Decision Support for Fetal Gestation Age Estimation

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Abstract

An inherent difficulty associated with the neonatal care domain is the uncertainty of the figure established for the chronological development (Gestational Age) of the fetus. This leads to difficulties when trying to match fetal subject parameters against established population metrics for standard fetal development. The Gestation Age (GA) metric can be grossly inaccurate, depending upon when in the pregnancy it is considered, and by what means of certainty it is established. The Gestation Age System is intended to provide a support tool for estimating Gestation Age and to establish accuracy indicators that will provide tolerances for its later use in growth and health evaluation. It provides to clinicians the ability to incorporate accuracy levels for the gestation age estimate and also to update the actual age estimate. This paper describes the Gestation Age System, outlining the Decision Support factors influencing its design.

Keywords
Decision Support, Health Informatics, Fetal Medicine, Gestation Age, Obstetrics

INTRODUCTION

Fetal development is normally evaluated by comparing morphological measurements of the fetus, obtained from non-invasive ultrasound examinations, against fetal growth curves. These curves are generated from collected data representing the ethnographic population statistics for fetal development such as the study by Altman (1994) and Chitty et al (1994a, 1994b, 1994c). Neonatal morphometric measurements are usually taken for femur length, abdominal circumference, biparietal diameter and head circumference in ultrasound examinations of a fetus in its second trimester, while the fetal crown-rump length is the measurement used in the first trimester (Robinson, 1979) (Greene 1990) (Dombrowski 1992). Once the gestation age of the fetus has been determined by a clinician it is then used as a basis to determine the normality of growth of the fetus. It becomes the common factor when parameters indicative of fetal development are checked. The estimate of fetal age is also important in the determination of treatment after delivery of the fetus, although other means of gestation age estimation are taken such as the Dubowitz Score (Cloherty 1990) (Vik 1997).

GESTATION AGE DETERMINATION

The estimation of gestation age for a fetus is normally achieved by taking the duration since the first day of the mother's last menstrual period (LMP). This is complicated in cases where the mother's menstrual cycle is irregular and varies from the normal 28 day cycle. When this occurs the time interval obtained from the LMP is adjusted according to the mother's deviation from the normal cycle, either adding or subtracting the specified number of days. Sometimes the mother is unsure of the start date of her last period and in these cases the figure obtained using the LMP as a basis for gestational age is classified with a large degree of uncertainty. This problem is a well-documented, general consideration of medical decision support systems, where the amnestic nature of data acquired in a clinical context often affects the quality of the information obtained (Lavrac et al 1993).

When a mother is unsure of her menstrual dates, or if the ultrasound estimate of fetal age differs by more than ±7 days and indicates a gestation age < 12 weeks, or ±10days in an ultrasound estimate between 12 and 20 weeks, then the ultrasound age estimate is taken as the basis for fetal gestation age (JHH 1997). The earlier the ultrasound examination, the more accurate is its estimate of fetal age. When the gestation age has been fixed by ultrasound corroboration, the resulting age estimate is not altered and any further deviations of morphological parameters are generally attributed to fetal growth anomalies. Taking the earliest estimate of gestational age as the most accurate is reflected in the practice of retaining the estimate of gestation age determined from the menstrual history if there is no significant deviation from the ultrasound estimate. In such cases the gestation estimate is said to be derived from the LMP and *confirmed* by ultrasound.

It must be remembered that the gestation estimate is just that – an estimate. The fetal age depends upon the actual date of conception which may be difficult to obtain for general cases, but which can be determined in specialised circumstances such as *in vitro* fertilisation. The growth curves used in fetal development checks are also generally based on gestation age estimates rather than actual conception dates.

If the estimate of gestation age is inaccurate it can have effects in two important clinical decision areas. The first is the establishment of the estimated date of confinement (EDC) for the mother, ie the expected term of the pregnancy. This may become very important when complicating factors, such as the presence of diabetes, are included. The second decision area is the interpretation of test results taken during the course of the pregnancy, eg an AFP test result. (a test undertaken to determine spinobifida which is best performed at 16 weeks gestation).

The gestation period for a normal fetus, whose mother has a normal menstrual cycle, is generally accepted to be 280 days from the date of the first day of the mother's last menstrual period. The menstrual history is also used to derive the EDC. This is calculated by counting back 3 months from the first day of the last menses and then adding 7 days (plus or minus the variations of the mother's menses from the normal 28 day menstrual cycle). This method of calculation is commonly known as Naegele's rule as it is derived from observations that were first reported by Franz Naegele in 1812 and which are still in use today (in Hutchon 1998). Naegele's rule is based on the assumption that conception occurs on day 14 of the menstrual period, ie that the actual length of a pregnancy, assuming normality, will be 266 days from conception to delivery (Kmom 1997).

If the estimated date of confinement is underestimated then the fetus may be presumed to be *postdates*, ie overdue, when in fact it is not. A postdates determination is given for a pregnancy of ≥ 42 weeks. Such a determination for a normal fetus may lead to surgical intervention and to possible Caesarian section. This is undesirable if a natural delivery of a normal-term fetus is the alternative.

The second area of concern deals with the misinterpretation of a test result leading to increased risk to the fetus, where the interpretation of the result requires an accurate measure of gestation age. This is illustrated in the possibility of mis-interpretation of a Triple Test result, used to give indications of the possibility of a fetus having Down syndrome, which may lead to a further test such as amniocentesis that has a potential risk to the fetus (Kmom 1997).

There is also controversy in the literature as to the accuracy of Naegele's rule. Mittendorf (1990) suggested that the number of previous births affect the length of pregnancy, with multiparas (women who have experienced previous childbirths) having a median pregnancy 3 days more than Naegele's rule predicts and primiparas (women experiencing their first childbirth) having 8 days more than that predicted using Naegele's rule. In a later study he indicated that the age and race of the mother also needs to be included in the determination of the length of pregnancy (Mittendorf 1993). In these cases the use of Naegele's rule will result in an underestimate of gestation age.

It can be seen therefore that initial estimation of gestation age is important in the further interpretation of fetal development and the determination of fetal treatment. One of the intentions of the Gestation Age Subsystem is to provide an instrument that may allow a more accurate determination of the initial gestation estimate. We have concentrated on the confirmation of LMP through ultrasound measurements and use, as per the John Hunter Hospital Guidelines, Naegele's Rule in the estimation of the estimated date of confinement.

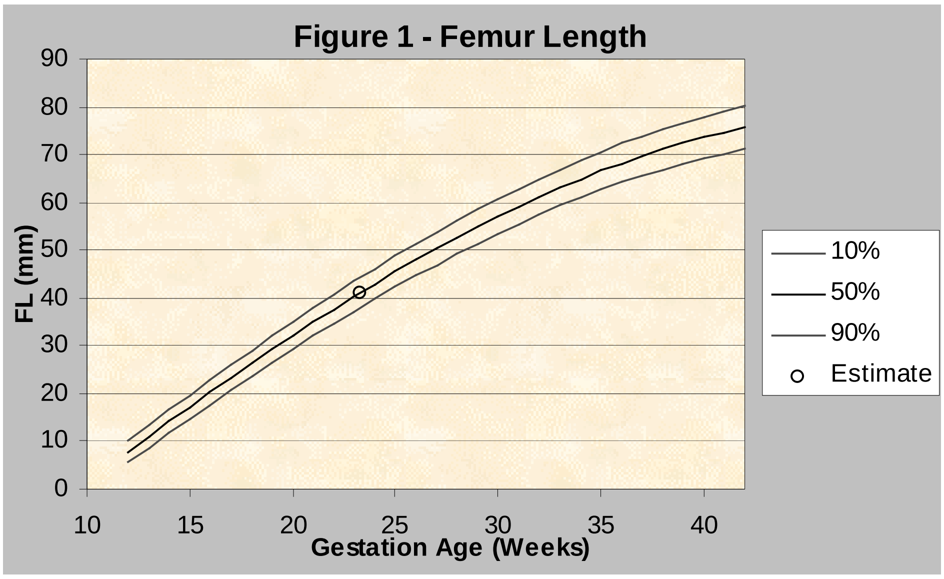
GESTATION AGE SYSTEM

The module that will be described forms part of a subsystem of the Fetal Health Decision Support System (FHDSS) described by Falconer et al (1995). The sub-system comprises two modules: one for gestation age determination of a fetus and the other concerned with growth tracking. We will be concentrating on the gestation age determination module and its integration to the larger subsystem.

An early design approach of the FHDSS was to create a "model" of a fetus, built from stored data in the knowledge base. This model forms an idealised "normal" fetus to which the fetus under study can is compared. This could be done mathematically, or in the form of a graph. The model can hold simple relationships for specific fetal characteristics. An example might be the storage of the range of expected head sizes for a normally developing fetus at different gestation ages The FHDSS will generate outputs that relate to the observed behaviour of the fetus under study. As these should be clear and quickly understood, graphs or charts are used to indicate some of the outputs, giving the clinician the capacity to quickly and easily examine specific measurements, derived metrics or decisions to the level of detail considered appropriate.

Plots of fetal growth parameters are used to represent the knowledge of an ideal fetal model. These plots are routinely used by clinicians at the John Hunter Hospital when determining the gestation age based upon ultrasound measurements. The measurements used in the subsystem are femur length, abdominal circumference, biparietal diameter and head circumference. These are represented as plots across gestation age expressed in weeks. As an example, Figure 1 shows a plot of femur length versus gestation age with the 10^{th}, 50^{th} and 90^{th} percentiles indicated. For ease of development and to test basic proof-of-concept, we use the fetal growth statistics provided by Chitty (1994a, 1994b, 1994c) and Altman (1994).

Individual parameters regarding fetal state are tested in a "static" sense, eg a femur length measurement of the fetus under study is compared to a charted range of values indicating a "normal" femur length. This allows a simple interface design for the clinician and validation of out-of-range situations, indicated by deviations more than two standard deviations from the mean.



The sub-system is currently implemented in a PC platform package for development and mobility purposes. The packages used are an expert system shell (Level 5 Object) with interfaces to a database (dBase IV) and a spreadsheet (Microsoft Excel) running under Windows95. It is also implemented in Gensym G2 running on a Unix platform to enable future scaling into a larger hospital environment.

Menstrual history data is entered into the Level 5 object knowledge base, either by direct entry in a clinical session or from a patient's clinical record read from the database. This data (LMP plus variations from a normal cycle) is passed to a spreadsheet which is used to calculate the estimated date of confinement using Naegele's rule. At this stage we are following the guidelines of the John Hunter Hospital (JHH 1997) where the only variation is that due to the mother's cycle. No amendments are made for previous births, age or race. It must be remembered that the published trials dealing with these factors are based on non-Australian populations.

The use of the Excel spreadsheet in the PC implementation was due to limitations in the charting abilities of Level 5 object, where X-Y plots of fetal parameters versus gestational age could not be implemented effectively. As Excel was then perceived as an additional interface to the clinician within a Windows environment, we decided to also include some reasoning ability via its native functions and its underlying VBA programming language. To this extent some data operations, such as the current ultrasound measurements, are currently entered into the spreadsheet directly, however there is nothing to stop these being entered into the Level 5 object knowledge base and transferred to Excel. As a logical design structure, the knowledge base should be considered as a composite of Level 5 Object and the Excel spreadsheet.

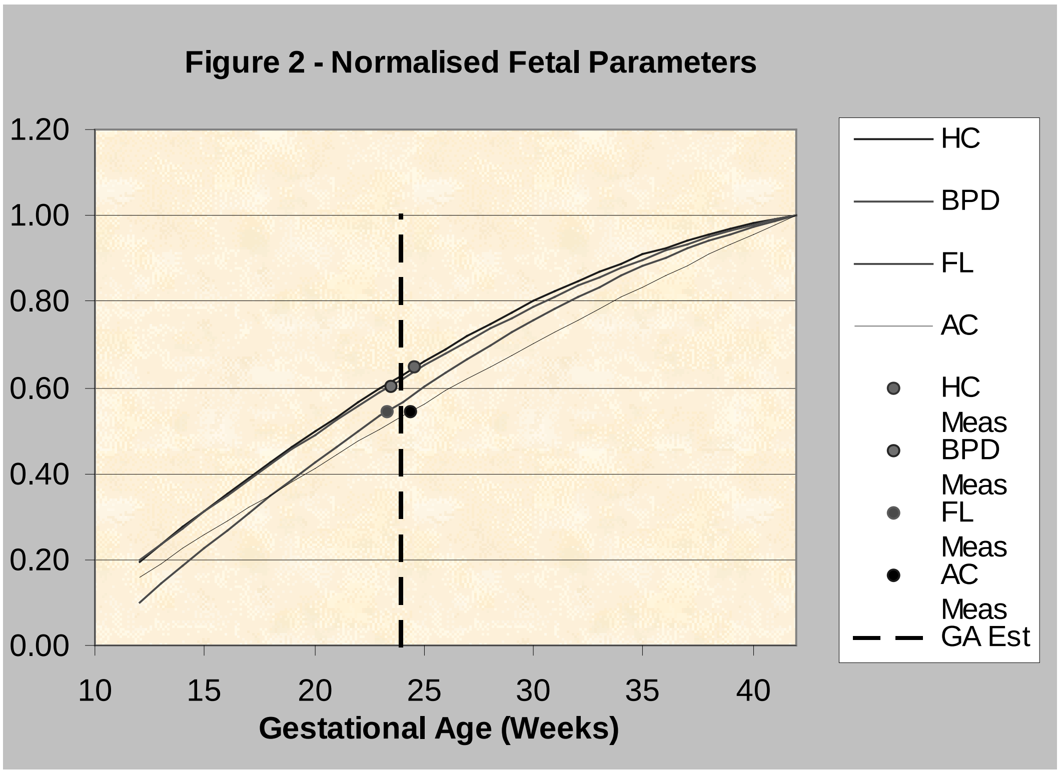
The spreadsheet calculates the estimated gestational age for each of the ultrasound parameters. We do this utilising regression equations for the mean and standard deviations derived by Chitty and Altman for each of their measured parameters (Altman 1994) (Chitty et al 1994a, 1994b, 1994c). The age estimated for each fetal parameter is based on the mean growth curve for that particular parameter, or in other words we assume a perfectly normal fetus for any particular parameter.

The spreadsheet performs a simple decision support role in that it will provide advice regarding the most appropriate gestation age for the fetus. It calculates both the gestation age derived from the menstrual history, ie the LMP and the mother's menstrual cycle variation, and also that due to the ultrasound estimates. The final ultrasound-derived gestation age estimate is obtained by averaging each of the four ages obtained for the measured parameters. Although the ultrasound measured parameters have different accuracy's as predictors of gestation age at different stages of the pregnancy, eg the femur length is a more accurate gestation age predictor than biparietal diameter in the third trimester (Greene 1990) (Dombrowski et al 1992), an averaging composite of the four parameters was considered the best course of action for the gestation ranges considered. The guidelines for the Creighton University Medical Centre agree that taking a simple average is preferable to using a complicated multiple variable which, in the case of a misleading outlier that is close to a normal parameter may give it undue weighting (Creighton 1999).

The spreadsheet implements rules derived from the John Hunter Guidelines (JHH 1997) to indicate the most preferable gestation estimate. This is the estimate that will be used in future decisions regarding the interpretation of age-based fetal metrics and indeed, decisions regarding the delivery options for the fetus.

As indicated by Lavrac et al (1993) in their study of rheumatic disease diagnosis, anamnestic knowledge is very noisy, due both to its broad qualitative nature as being a patients description of their disease and the interpretation of this broad qualitative descriptive data by different specialists. Their result is useful for our application area as it serves to indicate that qualitative data metrics, whilst important, should not be relied upon in isolation and should be used with guidelines that are obtained from the user/physician for the specific case/fetus under study. The result also emphasises that differences in expert views can occur and that, whilst qualitative abnormalities should be flagged to the user/clinician, the clinician is perceived as having the role of the final arbiter for resolution as to the particular fetus under study.

We have introduced a plot of normalised fetal parameters that allows quick comparison between the four measured parameters. The normalisation is achieved with respect to postdates gestation, ie 42 weeks, by dividing each parameter value by the 42 week value to allow a sufficient range for fetal age. This is illustrated in Figure 2. The clinician is given evidence as to the relative contribution of each of the measured ultrasound parameter to the final ultrasound-derived gestation age. The clinician is also provided with a quick illustration of the range of the various measured parameters when taken as an estimate of normal fetal growth. This type of plot allows



outliers to be easily identified and examined and can be a quick indicator of abnormal fetal growth for the clinician.

We also provide a calculation of the percentiles that each ultrasound measured parameter would occupy if the LMP derived gestation age were taken as the basis for the final gestation estimate. These percentiles are calculated using the statistical functions of Excel applied to the probability distributions derived by Chitty et al (1994a, 1994b, 1994c) and Altman (1994). They are presented on the Excel spreadsheet in close proximity to their respective parameter plots. They provide a finer resolution than the graphical data and are useful when the clinician must examine particular measurements in greater detail

CLINICAL CONTROL ISSUES

The sub-system allows the clinician to override its automated decision as to the final gestation age estimate. This is in line with the design policy of making the clinician the final arbiter for decisions. This option is necessary as the basis of both gestation age methods used by the decision support process is the assumption that the fetus is growing normally. The option is also included in the Growth Determination module.

When the final estimate of gestation is derived, from either of the automated methods or due to an override decision by the clinician, it is passed back from Excel to Level 5 object and is recorded in the patient history. This becomes the basal date used for future decisions involving gestation estimates within the FHDSS.

One of the potential problems in any medical decision system is that it may lead to legal liability. This would be especially true in a closed-loop control system. Our system is not closed-loop, except as far as the clinician provides any feedback path. The system presents information to the clinician who is free to accept or reject any of the system indications (completely or with modification), ie the system under development offers only a *service* to the clinician user. Krause et al (1993) indicate potential legal liabilities for the implementation of a Medical Decision Support System. They state that most of the liabilities mentioned are able to be avoided by full and clear detail in the specifications and limits of the scope of the system. They outline that a liability that may arise from its future use is: "an expert system furnishes incorrect information...". This may arise from a number of factors, and should be considered in a DSS design. One of these factors is stated as: "correct data has been presented to the user, but in a misleading format;...".

The plots used in the Gestation Age module will also be used in the Growth Determination module. In this module the clinician is provided with indicators of anomalies determined from successive, chronological ultrasound parameter measurements. Exception alarms report any deviations from tolerances (as well as the tolerance limits) by the fetus under study from the idealised "normal" fetal model. They serve to direct the clinicians attention to a specific fetal characteristic. An instance might be an abnormal head size alert that focuses the clinician to investigate a graph indicating chronological head size of the fetus as well as the allowable tolerances.

CONCLUSIONS and FUTURE WORK

We have described the Gestation Age System and illustrated how it used as a support tool for the estimation of Gestation Age. We have shown how it provides metrics for later use in growth and health evaluation modules. We have also indicated how it gives clinicians the ability to incorporate accuracy levels for the gestation age estimate and to update the actual age estimate.

The perception of the clinician as the final arbiter and a system's ability for clinician override has been described as crucial in clinical decision support system integration. The issues relating to the requirements for clinician control indicate that close co-operation with medical staff is crucial in the development of our system to ensure that it can be successfully implemented. Full disclosure of the assumptions involved in the design of the system is also vital, eg the source of the population statistics used as well as the specific medical guidelines which are followed. Once again this requires a close relationship between the knowledge engineer and the expert medical staff during development to ensure that clinical guidelines are understood and are being implemented correctly.

Future research is oriented towards the incorporation of the metrics produced by the fixing of gestation age into dependant modules, such as the Growth Determination module discussed. Another module that is yet to be developed would give advice regarding fetal health and delivery options for a diabetic mother. In this case there is an important requirement for an accurate figure of gestation age and the knowledge of the tolerances used in its estimation.

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