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ARTICLE INFORMATION

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Article Title	The relationship between dens height and alar ligament orientation: A radiological study
MeSH terms – only use MeSH terms that can be found at http://www.nlm.nih.gov/mesh/meshhome.html	Cervical vertebrae; Odontoid process; Ligament; Magnetic resonance imaging
Running head - no more than 40 letters/ spaces	Alar ligament angle and dens height
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Word count for structured abstract (approx 250 words or less)	217
3 to 5 short sentences that summarize the practical applications of the findings of the study	• first known study to establish quantitative data on alar ligament orientation relative to dens height. • no statistically significant association between dens height and ligament orientation as cited as the underlying reason for multiplanar clinical testing. • normal variation in alar ligament orientation suggests that multiplanar testing for the alar ligament is appropriate despite the anatomical rationale proposed to explain this variation being refuted.
Short description for the JMPT Highlights, approximately 2 sentences (40 words)	Osmotherly et al examined the anatomical assumptions underlying pre-manipulative multiplanar stress testing of the alar ligaments. Using prospectively collected CT studies, the relationship between dens height and alar ligament orientation was assessed and quantified using standardized radiological measures.
State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available. Clearly state if study received direct NIH funding.	Nil
List any present or potential conflict s of interest for all authors	Nil

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Abstract

Objective: This study examined the anatomical assumptions underlying multiplanar alar ligament stress testing. The alar ligament has been described as occurring in one of three planes; caudocranial, horizontal and craniocaudal. This has been stated to result from variation in dens height. Stress testing in all three planes is suggested, with increased translation present in all positions to infer instability.

Methods: CT scans with no diagnosed bony or ligamentous abnormally were prospectively and sequentially analysed. The height of the dens relative to the occipital condyles was measured using McRae’s line and the bimastoid line. The orientation of the alar ligament was measured relative to the vertical axis of the dens as well as a vertical line defined by specified occipital and spinal bony landmarks. These results were correlated with dens height.

Results: Following exclusions, forty-two individual CT studies were analysed yielding sixty-four clearly discernable ligaments. A vertical line derived from the digastric line provided the smallest variation in results. The mean ligament orientation given by this measure was 110.06° (85°-127°). There was no correlation between measured dens height relative to the occiput and ligament orientation.

Conclusion: Our findings reinforce the existence of normal anatomical variation in dens height and alar ligament orientation. However, variation in dens height as a cause of variation in ligament orientation is not supported.

Key Words: Cervical vertebrae, Odontoid process, Ligament, Magnetic resonance imaging

INTRODUCTION

The alar ligaments in the upper cervical spine pass from the lateral aspect of the dens of the second cervical vertebra to the margins of the foramen magnum.[1] These ligaments are reported to serve as a primary restraint to axial rotation[2-7] and lateral flexion[2, 5-7] in the occipito-atlanto-axial complex. Trauma and degenerative diseases may compromise the integrity of the alar ligaments, impacting on the stability of the upper cervical spine[8] and creating the potential to damage sensitive neurological and vascular structures in this region.[8]

Stress testing of the alar ligaments has been recommended prior to any end range mobilisation or manipulation procedure in the upper cervical region.[8, 9] Clinical testing is described by Aspinall[8] as performed in multiple planes; flexion, neutral and extension as a result of variation in sagittal plane orientation of the alar ligaments. This variation has been stated to be a function of the height difference between the tip of the dens and the occipital condyles.[2, 10] Increased joint translation is required to be present in all three planes to infer the presence of pathology.[8]

Based on dissectional review, Dvorak and Panjabi[2] describe the alar ligament orientation along its course from dens to occiput as variably craniocaudal, horizontal or caudocranial. The assumption of underlying variance of the height of the dens was suggested to account for observed variation in ligament orientation.[2] Dvorak et al[11] measured the orientation of the alar ligament with a hand-held goniometer by defining the angle formed between the ligaments in a horizontal dissectional section and using undescribed reference points in the frontal plane. The orientation was reported as primarily horizontal.[11]

To date, radiological measures of the orientation of the alar ligament have relied primarily on either general impression or basic comparison to the axis of the dens using goniometry or basic angular measures.[12] No clearly outlined protocol for the measurement of alar ligaments in coronal section using computerised tomography (CT) or magnetic resonance imaging (MR) has been specified, despite many studies reporting orientation.

Previous imaging studies have considered the orientation of the alar ligament in the context of radiological assessment. Daniels et al[13] used CT scans which were compared with cadaveric specimens to show the efficacy of CT as a medium for examining the alar ligaments. The ligament orientation in this study was reported as caudocranial from the lateral aspect of the tip of the dens to the medial inferior aspect of the occipital condyles.[13] Pfirrmann et al[14] used MR, reporting approximately equal numbers of caudocranial and horizontal orientations in fifty asymptomatic subjects. Asymmetry of the dens as indicated by asymmetry of the odontoid-atlantal lateral mass interspaces was reported in twenty three of these fifty subjects.[14] Krakenes et al[15] also used MR, reporting horizontal ligament orientation in twenty two of thirty healthy subjects. The major limitation in radiological studies to date is a lack of use of validated clinical radiological measures or described protocols for determining the orientation of the alar ligament relative to bony anatomy which will influence the radiological relationships. The application of a standardized and explicitly described approach would reduce the uncertainty in estimates of alar ligament orientation.

The aim of this study was to examine the assumptions underlying multiplanar assessment of alar ligament stress test by describing the relationship between dens height and ligament orientation, as well as reporting the range of variation present within a normal population sample.

METHODS

This study was a morphological examination using prospectively collected CT images. Approval for this study was granted by Hunter New England Research Ethics Committee, Newcastle, Australia.

Participants

Fifty de-identified CT studies of the cervical spine were prospectively and sequentially collected over a three month period from a teaching hospital in Newcastle, Australia; using a Philips Brilliance 16 slice CT scanner (Philips Medical Systems, Cleveland). All images included in the study were derived from skeletally mature individuals. The studies were examined by a specialist musculoskeletal radiologist to exclude bony abnormality, rupture of the alar ligament, congenital or inflammatory disorders of the region which may alter the anatomical relationships visualised on CT. Exclusion criteria included identified bony or alar ligament pathology. Bone weighted images were used in occipitodental measurement and soft-tissue weighted images were used to measure ligament orientation.

CT data was analysed using Amicas Viewer 6.0.1.53291 (Amicas, Boston, MA). Data analysis included measurement of the height of the dens relative to the occipital condyles using previously published accepted and standardised clinical radiological measures. Inter-rater and intra-rater reliability of measurements were each established using a pilot sample of ten CT studies. Intra-rater reliability was examined using the sample of ten studies examined on two separate occasions one-week apart by one rater. Each reviewer of CT data had undergone instruction by the specialist musculoskeletal radiologist and received ongoing assessment and support from a senior academic radiographer.

Calculation of dens height relative to the occipital condyles was established in sagittal section using McRae's line.[16] This was given by a line drawn between the anterior (basion) and posterior (opsithion) margins of the foramen magnum (Figure 1). In normal individuals the inferior margin of the occipital bone should lie at or below this line.[17] As a comparison, a modified bimastoid line, defined by a line extending from the tips of the left and right mastoid processes in coronal view was used to define the dens height relative to the occiput (Figure 2a and 2b).[17] These measures provide a baseline indication of the position of the dens relative to the occipital condyles.[17]

The orientation of the alar ligament was measured in the coronal plane according to the following clearly defined protocol. The relative orientation of the midsubstance of each alar ligament was calculated in three ways with respect to 1) a line running along the vertical axis of the dens process; 2) a line positioned orthogonally to the digastric line and passing through the tip of the dens (Figure 3a); 3) a line orthogonal to a line drawn between the most lateral aspects of the inferior articular processes of the atlas (Figure 4).[17]

The initial measurement of alar ligament orientation was taken from an image aligned in coronal section along the breadth of the atlas defined by the anterior most point of the left and right transverse foramina. A coronal image at this point, including the left and right alar ligaments was selected for measurement. The axis of the dens was plotted and the angle calculated with respect to a line drawn along the midsubstance of the alar ligament. This measure is considered to reproduce that used by Krakenes et al[15] and Daniels et al[13].

A modified digastric line was used to measure the orientation of the alar ligament relative to true vertical as defined by the skull. The digastric line connects the superior points of the digastric grooves located medial to the base of the mastoid process.[17, 18] Once the digastric line was defined in coronal section, this line was maintained as a plane while the CT reconstruction was followed anteriorly to define the dens (Figure 3a). A line perpendicular to the digastric line and bisecting the tip of the dens provided a measure of vertical from which the alar ligaments were measured (Figures 3a and b).

The third image for analysis used a line orthogonal to spinal landmarks. It was determined using a coronal slice sectioned along the anterior margin of the vertebral foramina of the atlas and orthogonal to a sagittal line from the anterior midpoint of the dens process to midpoint of the posterior arch of the atlas at the level of the atlas. In this section, a line between the inferior articular processes of the atlas was used to define an orthogonal line bisecting the mid-point of the dens (Figure 4). The relative angle of the alar ligaments was measured from this line.

As each ligament was considered a separate entity for measurement, coronal asymmetry of the dens was considered as a potential source of measurement error in ligament orientation. A vertical axis through the dens was defined by a line extrapolated from the midpoint of the base of the dens and a point 7mm superior to this. The angle formed by the intersection of this vertical axis and the digastric line was correlated with ligament orientation relative to the atlas (Figure 5). This assured that our protocol for measuring ligament orientation compensated for normal asymmetry, hence each ligament could be considered independently.

Statistical Analysis

All statistical analysis was completed using STATA 11.0 (STATA Corporation, Texas)

Inter-rater and intra-rater reliability of measurements were assessed using intra class correlation coefficients (ICC). ICCs were interpreted using the classification system outlined by Shrout.[19]

The mean and range of distances from the dens process to McRae’s line and from the dens process to the bimastoid line were reported.

The measurement of the orientation of the alar ligament was summarised as the mean and range in each measurement protocol described. Left and right ligaments were pooled for analysis as they were considered independent due to normal anatomical variability. Correlation of dens height and ligament orientation, using the measure derived from the atlas, tested the association between dens height and ligament orientation hypothesised by Dvorak and Panjabi.[2]

RESULTS

Forty-two of the 50 CT studies were analysed. Two were excluded due to skeletal immaturity, 2 due to fractures, 1 due to rotational subluxation and 4 due to extreme positioning or image quality impeding the ability to take skeletal measures. The sample analysed had a mean age of 41.6 years (16.5 to 94.4 years) and consisted of 30 males and 12 females.

Sixty-four alar ligaments were measured using the initial and digastrics measure and 63 ligaments were measured using the C1 alignment method. The remaining ligaments were classified as ‘undefinable’ as we were unable to clearly define both an upper and lower edge. As reconstructions were rotated around multiple axes to locate anatomical landmarks, ligaments were not necessarily definable for all three measures.

The mean distance from the occipital condyles to the tip of the dens process using McRae’s line and the bimastoid line is given in Table 1. Ligament orientation is given in Table 2. The greatest variation in measurement was given by the initial measure of ligament orientation relative to the dens. The least variation was produced by the measure relative to the digastric line. The mean angle ranged from 109.09 to 110.06 degrees.

There was no significant correlation between dens height defined by McRae's line-dens interval and ligament orientation, defined by a line relative to inferior articular processes of the atlas, with Spearman rho=0.12 (p=0.36) (Figure 6).

Asymmetry of the dens when viewed in the coronal plane was evident with deviation of up to 11° from a line orthogonal to the digastric line. There was no significant correlation between coronal asymmetry and ligament orientation relative to the atlas, with Spearman rho=0.04 (p=0.74) (Figure 7).

Inter-rater and intra-rater ICCs were demonstrated to be fair to substantial using the classification scheme given by Shrout[19] (Table 3), indicating reliability of the measurement methods used.

DISCUSSION

Seventy-six percent of ligaments were visualised in this study. This rate of identification is comparable to the limited number of previous imaging studies describing the alar ligaments. Krakenes et al[15] reported 100% of ligaments were defined with 1.5 T MR imaging and Pfirrmann et al[14] reported visible alar ligaments in 80% of specimens using 1.0 T MR. In the only comparable study to use CT, Daniels et al[13] provide a descriptive study of the radiological features of alar ligaments but do not give any indication of the proportion of ligaments visualised using this modality.

CT was chosen over MR for this study due to the superior bony definition. This allowed accurate ascertainment of structure and ligament attachment sites. It also provided the best modality for measurement using modified plain film measures.[20]

The two measures of occipitodental distance reflected a range of normal variation within this sample, supporting variation of dens height as a normal phenomenon. The McRae's line showed that all dens' examined were below its plane. The limitation of this measure is that the alar ligaments attach on the posterolateral surface of the dens and insert more laterally on the occipital condyles than shown in this sagittal section. The bimastoid line showed that a number of dens' examined were above the level of the occipital condyles as defined by the bimastoid measure. This finding may explain the range of craniocaudal measurements of the alar ligament reported in previous studies. However, the alar ligament does not originate from the tip of the dens, rather its lateral aspect,[1] implying that ligament orientation may not be directly affected by the position of the tip of the dens.

The orientation of each ligament included in this study was measured using three techniques. The greatest variability in measurements came from the initial measure of ligament orientation relative to the axis of the dens. As this replicated previously published methodology, it may contribute to the amount of variability described in the estimates of angles in the literature to date. A caudocranial orientation is described by Daniels et al[13] in their descriptive study of alar ligaments on CT. Other radiological studies reviewed used MR as their imaging modality. Pfirrmann et al[14] described 43.7% of the ligaments being caudocranial and 50% horizontal while Krakenes et al[15] describes twenty-two of thirty ligaments as horizontal and of the remaining ligaments an even number of craniocaudal and caudocranial ligaments were reported. Such results need to be treated with caution as ligament orientation is not described quantitatively, but rather as a subjective judgement which may potentially be influenced by a number of factors including patient positioning in the scanner. There is no established classification scheme for range of caudocranial, horizontal and craniocaudal classification using recognised methods of measurement. Nor is there an indication of the reliability of classification used in these studies.

The mean and range of results for ligament orientation between skeletally derived methods were comparable when measured relative to either the occiput or to the atlas. The measure relative to the atlas was preferred as the digastric method presented a greater margin for error as planes were maintained while panning through reconstructed images to locate the ligaments.

The rationale for multiplanar alar ligament testing assumes that an individual's ligaments may be placed under tension in some ranges of sagittal plane positioning and not in others as a result of their orientation. This assumption necessitates electing to test in three positions to increase the likelihood of stressing the ligament effectively and achieving a valid screening result. Our findings confirm the variation in orientation of the alar ligaments. However, measured orientation appears not to be related to dens height as proposed by Dvorak.[2, 10] Despite some textbooks and published journals descriptions of the alar ligaments attaching to the tip of the dens,[6, 21-24] our finding reflects the more accurate anatomical descriptions of previous authors in characterizing the alar ligaments as taking attachment from the lateral aspect of the upper one-third of the dens rather than its tip.[14, 25-27]

Coronal asymmetry was present within this sample supporting the findings of Pfirrmann et al.[14] There is no quantitative data available for comparison. As there was no correlation between asymmetry and ligament orientation measured relative to the atlas, our measurement protocol appears to compensate for normal asymmetry allowing each ligament to be considered independently.

The bimastoid line was considered as a core measure of occipitodental distance as it is designed to bisect the vertical axis of the dens at the level of the occipital condyles.[17] As a measure of basilar invagination, the bimastoid line has been superceeded by the digastric line.[17] This is mostly due to the variability of the length of the mastoid processes. We elected to use the digastric line in preference to the bimastoid line to generate our estimates of a reference vertical line. This was due to its previously demonstrated superior accuracy and reliability.[17]

Some limitations exist in interpreting the findings of this study. Firstly, this study considers the ligament in the neutral position. Future clarification of joint mechanics considering the vertical displacement of the occipital condyles in craniocervical sagittal motion would further inform the value of multiplanar testing. The use of CT as a modality suitable for imaging measurement of ligament orientation also imposes limitations upon the study due to the fact that not all ligaments and their boundaries can be clearly identified and delineated.

CONCLUSION

There was no statistically significant association between dens height and ligament orientation as previously hypothesised. This study provides quantitative data on ligament orientation in the neutral position. These results refute the underlying assumption that dens height is associated with alar ligament orientation. Whilst not supporting the proposal that variation in dens height is directly associated with orientation of the alar ligaments, our findings continue to reinforce the existence of normal anatomical variation in alar ligament orientation upon which the presumption of ligament testing in three planes is based. Further investigation on the effect of sagittal motion at the occipito-atlantoaxial joint complex and its influence on alar ligament orientation and tension will provide further clarification of the value of multiplanar clinical stress testing for the alar ligament.

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TABLE AND FIGURE LEGENDS

Table 1. Dens height relative to occipital condyles

Table 2. Orientation of the alar ligament relative to dens midline and specified bony landmarks

Table 3. Reliability of inter-rater and intra-rater measurement

Figure 1. Dens height relative to McRae's line. Calculated as the interval (b) projected above a line bisecting the dens (a).

Figure 2a. Alignment of bimastoid line

Figure 2b. Measurement of bimastoid to dens interval. (a) Transposed bimastoid line. (b) Interval from tip of the dens to the bimastoid line.

Figure 3a and b. Alar ligaments relative to line drawn orthogonal to the digastric line (b). (a) indicates the digastric line. Alar ligaments are indicated by arrows. Measured angle indicated by θ.

Figure 4. Alar ligaments relative to the alignment of inferior transverse processes of the atlas. Alar ligaments are indicated by arrows.

Figure 5. Measurement of coronal asymmetry. (a) indicates the digastic line. (b) indicates a line bisecting the dens.

Figure 6. Scatter plot diagram of dens height and ligament orientation

Figure 7. Scatter plot diagram of coronal asymmetry and ligament orientation

TABLE 1.

	Mean	Range	Std. Dev.
Distance from tip of dens to McRae's line (mm)	5.61	3.16-9.85	1.69
Distance from tip of dens to bimastoid line (mm)	5.17	-3.00-13.04†	4.14

*Negative values indicate that the tip of the dens was located below the bimastoid line

TABLE 2.

	Mean angle (degrees)	Range (degrees)	Std. Dev.
Angle relative to longitudinal axis of dens	109.09	77-129	10.30
Angle relative to orthogonal line relative to alignment of the atlas	109.38	81-132	8.91
Angle relative to orthogonal line derived from digastric line	110.06	85-127	8.00

TABLE 3.

	ICC	SEM
Inter-rater reliability		
Distance dens to McRae’s Line	0.84	0.15
Distance dens to bimastoid	0.99	<0.01
Angle of alar ligament relative to dens	0.68	0.23
Angle of alar ligament relative to digastric	0.69	0.27
Angle of alar ligament relative to the atlas	0.42	>0.01
Intra-rater reliability		
Distance dens to McRae’s Line	0.56	0.33
Distance dens to bimastoid	0.90	0.23
Angle of alar ligament relative to dens	0.76	0.21
Angle of alar ligament relative to digastric	0.62	0.29
Angle of alar ligament relative to the atlas	0.94	0.09

Figure 1

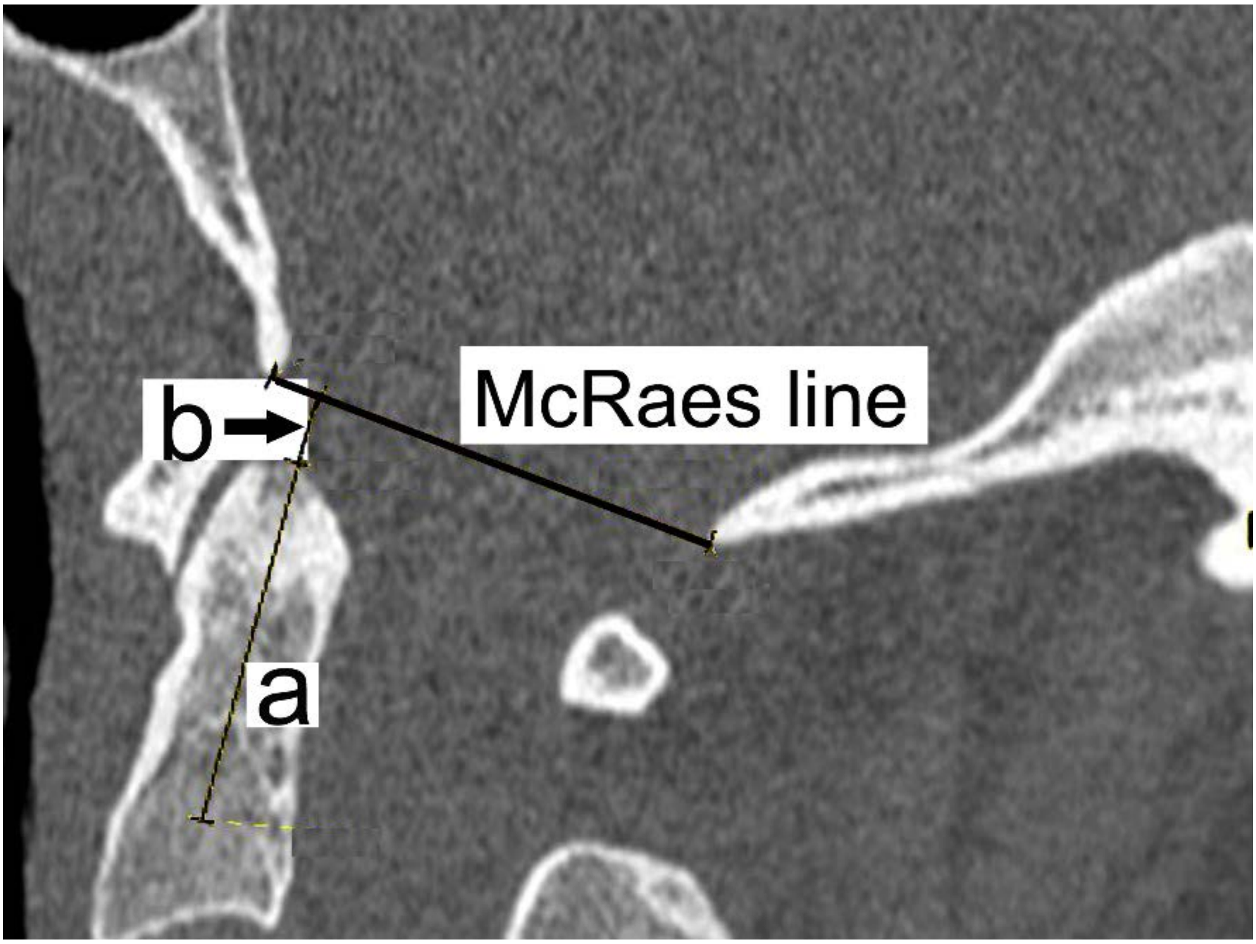


Figure 2

A.

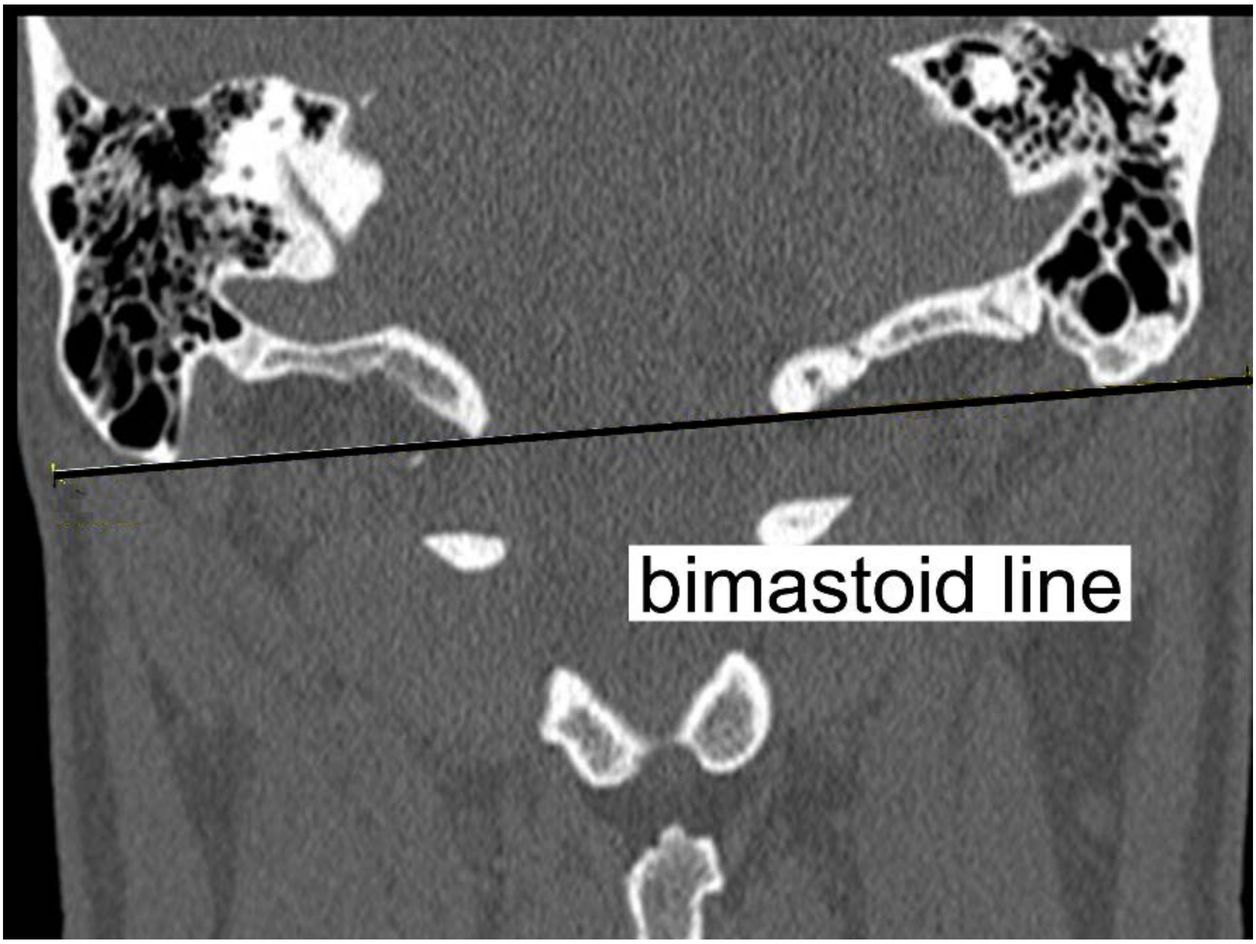


Figure 2

B.

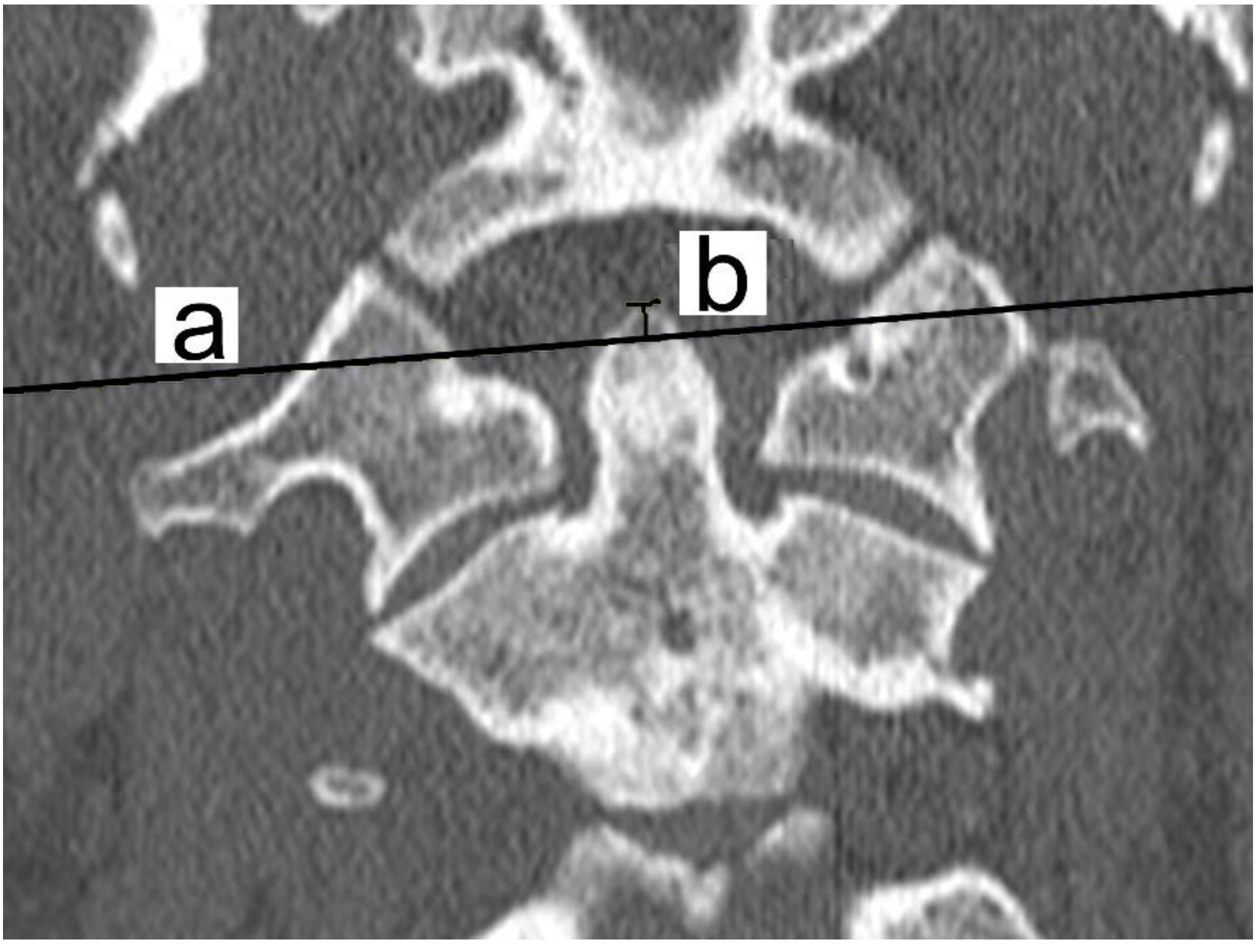
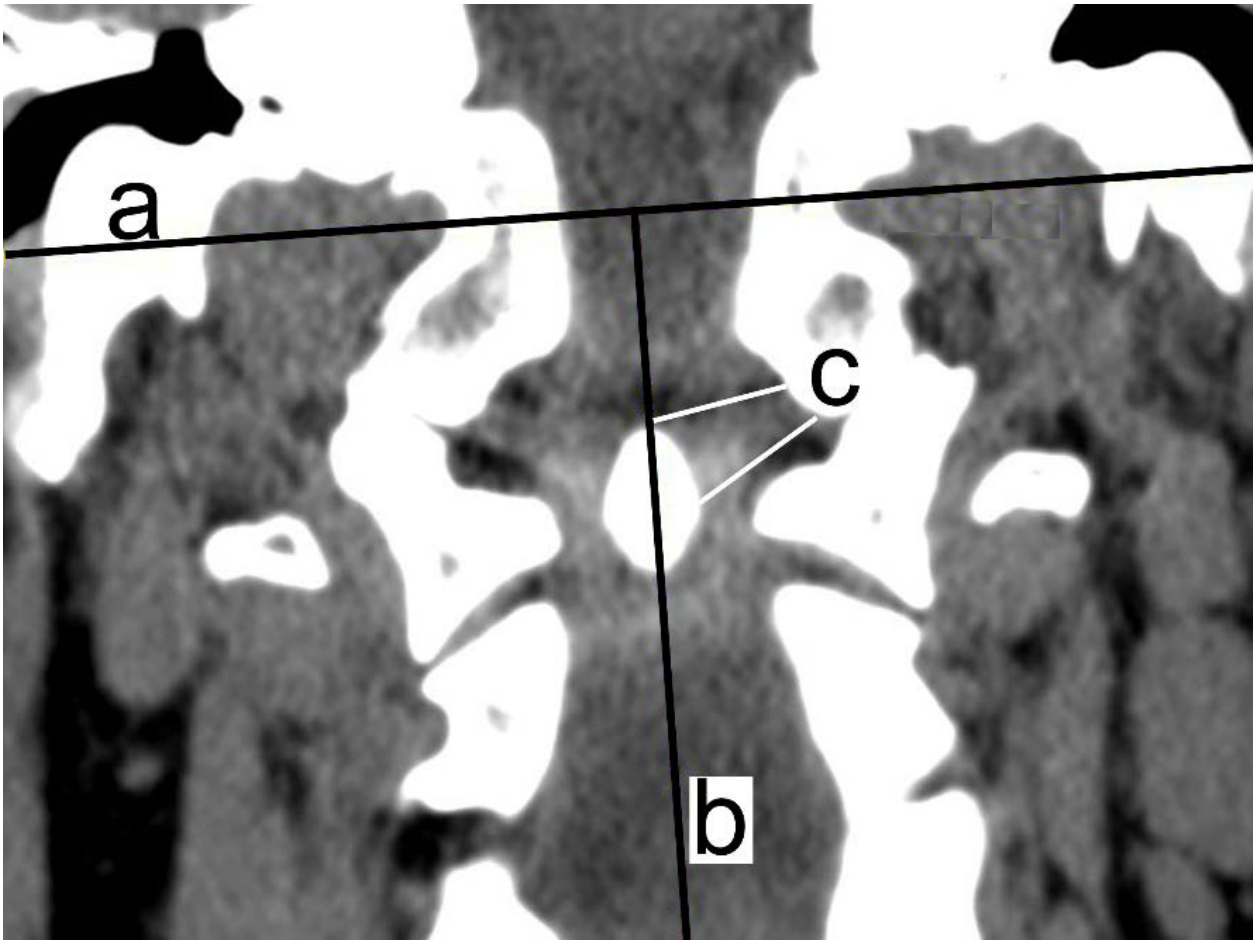


Figure 3

A.



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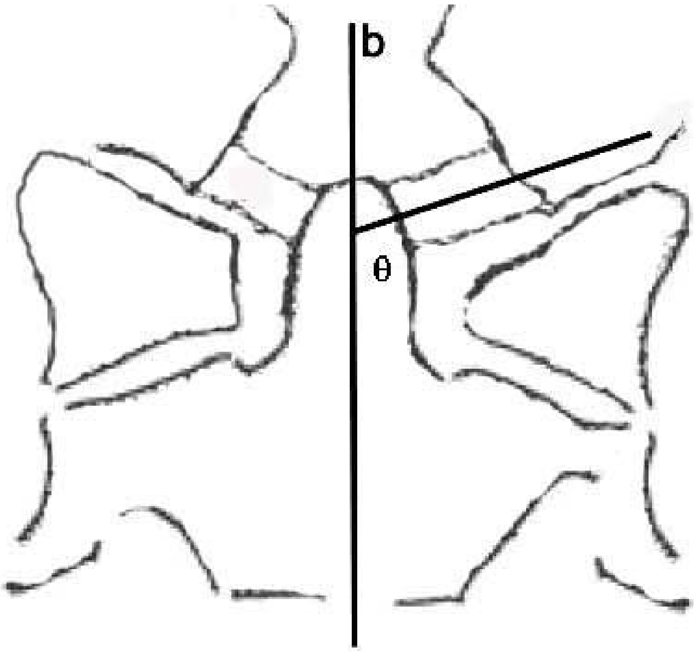


Figure 4

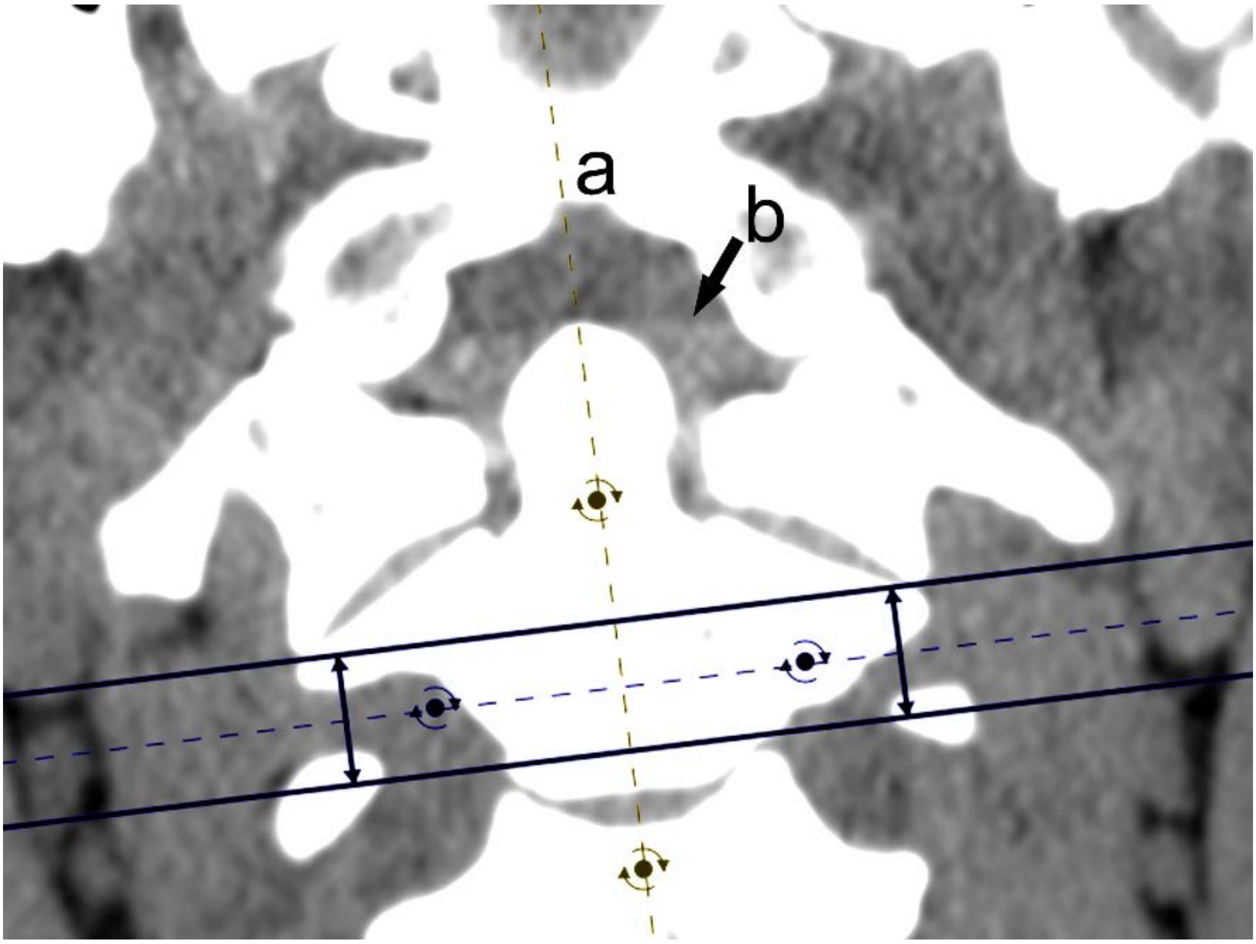


Figure 5

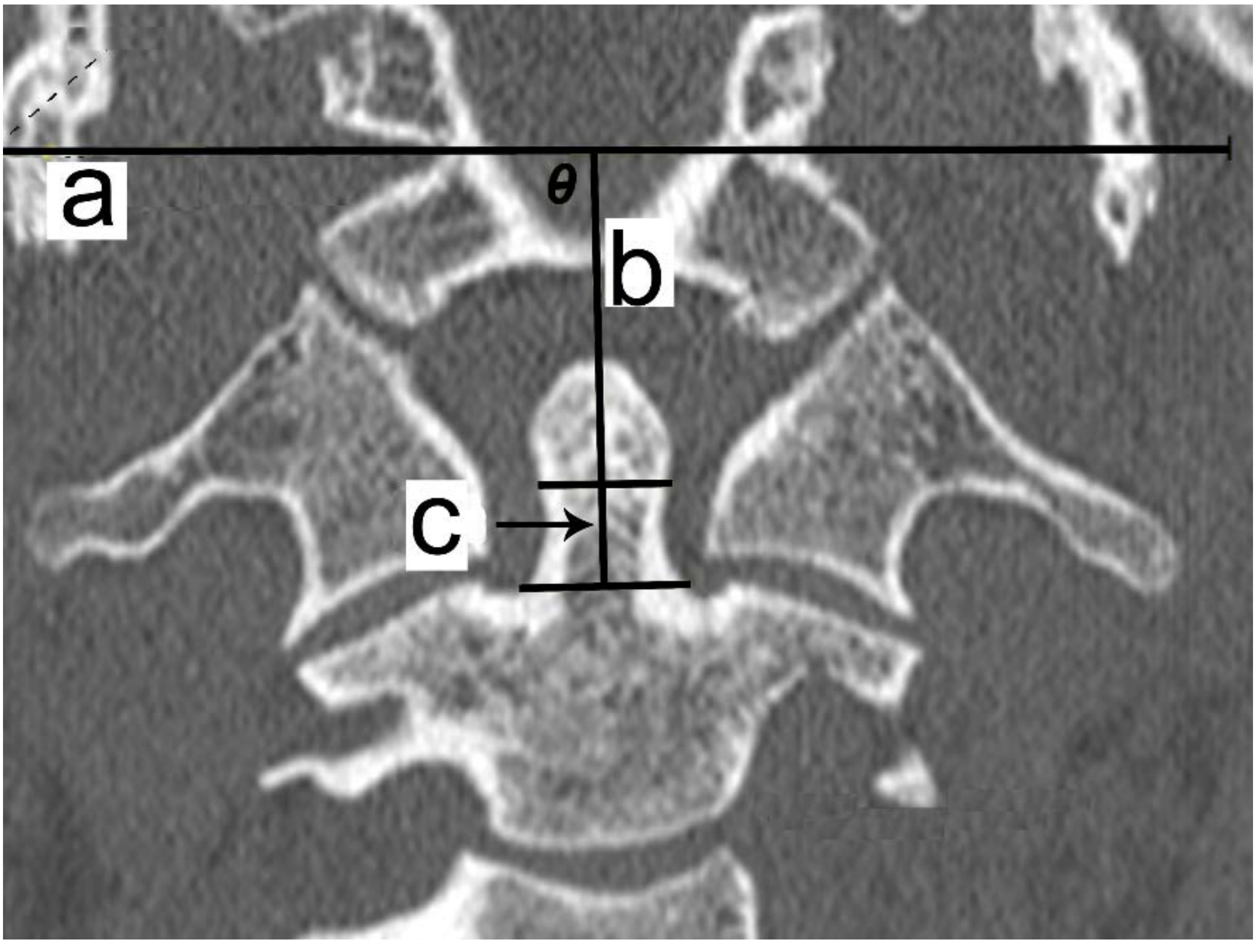
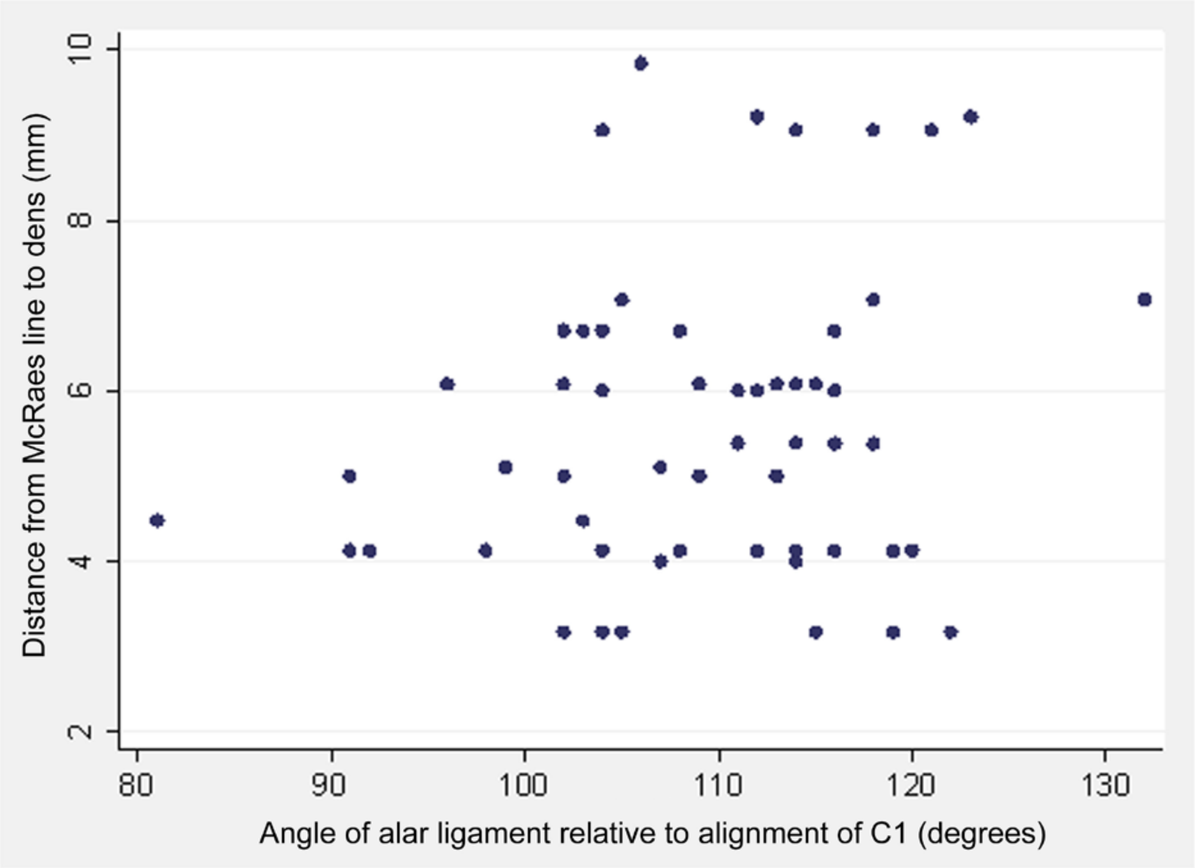
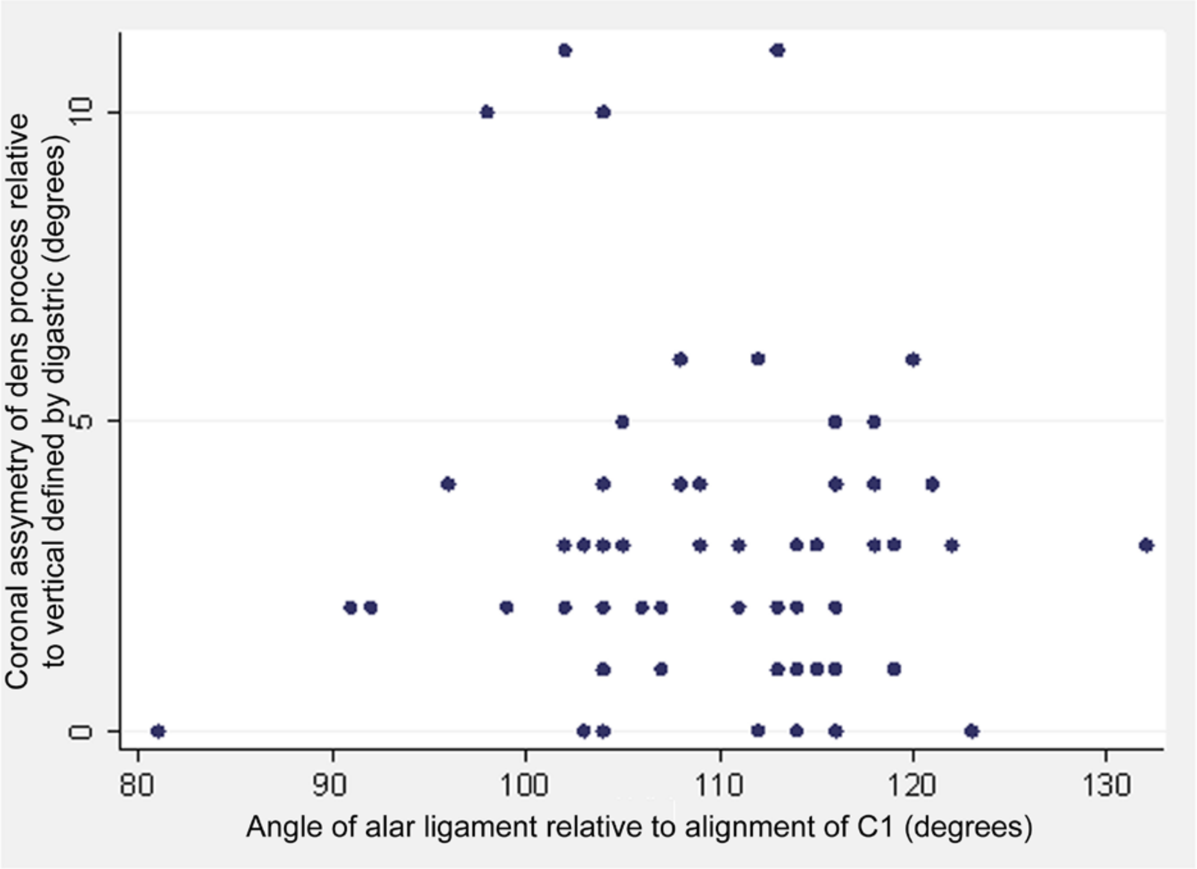


Figure 6


Distance from McRaes line to dens (mm)
10
8
6
4
2
80
90
100
110
120
130
Angle of alar ligament relative to alignment of C1 (degrees)

462 Figure 7



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