the axis rotates. The lateral flexion thus produced will then tighten the contralateral alar ligament (Werne, 1957, 1959). This is illustrated in Figure 8.9.

Whilst the majority of authors describing rotation testing of the alar ligaments ascribe to the view that the contralateral alar ligament is always implicated during these manoeuvres (Beeton, 1995; Meadows, 1999b; Pettman, 1994; von Piekartz, 2007), there is considerable comment in the anatomical and biomechanical literature suggesting that the alar ligaments exert a bilateral influence on the upper cervical segments during rotation. Indeed, Werne (1959) explicitly states that based upon his observations, movement between the craniovertebral segments during rotation is not limited until both alar ligaments are tight.

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Figure 8.9. Alar ligaments during occipito-atlanto-axial rotation.

A: In the mid position the alar ligaments are not tensioned.B: On moderate rotation, the ipsilateral alar ligament is tightened.C: On extreme rotation, the ipsilateral alar ligament is shortened by winding around the odontoid process. The ipsilateral condyle approaches the odontoid process producing lateral flexion to that direction at the atlanto-occipital joints and the contralateral alar ligament is thus tightened.

Reproduced from Werne (1957). p.48.

Descriptions of alar ligament function in Gray's Anatomy (Williams & Warwick, 1980) attribute tension developed in different portions of the ligament to the limitation of segmental movement. According to the model proposed, the motion of rotation to the right will be checked by tension created in the fibres of the right alar ligament which attach to the odontoid process anterior to the axis of rotation and by tension developed in the fibres of the left alar ligament which attach to the odontoid process behind the centre of movement (Williams & Warwick, 1980). Implicit in this model is the assumption stated by the authors, describing the alar ligaments as "taut" in the neutral position. This permits modelling of the ligament as a more rigid structure, simplifying explanation of the development of tension and course of movement. However, other studies have found the alar ligaments to be lax in the neutral position (Dvorak & Panjabi, 1987; Werne, 1957), bringing into question the use of rigid modelling for these structures.

Using more sophisticated mathematical modelling, Crisco and colleagues (1991) proposed an alternative description for the action of the alar ligaments. According to their model, the alar ligaments reach their maximum length simultaneously. This results in a movement of the centre of rotation away from the midpoint of the dens toward the origin of the ligament. If the ligament is intact, this alteration in the centre of movement toward the origins is contrary thus no further rotation will occur. If one ligament is transected, rotation to both sides should increase (Crisco, Panjabi, & Dvorak, 1991). A schematic of this model is provided in Figure 8.10.

Further three-dimensional computer modelling was undertaken by Goel and colleagues (1992) based upon sliced and digitised tracings of the bony structure of the occipitoatlanto-axial complex from a fresh cadaveric specimen. This model suggests that at 40° of axial rotation, the posterior portion of the contralateral alar ligament and the anterior portion of the ipsilateral alar ligament will exhibit increased strain. This reflects the different paths taken by these fibres in the model during rotation whereby the posterior fibres on the contralateral side move farther away from the centre of rotation at a higher rate than the anterior fibres. The converse occurs ipsilaterally (Goel, Yamanishi, & Chang, 1992). The authors suggest that maximum strain of the alar ligaments occurs at sixty degrees of rotation. This highlights one of the limitations of this type of modelling. Whilst providing useful information on movement and limitation to movement in the upper cervical spine, this modelling can only provide information within the limits of the data imputed. The occipito-atlanto-axial complex is not physiologically capable of rotating sixty degrees in any one direction. Hence, the reasonableness of this comment and the implications for injury of the ligaments are dubious, especially considering that the alar ligaments have been demonstrated to sustain injury at far less rotated positions.



**Figure 8.10**. Caudal view of the modelling of rotation of the occiput around the odontoid process.

Reproduced from Crisco et al. (1991). pp 607-614.

The most conclusive work to date exploring the role of the alar ligaments in limiting rotation in the craniovertebral region are the transection studies of the ligaments themselves. However, these studies have none the less yielded inconsistent results. Dvorak et al (1987) examined rotation in twelve cadavers using images derived from CT scans taken in neutral and end range rotation to either direction. The imaging was repeated following transection of the left alar ligament. Transection yielded an average increase of 10.8 degrees of right rotation compared to a 1.8° average increase in available range of rotation to the left, suggesting a 30% increase in range of contralateral occipitoatlanto-axial rotation. Interestingly, about one-half of the increased rotation was found to occur at the occipito-atlantal level with average range increasing from 4.4 degrees to 9.4 degrees. The primary restraint to rotation between the occiput and the atlas is considered to be joint shape itself, often described as "cup-like" (Bogduk & Mercer, 2000; Krag, 1997; White & Panjabi, 1990). So congruent is the anatomy of this articulation that rotation at this level is considered very slight. It has been noted under experimental anatomical conditions that if the head is forcibly rotated with respect to the atlas, the occipital condyles are lifted out of the superior atlantal sockets. This has been suggested to normally be prevented by tightness of the alar ligaments but this motion is not considered physiological (Bogduk & Mercer, 2000; Penning, 1998).

Similar exploration of upper cervical spine rotation was undertaken using ten fresh cadaveric specimens (Panjabi, Dvorak, Crisco, Oda, Wang et al., 1991). Movements were recorded photographically by two cameras and sequential severing of the alar ligaments undertaken, left preceding right. The results of this study contrast to those of Dvorak et al (1987) described above. Transection of a single alar ligament resulted in increases in rotation to both directions, suggesting that injury to one ligament affects the entire rotator stability of the joint complex. Segmentally, atlanto-occipital rotation increased from 3.3 degrees to 5 degrees during left rotation and from 6 degrees to 8.1 degrees on rotation to the right following transection of the left alar ligament. Atlanto-axial rotation to the left did not alter by more than 2.5 degrees following transection of the left alar ligament ranged from eight to ten percent. The transection of the second alar ligament had little additional impact on range of rotation between occiput and axis compared to measurements obtained following transection of the left alar ligament only.

It should be borne in mind when considering these transection studies that in order to access and transect the alar ligament, the tectorial membrane must be removed. Therefore, the influence of the tectorial membrane as a stabilising or limiting structure during rotation of the upper cervical segments cannot be commented upon.

Guttman (1981, cited in Dvorak, et al., 2008) reports that when the head is turned, both the atlas and axis will rotate with it simultaneously. This description is not supported by the later work of Iai et al (1993) who used biplanar radiographs to examine the rotation motion in twenty adult males with asymptomatic cervical spines. According to these authors, the atlas consistently counter-rotated approximately four degrees beneath the occiput, thus ensuring an upright position of the head throughout the movement (Iai et al., 1993). Segmentally, atlanto-occipital lateral flexion occurred in the same direction as the segmental rotation, whilst atlantoaxial lateral flexion occurred in the opposite direction to the segmental rotation to compensate for the lateral bending of the lower cervical vertebra. Whilst the alar ligaments do not directly limit movement of the atlas during rotation, their action in limiting range of movement of the head provides a secondary limitation to the movement of the atlas (Bogduk & Mercer, 2000).

#### 8.3.3 The alar ligaments in craniocervical flexion

The alar ligaments are frequently cited as having a role in the limitation of craniocervical flexion. However, this proposed function is not represented in clinical tests for the alar ligaments themselves. Alar ligament related limitation of flexion is proposed by Dvorak (2008) but few studies have explored this role.

Panjabi et al (1991) examined changes in flexion range of movement as a part of their cadaveric transection studies. Following transection of one alar ligament, mean occipio-atlanto-axial flexion increased twenty percent, the greater proportion of change occurring at the atlantoaxial joint (Panjabi, Dvorak, Crisco, Oda, Hilibrand et al., 1991). This finding suggests that flexion stability is contributed to by the alar ligaments.

A number of authors have suggested that the alar ligaments perform a secondary line of protection against flexion of the upper cervical segments, supplementing the stability provided by the nuchal ligament, posterior longitudinal membrane and the tectorial membrane (Dvorak & Panjabi, 1987; Fielding et al., 1974; Steel, 1968). This view is countered by the three-dimensional computer modelling of Goel et al (1992) who

calculated no significant increase in alar ligament strain moving into flexion leading these authors to conclude that the alar ligaments play no role in inhibiting flexion. Instead, it was suggested that the tension in the ligaments will increase with upper cervical spine extension, maximising at an increase of 18% by forty degrees of extension (Goel et al., 1992).

Rather than flexion, the alar ligament has been implicated in limiting anterior translation at the atlantoaxial joints, with some suggestion that anterior translation is limited by both the transverse ligament and alar ligaments. (Bogduk & Mercer, 2000; Mercer & Bogduk, 2001). These authors have suggested that provided either the transverse ligament or the alar ligaments remain intact, the integrity of the atlantoaxial joint is maintained and dislocation of the atlas is prevented. This view is countered by Werne (1957) who considered that the laxity of the alar ligaments in the mid position made them unsuited to resist horizontal translation in the neutral position.

Perhaps the only study to quantitatively assess the role of the alar ligaments in limiting anterior translation was a finite elements model generated to examine atlantoaxial subluxation in rheumatoid arthritis (Puttlitz et al., 2000). The findings support the view that the alar ligaments may constitute a second line of defence in preventing atlantoaxial subluxation. In the absence of any transverse ligament disruption, alar ligament compromise did not significantly contribute to the development of atlantoaxial instability. However, when transverse ligament compromise was present, alar ligament disruption increased the atlantoaxial subluxation more than transverse ligament disruption alone.

#### 8.4 Tectorial membrane related biomechanics

Clinical assessment of the integrity of the tectorial membrane is constructed around the observation that the tectorial membrane is the primary stabiliser resisting distraction of the head on the cervical spine. This essentially non-physiological test movement is sensitised by incorporating upper cervical spine flexion and extension into the test positions (Aspinall, 1990; Beeton, 1995; Pettman, 1994; Westerhuis, 2007). Only one investigation appears to have evaluated this structure as a limiting factor in vertical displacement of the head on the spine. Werne (1957) provides brief comment in his anatomical descriptions noting that the tectorial membrane limited vertical translation in 19 of the 24 specimens examined. No subsequent study has been identified to further examine this suggested role for the tectorial membrane, perhaps due to the non-physiological nature of this movement.

Consensus is yet to be achieved amongst researchers and authors regarding the role of the tectorial membrane in the limitation of movement of the craniovertebral segments. Most authors cite a role in the limitation of flexion (Mercer, 2004; White & Panjabi, 1990). However, it has also been implicated in the limitation of extension, axial rotation and vertical translation in the occipito-atlanto-axial segments (Dvorak et al., 2008; Oda, Panjabi, Crisco, Bueff et al., 1992; Penning, 1998; Werne, 1959; White & Panjabi, 1990).

Early observational cadaveric studies suggested that the tectorial membrane acts to limit flexion of the head on the vertebral column. This was based upon the observation that following transection of the superior insertion of the tectorial membrane, the range of flexion was markedly increased in the craniovertebral complex (Poirier et al., 1911).

In his descriptive study of 24 cadaveric specimens, Werne (1957) attempted to refine this observation by describing the limiting role of this structure in relation to segmental motion. According to Werne's observations, during occipito-atlantal flexion, the anterior portion of the skull descends, carrying with it the insertion of the tectorial membrane on the clivus. This movement results in the approximation of the insertion of the tectorial membrane with its portion overlying the dens, creating relative slack in the ligament and preventing it from limiting atlanto-occipital flexion. With further flexion, the anterior margin of the foramen magnum contacts the dens, via the interposed bursa apicis dentis, to check the movement.

Following atlanto-occipital flexion, Werne noted that the anterior margin of the foramen magnum passed forward and downward over the dens as the atlantoaxial joint began to flex. Tension was thus generated in the tectorial membrane by atlantoaxial flexion, with the dens acting as a fulcrum during this movement. Subsequent removal of the tectorial membrane reportedly increased the available range of atlantoaxial flexion by a magnitude of between two and five degrees, with the alar ligaments eventually tensioning to limit further movement (Werne, 1957).

The limiting function of the tectorial membrane is supported by Dvorak and Panjabi (1987) whose results of a descriptive anatomical examination of 19 fresh cadavers ascribe this contribution (together with the nuchal and transverse ligaments) as limiting upper cervical spine flexion. Curiously, in their paper these authors describe the sectioning and removal of the tectorial membrane during specimen preparation prior to observation, suggesting that this is not a direct observation derived from this study (Dvorak & Panjabi, 1987).

More compelling evidence is provided by the work of Harris and colleagues (1993). Using lateral radiographs, these authors examined flexion and extension of the occiptoatlanto-axial complex in six fresh cadavers, before and after ligament transection. They noted that following transection of the tectorial membrane, instability occurred during atlanto-occipital flexion. This manifested as an appreciable sagittal translation at the atlanto-occipital level indicating a substantial role for the tectorial membrane in maintaining sagittal stability during upper cervical spine flexion (Harris et al., 1993).

Oda et al (1992) provide more quantitative assessment of the effect of tectorial membrane transection upon kinematics of the upper cervical spine. Using five fresh cadaveric specimens extending from the occiput to the third cervical vertebra, these authors radiographically demonstrated alterations in available range of craniovertebral movement following transection of the tectorial membrane at its occipital attachment site and reflection of the sectioned structure to the C2 level. Following transection, the mean range of occipito-atlanto-axial flexion increased from 23.5 degrees to 30.2 degrees; an

overall increase of 28.4%. This increase was evident in both levels of the craniovertebral complex, with occipito-atlantal flexion increasing by 22.8% and atlantoaxial flexion by 33.4% (Oda, Panjabi, Crisco, Bueff et al., 1992).

Using goniometric measurement in 13 formalin-fixed cadavers, Tubbs et al (2007) reported the tectorial membrane to be "fully taut" following imposition of a mean craniocervical flexion of 15 degrees. At this point, the authors noted that the middle portion of the tectorial membrane was stretched over the odontoid process leading them to conclude that the functional importance of the tensioning of the tectorial membrane during flexion was not to limit sagittal movement per se but to inhibit potentially injurious posterior movement of the odontoid process into the cervical canal (Tubbs et al., 2007).

The findings regarding tectorial membrane transection raise questions regarding published opinions of the importance of the alar ligaments in resisting cervical flexion. Alar ligament transection in cadavers requires that the tectorial membrane be removed to access the ligaments. Hence, the figures published by Panjabi et al (1991) pertain to combined lesions of both the alar ligaments and tectorial membrane. Following transection of the tectorial membrane alone, Oda et al report a 28.4% increase in the available range of flexion. This figure is identical to the percentage increase in flexion reported by Panjabi et al in their alar ligament transection studies, suggesting that the alar ligaments do not appreciably add to the resistance to craniocervical flexion already provided by the tectorial membrane.

The role of the tectorial membrane in limiting extension is supported and described by Werne (1957) in his observation of 24 anatomical specimens. During occipito-atlantal extension, he noted that the attachment of the tectorial membrane moved away from the point where it rides over the dens resulting in the ligament being tightened and checking the extension movement. This pre-existing tension generated at the extended O-C1 segment would then inhibit atlantoaxial extension by exerting a counter pull (Werne, 1957). This function was also described by Tubbs et al (2007), reporting the tectorial membrane to be maximally tensioned at twenty degrees of craniocervical extension.

Contrary viewpoints have been expressed by Oda et al (1992) and Harris et al (1993). Both of these studies analysed radiographic measurements before and after transection of the tectorial membrane. Neither study found any appreciable increase in joint rotation or translation during extension in the interval spanning occiput to axis following excision of the tectorial membrane.

The funnel shape of the tectorial membrane described in both our anatomical study and previous anatomical studies (Fick, 1904; Poirier et al., 1911; Werne, 1957) has raised suggestions that the tectorial membrane may have a role in limiting segmental axial rotation between the occiput and the axis. This viewpoint is addressed by Werne (1957) in an examination of rotation in 16 specimens. Werne found no measureable increase in range of rotation in eight specimens following removal of the tectorial membrane and differences within the error of protractor measurement in the remaining eight specimens.

This supports the notion that the tectorial membrane offers no resistance to rotation in addition to that provided by the alar ligaments. Werne's conclusion following this cadaveric examination is that the torsion that would be required to be generated in the tectorial membrane to limit the movement would be far greater than the range of rotation available at these joints (Werne, 1957).

In contrast, Oda et al (1992) have suggested that resistance to axial rotation is an important component of multidirectional stability of the upper cervical spine provided by the tectorial membrane. Cadaveric examination of the occipito-atlanto-axial motion of five specimens indicated a mean increase in range of bilateral rotation from 75.5 degrees to 81.4 degrees, an overall increase of 7.8%. When these results are examined segmentally, a 4.5 degree (35.4%) mean increase occurred between the occiput and atlas while only a 1.4 degree (2.3%) mean increase was measured between atlas and axis. The resultant rotation at the occipto-atlantal joints in excess of seventeen degrees should not be considered physiological when the rounded and congruent articular shapes are considered. Such an amount of forced rotation between occiput and atlas would result in the lifting of the occipital condyles out of the superior atlantal sockets (Penning, 1998), a situation that does not occur in normal physiological movement and has only been demonstrated in cadaveric studies. If the tectorial membrane has a role during normal rotation movement it may be to prevent lifting, and hence rotation, of the occipital condyles from the superior atlantal sockets (Penning, 1998).

# **CHAPTER 9**

# LITERATURE REVIEW OF THE CLINICAL TESTS FOR CRANIOVERTEBRAL INSTABILITY

A number of clinical tests have been proposed to assess the integrity of the ligaments of the craniovertebral region. A description of these tests and their characteristics is given below.

## 9.1 Tests for the transverse ligament

#### 9.1.1 Sharp-Purser Test

First described in 1961, this test was proposed as a clinical method of assessing spontaneous atlanto-axial dislocation in people with ankylosing spondylitis and rheumatoid arthritis (Sharp & Purser, 1961).

The rationale for the development of the test lay in two earlier observations. Coutts (1934) published a case series of 34 patients. In his description, he noted that on radiological examination, an increase in the interval between the odontoid process and the anterior arch of the atlas in the absence of a fracture of the odontoid process indicated atlanto-axial subluxation (Coutts, 1934). Later, an anatomical study conducted by Werne (1957) noted that no forward slipping of the atlas on the axis occurred on cervical flexion until the transverse ligament was divided.

The Sharp-Purser test is performed with the patient seated. The test as originally described is as follows; "The palm of one hand was placed on the patient's forehead and the thumb of the other on the tip of the spinous process of the axis. The patient was then asked to relax the neck in a semi-flexed position. By pressing backwards with the palm a sliding motion of the head backwards in relation to the spine of the axis could be demonstrated" (Sharp & Purser, 1961).

Variations on the neck position and method of stabilisation of the axis and on methods of applying posteriorly directed pressure have been reported. Uitvlught and Indembaum (1988) described controlling the axis with an index finger rather than the thumb as originally described. The inset in Figure 9.1 illustrates stabilisation of the axis using a pinch grip as suggested by Pettman (1994) and Hing and Reid (2004). Posterior gliding of the occiput has also been described as supporting the head with the forearm placed along the zygomatic arch (Beeton, 1995; Hing & Reid, 2004) (Figure 9.2). Pettman (1994) also described performing the test with the neck in full flexion rather than the semi-flexion position described by Sharp and Purser.

Interpretation of the test in its original form was that any sliding motion of the head when pressure was applied in a posterior direction indicated atlanto-axial instability (Aspinall, 1990; Beeton, 1995; Meadows, 1998; Uitvlugt & Indenbaum, 1988). Other descriptions of the interpretation of the Sharp-Purser test relate to symptom modification. As the test is proposed to relocate the odontoid process against the anterior arch of the atlas, it is considered that symptoms associated with this position may be relieved or ablated (Gibbons & Tehan, 2004; Hing & Reid, 2004; Lincoln, 2000; Mintken et al., 2008; Pettman, 1994; Westerhuis, 2007). A 'clunk' on relocation of the atlas has also been interpreted as a positive finding (Beeton, 1995; Hing & Reid, 2004; Pettman, 1994).



**Figure 9.1.** The Sharp-Purser test. Arrows indicate the direction of forces applied to the axis and the patient's forehead.

Reproduced from Pettman (1994). p 533



**Figure 9.2.** Alternate position for Sharp-Purser test. The posterior glide of the occiput is imposed by grasping the head with the forearm around the patients zygomatic arch.

Reproduced from Hing & Reid, D. (2004).

Interpretation of the test by symptom behaviour has been a controversial development, particularly in the presence of central neurological signs. Whilst Pettman (1994) describes altering these symptoms as diagnostic and hence useful in determining the level of cord compression, other authors contend that the risk of increased neurological damage makes the test unsafe in the presence of neurological signs (Rana et al., 1973) or that the sustained stress on the transverse ligament, particularly in the presence of an anxious clinician confronted by a patient with an onset of cardinal signs, could lead to further tearing or rupture of the transverse ligament (Meadows, 1998).

The most commonly cited assessment of the validity of the Sharp-Purser test was conducted by Uitvlught and Indenbaum (1988) in a sample of 123 patients with rheumatoid arthritis. Diagnosis of atlanto-axial instability was based on measurement of the atlanto-dental interval from lateral x-rays in full flexion and extension. An atlantodental interval greater than three millimetres was classified as abnormal. Thirty-two patients (26%) in this sample were considered unstable based on this criterion. Results published from this study indicate a sensitivity of 69%, specificity of 96% and a positive predictive value of 85%. Patients classed as having false negative findings on Sharp-Purser testing had measured atlanto-dental intervals on average 4.2 millimetres compared with an average of 5.5 millimetres in the group with positive Sharp-Purser test results. When the authors recalculated their results on a definition of instability of an atlantodens interval greater than four millimetres, sensitivity rose to 88%.

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Forrester and Barlas (1999) also used an atlantodental interval of three millimetres to assess the Sharp-Purser test in a population of 31 rhematoid arthritis patients. The prevalence of instability in their sample when judged by radiographic criterion was 16%. In contrast to Uitvlught and Indenbaum, these authors achieved a sensitivity of only 43%, specificity of 77% and a positive predictive value of 89%. Such results would indicate that the test should not be considered valid as a test for atlanto-axial instability.

These results were consistent with the findings of earlier studies using larger samples of rheumatoid arthritis patients. Judging by the same gold standard as the other described studies, Stevens et al. (1971) assessed one-hundred patients using the Sharp-Purser test. Their results indicated a sensitivity of 44% and a specificity of 98% leading them to conclude that the test, when positive, was clinically useful (Stevens et al., 1971). Again, using individuals with rheumatoid arthritis and the same assessment criteria, 76 patients were assessed using the Sharp-Purser test by (Mathews, 1969). Reanalysis of his results indicate a sensitivity of 47%, specificity of 56% and a positive predictive value of only 19%.

Reliability of the Sharp-Purser test was examined by Cattrysse et al. (1997) using a sample of eleven children with Down syndrome. Four manual therapy practitioners with different degrees of experience in manual therapy evaluated each child. Kappa values for interobserver reliability varied between examiners from 0.29 to 0.67 with statistical significance at the 0.05 level reached for only two of the four examiners. Interobserver reliability ranged from 0.09 to 0.67 and was significant at the 0.05 level between two

examiners only. The conclusion of the authors was that the Sharp-Purser test showed no significant reproducibility in a Down syndrome population as both the levels of intra- and interobserver reliability were unacceptable (Cattrysse et al., 1997). Forrester and Barlas (1999) also examined the reliability of this test using six physiotherapists and a population of 31 patients with rheumatoid arthritis. The overall Kappa value obtained for interobserver reliability was 0.20, indicating poor interobserver reliability (Forrester & Barlas, 1999). Once again, these results bring into question the reliability of the Sharp-Purser test.

It should be noted that all assessments of the validity and reliability of this test have been performed in non-traumatic populations. Whilst we may infer that the mechanism by which the test is proposed to be effective is the same, the applicability of the test to a traumatic population is not truly known.

#### 9.1.2 Anterior shear test

Unlike the Sharp-Purser test, the anterior shear test is potentially a provocation test. For this reason, some authors have urged caution in its use and suggest it should only be used in the presence of a negative Sharp-Purser test (Aspinall, 1990; Beeton, 1995).

The test is performed with the patient in a supine lying position with a neutrally positioned cervical spine and the clinician standing or seated at the head of the couch, with both index fingers placed posteriorly against the atlas and fingers III and IV resting

against the occiput. The axis is then fixed by stabilisation on the anterior aspect of the transverse processes by the clinician's thumbs. Gentle pressure is then applied to the posterior arch of the atlas, the head and atlas moving anteriorly as a unit whilst gravity fixes the lower portion of the cervical spine (Figure 9.3). No movement should be detected or symptoms produced if the transverse ligament is normal (Aspinall, 1990; Beeton, 1995; Meadows, 1999b; Mintken et al., 2008; Pettman, 1994; Westerhuis, 2007).

An abnormal response occurs when the atlas glides forward on the axis, potentially allowing the dens to move into the space available for the cord. In addition to movement, patient symptoms may be provoked or reproduced, including cardinal signs or a feeling of a 'lump in the throat', and a 'clunk' may be heard as the atlas moves forward on the axis (Aspinall, 1990; Beeton, 1995; Pettman, 1994). No examination of the validity and reliability of the anterior shear test has been published to date.

However, a variation on this test was published by Kaale et al. (2008). In his description, the patient is seated, the head in a neutral position and the axis is stabilised anteriorly by index and middle finger pressure over the transverse process on one side, and thumb pressure on the other. Using the other hand, the thumb is then pressed onto the posterior aspect of one lateral mass of the atlas and finger pressure from the index and middle fingers applied on the contralateral lateral mass. The atlas is pressed anteriorly and the axis pressed posteriorly simultaneously, allowing translation to be assessed. The test is repeated in varying degrees of cervical flexion (Kaale, Krakenes, Albrektsen, & Wester, 2008). These authors examined the accuracy of this technique by comparing the results to

MRI findings of transverse ligament injury in a sample of 122 people, 92 of whom had sustained a whiplash associated disorder and 30 control subjects. They demonstrated a sensitivity of 65%, specificity of 99% and positive predictive value of 97%.



**Figure 9.3** The anterior shear test. Gentle pressure is applied to the posterior arch of the atlas, the head and atlas moving anteriorly as a unit whilst gravity fixes the lower portion of the cervical spine.

Reproduced from Westerhuis, P. (2007). p 134.

#### 9.1.3 Palate sign

The palate sign, as described by Mathews (1969), involves palpation of the posterior pharyngeal wall to detect separation of the anterior arch of the atlas from the body of the axis during cervical flexion (Figure 9.4). The clinician's index finger is slid along the dorsum of the tongue until the posterior pharyngeal wall is encountered. It is then moved up and down until the ligament between the anterior arch of the atlas and the body of the axis can be felt. The opposite hand then passively moves the patient's neck into flexion and extension, whilst the examining finger assesses for abnormal separation between the two bones.

Mathews considered this test reliable after examining its utility in 76 patients with rheumatoid arthritis. His results indicate sensitivity of 26%, specificity of 96% and a positive predictive value of 71%.

The test has been criticised as too difficult to perform and too uncomfortable for the patient to use as a screening test. Additionally, the test often elicits the gag reflex, adding to patient distress (Beeton, 1995; Uitvlugt & Indenbaum, 1988).



**Figure 9.4** The palate sign demonstrating palpation of the posterior pharyngeal wall to detect separation of the anterior arch of the atlas from the body of the axis during cervical flexion.

Reproduced from Mathews (1969). pp 260-265.

#### 9.1.4 'Clunk' test

This test involves the repeated flexion and extension of the patient's cervical spine, either in sitting or supine. 'Clunking', defined as a distinct jerk in the normally smooth movement that can be seen or felt, is considered to be a positive response to the test (Mathews, 1969). Data from the only study published examining this test suggests that it has a sensitivity of only 10%, specificity 92% and positive predictive value of 33%.

The test has also been labelled dangerous by some authors due to the potential for anterior subluxation of the atlantoaxial joint allowing potential cord compromise (Uitvlugt & Indenbaum, 1988).

## 9.1.5 Posterior-anterior glide of the axis

Designed as an adaptation of the Sharp-Purser test, the posterior-anterior glide is performed with the patient in supine lying and with their upper cervical spine flexed to the position of the onset of symptoms. The examiner is positioned either sitting or standing at the head of the plinth. The clinician holds the patients head on either side using their thenar eminences and exerts pressure on the posterior aspect of the axis in an attempt to move it ventrally. In the case of an instability, subluxation and corresponding symptoms would be reduced (Westerhuis, 2007).

#### 9.2 Tests for the alar ligaments

#### 9.2.1 Side-bending stress test

This stress test was first proposed by Aspinall (1990) and is predicated on the descriptions of anatomy and biomechanics published by Dvorak and colleagues.

Aspinall's described test is based upon the acceptance of the following features described in the anatomical literature:

- The alar ligaments commonly consist of both occipital and atlantal portions. Atlantal portions are oriented obliquely from dens to atlas and are approximately three millimetres in length (Dvorak & Panjabi, 1987).
- 2. During side-bending, the ipsilateral occipital portion of the ligament is relaxed and the ipsilateral atlantal portion is tensioned. With further side-bending, the contralateral occipital portion of the ligament is stretched (Dvorak et al., 1988).
- 3. The stretched portion on the contralateral side, together with the tensioned ipsilateral atlantal portion, induce forced rotation of the axis in the direction of the side-bending (Dvorak, Hayek et al., 1987a cited in Aspinall 1990).
- Fibre orientation of the ligaments is dependent on dens height in relation to the occipital condyles and ligaments may be oriented horizontally, craniocaudally or caudocranially (Dvorak & Panjabi, 1987).

Combining points one to three illustrates the presumed biomechanical rationale on which the test is based. Side-bending of the occiput on the atlas is accompanied by immediate ipsilateral rotation of the axis beneath the atlas as a result of tension developed in the alar ligaments (Derrick & Chesworth, 1992; Pettman, 1994). The test has been described in both sitting (Gibbons & Tehan, 2004; Westerhuis, 2007) and supine lying (Hing & Reid, 2004).

The spinous process and lamina of the axis is stabilised by the therapist to prevent both side-bending and rotation of the segment (Aspinall, 1990). This is achieved by placing the thumb along one side of the neural arch of the axis and the index finger along the other (Pettman, 1994). Slight compression is applied to the occiput through the crown of the head. This is used to facilitate atlanto-occipital side-bending. Passive side-bending is then applied using pressure through the patients head, in effect directing the patient's ear toward the opposite side of the neck, i.e. head on neck movement (Figure 9.5) (Aspinall, 1990; Beeton, 1995; Gibbons & Tehan, 2004; Pettman, 1994). Given the variation in height of the dens relative to the occipital condyles and consequent variation in orientation of the alar ligaments, the test is recommended to be performed in three planes, i.e. neutral, flexion and extension (Aspinall, 1990; Beeton, 1995). It is also suggested by Beeton (1995) that testing needs to be done for both sides on the basis of Dvorak et al.'s (1987) suggestion that the occipital portion of the ligament contralaterally and the atlantal portion ipsilaterally will both be tensioned simultaneously. Hence, testing in both directions is required to stress both components of the ligament on one side.





B

Figure 9.5 Side-bending stress test for the alar ligament.
A. Starting position in neutral.
B. Side-binding to the left whilst maintaining stabilisation of the axis. Reproduced from Hing & Reid (2004). p.21.

If fixation of the axis is adequate, the proposed coupled movement will not be permitted to occur. Hence, no lateral flexion should occur. Due to variation in ligament orientation, some 'play' may be experienced in some positions. This is considered within accepted 'normal' limits. Therefore, for a side-bending stress test to be considered positive for an alar ligament tear, excessive movement in all three planes of testing should be perceived (Beeton, 1995; Pettman, 1994). Some authors also suggest the onset or provocation of signs or symptoms to be a positive response to this test (Gibbons & Tehan, 2004).

There have been no published examinations in any population of either the validity or reliability of this clinical test in regard to detection of alar ligament lesions.

#### 9.2.2 Rotation stress test

The biomechanical concept underlying the rotation stress test is exactly the same as described above for the side-bending stress test, i.e. the coupling of movements in the occipito-atlanto-axial complex as a result of the consequences of the alar ligament attachments. This test is regarded as primarily stressing the contralateral alar ligament in accordance with the description of Dvorak et al. (1988) of the contralateral ligament being the primary restraint at end range craniocervical rotation.

The axis is stabilised around its laminae and spinous process using a lumbrical grip. The cranium is grasped with a wide hand span and then rotated, the occiput taking the atlas segment with it, to the end of available range (Figure 9.6). No lateral flexion is to be permitted. As with the side-bending test, the test is repeated in three planes (Beeton, 1995; Hing & Reid, 2004; Pettman, 1994). Once again, the test is described in both sitting (Beeton, 1995; Pettman, 1994) and supine lying (Hing & Reid, 2004).

The test should only be considered positive if laxity is detected in all three planes of testing. Interpretation of the test in the literature contains some inconsistency. All authors agree that some rotation will occur but the extent of rotation within the bounds of normal is subject to some variation. Beeton (1995) reports that normal range of rotation is approximately 20° with a firm end feel with appropriate stabilisation of the axis. She recommends that more than 30° of rotation is indicative of alar ligament compromise. Both Gibbons and Tehan (2004) and Pettman (2004) agree with this estimate, regarding

more than 30° as indicative of ligament incompetence. Gibbons and Tehan (2004) also suggest a positive response may be characterised by the onset of signs or symptoms. Westerhuis (2007) suggests 35° should be considered the maximum value whilst Hing and Reid (2004) considered 35° to 40° of rotation to be the upper acceptable limits of normal. This presents considerable variation as to what is considered normal.

There have been no published examinations in any population of either the validity or reliability of this clinical test in regard to detection of alar ligament lesions.



**Figure 9.6** The rotation stress test for the alar ligament. The axis is stabilised around its laminae and spinous process using a lumbrical grip. The cranium is grasped with a wide hand span and then rotated to the end of available range.

Reproduced from Westerhuis (2007). p 131.

#### 9.2.3 Passive intervertebral movement – occipito-atlanto-axial rotation

This test is used to manually assess the quality of rotation between the segments from occiput to axis. The following description was published by Kaale et al. (2008).

Both hands are positioned on the same side of the patient's upper cervical spine. The lower hand stabilises the axis by pressing the index and middle fingers against the lateral aspect of C2 and pulling this backward (Figure 9.7). The upper hand provides the motion for the test. The middle finger of the upper hand is placed beneath the lateral mass of the atlas and the index finger under the mastoid process. The test is performed by an 'upward pull into rotation' using the fingers of the upper hand. The test is performed in different angles of rotation to ascertain the position in which rotation between atlas and axis is maximised (Kaale et al., 2008). Interpretation of the test is by clinician perception of hypermobility between the segments.

An examination of this method of testing using a single experienced manual therapist examiner assessing 122 patients and comparing with MRI findings demonstrated good results. For grading alar ligament tears on a 0 (not damaged) to 3 (ruptured) scale, sensitivity was 0.69 for the left alar ligament and 0.72 for the right. Specificity and positive predictive values were calculated as 1.00 and 1.00 for the right ligament and 0.96 and 0.93 for the left ligament respectively (Kaale et al., 2008). When categories were altered to the dichotomous 'normal' or 'abnormal', sensitivity increased to 0.89 for the right and 0.85 for the left alar ligaments.



**Figure 9.7** The occipito-atlanto-axial rotation test. The occiput and atlas are pulled upward into rotation whilst the axis is stabilised.

Reproduced from Kaale et al. (2008). p 400.

#### **9.2.4 Lateral translation stress test**

This test has been suggested by Aspinall (1990) as a means of testing the integrity of the dens along with the osseous attachments of the alar ligaments.

The rationale behind this test is that the dens is a major structural stabiliser for the atlanto-axial complex. When sidebending occurs at this complex, the occiput and atlas move laterally together, widening the atlantodental space on the side to which sidebending occurs. In addition to the combined movement of the occiput and atlas, the atlas undergoes a small translation toward the concave side relative to the occipital condyles (Penning, 1978).

To conduct the test, the patient is positioned in supine lying. The head on neck is positioned in sidebending, e.g. sidebending to the left. The atlas is passively stabilised from the right using the therapist's web space, maintaining the lateral shift of the atlas to the left. This position is described as tensioning the left atlantal portion of the alar ligament and the right occipital attachment. After taking up soft tissue slack, the axis is then passively translated to the right on a stabilised atlas (Figure 9.8). The test is performed to both sides in all positions of the head on the neck (neutral, flexion and extension) to account for variation in the orientation of the fibres of the alar ligaments (Aspinall, 1990; Beeton, 1995; Pettman, 1994). Ideally, there should be virtually no movement detected (Beeton, 1995; Cattrysse et al., 1997).
For the test to be considered positive, an abnormal end feel should be present in all three positions. If this occurs, the interpretation would be that either the alar ligaments are lax or the odontoid process is compromised from a congenital or pathological disorder (Aspinall, 1990; Beeton, 1995). To date, no study has been published exploring the validity of this stress test.

Cattryse et al. (1997) examined the reliability of the lateral translation stress test in a sample of eleven children with Down syndrome assessed by four manual therapy practitioners. Tests in this study were graded dichotomously as positive (i.e., instability observed), or negative. Intraobserver reliability varied from poor to moderate amongst the four practitioners (Kappa values from 0.09 to 0.67) whilst inter rater reliability showed no significant level of agreement for any combination of assessors. This lead these authors to conclude that the lateral displacement test could be considered a good reproducible method for investigating upper cervical instability (Cattrysse et al., 1997).





Figure 9.8 The lateral translation stress test.

A. The axis is passively translated to the right on a stabilised atlas. Reproduced from Beeton (1995). p. 27.

B. The direction of stresses applied during the lateral translation stress test. Reproduced from Pettman, E. (1994). p. 535

#### 9.3 Tests for the tectorial membrane

# 9.3.1. Distraction test

Distraction testing is used to assess the integrity of the tectorial membrane because of its described role as a limiting factor in vertical translation (Werne, 1957; White & Panjabi, 1990).

The patient is positioned in supine lying with their head resting on a pillow. This is proposed to relax the upper cervical musculature (Beeton, 1995) and to eliminate the stabilising effect of the ligamentum nuchae (Pettman, 1994). The therapist is positioned sitting or standing at the head of the plinth. With their lower hand, the therapist gently fixates the axis around its neural arch and cups the occiput with their upper hand. A manual traction is then applied to the head (Figure 9.9). The test is performed in the three positions of neutral, flexion and extension (Aspinall, 1990; Beeton, 1995; Hing & Reid, 2004).

It is generally accepted that some movement on application of a distraction force is normal. A positive test response is considered to be excessive vertical translation when distraction is applied. Separation should not be greater than one millimetre (Westerhuis, 2007) to two millimetres (Beeton, 1995; Hing & Reid, 2004).

There have been no examinations of the validity and reliability of this test published to date.



**Figure 9.9** Distraction test for the tectorial membrane. A manual distraction is applied to the occiput whilst stabilisation of the axis is maintained.

Reproduced from Hing & Reid (2004).

# 9.3.2. Distraction in upper cervical flexion

Distraction in upper cervical flexion is a progression of the distraction test described above. It utilises the descriptions of the tectorial membrane becoming tensioned in a position of upper cervical flexion (Driscoll, 1987; Krakenes et al., 2001; Oda, Panjabi, Crisco, Bueff et al., 1992; Werne, 1959) and is performed only if the patient's response to the distraction test is negative (Pettman, 1994).

The method of testing is identical to that described above with the addition of craniovertebral flexion to the starting position to attempt to stress the tectorial membrane further. No studies examining the validity or reliability of this technique have been published to date.

# 9.3.3. Upper cervical flexion test

Upper cervical flexion is proposed as a test for the tectorial membrane as the atlas is described as moving anteriorly, and the dens relatively posteriorly, causing development of tension within the membrane (Pettman, 1992b).

The test as described commences with the patient in supine lying and the clinician standing at the head end of the plinth. The clinician stabilises the axis by maintaining a grip on its arch using thumb and index finger. The other hand is placed on the patients occiput. The clinicians shoulder is in contact with the patient's forehead. Using these two points of contact on the head, a subtle ventral flexion movement of the head on the neck is made. Interpretation of the test is by the clinicians assessment of ligamentous laxity and by provocation of neurological disturbances (van der El, 1992). No examination of the validity of this test has been published to date.

Cattryse et al. (1997) examined the reliability of the upper cervical flexion test in eleven children with Down syndrome assessed by four manual therapists. There results suggested acceptable degrees of both intra (p < 0.05 in three out of four observers) and inter assessor reliability (kappa values between 0.5 and 1.0) in this group.

#### 9.3.4. Ventral horizontal translation between occiput-atlas-axis

This technique has been described by Kaale et al. (2008) to assess the integrity of the tectorial membrane.

The upper hand, which will perform the test movement, is positioned in the suboccipital area with the thumb and index finger pressed against the lower part of the occiput. These fingers are supported from below by fingers III to V. The axis is stabilised by a frontal grip as illustrated below (Figure 9.10). The test movement is a forward pressure with the upper hand combined with a traction force. During this movement, the atlas should follow the ventral and cranial movement of the occiput. The test is repeated in various amounts of flexion and differing degrees of traction. A positive test result is considered to be excessive translation between occiput/atlas and the axis (Kaale et al., 2008).

In their assessment of this technique against MRI findings in 122 people, Kaale et al. (2008) reported sensitivity of 0.94, specificity of 0.99 and a positive predictive value of 0.94. These results are impressive but it should be remembered that they used one expert manual therapist to assess. Hence, it is unclear whether these results would be replicated in a wider clinical situation.



**Figure 9.10** Ventral horizontal translation between occiput-atlas-axis. Forward pressure is applied to the occiput combined with a traction force whilst the axis is stabilised.

Reproduced from Kaale et al. (2008), p 400.

# **CHAPTER 10**

# CLINICAL EXAMINATION OF SELECTED CRANIOVERTEBRAL INSTABILITY STRESS TESTS USING MAGNETIC RESONANCE IMAGING

Content from this chapter has been published as;

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Osmotherly PG, Rivett DA, Rowe LJ. (2012). An examination of the anterior shear and distraction tests for craniocervical instability. An evaluation using magnetic resonance imaging. *Manual Therapy*. 17(5):416-421.

# **10.1** Introduction and aims

The lack of examination of the validity of the tests of ligamentous stability of the upper cervical spine brings into question their ability to detect instabilities in this region. Given the possible seriousness of consequences of adverse outcome for a patient undergoing treatment with manipulative techniques if an upper cervical instability is not detected in the clinical setting, this area requires further exploration and research to improve both the safety and treatment outcomes for patients undergoing physiotherapy management of upper cervical spine disorders. In seeking to address the validity of craniovertebral stress tests through the construct of empirical proof, we must address the question of whether the tests have a direct and measurable effect on the target ligaments. The premise behind all ligament testing is that increasing the distance between points of bony contact or attachment should place tension along the fibres of the ligament and hence place that ligament under stress (Meadows, 1999a). Measurement of testing in this study examined both the degree of separation between points of bony contact or attachment and the measurable deformation of the imaged ligaments themselves. It was expected that successful ligament testing should both demonstrate increased bony separation and measured ligament length.

Previous work presented in this thesis has demonstrated the suitability of magnetic resonance imaging in defining both the bony and ligamentous structures under examination. To date, this form of imaging has proven to be the best available means of visualising all of these structures in a patient. As described in Chapter 7, numerous studies have now been published demonstrating the radiological appearance of the craniovertebral ligaments using magnetic resonance imaging. Whilst these have all entailed static examination of the ligaments alone, the potential for use of this modality to assess dynamic situations such as ligament testing makes this the modality of choice for this study. Additionally, it has the advantage of using non-ionising radiation and is therefore deemed a safe modality for research purposes for both the study participant and the operator performing the clinical examination.

# **10.2 Methods**

#### 10.2.1 Approval

Ethical approval for this study was granted by Hunter New England Human Research Ethics Committee on 10 November 2008 (HNEHREC reference 08/09/17/5.01) and The University of Newcastle's Human Research Ethics Committee on 12 December 2008 (HREC Approval No: H-2008-0408).

# 10.2.2 Study participants

Sixteen participants considered to represent normal cervical spines were recruited for this study. Participants were limited to between the ages of 18 and 35 years. Subjects in this age range were preferentially recruited due to the higher water content of ligaments of younger people, thereby improving the quality of images created through magnetic resonance imaging. The upper age limit was also imposed to mitigate the effect of degenerative change on cervical spine movement during testing.

To be eligible for inclusion, participants had to meet the following criteria;

- No history of cervical spine or head trauma
- No diagnosed inflammatory disease
- No history of recurrent pharyngeal infection
- Free of congenital disorders recognised to have the potential for instability of the craniovertebral region
- No history of claustrophobia or discomfort in confined spaces.

Demographic information including age and gender was collected for each participant.

# 10.2.3 Clinical stress tests examined

The stress tests examined in this study were:

- Anterior shear test for the transverse ligament (Aspinall 1990)
- Side bending stress test for the alar ligament (Aspinall 1990), with a right side bend imposed as the test movement. This test was performed in the neutral plane only.
- Rotation stress test for the alar ligament (Pettman 1994), with rotation to the right imposed as the test movement. This test was performed in the neutral plane only.
- Distraction test for the tectorial membrane (Aspinall 1990). This test was performed in the neutral plane only.

Testing was not performed out of the neutral plane as the required degree of sagittal plane positioning moved the target structures away from the posterior imaging coil rendering them unclear on the resultant images.

Each of these tests has been described in detail in Chapter 9 of this thesis.

# **10.2.4 Imaging of participants**

All ligament tests were performed in supine lying within the MRI tunnel with participants enclosed in a standard neck coil (Figures 10.1 a and b) The neutral head and neck

position for each participant was defined using previously published criteria whereby the participant was positioned such that a line between the subject's forehead and chin was horizontal and parallel to the examination table and an imaginary line run parallel to the table extended from the tragus of the ear bisecting the neck longitudinally (Falla, Jull, & Hodges, 2004).

A rest period in neutral was provided for each participant between test procedures. The length of the rest period was determined by the participant's comfort.

Images were acquired in the coronal plane using a Siemens Magnetom Verio syngo MR B17 magnetic resonance imaging system (Siemens Medical Solutions, Erlangen, Germany) with a 3-Tesla magnet. A proton density-weighted SPACE sequence was used with the following parameters: TR = 1000ms, TE = 38, field-of-view 150 x 150mm, image matrix 320 x 320, image resolution 0.5 x 0.5 x 1.5mm (phase encoding direction right to left). Sixty slices were generated of slice thickness 1.5mm. Averages = 1.8. The total acquisition time for each sequence was 3 minutes and 20 seconds.





a.



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**Figure 10.1** a. Subject positioned for testing in the MRI tunnel.

b. Subject position in standard neck coil for testing during imaging.

#### 10.2.5 Analysis of MRI images

Viewing and analysis of all images was performed using OsiriX 3.5 image processing software (Pixmeo, Geneva, Switzerland).

#### Method of standardising reference position

Each test examined has been described as movement of the atlas or occiput with respect to a stationary manually stabilised axis. To account for this and permit accurate and reproducible measurement, each image was measured with reference to a standardised position of the axis.

In order to create anatomically based scan planes to standardise axis position, each dataset was displayed using a multiplanar reconstruction. In the sagittal reconstruction, a section was selected passing parallel to the longitudinal axis of the odontoid process and orthogonal to the plane of the interbody joint of C2-3. In the coronal reconstruction, a section was selected passing longitudinally down the midline of the odontoid process and bisecting the body of the second cervical vertebra. In horizontal reconstruction, a section was selected on the centre point of the cross-section of the odontoid process. To account for any rotation of the axis present, the image was rotated when necessary such that the plane of section contained the transverse foramina of the axis in alignment.

# Assessment of image quality

The ability to accurately measure each image is dependent upon the quality of the image obtained. Since each position was maintained at an end-range position by the operator for in excess of three minutes, there was potential for the image quality to be compromised due to movement occurring during the acquisition period.

The clarity of images was classified in both the neutral and test positions according to the system used by Pfirrman et al (2001) in their examination of the alar ligaments. Bony and ligament structures to be examined in each image were classified on a three point system as;

- a. Well defined with regular contours
- b. Defined with irregular contours, or
- c. Unable to be differentiated from surrounding tissue.

### Methods of measurement for each ligament test position

All images were measured on two separate occasions to establish reliability of measurement according to the following protocol:

#### i. Alar ligament tests

The effectiveness of these tests in tensioning the alar ligaments was measured in the coronal plane using both direct and indirect techniques:

- a. To estimate displacement of the occiput from the stabilised axis, the distance from the tip of the odontoid process to the inferior aspect of the foramen magnum was measured bilaterally.
- b. Direct estimation was performed by selecting the midpoint of the dental attachment of the alar ligament. A line corresponding to the axis of the ligament between origin midpoint and insertion into the occiput was created and measured.
  These measurements are depicted in Figures 10.2 a and b.

ii. Anterior shear test for the transverse ligament

The effectiveness of this test in displacing the anterior arch of the atlas forward from the odontoid process was assessed in two anatomical planes:

a. In a midline sagittal view, the atlantodental interval was assessed using previously defined and validated methods whereby the distance from the posteroinferior aspect of the anterior arch of the atlas to the adjacent anterior surface of the odontoid process is measured (Hinck & Hopkins, 1960; Keats, 1990; Locke et al., 1966b). To achieve this, a line was created connecting the inferior margin of the anterior arch of the atlas to the inferior margin of the posterior arch of the atlas. The distance along this line from the posteroinferior margin of the anterior arch of the anterior surface of the dens constituted the measured atlantodental interval (Douglas et al., 2007). This is illustrated in Figure 10.3 a. This method was selected due to greater reproducibility than other described

methods utilising the mid median atlantoaxial joint position (Jackson, 1983; Wellborn, Sturm, Hatch, Bomze, & Jablonski, 2000).

b. In sagittal view, a slice through the middle of the median atlantoaxial joint was selected. In horizontal reconstruction, a line was then superimposed in the midline of the horizontal slice, bisecting both the anterior arch of the atlas and the odontoid process. The measured interval was the distance along this line from the point where it crossed the posterior aspect of the anterior arch of the atlas to the point where it crossed the posterior aspect of the odontoid process (Figure 10.3 b). The posterior aspect of the odontoid process was selected in preference to the anterior aspect to create a longer interval, thereby reducing error associated with the accurate comparison of shorter intervals.



b.

**Figure 10.2** Direct and indirect techniques to assess the effectiveness of the tests in tensioning the alar ligaments.

a.

- a. Measurement from tip of odontoid process to the inferior margin of the foramen magnum indicated by the arrow.
- b. Direct estimation of alar ligament length. A line corresponding to the axis of the ligament (indicated by the arrow) is generated and measured between origin midpoint and insertion into the occiput.





a.

b.

# Figure 10.3 Direct and indirect techniques to assess the anterior shear test

a. Measurement of the atlantodental interval.

b. Measurement of anterior displacement of the atlas in horizontal section. The measured interval was the distance along a line bisecting both the anterior arch of the atlas and the odontoid process from the point of crossing the posterior aspect of the anterior arch of the atlas to the point of crossing the posterior aspect of the odontoid process.

# iii. Distraction test for the tectorial membrane

The effectiveness of this test was assessed using two methods; one indirect and one direct. Each method was performed using a sagittal section selected to be the midline of the dens and second cervical vertebra:

- a. The indirect method was based upon the notion that a positive test for the tectorial membrane relies on successfully distracting the occiput in a caudal direction away from the stabilised axis. The basion-dental interval was originally described as a method of assessing atlanto-occipital dissociation following trauma (Harris, Carson, & Wagner, 1994). It has been strongly advocated as a method of choice for use in assessing the spatial relationship between occiput, atlas and axis (Bono et al., 2007). The basion-dental interval is described by Harris et al. as the distance from the basion to the closest point of the tip of the dens on lateral radiographic view (Figure 10.4 and Figure 10.5 a).
- b. The direct method to assess tectorial membrane length involved overlying the visualised tectorial membrane on the image with markings using the curved measurement tool contained in the imaging analysis software. The curved interval generated commenced over the point where the tectorial membrane overlay the basion and terminated at the inferior border of the body of the axis. An estimate of length of the curved interval was automatically calculated (Figure 10.5.b).



**Figure 10.4** The basion-dental interval comprising a line joining the basion to the closest point on the tip of the dens on lateral view.

Modified from Bono (2007).





a.

b.



- a. The basion-dental interval.
- b. Direct measurement of the tectorial membrane.

#### 10.2.6 Statistical analysis

Analysis of all data was performed using Stata 11.0 statistical software (Stata Corporation, Texas).

# Analysis of alar ligament testing

Due to the inherent asymmetries of the morphology of the region including variation in orientation of the odontoid process and the individual ligaments in all three anatomical planes, analysis of the alar ligament tests were undertaken using the difference between left and right sided measurements as the base variable of analysis. A variable representing the difference in measured distance between bony landmarks and between alar ligament lengths was generated for each measure in all test positions as the measure of the right side subtracted from the measure of the left side.

Exploratory data analysis was used to describe the mean difference and spread of data representing the generated variables of the left to right difference for each measure. The distribution of each variable was assessed both visually using histograms of the data and normal probability plots, and statistically using the Shapiro-Wilk test for normality. Hypothesis testing comparing the left to right differences in both measured distance between bony landmarks and actual ligament length were made by analysing the difference estimates in the test positions compared to the difference estimates in the neutral position. Each hypothesis test was performed using the non-parametric Wilcoxon Sign Rank test for paired variables.

# Analysis of anterior shear testing for the transverse ligament

Atlantodental interval was analysed by assessing the change in distance between the test and the neutral position for each participant. Each hypothesis test was performed using the Wilcoxon Sign Rank test for paired variables.

Assessment in horizontal section was performed comparing the distance along the described interval from the posterior aspect of the anterior arch of the atlas to the posterior aspect of the odontoid process in neutral and test positions. Analysis of these measurements was by paired t-test or Wicoxon Sign Rank test dependent upon the normality of the distribution of the data.

# Analysis of distraction testing for the tectorial membrane

Basion-dental interval was compared between neutral and test positions using the Wilcoxon Sign Rank test.

Difference in direct measurements of tectorial membrane length were assessed using the paired t-test as all data were normally distributed.

# Estimates of reliability

Reliability of measurements for each image was assessed by estimation of intra-class correlation coefficients between the recorded measurements of the image taken on two separate occasions.

#### **10.3 Results**

# **10.3.1** Characteristics of participants

Eight males and eight females satisfying all criteria for inclusion volunteered to participate. Ages ranged from 19 to 32 years. The average of age of female participants was 23 years, 10.6 months (SD 72.3 months). The average age of male participants was 25 years, 4.6 months (57.6 months).

# 10.3.2 Alar ligament stress tests

The measured lengths of the distance between the tip of the odontoid process and the foramen magnum and the direct measurements of the alar ligaments for each side and for each position are given in Table 10.1. Following application of each stress test for the alar ligament, an increase in left sided length was evident in each participant (Figure 10.6).

<b>Table 10.1</b>	Indirect and direct methods measurements of ligament length for left and
	right alar ligaments.

Position	Left side				Right side			
	Bo	ny	Ligament		Bony		Ligament	
	measurement		measurement		measurement		measurement	
	Length	SD	Length	SD	Length	SD	Length	SD
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Neutral	9.9	1.0	6.4	0.8	9.9	1.3	6.4	0.9
Right side								
bending	10.6	1.2	6.8	1.1	9.4	1.4	5.3	1.0
Right	10.5	1.5	7.2	1.2	8.9	1.3	5.3	1.0
rotation								

SD = standard deviation, mm = millimetres.



**Figure 10.6** The alar ligaments (circled) following imposition of the right side-bending stress test. The left alar ligament is seen to be lengthened.

# Bony estimation: tip of the odontoid process to the foramen magnum

In the neutral position, the left-right difference in this measure was 0.0 mm (standard deviation 0.8 mm). Following imposition of the right side-bending stress test, the left-right difference was calculated as 1.2 mm (standard deviation 1.5 mm) indicating a lengthening of the interval on the left side compared to the neutral position. On right rotation stress testing, the mean left-right difference was calculated as 1.6 mm (standard deviation 1.8 mm), again indicating an increased distance between landmarks on the left

side. Between position comparisons with the neutral and test position measurements were statistically significant for each alar ligament stress test (Table 10.2).

# Direct measurement of alar ligament length

The left-right difference in alar ligament length in the neutral position was 0.0 mm (standard deviation 0.5 mm). With the imposition of the right side bending stress test, the left-right difference increased to 1.2mm (standard deviation 1.0mm) indicating a greater length of the left sided alar ligament. Upon right rotation stress testing, the mean left-right difference increased to 1.9mm (standard deviation 1.0mm), again indicating an increase in measurable length of the left sided alar ligament. Between stress test position comparisons with the neutral position were statistically significant for each stress test examined (Table 10.2).

<b>Table 10.2</b>	Summary of findings following the examination of alar ligament stress
	testing.

Test position	Left-right difference					
	Distance tip of odontoid process to			Direct measurement of alar ligament		
	foramen magnum (millimetres)			length (millimetres)		
	Mean	SD	p-value for difference	Mean	SD	p-value for difference
Neutral	0.0	0.8		0.0	0.5	
Right side bending stress test	1.2	1.5	0.002	1.2	1.0	<0.001
Right rotation stress test	1.6	1.8	<0.001	1.9	1.0	<0.001
SD-standard deviation						

SD= standard deviation

Intraclass correlation coefficients for the estimation of left-right difference for each measurement in each position are given in Table 10.3. Reliability of measurement ranged from moderate to substantial according to accepted criteria (Shrout, 1998).

**Table 10.3**Intraclass correlation coefficients for the left-right difference in alar<br/>ligament length estimates.

Position	Left-right difference assessed	ICC	95% CI
Neutral	Odontoid process to foramen magnum	0.85	0.63 to 0.95
	Direct measurement of ligament length	0.81	0.54 to 0.93
Side bending	Odontoid process to foramen magnum	0.63	0.24 to 0.86
	Direct measurement of ligament length	0.83	0.58 to 0.94
Rotation	Odontoid process to foramen magnum	0.68	0.29 to 0.88
	Direct measurement of ligament length	0.62	0.22 to 0.85

ICC = intraclass correlation coefficient, CI = confidence interval

#### 10.3.3 Anterior shear test for the transverse ligament

In the neutral position, bony structures and the transverse ligament were classified as well defined with regular contours in six participants. Images of ten participants were classified as defined with irregular contours. In the test position, structures contained in the images were classified as well defined with regular contours for two participants and

defined with irregular contours for 13 participants. Images of one participant were classified as unmeasurable due to image quality.

# Atlantodental interval

The mean distance of the atlantodental interval in the neutral position was 2.3mm (standard deviation 0.5mm). In the test position, the mean atlantodental interval was measured as 2.7mm (standard deviation 0.6mm). The resulting difference between positions of 0.4mm (standard deviation 0.6mm) was statistically significant (p = 0.03).

# Horizontal plane measurement

The mean distance from the posterior arch of the atlas to the posterior aspect of the odontoid process measured in the neutral position was 11.9mm (standard deviation 1.5mm). The mean distance in the test position was 12.2mm (standard deviation 1.5mm). The resulting difference between positions was 0.3mm (standard deviation 0.7mm, p = 0.05).

Reliability of individual measurements ranged from moderate to substantial using the criteria of Shrout (1998). Intraclass correlation coefficients and their 95% confidence intervals for each test position are given in Table 10.4.

#### **10.3.4 Distraction test for the tectorial membrane**

In the neutral position, images of the tectorial membrane and the relevant bony landmarks were classified as well defined with regular contours in 13 participants and defined with irregular contours in three participants. In the test position, these structures were classified as well defined with regular contours in images of three participants, defined with irregular contours in 12 participants and unable to be defined in one participant.

# Basion-dental interval

In neutral, the mean basion-dental interval was 7.1mm (standard deviation 2.3mm). In the distracted position, the mean basion-dental interval was 7.7mm (standard deviation 2.5mm). The difference in measured intervals between neutral and test positions was 0.6mm (standard deviation 0.6mm, p < 0.01).

# Direct measurement of tectorial membrane length

Tectorial membrane curved length between the inferior border of the axis and the point where the tectorial membrane overlay the basion was measured as 43.3mm (standard deviation 2.3mm) in the neutral position and 44.4mm (standard deviation 3.0mm) in the distracted position. The mean difference in curved length measured was 1.1mm (standard deviation 1.6mm, p = 0.02).

The reliability of all measurements of the tectorial membrane were substantial according to the criteria of Shrout (1998) with intraclass correlation coefficients all in excess of 0.9. Intraclass correlation coefficients and their 95% confidence intervals for each test position are given in Table 10.4.

**Table 10.4**Assessment of the reliability of individual measurements of the transverseligament and the tectorial membrane.

Structure examined	Measurement assessed	ICC	95% CI
Transverse ligament	ADI in neutral	0.90	0.72 to 0.97
	ADI with anterior shear test	0.84	0.52 to 0.95
	Posterior atlas to posterior odontoid process in neutral	0.80	0.50 to 0.93
	Posterior atlas to posterior odontoid process with anterior shear	0.74	0.40 to 0.90
Tectorial membrane	BDI in neutral	0.98	0.96 to 0.99
	BDI in distraction	0.99	0.96 to 0.99
	Direct measurement of tectorial membrane in neutral	0.93	0.82 to 0.98
	Direct measurement of tectorial membrane in distraction	0.99	0.98 to 0.99

ICC = intraclass correlation coefficient, CI = confidence interval, ADI = atlantodental interval, BDI = basion dental interval

#### **10.4 Discussion of the results of ligament testing**

The use of a detailed standardised protocol to orientate and measure the images of the testing procedures provides considerable rigour and consistency to the findings of this study. This is underlined by the magnitude of the intraclass correlations assessed between each measurement in each position imaged. This standardised protocol, using three-dimensional reconstructions to create a reference position for the axis, accounted for movements occurring across all three planes during the performance of the testing procedures.

The substantial reliability of image measurement demonstrated that the inherent inaccuracies in measurement due to vibration whilst sustaining end-range positions was minimised despite the subsequent reduction in image quality. The image quality is shown by changes in clarity ratings. The main undesirable effect of sustaining each test position for in excess of three minutes would be to lose the end-range position and hence reduce the measured differences between the test and neutral position. Thus the changes shown in this study may possibly be considered an underestimate of the potential displacement occurring during the performance of these tests. The consistency of findings of a measureable displacement should then be considered to be a conservative estimate of the true displacement which may be achieved during the application of these stress tests.

#### **10.4.1** Alar ligament stress tests

In the neutral position, no significant difference was noted in the ligament lengths measured or the bony estimations of ligament attachment. Thus, any left-right difference found on testing may be attributed to the application of the test procedure.

Both the side bending and the rotation stress tests resulted in a measurable change in the distances assessed. In each case, the left side measurements increased relative to the right side indicating a direct lengthening of the left, that is contralateral, alar ligament. This indicates that the stress tests applied in this study both demonstrated a direct effect on the alar ligaments.

As described in detail in Chapter 9, Aspinall (1990) proposed the side bending stress test as a mechanism for testing the contralateral alar ligament. These findings are consistent with the testing mechanism as described by Aspinall. However, based upon the descriptions of Dvorak et al. (1987), it has also been suggested that testing in both directions is necessary to infer instability due to both alar ligaments tensioning bilaterally during side bending (Beeton, 1995). In the current study, a clear difference between sides was evident during side bending testing. This would indicate that within the ranges in which these ligaments were tested, a bilateral effect on the alar ligaments is not evident and the need for a finding of laxity in both directions is not necessary to infer instability.

The mechanism attributed to the rotation stress test is the prevention of coupled movement within the occipito-atlanto-axial complex. Rotation of the occiput over a

stationary axis results in the contralateral alar ligament being wound around the odontoid process due to its posterior attachment on the odontoid (Dvorak et al., 1988). Under normal circumstances, the odontoid would be permitted to shift laterally, then tensioning the ipsilateral ligament. However, if the maintenance of the axis position is effective and craniocervical lateral flexion is effectively minimised through manual stabilisation, the limiting feature of the rotation movement should be the tension developed in the contralateral alar ligament. The findings of the current study are consistent with this mechanism. There was a clear difference in length developed between the alar ligaments in each participant with the contralateral ligament placed in a comparatively lengthened position under the test positions in all participants.

The side bending stress test resulted in a mean increase in skeletal measurements of 1.2mm and a direct ligament measurement increase of 1.2mm. Hence, both indications of ligament length are consistent and strongly correlated (r = 0.76). Rotation stress testing resulted in a mean increase in ligament approximation by skeletal measurement of 1.6mm and a direct ligament measurement of 1.9mm. Once again, the measured effect on ligament length was consistent in direction with moderate correlation between these measures (r = 0.65). From these findings, it may be considered that the rotation stress test produces a greater measurable stress on the contralateral alar ligament than the side bending stress test.

Effective stabilisation of the atlas during the performance of the side bending test should ensure that the axis is prevented from undergoing rotation in the same direction as the clinician imposed atlanto-occipital lateral flexion (Aspinall, 1990; Beeton, 1995; Hing & Reid, 2004; Pettman, 1994). Hence, displacement of the spinous process of the axis relative to the midline provides an indication of the effectiveness of the manual stabilisation at this level during the test. The degree of stabilisation of the axis was unable to be assessed using this imaging protocol as the spinous process was not included in the field of view. To include this landmark, the expansion of the field of view would have substantially increased the acquisition time for each image necessitating a marked increase in the end-range hold time required for each test position. This would have resulted in further degradation of image quality through vibration or other small movements occurring whilst holding the end-range test position.

Whilst assessment of the alar ligaments were only made in the neutral plane for imaging reasons as previously described, testing into both flexion and extension should exhibit the same findings with regard to the mechanism of the clinical tests applied. Furthermore, the majority of alar ligament specimens examined in the previous dissection and radiological were oriented in the horizontal plane. Where caudal or cranial orientation was noted, the angles were smaller than illustrated in standard texts. Hence, findings in the neutral position will be translatable to the majority of alar ligaments in the adult population.

Previous studies have also indicated that a proportion of alar ligaments either have anterior portions that do not attach to the odontoid process or may even bypass the odontoid process in entirety. It is not possible to identify people whose ligament arrangement might reflect this morphology under clinical examination. Hence, some radiologically demonstrable ligament injuries may not be perceptible in some individuals using these standard clinical stress tests.

#### 10.4.2 Anterior shear test for the transverse ligament

The premise underlying the anterior shear test for the transverse ligament is that the atlas may be translated anteriorly on a fixed axis to a degree that symptom reproduction may be elicited in a patient with transverse ligament insufficiency.

Displacement of the atlas in this study was measured in two ways; change in atlantodental interval and displacement of the atlas with respect to the odontoid process of the axis in the horizontal plane. In each method of examination, the atlas was demonstrated to have been displaced anteriorly with respect to the axis. This is consistent with the mechanism described. The acceptable levels of reliability for these measurements as indicated by the intra-class correlation coefficients indicate that these findings are reproducible. This is the first study to demonstrate the ability of a clinician to displace the atlas away from the axis using the anterior shear test.

The mean magnitude of change elicited during examination of this test was 0.4 mm for the atlantodental interval (p = 0.02) and 0.7 mm for the displacement in the horizontal plane (p = 0.05). Whilst consistent in magnitude and direction, these displacements are considerably less than those suggested to be required to cause compromise in an unstable atlantoaxial segment. However, the displacement required to elicit non-cardinal symptoms remains unknown. This examination in normal individuals permits the
inference that a clinician may cause displacement of the atlas within the segment and hence provides a measure of empirical support for the validity of this test. Whether the degree of displacement achieved is sufficient for symptom reproduction cannot be inferred.

### **10.4.3** Distraction test for the tectorial membrane

The two measures used for distraction testing of the tectorial membrane provide information on different aspects of this clinical test. The fact that the changes elicited by each measure are consistent with each other provides added strength to the associations derived. The methods used to assess the tectorial membrane, both directly and indirectly, displayed high reliability with all ICCs in excess of 0.9.

As a measure of vertical distraction, the change in basion dental interval provides an indication of the ability to produce a spatial change between the adjacent segments through manual application of force. The mean change in basion-dental interval in the sample tested was 0.6mm. This mean change was statistically significant (p < 0.01), but may also have clinical relevance attributed to it. The direction of movement is consistent with the descriptions of the clinical test and thus supports the rationale behind its application as a method of assessing tectorial membrane integrity. The magnitude of the change lies within the parameters of 1 to 2mm accepted to be indicative of a normal test (Beeton, 1995; Hing & Reid, 2004; Westerhuis, 2007), as should be the case in this sample, thus reinforcing the interpretation of a normal test result.

The increase in vertical distraction has been demonstrated to have a direct effect on tectorial membrane length in this sample. Measuring between predefined points along the course of the tectorial membrane showed an overall mean increase in length of this structure of 1.1mm between the axis and the occiput (p = 0.02). The greater change in length of the structure itself compared to the magnitude of change in vertical distance is expected since the course of tectorial membrane does not follow a linear path as it passes cephalad, instead coursing antero-superiorly from the tip of the odontoid process toward the occiput.

### 10.5 Conclusion

This study has successfully established a reproducible methodology for the assessment of the clinical stress tests of this region. By using rigorously defined methods of standardisation of the axis as a reference position and a clearly defined measurement protocol, the measurements produced have been demonstrated to be highly reliable. This has addressed an important limitation of previous studies using magnetic resonance imaging and will permit further accurate examination of these structures in future research.

The results of this study satisfy the criteria establishing empirical proof that the clinical stress tests as described have a direct and measurable influence on the ligaments being assessed. In each test assessed, a pre-post test difference was observed in both the bony relationships between points of ligament attachment, or proximity in the case of the

transverse ligament, as well as measurable change in the lengths of the ligaments themselves.

Both the rotation and the side bending stress tests for the alar ligaments have been demonstrated to increase the length of the contralateral alar ligament during testing. In contrast to the opinions of some previous authors, no bilateral effect was observed.

Assessment of the anterior shear test has indicated that displacement of the atlas on the axis can be produced by the application of manual force. Thus, the mechanism underlying the test has been shown to be plausible. Questions regarding the magnitude of the displacement necessary to reproduce a clinically meaningful response remain unresolved.

Distraction of the occiput on a manually fixed axis produces a measureable increase in length of the tectorial membrane consistent with the change observed in the basion-dental interval during testing. The magnitude of the change is consistent with current clinical opinion in regard to the interpretation of a normal test response.

### **CHAPTER 11**

# SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The concept underlying the series of studies presented in this thesis is the development of a process of structural corroboration through which the question of the validity of craniovertebral ligament testing could be examined. The vehicle used to explore this issue is the design of studies and appraisal of the information thus generated utilising the three complementary constructs described by Bogduk and Mercer (1995); convention, biological basis and empirical proof. Through the confluence of findings from the various studies presented with their differing perspectives, methodologies and inherent design strengths, a coherent case may now be advanced regarding the evaluation of the concept of validity as it pertains to craniovertebral instability testing.

From the perspective of convention, it would appear that the consensual validity, and consequently the content validity of craniovertebral ligament testing, is limited. The survey findings described in Chapter 3 revealed that the overall level of knowledge of instabilities of the craniovertebral region and the methods by which they could be assessed by physiotherapists was not high. Furthermore, where knowledge was greater in the post graduate education sub-group, consensus regarding the use and usefulness of the clinical tests themselves was low.

Fundamental to the lack of consensus was the lack of agreement on the definition of instability itself. Instability as a term has taken a variety of meanings in the contemporary physiotherapy vernacular. This has ensured that the dialogue thus produced regarding testing for instabilities in the craniovertebral region is confused. It must also be considered that the overall level of knowledge regarding patient presentation in individuals with potential instabilities of the upper cervical spine is low. However, the finding that four of the signs and symptoms listed in the questionnaire attained over 60% recognition as potentially present in individuals with instability suggests that a process of consensus is possible in defining a core set of criteria considered indicative of the presentation of a patient with craniovertebral instability. In the absence of a clear diagnostic gold standard, such a future exercise would need to take the form of a consensus approach such as a Delphi technique, whereby individuals recognised as having expertise in assessing dysfunction in this area could form an expert panel for discussion.

Understanding and use of the clinical stress tests amongst respondents overall was low, although knowledge was greater in respondents with post-graduate education in musculoskeletal physiotherapy. Whilst knowledge of the instability tests in this group was higher than in their less academically qualified counterparts, the consensus on the value of testing was less, with concerns of symptom provocation and a lack of formally evaluated validity being predominant in concerns expressed in this group. This finding highlighted the need for the subsequent studies in this thesis addressing the various aspects of validity of these tests. The biological basis of the validity of clinical testing was then examined from an anatomical perspective in Chapter 5. As stated in Chapter 1, the general principle upon which the performance of ligamentous stress testing is based is that one bone to which the ligament is attached should be fixed and another bone to which it is also attached should be moved away from it in order to be stretched maximally. For this to occur, the anatomical description of each ligament's structure needs to be well defined and that the tests themselves reflect the described structure.

The morphology of the ligaments of the craniovertebral complex was examined by fine dissection in 11 cadaveric specimens. Overall, the findings of these dissections provide a measure of consistency and confer face validity upon descriptions of the clinical stress tests relating to the alar and transverse ligaments and the tectorial membrane, with some consideration required of variation occurring within these structures.

The description of the alar ligaments as two cord-like structures passing bilaterally from the supero-posterior aspect of the odontoid process to the occiput, and positioned and oriented in such a manner such that they can be perceived to be capable of limiting axial rotation and side-bending of the segments of the upper cervical spine is supported by our findings. Variation occurring within the specimens did reveal the possibility that the alar ligaments may bypass the odontoid process in some individuals, hence contributing little to stability in rotated and side-bent positions in these particular individuals. Perhaps the most notable finding in relation to the alar ligaments was the lack of support for the existence of an atlantal portion of the alar ligaments. No such structure was identified in any of the 11 specimens examined in this series. Descriptions of the mechanism of ligament tensioning during the performance of clinical stress tests for the alar ligaments in standard manual therapy texts have highlighted the role of the atlantal portion of the alar ligaments. Our findings strongly suggest that the existence of any such structure should be considered an anatomical variant and no attempt at interpretation of the integrity of this component of the ligament be inferred from clinical testing.

Our findings with regard to the morphology of the transverse ligament of the atlas were consistent with past descriptions of this structure as a substantial band of tissue passing broadly behind the odontoid process and oriented in a manner to limit anterior displacement of the atlas on the axis. These findings support the clinical tests currently described for transverse ligament integrity, conferring both biological plausibility and face validity on these clinical manoeuvres.

Consideration of the morphology of the tectorial membrane demonstrated this to have a considerably more complex structure than has been traditionally attributed to it in standard anatomical texts. The layered and banded structure of the tectorial membrane suggests that it may be capable of limiting movement in a number of directions, particularly flexion, vertical translation and, most interestingly, axial rotation. Overall, the morphology of the tectorial membrane is consistent with mechanisms described for

clinical assessment of its integrity supporting the face validity of the tests, however, further examination of this extensive anatomical structure is required, which may lead to refinements of the existing stress tests to incorporate a rotation component.

The findings of the MRI and dissection study in Chapter 7 provide corroboration to the descriptions derived from the anatomical dissections. The observations on imaging of the alar and transverse ligaments were consistent with the descriptions from our previous studies and consistent with their proposed roles as structures capable of providing a passive restraint to movement for the craniovertebral segments. Once again, the biomechanical rationale and the face validity of the clinical tests for these structures as described is supported by these findings. The longitudinal course of the tectorial membrane and its orientation antero-superiorly as it passes over the odontoid process as seen on both imaged and dissected specimens was again consistent with the mechanisms described for testing of this structure.

In addition to providing further inference for the validity of the clinical tests, the study described in Chapter 7 was designed to explore the optimal MRI parameters which might be used at clinical resolution for the examination of the clinical tests in asymptomatic individuals. Results from clinical resolution images were compared to high resolution images and observations on gross dissection of the specimens. It was concluded that proton density-weighted acquisition sequences provided superior visualisation of the borders and attachment points of the alar and transverse ligaments compared to T1 or T2

weighted sequences. No sequence was optimal for identifying and measuring the tectorial membrane as identification of both structure and points of bony attachment was poor. Whilst the proton density-weighted sequence was preferred for the subsequent clinical study, it was evident that proxy measures of separation of bony points of attachment were also required to corroborate any findings of ligament deformation or to make any inference on direct effects on the tectorial membrane at all.

The final study in this series described in Chapter 10 successfully developed and used a reproducible methodology to assess the ligaments of the craniovertebral complex during testing. Reference positions of the axis were strictly standardised and the measurement protocol clearly defined, making this study novel in published work on this area to date. The findings of this study satisfy the criteria for empirical proof that the clinical stress tests have a direct and measurable influence on the target ligaments of the craniovertebral complex, whether judged upon observed ligament deformation or alterations in relationships of points of bony attachment of the ligaments. For each ligament and each clinical test examined, the findings consistently demonstrated measurable changes in accordance with the described mechanisms of the ligament tests. As a direct result of the findings of this study, we can state the anterior shear test for the transverse ligament of the atlas, the distraction test for the tectorial membrane, and the rotation and side-bending stress tests for the alar ligaments have construct validity. This is because a direct effect on the target ligament has been demonstrated upon imposition of the relevant test which is consistent with the proposed mechanism of action of each test.

In summary, testing for ligamentous instability of the craniovertebral region can be assessed in terms of the three axioms; convention, biological plausibility and empirical proof. The consensual validity of testing for stability/instability of the region is poor due to inconsistencies in knowledge and interpretation of what constitutes instability and its clinical manifestations. The biological plausibility and, hence, the face validity of testing is high. The anatomical descriptions derived from both fine dissection and imaging are consistent with directions orientation of the ligaments when placed under tension during the application of the clinical tests. Finally, empirical proof that the clinical tests themselves are capable of deforming the target ligaments has demonstrated the construct validity of each of the clinical tests examined.

Future research into the validity of these tests should address their ability to discriminate individuals with lesions of the alar ligaments, tectorial membrane and transverse ligament from others in a neck pain population. This thesis has demonstrated lower levels of validity for these clinical tests, without engaging in the assessment of individuals with confirmed pathology of these ligaments. The impediment to completing this work at this point in time is technological. As discussed in Chapter 2, the consideration of MRI being a 'gold standard' for the detection of lesions of the craniovertebral ligaments has been seriously questioned due to the lack of reproducibility of interpretation of high intensity signal changes within the cross-section of the ligaments and the consequent inability to determine pathological from normal ligaments. Further investigation of highly

reproducible methods to assess and measure ligament integrity is required before comparison of clinical tests against an acceptable reference standard may be undertaken.

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## **APPENDIX** A

# JOURNAL PUBLICATIONS RELATED TO WORK PRESENTED IN THIS THESIS

**Osmotherly PG**, Rivett DA. (2011). The knowledge and use of craniovertebral instability testing by Australian physiotherapists. *Manual Therapy*, *16:357-363* 

**Osmotherly PG**, Rivett DA, Rowe LJ. (2012). The construct validity of clinical tests for alar ligament integrity. An evaluation using magnetic resonance imaging. *Physical Therapy*, 92:718-725

**Osmotherly PG**, Rivett DA, Rowe LJ. (2012). The anterior shear and distraction tests for craniocervical instability. An evaluation using magnetic resonance imaging *Manual Therapy*, *17*:416-421

**Osmotherly PG**, Rivett DA, Mercer SR. (2013). Revisiting the clinical anatomy of the alar ligaments. *European Spine Journal*, 22: 60-64

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# Knowledge and use of craniovertebral instability testing by Australian physiotherapists

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#### ABSTRACT

Internationally, manual therapy has moved towards formalised guidelines for pre-manipulative screening of the cervical spine. A controversial aspect to emerge from this involves craniovertebral instability (CVI) testing. This study examined current practice, knowledge and attitudes of Australian physiotherapists regarding pre-manipulative testing for CVI. Members of Musculoskeletal Physiotherapy Australia were surveyed by formally validated questionnaire. Sub-group analysis was performed by post-graduate musculoskeletal qualification. The response rate was 37.8%. Respondents provided differing definitions of CVI; 46.5% describing loss of anatomical integrity and 24.9% a biomechanical problem. Over half indicated they rarely or never used stress tests for CVI screening. Of 42 published signs and symptoms associated with CVI, seven were identified by more than 50% of respondents. Of published disorders associated with CVI, four were considered worthy of testing by more than 30% of respondents. Support for inclusion of information on CVI in pre-manipulative guidelines was given by 87% of respondents. Recommendations for screening tests received less support, particularly among physiotherapists holding post-graduate musculoskeletal qualifications (p = 0.0002).

These results indicate disagreement regarding the nature and presentation of CVI. Clinical testing is inconsistent, reflecting underlying confusion about CVI. Currently, there is not an appropriate level of knowledge or willingness to recommend guidelines for CVI screening.

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#### 1. Introduction

The application of stress tests for the ligaments linking the upper cervical spine and skull is considered by some authorities to be a routine safety exercise prior to the treatment of a patient with pain or dysfunction of the upper cervical spine using manual techniques, particularly if the treatment involves high velocity thrust or endrange techniques (Pettman, 1994; Cattrysse et al., 1997; Hing and Reid, 2004).

Clinical screening tests are considered to be capable of detecting hypermobility and instability of the craniocervical ligaments, i.e. transverse and alar ligaments and tectorial membrane (Aspinall, 1990; Pettman, 1994). Detection of these problems should allow the manual therapist to select a treatment regime with a lesser risk of severe complications for these patients (Cattrysse et al., 1997). Potential complications arising from high velocity or end-range treatment techniques applied to an undiagnosed unstable upper cervical segment can be catastrophic and include the onset of cardinal neurological signs as the segment is displaced towards the brainstem, a situation that may be life threatening (Pettman, 1994). Consequences may include cerebrovascular accident (Rivett and Milburn, 1997), arterial dissection and brainstem injury (Di Fabio, 1999).

Interpretation of these tests frequently involves recognition of presence or ablation of symptoms other than pain. A review of the published literature indicates that there is considerable disagreement about the actual symptoms and signs exhibited by an individual with craniovertebral ligament lesions (Osmotherly and Rivett, 2005). Furthermore, there is inconsistency in the anatomical descriptions upon which clinical testing has been based (Osmotherly et al., 2008). Despite the recent work of Kaale et al. (2008) corresponding the results of specific manual tests with MRI findings in patients following whiplash trauma, the absence of a body of research establishing validity for most of the clinical stability tests used in manual therapy of the upper cervical spine (Mintken et al., 2008; Swinkels and Oostendorp, 1996a) and the varying estimates of reliability of these tests (Cattrysse et al., 1997; Olson et al., 1998; Swinkels and Oostendorp, 1996a) ensures inclusion of stress testing for CVI in pre-manipulative screening will remain contentious.

This study sought to examine the knowledge, understanding and practical application of CVI testing in Australian physiotherapists by



Original article



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surveying physiotherapists working in the management of musculoskeletal disorders. By appreciating the knowledge, attitudes and practices of clinicians, a better understanding of the need, benefits and obstacles pertaining to pre-manipulative screening guidelines incorporating CVI testing can be achieved.

#### 2. Methods

#### 2.1. Study sample

A survey designed to elicit the knowledge and understanding of CVI testing was disseminated to all 1528 members of Musculoskeletal Physiotherapy Australia (MPA). MPA is the special interest group of the Australian Physiotherapy Association (APA) for clinicians with an interest or specialist skills in musculoskeletal physiotherapy. By surveying the entire membership, an understanding of the knowledge and practice across differing levels of experience and post-graduate education was anticipated.

#### 2.2. Study design

A 21-item questionnaire was developed and validated. Following this process, questionnaires were distributed by post. After sixweeks, a follow-up questionnaire was posted to all non-respondents. Management of all postage was undertaken by the APA to maintain participant confidentiality.

#### 2.3. Survey instrument

The survey instrument was designed following an exhaustive review of the literature published in the area of CVI. Using open and closed questions and checklist responses, items were constructed to permit respondents to demonstrate their understanding of the clinical problem, signs and symptoms of instability disorders, assessment techniques available for diagnosing CVI, as well as current practice and attitudes toward screening for instability disorders of the upper cervical spine.

Demographic information collected included gender, years of experience in the treatment of musculoskeletal disorders, physiotherapy qualifications, frequency of treating disorders of the upper cervical spine and types of manual therapy techniques used in this region.

The instrument was further refined following a process examining face and content validity. The draft questionnaire was circulated for comment to all convenors of post-graduate manipulative physiotherapy programs in Australia and New Zealand (n = 10) and all authors who had published on the subject of CVI in the English language literature in the previous 20 years (n = 8). Responses were received from eight program convenors and four of the authors approached. Respondents were asked to comment on completeness of domains examined, including any other domains or content required to assess current knowledge and practice appropriately, and to express an opinion on the capability of the instrument to reflect knowledge, opinion and current practices of physiotherapists treating cervical spine problems.

Peer review of the validated instrument to clarify feasibility and language acceptability was performed in a convenience sample of six physiotherapists with post-graduate qualifications and clinical experience in musculoskeletal physiotherapy. Participants provided feedback in a structured open-ended interview examining item selection and terminology used in the questionnaire.

#### 2.4. Statistical analysis

Closed questions were evaluated by a frequency analysis of responses and expressed as a proportion of respondents in the sample. Open-ended responses were listed and examined by three physiotherapists with post-graduate qualifications and in excess of 20 years experience each in musculoskeletal physiotherapy. Responses were discussed until saturation with respect to categorisation of response was achieved.

Subgroup analysis was performed with respect to post-graduate qualifications in musculoskeletal physiotherapy. Between-group comparisons were subject to formal hypothesis testing using chi squared statistics.

#### 3. Results

#### 3.1. Response rate and respondents

In total, 578 surveys were completed and returned. This equated to a response rate of 37.8%. Demographics of respondents are included in Table 1.

Clinical assessment of a patient with an upper cervical spine disorder was performed at least once per week by 74.7% of respondents. Manual treatment options for the upper cervical spine utilised by respondents included upper cervical mobilisation (93.9%) and upper cervical high velocity thrust manipulation (27.9%).

#### 3.2. Defining craniovertebral instability

Participants' responses to the open-ended question "What do you understand by the term 'instability' in the upper cervical spine?" fell into five categories. Most respondents described instability in terms of loss of anatomical integrity (46.6%). Other responses included

Table	e 1
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	Characteristics	of	survey	respondents.
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	N (% of respondents)	MPA membership (%)
Gender		
Male	268 (46.4%)	45.7
Female	285 (49.3%)	54.3
Missing data	25 (4.3%)	
Employment setting		
Public hospital	58 (10.0%)	12.1
Private hospital	28 (4.8%)	4.4
Private practice	440 (76.1%)	72.7
Other	31 (5.4%)	10.8
Missing data	21 (3.6%)	
Entry qualifications in Phy	vsiotherapy	
Bachelor degree	440 (76.1%)	
Diploma	55 (9.5%)	
Graduate diploma	50 (8.7%)	
Masters degree	16 (2.8%)	
Missing data	17 (2.9%)	
Country of qualification		
Australia	520 (90.0%)	
Other	58 (10.0%)	
Post-graduate qualificatio	ons in musculoskeletal physi	otherapy
None	194 (33.6%)	
Graduate certificate	12 (2.1%)	
Graduate diploma	26 (4.5%)	
Coursework Masters	320 (55.4%)	
Research Masters	23 (4.0%)	
Professional Doctorate	1 (0.2%)	
Doctor of Philosophy	14 (2.4%)	
Other	9(16%)	

Legend: MPA = Musculoskeletal Physiotherapy Australia.

alteration in upper cervical biomechanics including descriptions of excessive joint range or translation (24.7%) or descriptions of inadequacy of muscular action influencing the joint collectively labelled changes in neuromuscular control (18.2%). Some respondents defined the problem clinically in terms of presenting signs and symptoms (6.5%). Responses, stratified by respondents' post-graduate qualifications in manual therapy, are given in Table 2.

#### 3.3. Detection of craniovertebral instability

Twenty-two percent of respondents reported detecting a previously undiagnosed craniovertebral instability using clinical stress tests, clinicians with further qualifications being significantly more likely to report detecting an upper cervical instability ( $\text{Chi}^2 = 7.31$ , p = 0.007) (Table 2).

A checklist of 42 items previously published in association with clinical presentations of CVI was provided. Respondents were asked which signs and symptoms they would associate with CVI. Only seven items were considered to be possible components of a CVI presentation by more than 50% of respondents (Table 2). Statistically significant differences between responses existed when examined by post-graduate qualification. However, the direction of the differences was inconsistent.

Fig. 1 lists percentage of responses to the item "Would you test for CVI when treating an upper cervical spine disorder in a patient with any of the following problems?" All disorders listed in this item had been previously published as associated with CVI. Clinicians responded with a clear association between CVI and cervical spine trauma (67.9%) including whiplash associated disorder (64.8%), as

#### Table 2

Respondent clinical characteristics and background knowledge of CVI.

well as rheumatoid arthritis (64.4%). Other possible inflammatory conditions associated with CVI received lesser recognition as potentially requiring screening. Headache was considered a disorder worthy of screening by 24.3% of respondents.

#### 3.4. Recognition and use of clinical stress tests

Recognition, use and self-rated ability to perform named stress tests are summarised in Table 3. Respondents with post-graduate qualifications were, on average, 1.4 times more likely to recognise the tests and 1.6 times more likely to report using the tests in clinical practice.

For the item "How often do you test for CVI?", the most common response given was "whenever indicated" (56% of therapists with and 47.9% without post-graduate qualifications). Testing prior to upper cervical manipulation (15.6% and 6.2% respectively) or endrange mobilisation of the upper cervical joints (10.2% and 20.1% respectively) was reported. The majority of respondents indicated that they either rarely or never used stress tests to screen for CVI (54.5% and 62.4% respectively). Clinicians with post-graduate qualifications were more likely to report screening for CVI in patients with cervical spine disorders (Chi<sup>2</sup> = 28.2, p < 0.001). Responses are summarised in Table 4.

#### 3.5. Attitudes toward testing, recommendations and guidelines

Respondents indicated their opinion of when CVI tests should be performed in clinical practice using a list of responses. Nomination of multiple responses was permitted. Again, the most common

	All respondents N (% of respondents)	Post-graduate qualifications N (% of respondents)	No post-graduate qualifications N (% of respondents)				
Frequency of upper cervical spine patient assessm	ent						
More than once/day	193 (33.4%)	143 (39.3%)	50 (26.0%)				
Once/day	72 (12.5%)	43 (11.8%)	29 (15.1%)				
Less than daily/more than weekly	120 (20.8%)	73 (20.1%)	47 (24.5%)				
Once/week	47(8.1%)	27 (7.4%)	20 (10.4%)				
Less than weekly/more than monthly	52 (9.0%)	34 (9.3%)	18 (9.4%)				
Once/month	21 (3.6%)	13 (3.6%)	8 (4.2%)				
Less than once/month	51 (8.8%)	31 (8.5%)	20 (10.4%)				
Missing data	22 (3.8%)	4 (1.1%)	1 (0.5%)				
Manual therapy used in the upper cervical spine							
None	8 (1.4%)	5 (1.4%)	3 (1.6%)				
Manipulation only	4 (0.7%)	4 (1.1%)	0 (0.00%)				
Mobilisation only	386 (66.8%)	219 (60.0%)	167 (87.0%)				
Mobilisation and manipulation	157 (27.2%)	136 (37.3%)	22 (11.5%)				
Missing data	22 (4.0%)	3 (0.8%)	2 (1.0%)				
Definition of the term 'instability' in the upper cer	vical spine						
Anatomical	307 (46.6%)	196 (44.7%)	111 (50.2%)				
Biomechanical	163 (24.7%)	122 (27.9%)	41 (18.6%)				
Neuromuscular control	120 (18.2%)	77 (17.6%)	43 (19.4%)				
Clinical (signs and symptoms)	43 (6.5%)	30 (6.8%)	13 (5.9%)				
Other	26 (4.0%)	13 (3.0%)	13 (5.9%)				
Past detection of a craniovertebral instability using	g stress tests						
Yes	125 (21.6%)	95 (25.2%)	30 (15.5%)				
No	437 (75.6%)	274 (72.7%)	163 (84.5%)				
Missing data	16 (2.8%)	8 (2.1%)	0 (0.0%)				
Most commonly recognised signs and symptoms of CVI							
Increased mobility on passive testing	429 (77.2%)	277 (76.1%)	152 (79.2%) p = 0.413				
Dizziness	375 (67.5%)	231 (63.5%)	144 (75.0%) p = 0.006				
Headache	370 (66.6%)	234 (64.3%)	136 (70.8%) p = 0.120				
Upper cervical pain	341 (61.3%)	215 (59.1%)	126~(65.6%)~p = 0.116				
Nausea or vomiting	321 (57.7%)	203 (55.8%)	118 (61.5%) <i>p</i> < 0.001				
Suboccipital pain	303 (54.6%)	191 (52.6%)	112 (58.3%) $p = 0.198$				
Bilateral/quadrilateral paraesthesia	299 (53.8%)	214 (58.8%)	85 (44.3%) p = 0.001				

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Fig. 1. Testing in presence of disorders associated with CVI. Abbreviations: PG = post-graduate, SLE = Systemic Lupus Erythematosus, WAD = Whiplash Associated Disorder.

response was "whenever indicated" (55.6% of respondents with and 47.9% without post-graduate qualifications), followed by "prior to upper cervical manipulation" (15.6% and 6.2% respectively) or upper cervical mobilisation (10.2% and 20.1% respectively). Responses are summarised in Fig. 2.

Open-ended questions permitted elaboration on their response. Clinicians with post-graduate qualifications were more likely to test based on clinical presentation than on the technique they intended to administer compared with their counterparts. A larger number of clinicians with post-graduate qualifications also indicated that in their opinion these tests should not be used clinically. Reasons suggested revolved around two themes; absence of validation of the individual tests and inherent risks due to provocation of symptoms.

When asked whether clinicians would support the use of CVI screening tests before applying manipulation or end-range techniques to the upper cervical spine if recommended by the APA, 76.9% of respondents indicated that they would comply with a recommendation. Respondents with post-graduate qualifications were less likely to state they would comply with guidelines (71.3% versus 87.4%,  $\text{Chi}^2 = 18.36 \ p < 0.001$ ). Respondents indicating in the negative were asked to provide free comment. Ninety-nine comments were received. Comments included assessment should be based on individual presentation rather than general recommendations (32.3%), the absence of published evidence to support the validity and reliability of CVI screening (28.3%) and lack of knowledge of the tests and their performance and interpretation (14.1%).

Finally, participants responded to the item asking whether information and recommendations regarding CVI testing should be included in the current "Clinical guidelines for assessing verte-brobasilar insufficiency in the management of cervical spine disorders" (Rivett et al., 2006). There was strong support from clinicians for inclusion of information in the guidelines with 82.5% of clinicians with and 97.8% without post-graduate qualifications indicating support (between-group comparison Chi<sup>2</sup> = 26.47, p < 0.001). Using open responses, 29.4% commented that patient safety and therapist knowledge would both be improved by inclusion of information and 15.6% commented that clinician awareness of the possible presence of CVI would be improved by inclusion.

Interestingly, 12.4% of respondents indicated that information regarding CVI would be a useful inclusion but recommendations for testing should not be made. Similarly, 10.6% of comments received from this group indicated that the decision to test should be based solely on the clinician's assessment of the individual patient. Comments from respondents who indicated they would not support inclusion of CVI information in the pre-manipulative guidelines included that the tests themselves lack the necessary reliability or validity for inclusion (23.7%), the current guidelines were only concerned with vertebrobasilar insufficiency, CVI being a separate issue (15.8%), testing should be based on patient presentation and examination alone (10.5%), and there are already too many guidelines and screening procedures which encumbered clinical practice (10.5%).

#### Table 3

Self report of knowledge and use of craniovertebral stress tests.

CVI Stress Test	Post-graduate qualifications N (% of respondents)			No post-graduate qualifications N (% of respondents)			
	Recognise	Can perform	Uses clinically	Recognise	Can perform	Uses clinically	
Sharp Purser (transverse ligament)	250 (68.7)	196 (54.1)	142 (39.3)	75 (38.7)	51 (26.3)	38 (19.8)	
Anterior shear (transverse ligament)	266 (73.3)	194 (54.2)	118 (32.7)	110 (56.7)	63 (32.5)	51 (26.6)	
Lateral stability (alar ligament and dens)	268 (73.8)	200 (56.2)	142 (39.3)	93 (47.9)	55 (28.4)	43 (22.4)	
Sidebending stress test (alar ligament)	261 (71.9)	212 (59.1)	157 (43.5)	111 (57.2)	88 (45.4)	60 (31.3)	
Rotation stress test (alar ligament)	225 (61.8)	174 (48.5)	109 (30.2)	102 (52.6)	76 (39.2)	57 (29.7)	
Distraction test (tectorial membrane)	215 (59.4)	179 (49.6)	107 (29.6)	92 (47.4)	61 (31.4)	38 (19.8)	
Passive upper cervical flexion (tectorial membrane)	236 (65.4)	198 (55.5)	123 (34.1)	123 (63.4)	88 (45.4)	55 (28.7)	
Distraction in craniovertebral flexion (tectorial membrane)	170 (47.1)	142 (39.6)	85 (23.6)	53 (27.3)	34 (17.5)	22 (11.5)	

Abbreviation: CVI = craniovertebral instability.

Table 4

Self report of CVI screening.						
	All respondents N (% of respondents)	Post-graduate qualifications N (% of respondents)	No post-graduate qualifications N (% of respondents)			
All cervical spine patients	35 (6.1)	24 (6.3)	11 (5.7)			
Whenever indicated	308 (52.9)	215 (56.0)	93 (47.9)			
Rarely	198 (34.3)	130 (33.9)	68 (35.1)			
Never	132 (23.0)	79 (20.6)	53 (27.3)			
Prior to cervical manipulation	71 (12.1)	45 (11.7)	26 (12.4)			
Prior to upper cervical manipulation	72 (12.3)	60 (15.6)	12 (6.2)			
Prior to end-range upper cervical mobilisation	78 (13.2)	39 (10.2)	39 (20.1)			
Prior to end-range assessment of upper cervical spine	44 (7.1)	21 (5.5)	23 (11.9)			
	2					

Between-group difference  $chi^2 = 29.2$ , p < 0.001.

Abbreviation: CVI = craniovertebral instability.

#### 4. Discussion

The response rate to the survey of 37.8% is considered low. Respondents do, however, reflect the demographics of the membership of MPA as indicated in Table 1 suggesting that these findings may be indicative of the opinions and attitudes of the membership as a whole. It is also within the range reported by other published surveys that have attempted to gauge the opinions of Australian physiotherapists. Wajon and Ada (2003) achieved a response rate of 22.2% in their examination of thumb pain in MPA members and Grimmer et al. (2002) achieved a 38% response rate researching knowledge of nonsteroidal anti-inflammatory medicine use in the same group. Our



Fig. 2. Response to the question "When should CVI tests be used in clinical practice?". Abbreviations: PG = post-graduate.

response rate may also reflect the comparatively lower level of preexisting knowledge and understanding CVI amongst the target group.

The variety of responses to the request to define CVI highlights the greatest difficulty in examining this and other areas of spinal instability; the absence of a clear and accepted definition of spinal instability. Given the complexity of clinical instability, the anatomical, biomechanical and clinical aspects listed could all be considered basic elements of the problem. This gives rise to differing interpretations of disorders classed as "instabilities" and an apparent conflict within the literature. In responding to our question, there is a clear difference in interpretation between clinicians with and without post-graduate qualifications in manual therapy. Respondents without post-graduate education more frequently classified CVI as an anatomical disruption, whereas a greater proportion of those with further education considered instability as a broader biomechanical disorder. This latter approach is more indicative of the model of stability proposed by Panjabi (1991) currently underpinning motor control approaches to spinal stability.

Given the absence of defined and agreed pathology constituting CVI, consensus regarding the clinical characteristics of patient presentation would not be expected. There are a number of possible reasons why more than 50% of our sample only considered a small number of the 42 listed signs and symptoms to be associated with CVI. Recognition of these disorders clinically may be low due both to their low prevalence in the clinical setting and poorly defined and varied presentation (Swinkels and Oostendorp, 1996a; Swinkels et al., 1996b). Many of the signs and symptoms listed are also a component of other cervical spine presentations and not specifically indicative of CVI on their own. A clinical reasoning process involves the processing of a set of clinical data inclusive of patient history in reaching a decision. Listing signs and symptoms as discrete criteria may not have been suggestive of CVI to our respondents without being placed in a broader clinical context. Finally, in summarising clinical presentations in some texts and review articles, some authors have described CVI in terms of presenting cardinal neurological symptoms or signs caused by central nervous system disorders such as spinal cord compression or vertebrobasilar insufficiency (Sanchez-Martin, 1992; Pettman, 1994; Swinkels and Oostendorp, 1996a; Meadows, 1998; Hing and Reid, 2004). Published clinical reports would suggest such severe presentations are rare in CVI. Many patients will tolerate marked instability without exhibiting neurological symptoms or signs, instead presenting with a wide variety of less severe symptoms (Uitvlugt and Indenbaum, 1988; Derrick and Chesworth, 1992; BenEliyahu, 1995; Swinkels et al., 1996b; Niibayashi, 1998).

The item asking whether clinicians would pre-manipulatively test for CVI in the presence of certain disorders showed an understanding that CVI may be associated with trauma, including motor vehicle accidents, and with rheumatoid arthritis. This is understandable given these types of problems commonly present clinically, but is interesting given that despite subsequent research (Kaale et al., 2008), no CVI stress test had been validated within a post-traumatic population prior to the performance of this survey. On the other hand, the finding that only 24% of clinicians would consider screening a patient with a headache for CVI is puzzling since two-thirds of respondents nominated headache as a symptom associated with CVI.

The low level of association of congenital disorders with CVI would once again indicate that clinicians do not encounter these disorders frequently and hence do not recognise the potential association. The non-recognition of inflammatory disorders as a potential predisposing factor to CVI represents a more critical gap in therapist knowledge. The association with inflammatory conditions extends beyond rheumatoid arthritis as ankylosing spondylitis and systemtic lupus erythematosus have also been linked to CVI (Swinkels and Oostendorp, 1996a; Swinkels et al., 1996b). Furthermore, atlantoaxial instability has been demonstrated following infections such as tonsillitis and pharyngitis (Sullivan, 1949; Locke et al., 1966; Gibb, 1969) where hyperaemia associated with inflammation may lead to local bone decalcification and softening of ligaments and their attachments (Yochum and Rowe, 1985; Hensinger, 1986; Roche et al., 2001).

Recognition and use of craniovertebral instability screening tests is associated in our sample with post-graduate studies in manual therapy. This suggests that testing for instability in the craniocervical region is not consistently taught in undergraduate curricula but is encountered through post-graduate study. Recognition of tests examining the integrity of the transverse and alar ligaments ranged from moderate to high in the post-graduate sample. There was less awareness of tests for the tectorial membrane, perhaps indicating that the role of this structure in craniocervical stabilisation receives less consideration. Self-reported rates of performance of these screening tests would indicate they are not in routine use with clinicians examining and treating the upper cervical spine. Of the tests listed, only the 'sidebending stress test' for the alar ligament was used by more than 40% of respondents with and over 30% without further qualifications.

Self-reported levels of CVI screening in our respondents are perplexing. Fifty-six percent of respondents with post-graduate qualifications and 48% of those without reported screening "whenever indicated". However, the most commonly utilised screening test, the sidebending stress test for the alar ligament, was only used by 43.5% and 31.3% of respondents respectively. If these rates of assessment are accurate, clinicians must be relying on other forms of assessment than just the described tests to assess for this disorder. Given the lack of agreement on clinical presentation and recognition of predisposing conditions, it remains unclear upon what basis respondents are judging whether screening for instability in the upper cervical spine is indicated. It is possible that clinicians are relying on other parts of the physical examination such as passive physiological intervertebral movement tests (PPIVM's) to assess for perceived excessive 'joint play' rather than the described specific tests for ligament integrity.

The use of the response option "whenever indicated" may need to be seen as a limitation in this study. Response options in this questionnaire were not exclusive. Therefore, this option did not limit choice of response. However, some respondents may have selected this response on the basis of an 'all covering' option, reducing the discriminative ability of these items.

This theme continues when the sample is asked to provide an opinion on when CVI screening tests should be used in clinical practice. The greatest response was to perform the tests "whenever indicated". Whilst this is an obvious response in the context of clinical examination and clinical reasoning processes, responses to the questions already discussed fail to show that we are clear about who is 'at risk' and how CVI might present clinically.

Whilst the majority of respondents indicated that they would support any recommendation made by their professional body in regard to clinical testing for CVI, there is clearly a sentiment that recommendations for routine required screening tests are not warranted in the current environment. This is particularly evident in the responses from physiotherapists with further qualifications in musculoskeletal physiotherapy. Free comments give an insight into the reasons why they are less likely to support recommendations for testing in clinical guidelines. Concerns expressed about the value of clinical reasoning and the related need to test in context, the largely unknown validity of the tests themselves, and the limited overall level of knowledge possessed by clinicians are reasons with considerable foundation and it is beyond doubt that the area of clinical diagnosis of CVI needs to be the subject of further research. It will not be possible to achieve consensus in clinical approach in the absence of consensus in the scientific literature regarding the validity of clinical testing. It remains questionable whether there is real support by Australian physiotherapists for any move towards formal prescriptive screening guidelines.

There is, however, a much stronger sentiment for the provision of accessible information in guidelines which clinicians may use to inform their clinical practice. Whilst this again garnered less support from those with higher qualifications, almost 90% of respondents indicated that they would support the inclusion of information on CVI in pre-manipulative clinical guidelines. Free comments provided reinforced this position as respondents expressed the desire for an accessible body of knowledge which could be used to improve clinician awareness and patient safety within a clinical reasoning framework but would highlight both the benefits and limitations of this form of screening.

#### 5. Conclusion

Instability is a term that has taken on a variety of meanings in the contemporary physiotherapy vernacular. This is reflected in our findings that when physiotherapists describe upper cervical instability, they appear to be considering differing aspects or interpretations of the term.

Similarly, there appears to be no accepted or consensus set of diagnostic criteria used by Australian physiotherapists through which they are able to determine whether CVI is present in patients presenting to them for treatment.

There is clearly support for inclusion of information regarding CVI testing in pre-manipulative guidelines as an aide to clinical reasoning but when we consider both the existing evidence for the accuracy of these clinical tests and responses of Australian physio-therapists in this study, we can at most state that this should include information on possible risk factors and aspects of potential presentation of CVI. There is not the appropriate underpinning of knowledge, evidence base or professional will to currently recommend guidelines for routine CVI screening for patients with cervical spine disorders. These findings do, however, highlight the directions required to further understand the nature of craniovertebral instability and its diagnosis.

#### Ethical approval

Ethical approval for this study was granted by The University of Newcastle's Human Research Ethics Committee.

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Construct Validity of Clinical Tests for Alar Ligament Integrity: An Evaluation Using Magnetic Resonance Imaging Peter G. Osmotherly, Darren A. Rivett and Lindsay J. Rowe PHYS THER. 2012; 92:718-725. Originally published online January 19, 2012 doi: 10.2522/ptj.20110261

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**Background.** The alar ligaments are integral to limiting occipito-atlanto-axial rotation and lateral flexion and enhancing craniocervical stability. Clinical testing of these ligaments is advocated prior to the application of some cervical spine manual therapy procedures. Given the absence of validation of these tests and the potential consequences if manipulation is applied to an unstable upper cervical spine segment, exploration of these tests is necessary.

**Objective.** The purpose of this study was to examine the direct effect of the side-bending and rotation stress tests on alar ligaments using magnetic resonance imaging (MRI).

**Design.** This was a within-participant experimental study.

**Methods.** Sixteen participants underwent MRI in neutral and end-range stress test positions using proton density-weighted sequences in a 3-Tesla system. Measurements followed a standardized protocol relative to the position of the axis. Distances were measured from dens tip to the inferior margin of the foramen magnum and from midsubstance of the dental attachment of the ligament to its occipital insertion. Between-side differences were calculated for each measurement to account for inherent asymmetries in morphology. Differences were compared between the test and neutral positions using a Wilcoxon signed rank test.

**Results.** Side-bending stress tests produced a median between-side difference in ligament length of  $\pm 1.15$  mm. Rotation stress tests produced a median between-side difference in ligament length of  $\pm 2.08$  mm. Both results indicate increased measurement of the contralateral alar ligament.

**Limitations.** Assessment could be made only in the neutral position due to imaging limitations. Clinical texts state that tests should be performed in 3 positions: neutral, flexion, and extension.

**Conclusions.** Both side-bending and rotation stress testing result in a measurable increase in length of the contralateral alar ligament. This finding is consistent with mechanisms that have been described to support their use in clinical practice.



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he lack of established validity of the tests of ligamentous stability of the upper cervical spine brings into question their ability to detect instabilities in this region. There is potential for an adverse outcome for a patient with an upper cervical spine instability undergoing treatment with manipulative techniques.<sup>1,2</sup> Given this possibility, this area warrants further research to improve both the safety and treatment outcomes for patients undergoing physical therapy management of upper cervical spine disorders. An early step in the validation process for these clinical tests is the establishment of construct validity to assess whether the tests are capable of influencing the alar ligaments.

The alar ligaments have been described primarily as limiting occipito-atlanto-axial rotation and lateral flexion.<sup>3-5</sup> They pass from the superolateral aspect of the dens to the medial surface of the occipital condyles.6-8 Loss of integrity of the alar ligaments removes a primary passive restraint to rotation in the upper cervical spine. A loss of control of rotation is associated with increased likelihood of adverse neurovascular events that have been associated with high-velocity thrust and end-range techniques used in the upper cervical spine.<sup>9,10</sup>

Both the side-bending and rotation stress tests for the alar ligaments are based on preventing the inherent coupling of rotation and lateral flexion in the occipito-atlanto-axial complex. That is, lateral flexion of the occiput on the atlas is accompanied by immediate ipsilateral rotation of the axis beneath the atlas. This rotation was proposed by Dvorak and Panjabi<sup>3</sup> to result from tension generated in the alar ligaments.

The side-bending stress test, first proposed by Aspinall,<sup>11</sup> has been described for both sitting<sup>12,13</sup> and

supine<sup>14</sup> positions. In performing this test, the spinous process and lamina of the axis are stabilized by the therapist to prevent both side bending and rotation of the segment.<sup>11</sup> Slight compression is applied through the crown of the head to facilitate atlanto-occipital side bending. Passive side bending then is applied using pressure through the patient's head; in effect, directing the patient's ear toward the opposite side of the neck.11,12,15,16 If fixation of the axis is adequate, the normal coupled movement will not be permitted to occur. Hence, no lateral flexion should occur. Testing is recommended to be performed in 3 planes (neutral, flexion, and extension) to account for variation in alar ligament orientation.11,16 For a sidebending stress test to be considered positive for an alar ligament lesion, excessive movement in all 3 planes of testing should be evident.15,16

The rotation stress test<sup>14-16</sup> is regarded as primarily stressing the contralateral alar ligament in accordance with the biomechanical description of Dvorak et al.<sup>6</sup> Again, the test is described for both sitting<sup>15,16</sup> and supine<sup>14</sup> positions. The axis is stabilized around its laminae and spinous process using a lumbrical grip. The cranium is grasped with a wide hand span and then rotated, the occiput taking the atlas segment with it, to the end of available range. No lateral flexion is permitted. Some rotation will occur during the test, but the extent of rotation within the bounds of normal is subject to some variation. Estimates of the range of normal rotation vary between 20 and 40 degrees.<sup>12-16</sup> As with the sidebending test, the test is repeated in 3 positions in the sagittal plane, with laxity in all 3 positions necessary to establish a positive test finding.14-16

The aim of the study was to examine through magnetic resonance imaging (MRI) the direct effect of clinical stress tests described for the alar ligaments to assess whether these tests are capable of demonstrating abnormalities of these structures. Using individuals without instabilityrelated pathologies of the craniovertebral region, we proposed to examine whether a measurable change in ligament length occurred when a specific stress test was applied to the ligament structure compared with measurements taken with the cervical spine in a neutral position.

#### Method Participants

Sixteen skeletally mature participants were recruited sequentially via advertisement from the population of The University of Newcastle, Newcastle, New South Wales, Australia. To be eligible for inclusion, participants had to be between the ages of 18 and 35 years. The upper age limit was imposed to mitigate the effect of degenerative change on cervical spine movement during testing. Potential participants were excluded if they had a history of cervical spine trauma or recurrent pharyngeal infection, had been diagnosed with an inflammatory disease or an instability of the craniovertebral region, had any congenital disorder recognized to have the potential for instability of the craniovertebral region, or experienced claustrophobia or discomfort in confined spaces.

Eight male and eight female individuals satisfying all criteria for inclusion volunteered to participate. The average age of the female participants was 23 years 10.6 months (SD=72.3 months). The average age of the male participants was 25 years 4.6 months (SD=57.6 months).

#### **Clinical Stress Tests Examined**

The stress tests examined in this study were the side-bending stress test<sup>11</sup> and the rotation stress test.<sup>15</sup> Each test was administered by a

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**Figure 1.** Patient position in standard neck coil for side-bending testing during imaging.

single investigator with the participants in a supine position. The sidebend or rotation movement imposed during each test was directed to the right in each case. Testing was not performed away from neutral in the sagittal plane because the required degree of sagittal-plane positioning would move the alar ligaments away from the posterior imaging coil, rendering them unclear on the resultant images.

#### **Imaging of Participants**

Images were acquired in the coronal plane using a Siemens Magnetom Verio Syngo MR B17 MRI system with a 3-Tesla magnet (Siemens AG, Erlangen, Germany). All ligament tests were performed consecutively in a supine position within the MRI bore, with participants enclosed in a phased array neck coil (Fig. 1). A neutral image was acquired as a reference study at the commencement of each participant's examination. The neutral head and neck position for each participant was defined using criteria published previously, whereby the participant was positioned such that a line between the forehead and chin was horizontal and parallel to the examination table and an imaginary line running parallel to the table extended from the tragus of the ear would pass along the axis of the neck longitudinally.<sup>17</sup>

A proton density-weighted turbo spin echo sequence was used with the following parameters: repetition time=1,000 milliseconds, echo time= 38, field-of-view  $150 \times 150$  mm, image matrix  $320 \times 320$ , image resolution  $0.5 \times 0.5 \times 1.5$  mm (phase encoding direction right to left). Sixty slices were generated with a slice thickness of 1.5 mm. The total acquisition time for each sequence was 3 minutes 20 seconds.

#### **Measurement of MRI Images**

Viewing and analysis of all images were performed using OsiriX 3.5 image processing software (Osirix Foundation, Geneva, Switzerland).

Method of standardizing reference position. Each test examined has been described as movement of the atlas or occiput with respect to a stationary, manually stabilized axis. To ensure consistency with the test description and permit accurate and reproducible measurement, each image was measured with reference to a standardized position of the axis.

To create anatomically based scan planes to standardize axis position, each data set was displayed using a multiplanar reconstruction. In the sagittal reconstruction, a section passing parallel to the longitudinal axis of the odontoid process and orthogonal to the plane of the interbody joint of C2-3 was selected. In the coronal reconstruction, a section passing longitudinally down the midline of the odontoid process and bisecting the body of the second cervical vertebra was selected. In horizontal reconstruction, a section centered on the center point of the cross-section of the odontoid process was selected. To account for any rotation of the axis present, the image was rotated when necessary such that the plane of the section contained the transverse foraminae of the axis in alignment.

Methods of measurement for each ligament test position. Each image was measured on 2 separate occasions to establish reliability of measurement according to the protocol that follows.

The effectiveness of the tests in tensioning the alar ligaments was measured in the coronal plane using both direct and indirect techniques. In the absence of validated published methods to assess alar ligament length, indirect estimation was used to provide concurrent measurement

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#### Figure 2.

(A) Measurement from the tip of the odontoid process to the inferior margin of the foramen magnum indicated by the arrow. (B) Direct estimation of alar ligament length. A line corresponding to the axis of the ligament (indicated by the arrow) is generated and measured between origin midpoint and insertion into the occiput.

of change in the relationship between points of bony prominence adjacent to the attachment sites of the ligaments. To estimate displacement of the occiput from the stabilized axis, the distance from the tip of the odontoid process to the inferior aspect of the foramen magnum was measured bilaterally. Direct estimation was performed by first selecting the midpoint of the dental attachment of the alar ligament. A line corresponding to the axis of the ligament between origin midpoint and insertion into the occiput was created and measured. These measurements are depicted in Figure 2 (A and B).

#### **Data Analysis**

Analysis of all data was performed using Stata 11.0 statistical software (Stata Corporation, College Station, Texas). Due to the inherent asymmetries of the morphology of the region, including variation in orientation of the odontoid process and the individual ligaments in all 3 anatomical planes, analysis of the alar ligament tests was undertaken using the difference between left-sided and right-sided measurements as the base variable of analysis. A variable representing the difference in measured distance between bony landmarks and between alar ligament lengths was generated for each measure in all test positions as the measure of the right side subtracted from the measure of the left side.

Exploratory data analysis was used to describe the difference and spread of data representing the generated variables of the left to right difference for each measure. The distribution of each variable was assessed both visually using histograms of the data and normal probability plots and statistically using the Shapiro-Wilk test for normality. Hypothesis testing comparing the left to right differences in both measured distance between bony landmarks and actual ligament length was done by analyzing the difference estimates in the test positions compared with the difference estimates in the neutral position. Each hypothesis test was performed using the nonparametric Wilcoxon signed rank test for paired variables. Reliability of measurements for each image was assessed by estimation of intraclass correlation coefficients for the recorded measurements of the image taken on 2 separate occasions.

#### **Role of the Funding Source**

This research was supported by a Physiotherapy Research Foundation grant.

#### Results

The measured lengths of the distance between the tip of the odontoid process and the foramen magnum and the direct measurements of the alar ligaments for each side and for each position are given in Table 1. After application of each stress test for the alar ligament, an increase in left-sided length was evident in each participant (Fig. 3).

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#### Table 1.

Measurements of Indirect and Direct Methods of Ligament Length for Left and Right Alar Ligaments

	Left Side				Right Side			
	Bony Measu	Bony Measurement Ligament Measurement		Bony Measurement		Ligament Measurement		
Position	Mean Length (mm)	SD (mm)	Mean Length (mm)	SD (mm)	Mean Length (mm)	SD (mm)	Mean Length (mm)	SD (mm)
Neutral	9.85	0.99	6.38	0.83	9.88	1.32	6.40	0.85
Side bending	10.64	1.24	6.76	1.06	9.40	1.40	5.34	0.96
Rotation	10.51	1.53	7.18	1.23	8.91	1.28	5.29	1.03

#### **Bony Estimation: Tip of the Odontoid Process to the Foramen Magnum**

In the neutral position, the median left-right difference in this measure was 0.02 mm (interquartile range [IQR] = -0.05 to 0.23). After imposition of the side-bending stress test, the median left-right difference was calculated as 0.85 mm (IQR=0.10 to 2.52), indicating a lengthening of the interval on the left side compared with the neutral position. On rotation stress testing, the median leftright difference was calculated as 1.44 mm (IQR=0.76 to 1.90), again indicating an increased distance between landmarks on the left side.

Between-position comparisons using the neutral and test position measurements were statistically significant for each alar ligament stress test (Tab. 2).

#### **Direct Measurement of Alar Ligament Length**

The median left-right difference in alar ligament length in the neutral position was -0.05 mm (IQR=-0.17to 0.36). With the imposition of the side-bending stress test, the median left-right difference increased to 1.15 mm (IQR=0.58 to 1.67), indicating a greater length of the leftsided alar ligament. Upon rotation stress testing, the median left-right difference increased to 2.08 mm (IQR=1.09 to 2.60), again indicating an increase in measurable length of the left-sided alar ligament. Comparisons between the stress test position and the neutral position were statistically significant for each stress test examined (Tab. 2).

Intraclass correlation coefficients for the estimation of left-right difference for each measurement in each position are given in Table 3. Reliability of measurement ranged from moderate to substantial according to accepted criteria.18

#### Discussion

This is the first study to demonstrate a direct effect of these clinical tests on the alar ligaments, providing support for the construct validity of these screening tests. The use of a detailed, standardized protocol to orient and measure the images of the testing procedures provides considerable rigor and consistency to the findings of this study. This consistency is underscored by the magnitude of the intraclass correlation coefficients assessed for each measurement in each position imaged. This standardized protocol, using 3-dimensional reconstructions to create a reference position for the axis, accounted for movements occurring across all 3 planes during the testing procedures.

The observed direct effect of testing on the alar ligaments has been corroborated by changes measured con-



#### Figure 3.

The alar ligaments (circled) following imposition of the side-bending stress test.



currently in the distance between the tip of the odontoid process and the foramen magnum. This finding indicates that the method of alar ligament measurement used is a valid representation of its length.

The substantial reliability of image measurement demonstrated that the inherent inaccuracies in measurement due to vibration while sustaining end-range positions were minimized, despite the subsequent reduction in image quality. The main undesirable effect of sustaining each test position in excess of 3 minutes would be to lose the endrange position and hence reduce the measured differences between the neutral and test positions. Thus, the changes shown in this study may possibly be considered an underestimate of the potential displacement occurring during these tests. The consistent findings of a measurable displacement thus should be considered to be a conservative estimate of the true displacement that may be achieved during the application of these stress tests.

In the neutral position, no significant difference was noted in the ligament lengths measured or the bony estimations of ligament attachment. Thus, any left-right difference found on testing may be attributed to the application of the test procedure. Both the side-bending and the rotation stress tests resulted in a measurable change in the distances assessed. In each case, the left-side measurements increased relative to the right side, indicating a direct lengthening of the left, that is, contralateral alar ligament. This finding indicates that the 2 stress tests applied in this study both demonstrated a direct effect on the alar ligaments.

Aspinall<sup>11</sup> proposed the side-bending stress test as a mechanism for testing the contralateral alar ligament. These

#### Table 2.

Summary of Findings Following the Examination of Alar Ligament Stress Testing

	Left-Right Difference							
	C For	Distance Tip Odontoid Proce amen Magnum	of ss to (mm)	Alar	Direct Measurement Ligament Leng	of th (mm)		
Position	Median	IQR″	<i>P</i> Value for Difference	Median	<i>P</i> Value for Difference			
Neutral	0.02	-0.05 to 0.23		-0.05	-0.17 to 0.36			
Side bending	0.85	0.10 to 2.52	.002	1.15	0.58 to 1.67	<.001		
Rotation	1.44	0.76 to 1.90	<.001	2.08	1.09 to 2.60	<.001		

<sup>a</sup> IQR=interquartile range.

#### Table 3.

Intraclass Correlation Coefficients (ICCs) for the Left-Right Difference in Alar Ligament Length Measurements

Position	Left-Right Difference Assessed	ю	95% Cl″
Neutral	Odontoid process to foramen magnum	.85	.63 to .95
	Direct measurement of ligament length	.81	.54 to .93
Side bending	Odontoid process to foramen magnum	.63	.24 to .86
	Direct measurement of ligament length	.83	.58 to .94
Rotation	Odontoid process to foramen magnum	.68	.29 to .88
	Direct measurement of ligament length	.62	.22 to .85

<sup>a</sup> CI=confidence interval.

findings are consistent with the testing mechanism as described by Aspinall. However, based on the descriptions of Dvorak and Panjabi,3 it also has been suggested that testing in both directions is necessary to infer instability due to both alar ligaments tensioning bilaterally during side bending.16 In the current study, a clear difference between sides was evident during sidebending testing. This finding indicates that within the ranges in which these ligaments were tested, a bilateral effect on the alar ligaments is not evident and the need for a finding of laxity in both directions is not necessary to infer instability.

The mechanism attributed to the rotation stress test is the prevention of coupled movement within the occipito-atlanto-axial complex. Rotation of the occiput over a stationary axis results in the contralateral alar ligament being wound around the odontoid process due to its posterior attachment on the odontoid.6 Under normal biomechanical circumstances, the odontoid would be permitted to shift laterally, thus tensioning the ipsilateral ligament. However, if the maintenance of the axis position is effective and craniocervical side bending is effectively minimized through manual stabilization, the limiting feature of the rotation movement should be the tension developed in the contralateral alar ligament. The findings of the current study are consistent with this mechanism. A clear difference in length developed between the alar ligaments in each participant, with the contralateral ligament placed in a comparatively lengthened position under test positions in all participants.

The side-bending stress test resulted in a mean increase in indirect mea-

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surements of 1.24 mm and an increase in direct ligament measurement of 1.22 mm. Hence, both indications of ligament length are consistent and strongly correlated (r=.76). Rotation stress testing resulted in a mean increase in ligament approximation by skeletal measurement of 1.60 mm and a direct ligament measurement of 1.88 mm. Again, the measured effect on ligament length was consistent in direction, with moderate correlation between these measures (r=.65). From these findings, it may be considered that the rotation stress test produces a greater measurable effect on the contralateral alar ligament than the sidebending stress test.

Although assessment of the alar ligaments was undertaken only in the neutral plane for imaging reasons as described previously, testing into both flexion and extension should exhibit the same findings, considering the mechanism of the clinical tests applied. Moreover, the majority of alar ligament specimens examined in previous dissection19 and radiological<sup>20</sup> studies were oriented in the horizontal plane. Where caudal or cranial orientation was noted, the angles were smaller than illustrated in standard texts.<sup>21</sup> Hence, findings in the neutral position will be transferable to the majority of alar ligaments in the adult population.

Previous studies also have indicated that a proportion of alar ligaments either have anterior portions that do not attach to the odontoid process or may even bypass the odontoid process entirely.<sup>22,23</sup> It is not possible to identify people whose ligament arrangement might reflect this morphology under clinical examination. Hence, some radiologically demonstrable ligament injuries may not be perceptible in some individuals using these standard clinical stress tests. Although clinical texts suggest that the alar ligament tests should be performed in 3 positions (neutral, flexion, and extension), we assessed these procedures only in the neutral position. Pretrial piloting of the techniques showed that retesting in further positions in the sagittal plane resulted in extensive loss of MRI signal due to the separation of the patient from the anterior portion of the head coil, rendering the images acquired unreadable.

Although the findings of this study provide support for the construct validity of these 2 clinical tests by demonstrating a direct effect on alar ligaments in an asymptomatic population, it should be noted that neither the validity nor the reliability of these tests has yet been established in a clinical population. In the only article published previously examining alar ligament testing, Kaale and colleagues<sup>24</sup> demonstrated high specificity and moderate sensitivity for detecting alar ligament lesions in a mixed population dominated by people with a history of chronic whiplash-associated disorder based on an assessment of the quality of occipito-atlanto-axial rotation performed by one examiner. Assessment of tests under conditions of pain and muscle spasm and in the presence of other induced symptoms is necessary to evaluate their clinical utility.

#### Conclusion

This study has established successfully a reproducible method for the assessment of the clinical stress tests of the upper cervical spine ligaments. By using rigorously defined methods of standardization of the axis as a reference position and a clearly defined measurement protocol, the measurements produced have been demonstrated to be highly reliable. This study has addressed an important limitation of previous studies using MRI and will permit more accurate examination of the alar ligaments in future research.

Both the rotation and the sidebending stress tests for the alar ligaments have been demonstrated to increase the length of the contralateral alar ligament during testing. In contrast to the opinions of some authors, no bilateral effect was observed.

Mr Osmotherly and Dr Rivett provided concept/idea/research design and writing. All authors provided data collection and fund procurement. Mr Osmotherly and Mr Rowe provided data analysis. Dr Rivett provided project management. Mr Osmotherly provided participants. Dr Rowe provided facilities/equipment, institutional liaisons, and consultation (including review of manuscript before submission).

Ethical approval for this study was granted by the Hunter New England Human Research Ethics Committee.

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Original article

### The anterior shear and distraction tests for craniocervical instability. An evaluation using magnetic resonance imaging

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#### A R T I C L E I N F O

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#### ABSTRACT

Screening for integrity of the ligaments of the craniocervical complex has been suggested prior to the application of manual techniques to the upper cervical spine. However, most tests proposed lack validation limiting their usefulness clinically. This study examined the effect of the anterior shear test for the transverse ligament and the distraction test for the tectorial membrane in normal volunteers. MRI was performed in supine in neutral and end-range stress test positions in 16 individuals using proton density-weighted sequences and a standard head coil in a 3-T system. Measurements were made with respect to a strictly standardised protocol. The anterior shear test was assessed using changes in atlantodental interval and distance from the anterior arch of the atlas to the posterior aspect of the odontoid process. Distraction testing for the tectorial membrane was assessed by changes in basiondental interval and by direct measurement of the tectorial membrane. Differences were compared using Wilcoxon Sign Rank tests or paired t-test depending upon each variables assessment of normality. Anterior shear testing resulted in a 0.41 mm mean increase in atlantodental interval (p = 0.03) and 0.35 mm mean increase in axial plane distance (p = 0.05). Distraction testing for the tectorial membrane resulted in a 0.64 mm increase in basion-dental interval (p < 0.01) and a 1.11 mm increase in direct ligament length measurement (p = 0.02). Reliability of measurements ranged from moderate to substantial. These results indicate that these tests produce a consistent direct effect on the transverse ligament and the tectorial membrane which is consistent with their theorised mechanism for clinical use.

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#### 1. Introduction

Pre-manipulative screening has been advocated prior to the treatment of disorders of the upper cervical spine (Aspinall, 1990; Swinkels and Oostendorp, 1996; Hing and Reid, 2004). The consequences of performing manual techniques on an unstable upper cervical spine segment potentially may include neural damage due to direct pressure on the spinal cord and lower brainstem or vascular injury (Sanchez-Martin, 1992; Meadows, 1998; Di Fabio, 1999).

Joint dysfunction in the upper cervical spine may be detected using clinical examination techniques (Kaale et al., 2008). To date, the inferences that can be made from clinical stress tests of this region have been limited by a lack of validation of these procedures (Swinkels et al., 1996; Osmotherly and Rivett, 2011). Of the published descriptions of clinical tests for the transverse ligaments and the tectorial membrane, only the Sharp–Purser test for transverse ligament integrity has been subject to validation, and this test only in patients diagnosed with rheumatoid arthritis (Uitvlugt and Indenbaum, 1988). Further examination of the currently recommended clinical tests is required to determine their influence on these ligamentous structures.

The transverse ligament is positioned across the atlas, serving to hold the dens against the anterior ring of the atlas (Dvorak et al., 1988; Panjabi et al., 1991). It arises from tubercles on the medial aspects of each lateral mass of the atlas (Wood Jones, 1953; Grant and Basmajian, 1965; Goel et al., 1990; Dvorak et al., 2008) and extends posteriorly to pass around the posterior surface of the dens below the origins of the alar and apical ligaments (Panjabi et al., 1991). The function of the transverse ligament is to restrict forward translation of the atlas relative to the axis (Mercer, 2004), particularly during flexion of the head on the neck (Dvorak et al., 1988).

The anterior shear test for transverse ligament integrity is performed with the patient in a supine lying position with a neutrally positioned cervical spine and the clinician standing or seated at the





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head of the couch, with both index fingers placed posteriorly against the atlas and fingers III and IV resting against the occiput. The axis is then fixed by stabilisation on the anterior aspect of the transverse processes by the clinician's thumbs. Gentle pressure is then applied to the posterior arch of the atlas, the head and atlas moving anteriorly as a unit whilst gravity fixes the lower portion of the cervical spine. No movement should be detected or symptoms produced if the transverse ligament is normal (Aspinall, 1990; Pettman, 1994; Beeton, 1995; Meadows, 1999; Westerhuis, 2007; Mintken et al., 2008). The anterior shear test is potentially a provocation test. For this reason, some authors have urged caution in its use and suggest it should only be used in the presence of a negative Sharp–Purser test (Aspinall, 1990; Beeton, 1995).

Distraction testing is used to assess the integrity of the tectorial membrane due to its described role as a limiting factor in vertical translation (Werne, 1957; White and Panjabi, 1990). The patient is positioned in supine lying with their head resting on a pillow. This is proposed to relax the upper cervical musculature (Beeton, 1995) and to eliminate the stabilising effect of the ligamentum nuchae (Pettman, 1994). The therapist is positioned sitting or standing at the head of the plinth. With their lower hand, the therapist gently fixates the axis around its neural arch and cups the occiput with their upper hand. A manual traction is then applied to the head. The test is performed in three planes; neutral, flexion and extension (Aspinall, 1990; Beeton, 1995; Hing and Reid, 2004; Torres-Cueco, 2008). It is generally accepted that some movement on application of a distraction force is normal. A positive test response is considered to be excessive vertical translation when distraction is applied. Separation should not be greater than one to 2 mm (Beeton, 1995; Hing and Reid, 2004; Westerhuis, 2007).

The aim of the current study was to examine through magnetic resonance imaging (MRI) the direct effect of the anterior shear test for transverse ligament integrity and the distraction test for tectorial membrane integrity. These tests have each been discussed by various authors as inclusions in pre-manipulative screening procedures for the cervical spine (Aspinall, 1990; Pettman, 1994; Beeton, 1995; Meadows, 1999; Hing and Reid, 2004; Westerhuis, 2007) and each may be feasibly examined within the confines of a MRI scanner. By examining individuals without pathologies of the craniovertebral region, we may determine whether a measurable change occurs when a specific stress test is applied to the ligament structure compared to measurements taken with the cervical spine in a neutral position. Demonstration of a direct effect would provide support for the construct validity of these tests, a first step in establishing whether the tests are capable of demonstrating abnormalities of these structures.

#### 2. Methods

Ethical approval for this study was granted by the Hunter New England Human Research Ethics Committee.

#### 2.1. Participants

Sixteen skeletally mature participants were recruited via advertisement from the population of The University of Newcastle, Australia. To be eligible for inclusion, participants had to be between the ages of 18 and 35 years. The upper age limit was imposed to minimise the effect of degenerative change on cervical spine movement during testing. Volunteers were excluded if they had a history of cervical spine trauma or recurrent pharyngeal infection, had been diagnosed with an inflammatory disease or an instability of the craniovertebral region, had any congenital disorder recognised to have the potential for instability of the craniovertebral region or experienced claustrophobia or discomfort in confined spaces.

#### 2.2. Clinical stress tests examined

#### 2.2.1. Anterior shear test for the transverse ligament

The effectiveness of this test in displacing the anterior arch of the atlas forward from the odontoid process was assessed in two anatomical planes.

- a. In a midline sagittal view, the atlantodental interval was assessed using previously defined and assessed methods whereby the distance from the posteroinferior aspect of the anterior arch of the atlas to the adjacent anterior surface of the odontoid process (Hinck and Hopkins, 1960; Locke et al., 1966; Keats, 1990). To achieve this, a line was created connecting the inferior margin of the anterior arch of the atlas to the inferior margin of the posterior arch of the atlas. The distance along this line from the posterior ferior margin of the anterior arch of the atlas and the anterior surface of the dens constituted the measured atlantodental interval (Douglas et al., 2007). This is illustrated in Fig. 1a and b. This method was selected due to greater reproducibility than other described methods utilising the mid median atlantoaxial joint position (Jackson, 1983; Wellborn et al., 2000).
- b. In sagittal view, a slice through the middle of the median atlantoaxial point was selected. In axial reconstruction, a line was then superimposed in the midline of the axial slice,



**Fig. 1.** Measurement of the atlantodental interval between the anterior arch of the atlas (a) and the odontoid process (b).

bisecting both the anterior arch of the atlas and the odontoid process. The measured interval was the distance along this line from the point where it crossed the posterior aspect of the anterior arch of the atlas to the point where it crossed the posterior aspect of the odontoid process (Fig. 2a and b). The posterior aspect of the odontoid process was selected in preference to the anterior aspect to create a longer interval, thereby reducing error associated with the accurate comparison of shorter intervals.

#### 2.2.2. Distraction test for the tectorial membrane

The effectiveness of this test was assessed using two methods; one indirect and one direct. Each method was performed using a sagittal section selected to be the midline of the dens and second cervical vertebra.

- a. The indirect method was based upon the notion that a positive test for the tectorial membrane relies on successfully distracting the occiput in a cephalad direction away from the stabilised axis. The basion-dental interval was originally described as a method of assessing atlanto-occipital dissociation following trauma (Harris et al., 1994). It has been strongly advocated as a method of choice for use in assessing the spatial relationship between occiput, atlas and axis (Bono et al., 2007). The basiondental interval is described by Harris et al. as the distance from the basion to the closest point of the tip of the dens on lateral radiographic view (Fig. 3a and b).
- b. The direct method to assess tectorial membrane length involved overlying the visualised tectorial membrane on the image with markings using the curved measurement tool contained in the imaging analysis software. The curved interval



**Fig. 2.** Measurement of anterior displacement of the atlas in horizontal section. The measured interval was the distance along a line bisecting both the anterior arch of the atlas (a) and the odontoid process (b) from the point of crossing the posterior aspect of the anterior arch of the atlas to the point of crossing the posterior aspect of the odontoid process.



generated commenced over the point where the tectorial membrane overlay the basion and terminated at the inferior border of the body of the axis. An estimate of length of the curved interval was automatically calculated (Fig. 4a and b).

#### 2.3. Imaging of participants

Images were acquired in the coronal plane using a Siemens Magnetom Verio syngo MR B17 MRI system with a 3-T magnet (Siemens AG, Erlangen, Germany). All ligament tests were performed in supine lying within the MRI bore with participants enclosed in a phased array neck coil. A neutral image was acquired as a reference study at the commencement of each patient's examination. The neutral head and neck position for each participant was defined using previously published criteria whereby the participants were positioned such that a line between the subjects forehead and chin was horizontal and parallel to the examination table and an imaginary line run parallel to the table extended from the tragus of the ear bisects the neck longitudinally (Falla et al., 2004).

A proton density-weighted SPACE sequence was used with the following parameters: TR = 1000 ms, TE = 38, field-of-view 150  $\times$  150 mm, image matrix 320  $\times$  320, image resolution 0.5  $\times$  0.5  $\times$  1.5 mm (phase encoding direction right to left). Sixty slices were generated of slice thickness 1.5 mm. Averages = 1.8. The total acquisition time for each sequence was 3 min, 20 s.



Fig. 4. Direct measurement of the tectorial membrane.

#### 2.4. Analysis of MRI images

Viewing and analysis of all images was performed using OsiriX 3.5 image processing software.

#### 2.4.1. Method of standardising reference position

Each test examined has been described as movement of the atlas or occiput with respect to a stationary manually stabilised axis. To account for this and permit accurate and reproducible measurement, each image was measured with reference to a standardised position of the axis.

Standardisation of axis position was achieved using a multiplanar reconstruction of the data. In the sagittal reconstruction, a section was selected passing parallel to the longitudinal axis of the odontoid process and orthogonal to the plane of the interbody joint of C2-3. In the coronal reconstruction, a section was selected passing longitudinally down the midline of the odontoid process and bisecting the body of the second cervical vertebra. In axial reconstruction, a section was selected centred on the centre point of the cross section of the odontoid process. To account for any rotation of the axis present, the image was rotated when necessary such that the plane of section contained the transverse foramina of the axis in alignment.

#### 2.4.2. Assessment of image quality

The ability to accurately measure each image is dependent upon the quality of the image obtained. Since each position was maintained at an end-range position by the operator for in excess of 3 min, there was potential for the image quality to be compromised due to movement occurring during the acquisition period.

The clarity of images was classified in both the neutral and test positions according to the system used by Pfirrmann et al. (2001) in their examination of the alar ligaments. Bony and ligament structures to be examined in each image were classified on a three point system as;

- a. Well defined with regular contours
- b. Defined with irregular contours or
- c. Unable to be differentiated from surrounding tissue.

#### 2.5. Statistical analysis

Analysis of all data was performed using Stata 11.0 statistical software (Stata Corporation, Texas).

#### 2.5.1. Analysis of anterior shear testing for the transverse ligament

Atlantodental interval was analysed by assessing the change in distance between the test and the neutral position for each participant. Each hypothesis test was performed using the Wilcoxon Sign Rank test for paired variables.

Assessment in axial section was performed comparing the distance along the described interval from the posterior aspect of the anterior arch of the atlas to the posterior aspect of the odontoid process in neutral and test positions. Analysis of these measurements was by Wilcoxon Sign Rank test.

#### 2.5.2. Analysis of distraction testing for the tectorial membrane

Basion-dental interval was compared between neutral and test positions using the Wilcoxon Sign Rank test.

Difference in direct measurements of tectorial membrane length were assessed using the paired *t*-test as all data were normally distributed.

#### 2.5.3. Estimates of reliability

Reliability of measurements for each image was assessed by estimation of intraclass correlation coefficients between the recorded measurements of the image taken on two separate occasions.

#### 3. Results

#### 3.1. Characteristics of participants

Eight males and eight females satisfying all criteria for inclusion volunteered to participate. Ages ranged from 19 to 32 years (mean age 24.6 years, SD 5.3).

#### 3.2. Anterior shear test for the transverse ligament

In the neutral position, bony structures and the transverse ligament were classified as well defined with regular contours in six participants. Images of ten participants were classified as defined with irregular contours. In the test position, structures contained in the images were classified as well defined with regular contours for two participants and defined with irregular contours for 13 participants. Images of one participant were classified as unmeasurable due to image quality and incomplete containment within the imaging field resulting in data from 15 participants being available for analysis.

#### 3.2.1. Atlantodental interval

The mean distance of the atlantodental interval in the neutral position was 2.29 mm (SD 0.47 mm). In the test position, the mean atlantodental interval was measured as 2.70 mm (SD 0.57 mm). The resulting difference between positions of 0.41 mm (SD 0.56 mm) was statistically significant (p = 0.03).

#### 3.2.2. Axial plane measurement

The mean distance from the posterior arch of the atlas to the posterior aspect of the odontoid process measured in the neutral position was 11.89 mm (SD 1.54 mm). The mean distance in the test position was 12.24 mm (SD 1.52 mm). The resulting difference between positions was 0.35 mm (SD 0.67 mm, p = 0.05).

Reliability of individual measurements ranged from moderate to substantial using the criteria of Shrout (1998). Intraclass correlation coefficients and their 95% confidence intervals for each test position are given in Table 1.

#### 3.3. Distraction test for the tectorial membrane

In the neutral position, images of the tectorial membrane and the relevant bony landmarks were classified as well defined with regular contours in 13 participants and defined with irregular contours in three participants. In the test position, these structures were classified as well defined with regular contours in images of three participants, defined with irregular contours in 12 participants and unable to be defined in one participant.

#### 3.3.1. Basion-dental interval

In neutral, the mean basion-dental interval was 7.05 mm (SD 2.28 mm). In the distracted position, the mean basion-dental interval was 7.69 mm (SD 2.45 mm). The difference in measured intervals between neutral and test positions was 0.64 mm (SD 0.58 mm, p < 0.01).

#### 3.3.2. Direct measurement of tectorial membrane length

Tectorial membrane mean curved length between the inferior border of the axis and the point where the tectorial membrane overlay the basion was measured as 43.28 mm (SD 2.29 mm) in the neutral position and 44.40 mm (SD 3.02 mm) in the distracted position. The mean difference in curved length measured was 1.12 mm (SD 1.64 mm, p = 0.02).

The reliability of all measurements of the tectorial membrane were substantial with intraclass correlation coefficients all in excess of 0.9. Intraclass correlation coefficients and their

#### Table 1

Assessment of the reliability of individual measurements of the transverse ligament and the tectorial membrane.

Structure examined	Measurement assessed	ICC	95% CI
Transverse	ADI in neutral	0.90	0.72 to 0.97
ligament	ADI with anterior shear test	0.84	0.52 to 0.95
	Posterior atlas to posterior	0.80	0.50 to 0.93
	odontoid process in neutral		
	Posterior atlas to posterior	0.74	0.40 to 0.90
	odontoid process with		
	anterior shear		
Tectorial	BDI in neutral	0.98	0.96 to 0.99
membrane	BDI in distraction	0.99	0.96 to 0.99
	Direct measurement of	0.93	0.82 to 0.98
	tectorial membrane in neutral		
	Direct measurement of	0.99	0.98 to 0.99
	tectorial membrane in distraction		

ICC = intraclass correlation coefficient, CI = confidence interval, ADI = atlantodental interval, BDI = basion-dental interval.

95% confidence intervals for each test position are given in Table 1.

#### 4. Discussion

This is the first study to demonstrate a direct effect of these clinical tests on the transverse ligament and the tectorial membrane. These findings provide support for the construct validity of these screening tests.

#### 4.1. Anterior shear test for the transverse ligament

The premise underlying the anterior shear test for the transverse ligament is that the atlas may be translated anteriorly on a fixed axis to a degree that symptom reproduction may be elicited in a patient with transverse ligament insufficiency. Displacement of the atlas in this study was measured in two ways; change in atlantodental interval and displacement of the atlas with respect to the odontoid process of the axis in the horizontal plane. In each method of examination, the atlas was demonstrated to have been displaced anteriorly with respect to the axis. This is consistent with the mechanism described. The acceptable levels of reliability for these measurements as indicated by the intraclass correlation coefficients indicate that these findings are reproducible. This is the first study to demonstrate the ability of a clinician to displace the atlas away from the axis using the anterior shear test.

The mean magnitude of change elicited during examination of this test was 0.41 mm for the atlantodental interval (p = 0.02) and 0.67 mm for the displacement in the axial plane (p = 0.05). Whilst consistent in magnitude and direction, these displacements are considerably less than those suggested to be required to cause compromise in an unstable atlantoaxial segment. However, the displacement required to elicit non-cardinal symptoms remains unknown. This examination in normal individuals permits the inference that a clinician may cause displacement of the atlas within the segment and hence provides a measure of empirical support for the validity of this test. Whether the degree of displacement achieved is sufficient for symptom reproduction cannot be inferred.

#### 4.2. Distraction test for the tectorial membrane

The two measures used for distraction testing of the tectorial membrane provide information on different aspects of this clinical test. The fact that the changes elicited by each measure are consistent with each other provides added strength to the associations derived. The methods used to assess the tectorial membrane, both directly and indirectly, displayed high reliability with all ICC's in excess of 0.9.

As a measure of vertical distraction, the change in basion-dental interval provides an indication of the ability to produce a spatial change between the adjacent segments through manual application of force. The mean change in basion-dental interval in the sample tested was 0.64 mm. This mean change was statistically significant (p < 0.01), but may also have clinical relevance attributed to it. The direction of movement is consistent with the descriptions of the clinical test and thus supports the rationale behind its application as a method of assessing tectorial membrane integrity. The magnitude of the change lies within the parameters of 1-2 mm accepted to be indicative of a normal test (Beeton, 1995; Hing and Reid, 2004; Westerhuis, 2007), as should be the case in this sample, thus reinforcing the interpretation of a normal test result.

The increase in vertical distraction has been demonstrated to have a direct effect on tectorial membrane length in this sample. Measuring between predefined points along the course of the tectorial membrane showed an overall mean increase in length of

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this structure of 1.11 mm between the axis and the occiput (p = 0.02). The greater change in length of the structure itself compared to the magnitude of change in vertical distance is expected since the course of tectorial membrane does not follow a linear path as it passes cephalad, instead coursing anterosuperiorly from the tip of the odontoid process towards the occiput.

Whilst the usual clinical tests for these structures would entail movement to end-range followed by an immediate release of the position, the imaging process requires the maintenance of an endrange position in excess of 3 min. The performance of each test also required some adaption of the operator position to permit testing within the neck coil and MRI bore. These factors may be considered to increase the potential to lose the end-range position and hence reduce the measured differences between the neutral and test positions. The magnitude of the ICCs for the image measurements demonstrates that inaccuracy due to vibration or loss of end-range position during testing was minimal. Given the consistent findings of reliably measured displacement, the results presented may be considered to be a conservative estimate of the true displacement achieved during clinical testing for transverse ligament or tectorial membrane integrity.

#### 5. Conclusion

Assessment of the anterior shear test has indicated that displacement of the atlas on the axis can be produced by the application of manual force. Thus, the mechanism underlying the test has been shown to be plausible. Questions regarding the magnitude of the displacement necessary to reproduce a clinically meaningful response remain unresolved.

Distraction of the occiput on a manually fixed axis produces a measureable increase in length of the tectorial membrane consistent with the change observed in the basion-dental interval during testing. The magnitude of the change is consistent with current clinical opinion in regard to the interpretation of a normal test response.

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# *Revisiting the clinical anatomy of the alar ligaments*

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ORIGINAL ARTICLE

## Revisiting the clinical anatomy of the alar ligaments

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#### Abstract

*Purpose* The morphology of the alar ligaments has been inconsistently described, particularly with regard to the existence of an atlantal portion. Despite these inconsistencies, these descriptions have been used to develop physical tests for the integrity of these ligaments in patients with cervical spine problems. The purpose of this study was to describe the detailed macrostructure of the alar ligaments.

*Methods* The alar ligaments of 11 cervical spine specimens from embalmed adult cadavers were examined by fine dissection. A detailed description of the macrostructure of these ligaments and their attachment sites was recorded. Measurements were performed with respect to ligament dimensions and relations with selected bony landmarks.

*Results* No atlantal portion of the alar ligament was viewed in any specimen. The attachment of the ligaments on the odontoid process occurred on its lateral and posterolateral aspects, frequently below the level of the apex. The occipital attachment was on the medial surface of the occipital condyles in close proximity to the atlanto-occipital joints. The orientation of the ligaments was primarily horizontal. The presence of transverse bands extending occiput to occiput with minimal or no attachment to the odontoid process was a common variant.

*Conclusions* The absence of findings with respect to the atlantal portion of the alar ligament suggests that it may be

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S. R. Mercer Newcastle Bone and Joint Institute, The University of Newcastle, Newcastle, Australia considered an anatomical variant, not an essential component for stability of the craniocervical complex. These findings may inform the use and interpretation of clinical tests for alar ligament integrity.

**Keywords** Alar ligaments · Craniocervical anatomy · Clinical stability test

#### Introduction

In recent years, discussion of the structure and biomechanics of the alar ligaments has largely been based upon descriptions of the alar ligaments as commonly consisting of both occipital and atlantal portions [1–3]. Each of these components have been ascribed functional significance in governing the coupling of movements within the craniocervical complex [2–4]. Reliance upon this description has particular relevance for practitioners of musculoskeletal medicine where clinical stress tests based upon this description have been described for alar ligament integrity as a component of stability testing of the cervical spine [5–9].

Cave[10] reported distinct bundles of fibres extending from the dens in a similar plane to those fibres extending occipitally, attaching to the pretubercular recess of the atlas. He noted that these bundles served to separate the anterior from the posterior median atlanto-axial joint spaces. This would be consistent with the interpretation of Gardner et al. [11] of the description given by Poirier et al. [12] which states that synovial cavities both in front and behind the dens each have their own capsular ligament and synovial membrane. Despite these early descriptions, no author revisited the possibility of an atlantal portion of the alar ligament until the work of Dvorak and Panjabi [1]. Of

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19 specimens examined by gross dissection, these authors reported a ligamentous connection between the dens and the lateral mass of the atlas in 12 cases. They described this as a distinct portion of the alar ligament of approximately 3 mm in length with fibres oriented obliquely craniocaudally from the dens to the lateral mass of the atlas. Based on these findings, it can be assumed that this structure is either not present or not identifiable in approximately onethird of the people.

More recent studies have not added strength to arguments for the consistent existence of an atlantal portion of the alar ligament. In a recent examination of the craniovertebral complex in 20 fresh cadavers, no atlantal portion of the alar ligament was observed in any specimen [13]. Magnetic resonance imaging techniques used to examine this area have also cast doubt on the presence of this structure. Krakenes et al. [14] did not report an atlantal attachment in a series of 30 people. Whilst other imaging studies have discussed the existence of an altantal portion of the alar ligaments, they have not gone on to state whether they could visualise this in any of the participants in their studies [15, 16].

The classical textbook description of the alar ligaments is of two strong, 'cord-like' structures extending to the occiput symmetrically placed on both sides of the dens in the sagittal plane [17–21]. The origin of the alar ligaments on the dens has been variously described as the lateral margins of the posterior surface of the upper one-third of the dens [22], the apex of the dens [11, 23], the dorsolateral surface of the tip of the dens [18, 24, 25] or the sides of the dens [19], broadening at this attachment to accommodate the compressive forces incurred during craniocervical rotation [26]. It has been suggested that a small proportion of fibres do not have a medial attachment at all onto the dens, but pass behind or above the dens to be continuous with the contralateral alar ligament [27]. This feature was also described by Testut and Latarjet [28] who described an inconsistently present arc-like cord with superior concavity extending from occiput to occiput, also known as the 'transverse ligament of the occiput of Lauth'. More recently, this was noted and described as a variant termed the transverse occipital ligament [29].

Each ligament runs laterally from the dens in the direction of the occipital condyles, with the two ligaments tilting away from the sagittal plane by approximately  $70^{\circ}$ , thus creating an included angle between them estimated as being between 140° and 180° [1, 4, 22]. The orientation of each ligament has often been described as superolateral [18, 20, 22], but has also been noted as closer to horizontal [28, 30, 31]. Dvorak and Panjabi [1] list three types of fibre orientation which were dependent on the height of the dens relative to the level of the occipital condyles. These authors found that in their series of 19 specimens, 9 specimens

displayed alar ligaments oriented craniocaudally, 6 specimens oriented horizontally and 4 specimens with a caudocranial orientation. A similar finding was reported by Okazaki[32] in an examination of 44 cadavers. In this study, 19 ligaments were described as caudocranially oriented, 24 as horizontal and 1 ligament was reported to have a craniocaudal orientation [32].

The occipital insertion is frequently reported to be onto the medial surface of the occipital condyles [2, 4, 11, 17, 18, 24, 25, 27], but has also been described as being on to the lateral walls of the foramen magnum [19, 20, 22].

Predating the work of Cave, Fick [27] described an inconsistently present doubled or accessory portion to the alar ligament. However, rather than having an atlantal attachment, this band of tissue was reported to pass vertically toward the occiput.

Given the inconsistent descriptions of the alar ligaments and the translation of selected works into clinical tests examining alar ligament integrity, the current study was undertaken to examine the gross morphology of this structure. We hypothesise that the presence of an atlantal portion of the alar ligaments is inconsistent and not essential to the stability of the craniocervical region.

#### Methods

Eleven cervical spine and head specimens (6 male and 5 female) were obtained from embalmed human adult cadavers with a mean age of 84.1 years (range 69–91 years). Trauma had not been a cause of death in any of the subjects.

Cervical spine columns were removed from each cadaver by disarticulation through the C6-C7 intervertebral disc and zygoapophysial joints. All muscle tissue was removed from each specimen leaving an osseoligamentous arrangement. The skull was sectioned at a level through the superior portion of the occipital bone and brain tissue removed. In accordance with methods previously described by Dvorak and colleagues [1, 2], a wide posterior wedge was cut from the occipital bone. Anteriorly, the bone was sectioned by a cut in the coronal plane. The posterior arch of the atlas and the posterior elements C2-C6 were resected. Brainstem, spinal cord, dura and tectorial membrane were removed to expose the alar ligaments.

The alar ligaments were examined using a dissecting microscope. Each ligament was progressively dissected by removal of small bundles of fibres. The orientation, location and attachment sites were recorded, sketched and photographed. Measurements of distance of attachment of the alar ligaments along the odontoid process, distance of the superior aspect of the attachment from the tip of the odontoid process, alar ligament length and width at the midpoint and occipital attachment were measured with

## Author's personal copy



Fig. 1 The alar ligaments arising from the odontoid process. The transverse and cruciform ligaments have been removed

callipers. Estimation of the orientation of the ligament was made with respect to the horizontal plane.

#### Results

Situated bilaterally, the alar ligaments were observed to run laterally from the odontoid process to the occiput. Each ligament inspected consisted of a thick bundle of fibres, ovoid in cross-section, oriented along the direction of the ligament passing laterally to the occiput (Fig. 1). No bands of fibres were observed between the odontoid process and atlas in any specimen.

The superior border of the medial attachment of the alar ligaments onto the odontoid process was frequently observed to be below the tip of the process (mean distance below odontoid process tip 1.72 mm, SD 1.85). Attachment occurred variably on either the lateral or the posterolateral aspect of the odontoid process, typically extending down its superior one-third but encompassing half of the distance down the odontoid process in some specimens. Distance of the attachment extended between 5 and 8 mm inferior to its superior margin (mean attachment distance 6.06 mm, SD 0.97). The variation in attachment distance from the tip of the odontoid process and the extent of the attachment onto the process reflected differences in magnitude of the ligament in individual specimens.

The lateral attachment of each ligament onto the occiput was observed to be a discrete area between 2 and 4 mm in diameter on the medial surface of the occipital condyles in ten specimens. The remaining specimens demonstrated a more diffuse attachment onto this area. Each attachment site was located in close proximity to the atlanto-occipital joint.

In progressing toward their attachment onto the occiput, the bands of the alar ligaments were observed to be oriented horizontally in seven specimens, with the remainder



Fig. 2 Band of fibres of the alar ligament traversing from occiput to occiput

assuming a slightly cranio-caudal orientation. The length of the alar ligaments between bony insertions ranged between 11 and 15 mm (mean length 12 mm, SD 1.25). The superior-inferior width of the ligaments viewed from a coronal plane ranged from 4 to 5 mm.

Five of the 11 specimens exhibited substantial bands passing between the medial surfaces of each occipital condyle which spanned the dens posteriorly with either minimal or no attachment to it (Fig. 2). Each band had a horizontal orientation with a width of up to 4 mm. Fascia and capillaries could be observed passing through the space between the two bands of the ligament in some specimens. These posterior bands of ligament permitted a degree of mobility as they passed behind the posterior aspect of the dens. Each of the five ligaments with transverse bands displayed a large proportion of fibres traversing directly from occipital condyle to occipital condyle. Whilst the transverse band in one of these specimens did not have any attachment to the dens (Fig. 3), the remaining four specimens displayed a weak but definite attachment to the posterior aspect of the superior portion of the odontoid process below the level of the tip. The thickest of these bands, displaying no attachment to the odontoid process, possessed a cartilaginous anterior surface similar to the under-surface observed in the transverse ligament.

#### Discussion

No atlantal portion of the alar ligament was noted in any specimen examined. This is a significant departure from the findings of Dvorak and Panjabi [1] who reported a distinct ligamentous connection between the odontoid process and the lateral mass of the atlas in 12 of 19 specimens examined by gross dissection. Whilst the existence of these bands would not be expected in all specimens, it would seem unexpected that if these structures were commonly



Fig. 3 Alar ligament with no medial attachment being lifted from the odontoid process

existing anatomical features they would not be apparent in any of the 11 specimens examined in this series. Two possible explanations may exist for this anomaly. Variation is common within normal anatomy and specific populations may exhibit some variations which may not be widely present beyond that population. One explanation could therefore be that the ligamentous bands described by these authors were specific to a population present within their study sample and hence may not be commonly present in other individuals. A second explanation that is also possible is that the structures reported were not, in fact, elements of the alar ligaments. Previous authors have noted bundles of connective tissue arising from the axis and passing to the atlas. These reports have attributed this tissue to elements of the median atlantoaxial joint capsule rather than the alar ligaments [10–12]. It was also noted in the present dissection series that elements of loose connective tissue associated with small vessels were present in this region. This could also be a possible source for the observations of Dvorak and Panjabi.

In this dissection series, the majority of alar ligaments were observed to be oriented horizontally, with four ligaments observed to run slightly cranio-caudally. This finding suggests that the orientation of the ligaments may be more horizontal than has been previously described. Whilst appreciating that atlantoaxial articular cartilage height may be reduced in specimens drawn from an elderly sample, horizontal orientation of the alar ligaments would be more in keeping with the described role of these structures in gradually developing tension through range under the influence of the vertical translation resulting from the biconvex atlantoaxial articulation, providing restraint against the extremes of rotation of the occiput on the atlantoaxial complex in the horizontal plane [33]. The rationale for variation in alar ligament orientation is given by Dvorak [3] as being due to variation in height of the odontoid process. This presupposes that the alar ligaments are attached to the tip of the odontoid process. This is not supported by the findings of this study. No alar ligament was observed to arise from the tip of the odontoid process in any specimen examined, with the mean distance being 2 mm from this bony landmark and the extent of attachment onto the process was measured as being up to 8 mm inferior to this. Hence, this explanation does not provide an adequate rationale for ligament orientation. It is more likely to simply be a function of normal variation between individuals.

The presence of transverse bands in nearly half of the specimens examined suggests that this is a common variant of the alar ligament. Complete overarching or minimal attachments to the odontoid process suggest that these bands, when present, may have a role assisting in maintenance of the relationship between occiput, atlas and odontoid process in the sagittal plane. Such a role has been previously described for the alar ligaments in the absence of an intact transverse ligament [12] and the similarity in orientation to the transverse ligament would make this a logical inference. Their mobile nature in relation to the odontoid process suggests that they do not encumber the odontoid process during craniovertebral rotation. In this case, these bands will not contribute to the coupling of lateral flexion and rotation occurring at the craniovertebral segments that has been attributed to tension developed within the alar ligaments.

The existence of a strong cord-like structure between the odontoid process and the medial aspect of the occiput is consistent and beyond dispute. The absence of findings with respect to the previously described atlantal portion of the alar ligament suggests that it may be considered an anatomical variant, and therefore not an essential component for stability of the craniocervical complex. Although clearly described by previous authors [1] and ascribed functional significance in descriptions of the biomechanics of this region [2], the inconsistency of findings in regard to their presence should lead the clinician to conclude that no weight should be attributed to any physical test finding regarding its integrity.

Conflict of interest None.

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## **APPENDIX B**

## ETHICS APPROVALS FOR STUDIES CONDUCTED AT THE UNIVERSITY OF NEWCASTLE



#### HUMAN RESEARCH ETHICS COMMITTEE

## Certificate of Approval for a research project involving humans

Applicant	
Chief Investigator/Project Supervisor: (First named in application)	Associate Professor Darren Rivett
Co-Investigators/Research Students:	Mr Peter Osmotherly
Project Title:	Physiotherapist's use of craniovertebral instability testing

In approving this project, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the *National Statement on Ethical Conduct in Research Involving Humans*, 1999, and the requirements within this University relating to human research.

Details of Approval				
HREC Approval No:	H-174-1205	Date of Approval:	14 December 2005	
Approval valid for: 3 years, or until project ceases, whichever occurs first.		Progress reports due: Annually		
NOTE: Approval is grante Research, and any addition	ed subject to the requirer onal comments or condit	nents set out in the attached ions noted below:	document Approval to Conduct Human	
14 December 20 Approved.	05	đi		

10 November 2008

# HUNTER NEW ENGLAND

Assoc Prof Darren Rivett School of Health Sciences University of Newcastle

Dear Professor Rivett,

Re: Clinical testing of craniocervical ligaments

#### HNEHREC reference number: 08/09/17/5.01 HREC reference number: 08/HNE/301 SSA reference number: SSA/08/HNE/370

Thank you for submitting an application for authorisation of this project. I am pleased to inform you that authorisation has been granted for this study to take place at the following sites:

John Hunter Hospital

The following conditions apply to this research project. These are additional to those conditions imposed by the Human Research Ethics Committee that granted ethical approval:

- Proposed amendments to the research protocol or conduct of the research which may affect the ethical acceptability of the project, and which are submitted to the lead HREC for review, are copied to the research governance officer;
- 2. Proposed amendments to the research protocol or conduct of the research which may affect the ongoing site acceptability of the project, are to be submitted to the research governance officer.

Yours faithfully

Lisa Woseen Research Governance Officer Hunter New England Health

> Hunter New England Human Research Ethics Committee (Locked Bag 1) (New Lambton NSW 2305)

Telephone: (02) 49214950 Facsimile: (02) 49214818 Email: <u>hnehrec@hnehealth.nsw.gov.au</u> Nicole.gerrand@hnehealth.nsw.gov.au Lisa.Woseen@hnehealth.nsw.gov.au http://www.hnehealth.nsw.gov.au/Human\_Research\_Ethics



## HUMAN RESEARCH ETHICS COMMITTEE Certificate of Approval

Applicant: (first named in application)	Associate Professor Darren Rivett
Co-Investigators / Research Students:	Assoc Professor Susan Mercer Assoc Professor Lindsay Rowe Mr Peter Osmotherly
Protocol:	Clinical testing of the craniocervical ligaments

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research*, 2007, and the requirements within this University relating to human research.

**Note:** Approval is granted subject to the requirements set out in the accompanying document *Approval to Conduct Human Research*, and any additional comments or conditions noted below.

Details of Approval				
HREC Approval No: H-2008-0408	Date of Initial 10-Dec-2008 Approval:			
Approved to: 26-Oct-2011 Approval is granted to this date or until the project is completed, whichever occurs first. If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.				
<b>Progress reports due:</b> Annually. If the approval of an External HREC has been "noted", the reporting period is as determined by that HREC.				
Initial Approval				
Approved				
With regard to the Participant Information Statement it is recommended that the undertaking for all data to be stored for five years be changed to all data will be stored for a minimum of five years. The Committee recommends you use the phrase 'for a minimum of (required number) years' in future applications.				
Renewal of Approval				
Variations to Approved Protocol				

Authorised Certificate held in Research Services

Professor Val Robertson Chair, Human Research Ethics Committee

### HUMAN RESEARCH ETHICS COMMITTEE



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### APPROVAL TO CONDUCT HUMAN RESEARCH

To Chief Investigator or Project Supervisor:Associate Professor Darren RivettCc Co-investigators / Research Students:Assoc Professor Susan Mercer<br/>Assoc Professor Lindsay Rowe<br/>Mr Peter OsmotherlyRe Protocol:Clinical testing of the craniocervical ligamentsDate:12-Dec-2008Reference No:H-2008-0408

Thank you for your recent application to the University of Newcastle Human Research Ethics Committee (HREC) for approval of the protocol identified above.

A Certificate of Approval is enclosed.

#### THE CERTIFICATE AND THIS ADVICE ARE TO BE RETAINED THEY ARE IMPORTANT DOCUMENTS

- Note any comments related to the approval.
- Where the HREC is the lead or primary HREC, if the research requires the use of an Information Statement, ensure the Reference No. is inserted into the complaints paragraph in the approved document(s) prior to distribution to potential participants.
- Where the research is the project of a higher degree candidate, it is the responsibility of the project supervisor to ensure that the candidate receives this approval advice.

#### Conditions of Approval

This approval has been granted subject to you complying with the requirements for *Monitoring of Progress*, *Reporting of Adverse Events*, and *Variations to the Approved Protocol* as <u>detailed below</u>.

#### PLEASE NOTE:

In the case where the HREC has "noted" the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, you will apply to the External HREC for approval in the first instance and then Register that approval with the University's HREC.

#### Monitoring of Progress

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. The *Certificate of Approval* identifies the period for which approval is granted and your progress report schedule. A progress report is required on an annual basis, you will be advised when a report is due.

#### Reporting of Adverse Events

- 1. It is the responsibility of the person first named on the Certificate to report adverse events.
- 2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
- Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Certificate to the (HREC) by way of the Adverse Event Report form within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
- 4. Serious adverse events are defined as:
  - Causing death, life threatening or serious disability.
  - Causing or prolonging hospitalisation.
  - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
  - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
  - o Any other event which might affect the continued ethical acceptability of the project.
- 5. Reports of adverse events must include:
  - o Participant's study identification number;
  - o date of birth;
  - o date of entry into the study;
  - o treatment arm (if applicable);
  - o date of event;
  - o details of event;
  - $\circ\;$  the investigator's opinion as to whether the event is related to the research procedures; and
  - o action taken in response to the event.
- 6. Adverse events which do not fall within the definition of serious, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.
- Variations to approved protocol

If you wish to change, or deviate from, the approved protocol, you will need to submit an *Application for Variation to Approved Human Research*. Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. **Variations must be approved by the (HREC) before they are implemented** except when Registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

#### Linkage of ethics approval to a new Grant

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

With best wishes for a successful project.

Professor Val Robertson Chair, Human Research Ethics Committee

For communications and enquiries: Human Research Ethics Administration

Research Services Research Office The University of Newcastle Callaghan NSW 2308 T +61 2 492 18999 F +61 2 492 17164 Human-Ethics@newcastle.edu.au

Funding Details

Funding body	Funding project title	First named investigator	Administering institution	Uni of Newc G Reference
Physiotherapy Research Foundation	Clinical assessment	Mr Peter Osmotherly	University of Newcastle	G0189010

## **APPENDIX C**

# QUESTIONNAIRE DEVELOPED FOR THE STUDY THE KNOWLEDGE AND USE OF CRANIOVERTEBRAL INSTABILITY TESTING BY AUSTRALIAN PHYSIOTHERAPISTS

#### Researchers

#### **Discipline of Physiotherapy**

Peter Osmotherly Discipline of Physiotherapy, The University of Newcastle

A/ Prof Darren Rivett Discipline of Physiotherapy, The University of Newcastle

A/Prof Susan Mercer Dept of Anatomy and Developmental Biology, The University of Queensland School of Health Sciences Faculty of Health The University of Newcastle University Drive, Callaghan NSW 2308 Australia Phone: +61 2 4921 7718 Fax: +61 2 4921 7902

### PHYSIOTHERAPISTS' USE OF CRANIOVERTEBRAL

#### **INSTABILITY TESTING**

Please answer the following questions by either:

 $\Box$  Placing a tick ( $\checkmark$ ) in the appropriate box or

..... Writing a response on the line provided

1. What do you understand by the term "instability" in the upper cervical spine?

2. Have you ever detected a patient with undiagnosed craniovertebral instability using stress tests?

\_\_\_\_\_

Yes	
-----	--

If yes, please provide details.

3. Which of the following signs and symptoms would you associate with craniovertebral instability?

-

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	A metallic taste in the mouth		Nausea or vomiting			
	Altered proprioception		Occipital numbness or paraesthesia			
	Altered sensation for deep pressure in the tongue		Altered sphincter control (Bladder/ bowel)			
- *	Altered sensation of vibration		Nystagmus on head/ neck movement			
	Pain within range of cervical motion		Paraesthesia of the lips reproduced by active or passive movement			
	Ataxia		Lingual deviation			
	Buzzing in the ears/tinnitus		Persistent, pain free torticollis ("Cock robin" position)			
	Cardiac distress		Popping in the ears			
	Difficulty co-ordinating walking		Recurring wry neck			
	Diplopia		Respiratory distress			
	Dizziness		Retro-ocular pain			
	Drop attacks		Seizures			
	Dysarthria		Spasticity			
	Dysphagia		Suboccipital pain			
	Facial pain or paraesthesia		Syncope			
	Feeling of a lump in the throat		Torticollis, with head rotated away			
	Headache		from the side of pain			
	Hyper-reflexia		Hypoaesthesia in distribution of the			
	Hypoaesthesia of both hands or both feet		occipitalis major nerve.			
	Loss of cervical lordosis		Upper cervical pain			
	Lower limb muscle weakness or wasting		Vagal nerve symptoms e.g. chest and abdominal pain, tachycardia			
	Bilateral or quadrilateral limb paraes movement	thesia I	reproduced by active or passive			
	Increased mobility on passive movement testing of the upper cervical spine					

4. The following are described tests of the craniovertebral articulations. Please indicate if you have heard of each test, know how to perform the test and if you use the test in your clinical practice.

Test	Have	you h	eard of	Can you perform Do you use			use this	
2				this test?			test?	
	Yes	No	Unsure	Yes	No	Unsure	Yes	No
Sharp Purser						-		
(Transverse ligament)								
Modified Sharp								
Purser								
(Transverse ligament)								
Anterior shear test								
(Transverse ligament)								
Lateral stability of the								
atlanto-axial joint (alar								
ligament, dens)								
Distraction								
(Tectorial membrane)								
Passive upper								
cervical flexion								
(Tectorial membrane)								
Distraction in								
craniovertebral flexion								
(Tectorial membrane)								
Side bending stress								
test (Alar ligament)				-				
Rotation stress test								
(Alar ligament)								

- 5. How often do you test for craniovertebral instability? (you may tick more than one box)
  - with all patients with upper cervical spine disorders
  - whenever indicated by the presentation
  - rarely
  - never
  - prior to any cervical spine manipulation
  - prior to any upper cervical spine manipulation
  - prior to any end-range mobilisation of the upper cervical spine
  - prior to any end-range assessment test of the upper cervical spine

6. Would you normally test for craniovertebral instability when treating an upper cervical spine disorder in a patient with any of the following problems?

Condition	Yes	No	Unsure
Ankylosing spondylitis			
Downs syndromo		-	
Lipodoobo			
Headache			
History of neck trauma			
Klippel-Feil syndrome			
Morquio syndrome			
Neck pain			
Pierre Robin syndrome			
Psoriatic arthritis			
Recurrent pharyngeal			
infection			
Recurrent tonsillitis			
Reiters disease			
Rheumatoid arthritis			
Septic arthritis			
Systemic Lupus			
Erythematosus			
Whiplash associated			
disorder			

- 7. In your opinion, when should craniovertebral instability tests be used in clinical practice? (you may tick more than one box).
  - with all patients with upper cervical spine disorders
  - whenever indicated by the presentation
  - **rarely**
  - **never**
  - prior to any cervical spine manipulation
  - prior to any upper cervical spine manipulation
  - prior to any end-range mobilisation of the upper cervical spine
  - prior to any end-range assessment test of the upper cervical spine

Please give a brief explanation for your response.

8.	In your opinion, should screening tests for craniovertebral instability be considered mandatory before performing manual therapy in the upper cervical region?
	Yes, prior to manipulation of the upper cervical spine only
	Yes, prior to end-range mobilisation or manipulation of the upper cervical spine
	Yes, prior to any end range assessment technique of the upper cervical spine
	No
9.	If screening tests for craniovertebral instability were recommended by the APA/ NZSP prior to the application of manipulation or end-range techniques to the upper cervical region, do you think you would perform the tests routinely?
	If no, please comment.
10.	In your opinion, do you think the current "Clinical guidelines for pre manipulative procedures for the cervical spine" should include information and recommendations about craniovertebral instability testing?
	Yes No Please explain your answer.

## About you.

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6

11.	In what state / region is your main place of employment?					
		ACT		Queensland		
		New South Wales		South Australia		
		Tasmania		Victoria		
		Northern Territory		Western Australia		
12.	You	r gender is	<del>)</del>	☐ female		
13. What is your level of professional association membership?						
MPA Level 1						
		2				
		□ 3				
14. Are you currently working clinically?				Full-time		
				Part-time		
				$\Box$ Not currently working clinically		

Please indicate the type of location in which you currently work (main place of employment);

 $\odot$ 

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15.

16.

17.

2	Public hospital					
a.						
2						
	Private practice					
	Other:					
b.	Is this;					
	metropolitan (population more than 100,000)					
	rural (population less than 100,000)					
How	many years have you practiced musculoskeletal physiotherapy?					
How com	frequently would you assess a patient with an upper cervical spine ponent to their disorder?					
	More than once per day					
	Once per day					
	Less than once per day but more than once per week					
	Once per week					
	Less than once per week but more than once per month					
	Once per month					
	Less than once per month					
Do y disor	ou use manual therapy techniques in managing upper cervical spine ders?					
	No					
	Yes. If yes, do you use an ipulation and mobilisation					

18.	at is your entry level qualification in physiotherapy?				
	Bachelors degree				
	Diploma				
	Graduate Diploma				
	Masters degree				
19.	Where did you qualify? Institution				
	Country				
20.	n what year was your final year of study for your entry level qualification?				
21.	Do you have postgraduate qualifications in musculoskeletal physiotherapy?				
	□ No				
	Graduate certificate				
	Graduate diploma				
	Masters (coursework)				
	Masters (research)				
	Professional doctorate				
	PhD				
	Other (please state)				
From which institution was the qualification(s) awarded?					

Please return the completed questionnaire in the enclosed envelope as soon as possible.

### THANK YOU FOR YOUR ASSISTANCE