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Fetal age determination with selected skull biometry: a fetal cadaveric study

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SUMMARY

Determining fetal age is probably the most difficult of the four main identifiers that must be established when a fetus is found during a forensic examination. This study aimed to assess the correlation between gestational age (GA) and selected skull biometric parameters—including standard, fontanelle, and suture measurements—using linear regression analysis. A total of 104 dissected fetal skulls were used for this study. Measurements of head circumference (HC), biparietal diameter (BPD), biparietal length (BPL), bitemporal length (BTL), glabella to external occipital protuberance (G-EOP), anterior fontanelle width (AFW), anterior fontanelle length (AFL), posterior fontanelle width (PFW), posterior fontanelle length (PFL), coronal (C), sagittal (S), lambdoid (L), and metopic (M) were analyzed with GA of all fetuses. All standard measurements HC, BPD, BPL, BTL, and G-EOP showed strong positive correlations with GA (r= 0.85, 0.89, 0.9, 0.94, and 0.91, respectively). The sutural lengths C, L, and S also showed strong correlations with GA (r = 0.9, 0.83, and 0.78, respectively). The M length showed a positive correlation with GA (r = 0.68). Also, it was noted that the above parameters do not all increase at the same rate, with GA suggesting that the various parts of the fetal skull appear to grow non-linearly. All fontanelle parameters, however, showed a poor correlation with the GA (r< 0.2), and their overall sizes also varied widely with GA. The BTL, G-EOP, C, BPL, BPD, HC, L, S, and M may be independently or completely used to calculate the fetal GA from isolated skull fragments or a complete skull, respectively, with varying degrees of accuracy.

Key words: Age – Cadaveric – Fetal – Skull

INTRODUCTION

When human remains are discovered, they are often in different stages of decomposition (Pinheiro and Cunha, 2006). They are entrusted to forensic analysts, whose expertise is vital in helping to establish the identity of the deceased (Pinheiro and Cunha, 2006). Likewise, when natural disasters take place and many deaths occur, deceased individuals are required to be separated, identified, and correctly returned to family members for interment. Age estimation of the deceased is one of the four fundamental pillars of forensic identification, alongside the determination of sex, race, and stature. Determining fetal age is as important as determining the identity of a fetus (Sabarinath, 2011). There are several established methods used to determine the age of fetuses, such as crown-rump length, foot length, femur length, abdominal circumference, crown heel length, and biparietal diameter BPD (Kumar et al., 2013;

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MacKenzie et al., 2019; Unger et al., 2019; Bavini et al., 2022). Some methods offer greater accuracy than others, and combining multiple approaches often yields more reliable results than relying on a single estimate (Hadlock et al., 1984). However, age determination with regard to skull biometry of fetuses is based on BPD. In ultrasonography, the measurement of the fetal BPD has been identified to be a more reliable method for fetal age estimation and for predicting the date of spontaneous delivery (Okupe et al., 1984; Waldenstrom et al., 1990; Mongelli et al., 1998; Salpou et al., 2008). The BPD was found to be reliable in the second trimester (estimate of ±1.5 weeks) and in the 3rd trimester (estimate of ±3 weeks) of gestation.

Although there are many studies using fetal skull biometry to determine gestational age (GA) (Hadlock et al., 1981, 1982; Sundaresan, 1990; Adeyemo, 1991; Soboleski et al., 1997; Salpou et al., 2008; Rajlakshmi et al., 2009), very few data exist with regard to measurements taken directly on the external surface of the fetal skull, such as head circumference (HC) (Hadlock et al., 1982; Salpou et al., 2008), width and thickness of sutures, and length and width of fontanelles (Sundaresan, 1990; Adeyemo, 1991). Should only parts of a skull be found, the key features on the external surface, such as the sutures, fontanelles, and protuberance of the skull, can usually be easily measured (Hadlock et al., 1982; Sundaresan, 1990; Adeyemo, 1991; Salpou et al., 2008). Establishing a reliable and consistent relationship between fetal skull measurements and GA could offer a cost-effective and accurate method for estimating this parameter. This is of great value, especially if only parts of a fetal skull are available. To date, there are very few reliable methods to determine the age of the fetus from parameters of the fetal skull, such as isolated skull bone fragments, sutures, or fontanelles. In addition, Salpou et al. (2008) noted that few parameters besides BPD and HC are reliable in determining GA, which was also noted by Salpou et al. (2008). This creates a difficulty when only isolated fragments of bone are available. Hence, this study sets out to determine the correlation using linear regression analysis between the GA and the standard, fontanelle, and suture measurements.

MATERIALS AND METHODS

A total of 104 fetuses in the Discipline of Clinical Anatomy, University of KwaZulu-Natal, Westville Campus, South Africa, were used in this study. The intra-uterine gestational (IUG) age range of these fetal skulls varied between 13 and 29 weeks (98.3% of the samples were in the 2nd trimester). Institutional ethical approval was obtained with ethical number BE098/09.

For the sample age profile, the data were grouped into a GA range of 3 weeks, allowing for an error estimate of ±1week (Table 1).

Method of data collection

Dissection

The fetal skin was dissected from the glabella laterally above the eyebrows, inferiorly to the level of the upper ear lobe, posteriorly to the occipital region of the skull, and inferior to the external occipital protuberance from both sides. The skin covering the temporal bone was pulled down to expose the temporalis muscle. The temporalis muscle was dissected to expose the temporal bone. The sutures and fontanelles were clearly visible after the scalp was removed.

Measurements

Nonelastic fine thread, a permanent marker, and a Wilson Wolpert 110-15DAB digital caliper were used to take measurements. Standard measurements, as well as measurements of the fontanelles and sutures taken, are described in Figs. 1, 2, and 3 and Table 2. A Panasonic Lumix DMC-LZ7 digital camera was used to photograph the dissected specimens. The foot length (FL) of each fetus was directly measured from the most dorsal point on the heel to the tip of the longest toe. The formula GA (weeks) = FL (cm) × 3.4863 + 8.8649 (with an error bound of +/-0.75weeks) was used to calculate the ages of the fetuses (Kumar and Kumar, 1994). The results obtained were recorded manually and then transferred to a Microsoft® Excel 2003/7 spreadsheet.

Method of data analysis

The measurements were plotted on an XY scatter graph against the ages of the fetuses obtained using the formula GA (weeks) = FL (cm) × 3.4863 + 8.8649 (with an error bound of +/-0.75weeks). The analysis was done in Microsoft® Excel using the Linear Regression toolbox. The types of relationships that exist between the various skull biometric parameters were then studied.

RESULTS

To evaluate the relationship between gestational age (GA) and various cranial parameters, linear regression analyses were performed using the full dataset. These analyses focused on three key categories of fetal skull measurements, viz. standard dimensions, fontanelle sizes, and suture lengths. Figures 5, 6, and 7 illustrate the strength and pattern of association between each set of measurements and GA.

Standard measurements

As shown in Fig. 5A-E and Table 3, all standard measurements strongly correlate with the GA (r > 0.8). The growth rate of HC is greater than that of G-EOP (9.64 mm and 6.11 mm /week, respectively). The G-EOP and the BTL have similar growth rates (6.11 mm and 6.31 mm/week, respectively).

Fontanelle measurements

For the fontanelle measurements, PFL and PFW were shown to be poorly correlated with GA (r <0.2). The growth rates of the fontanelle length and width are: AFW (0.38 mm/week) > AFL (0.21 mm/week), and PFW = PFL (0.13 mm/week and 0.14 mm/week) (Fig. 6A-D) (Table 3).

Suture measurements

In the suture measurement group, C and L are

Table 1. Distribution of fetuses according to gestational age groupings

Gestational age groupings (weeks)	Frequency	Percentage (%)
13-15	14	12.1
16-18	52	44.8
19-21	37	31.9
22-24	11	9.5
25-29	2	1.7

Table 2. Definition of measurements

Standard measurements	
Measurements	**Measurement Definitions**
Head Circumference (HC)	Circumference taken at the level of the parietal eminence
Biparietal Diameter (BPD)	Linear length between the two parietal eminences
Biparietal Length (BPL)	Actual surface length between the two parietal eminences
Bitemporal Length (BTL)	Actual surface length between the two midpoints of the temporal bone
Glabella to External Occipital Protuberance Length (G-EOP)	Actual surface length between the glabella and external occipital protuberance
Fontanelle measurements	
Anterior Fontanelle Width (AFW)	Maximal surface distance of the fontanelle in the sagittal section
Anterior Fontanelle Length (AFL)	Maximal surface distance of the fontanelle in the coronal section
Posterior Fontanelle Width (PFW)	Maximal surface distance of the fontanelle in the sagittal section
Posterior Fontanelle Length (PFL)	Surface length of the occipital bone that forms the boundary of the posterior fontanelle
Suture measurements	
Coronal Suture (C)	Length of the coronal suture
Sagittal Suture (S)	Length of the sagittal suture
Metopic Suture (M)	Length of the metopic suture
Lambdoid Suture (L)	Length of the lambdoid suture

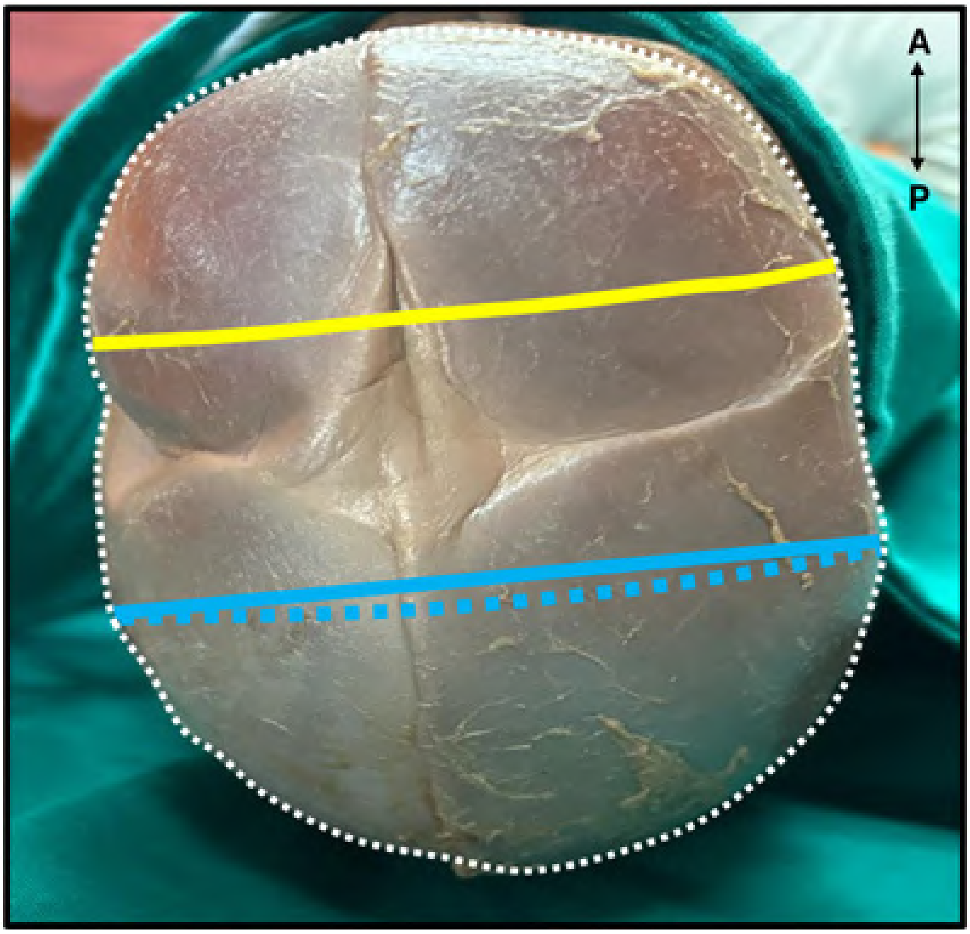

Fig. 1.- Superior view of the fetal skull. White dash– Head Circumference (HC); Yellow solid– Bitemporal length (BTL); Blue solid– Biparietal diameter (BPD); Blue dash– Biparietal length (BPL).

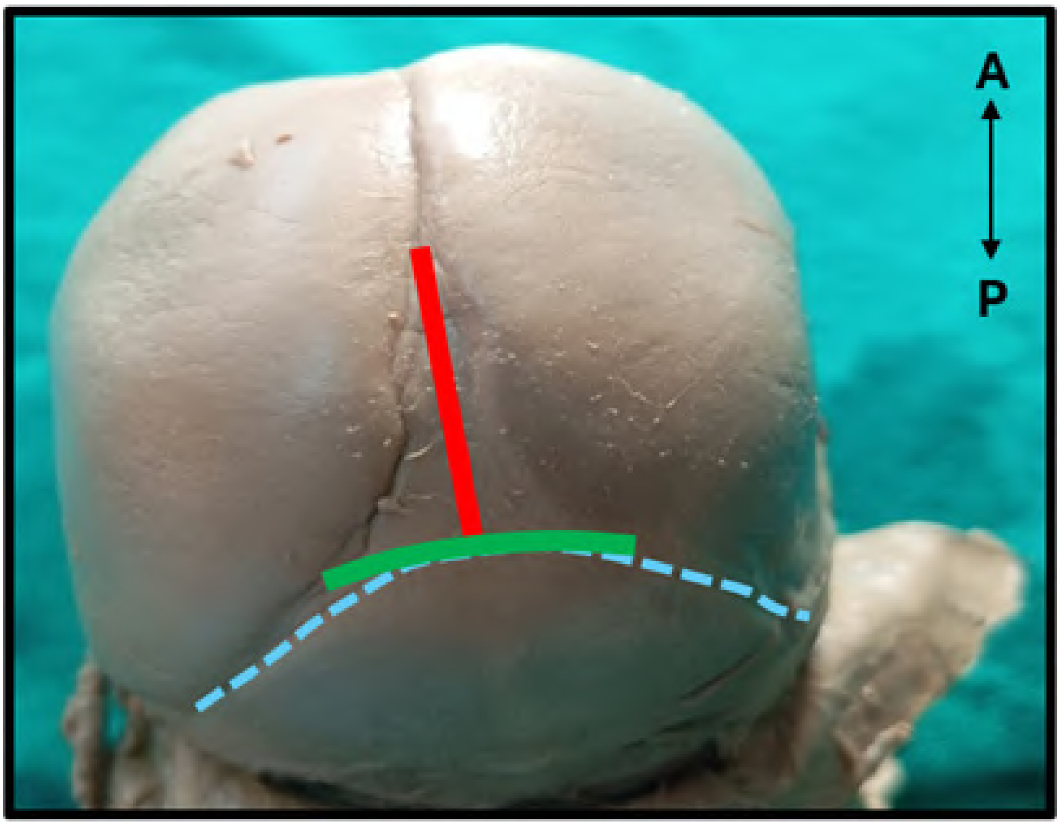

Fig. 2.- Posterior view of the fetal skull. Green solid– Posterior Fontanelle Length (PFL); Red solid– Posterior Fontanelle Width (PFW); Blue dashes– Lambdoid suture (L).

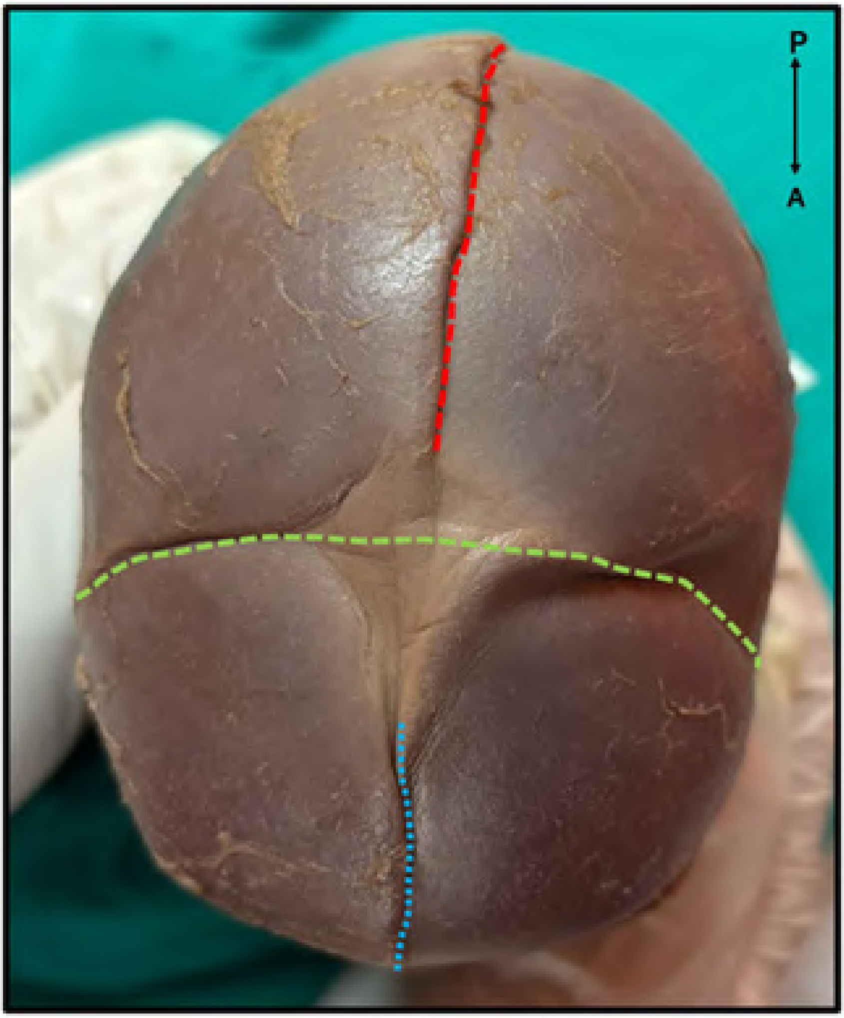

Fig. 3.- Superior view of the fetal skull. Red dash– Sagittal suture (S); Green dash– Coronal suture (C); Blue dash– Metopic suture (M).

very strongly correlated with GA. The length of C is the largest of all the sutures (C>L>S>M). The growth rate of the C and L (4.12 mm and 4.42 mm/week) was almost twice the rate of the S and M (2.69 mm and 1.84 mm/week) (Fig. 7A-D) (Table 3).

DISCUSSION

One vital aspect of the forensic sciences is determining fetal age (Bertwistle, 1948; Carneiro et al., 2016; Schweitzer et al., 2025). It is not only of purely academic interest but is of equal importance medically and legally (Schweitzer et al., 2025). In cases of abortion or rape, the calculation of the fetal age is important in determining the time of conception (Santee and Henshaw, 1992), which could be also used as evidence, medicolegally (Kruesi, 2022). The present study investigated the correlation between GA and measurements of external features of a fetal skull.

In the present study, there was a very strong correlation with the GA ($r > 0.8$) for standard measurements. This agrees with the studies that reported a good correlation between GA with BPD (Menaa et al., 2020), BTL (Ganware et al., 2021), and HC (Lohia et al., 2021). The growth rate of HC is greater than that of G-EOP (9.64 mm and 6.11 mm /week, respectively). The G-EOP and the BTL have similar growth rates (6.11 mm and 6.31 mm/week, respectively). The correlations with the GA in order of descending strength are BTL>G-EOP>BPL> BPD>HC. The growth pattern for HC is consistent with that given by Hadlock (1981), i.e., a linear growth pattern for fetuses between 14-40/52 IUG. The Hadlock (1981) study also found the HC to be a more reliable measure of fetal age than the BPD, although Fujimura and Seryu (1977) found that increases in HC slowed from 31-

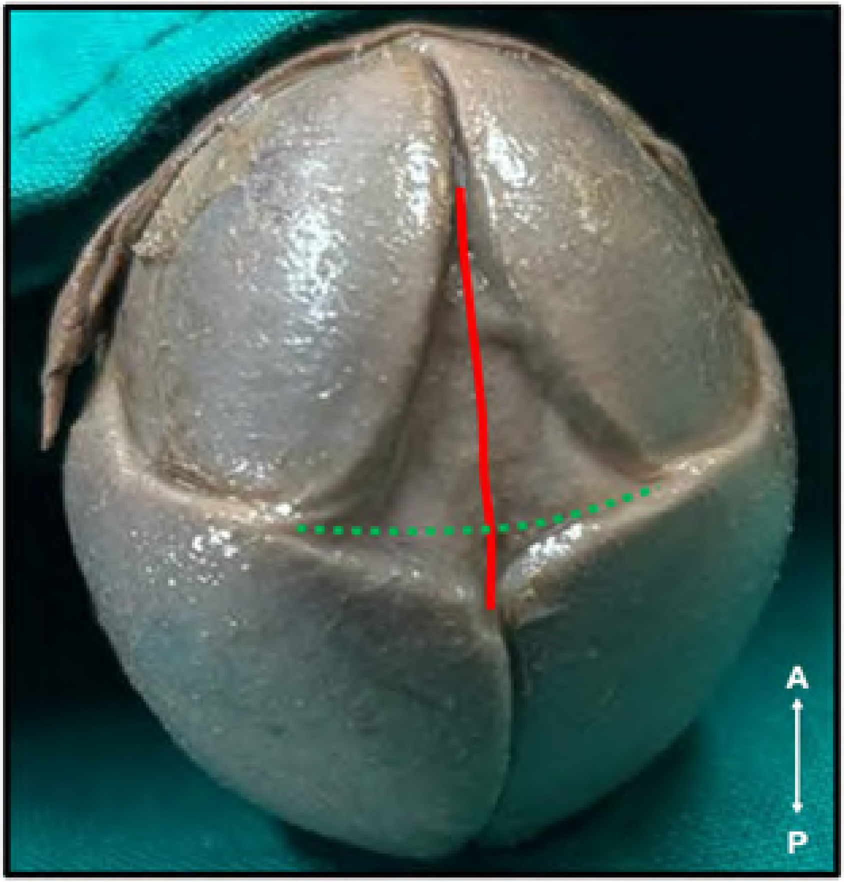

Fig. 4.- Superior view of the fetal skull. Red solid – Anterior fontanelle width (AFW); Green dash– Anterior fontanelle length (AFL).

40 weeks of IUG. This study found that in the age range 13-29/52 IUG, BPD appeared to be the more reliable indicator of fetal age than HC (r = 0.89 versus 0.85). This agrees well with the studies of Hadlock et al. (1982) and Salpou et al. (2008), which show that BPD is a simple and accurate method for estimating fetal age (2nd trimester ±1.5 weeks and 3rd trimester ±3 weeks).

Furthermore, when there is significant distortion in the shape of the fetal skull, the HC has still proven to be a more precise method of age determination than BPD (Hadlock et al., 1981). It is important to note that Salpou (2008) found that measurements obtained from different ethnic groups did not significantly contribute to significant errors in fetal GA determination. Therefore, ethnicity does not appear to be a confounding factor in this study, considering the fetal status in this regard was unknown. The results may, therefore, be used across ethnic groups in the relevant age range.

In fontanelle measurements, the area of AF is noticeably larger than the PF. The diamond-shaped AF sizes, as measured by their length and width (i.e., AFL and AFW), and the triangular-shaped PF, as measured by the occipital base and its maximum height (PFL and PFW), were shown to be poorly correlated with GA (r <0.2). The growth rates of the fontanelle length and width are AFW (0.38 mm/week) > AFL (0.21 mm/week), and PFW = PFL (0.13 mm/week and 0.14 mm/week). Adeyemo (1991) showed that the anterior fontanelle size (as measured by half the sum of the length and width of the fontanelle) had a low positive correlation with gestational age. It was also found that measurements of the posterior fontanelle showed no clear relationship with gestational age. This is probably because in the third trimester, the occipital area of the calvarium does not grow at the same rate as the frontal and parietal bones. Sundaresan et al. (1990) also found that overall fontanelle sizes changed little over the same period.

The reasons for the dissimilar growth rates of

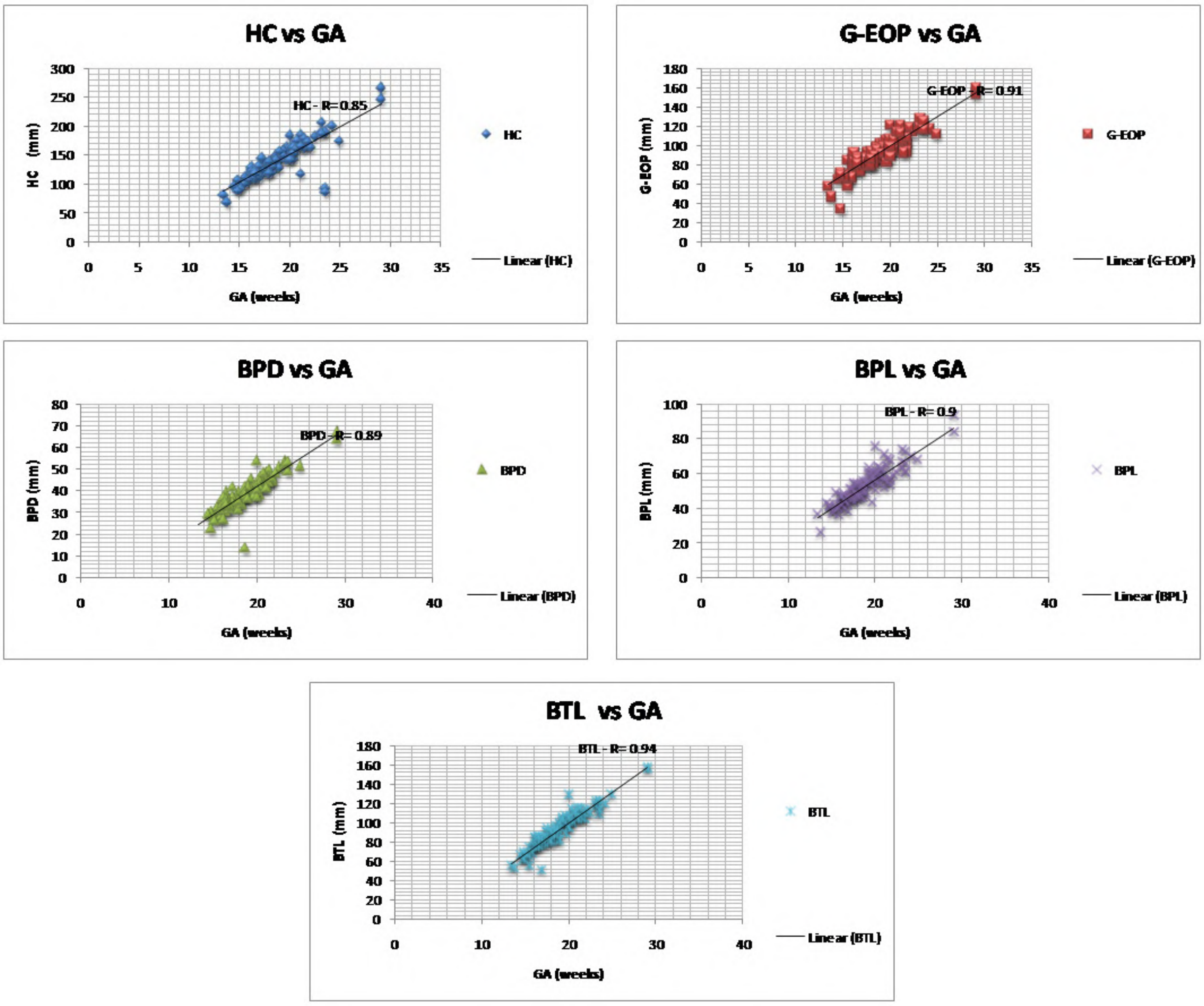

Fig. 5.- Linear regression analysis using the full set of data of standard measurements. A- head circumference against gestational age; B- glabella to external occipital protuberance length against gestational age; C- biparietal diameter against gestational age; D- biparietal length against gestational age; E- bitemporal length against gestational age.

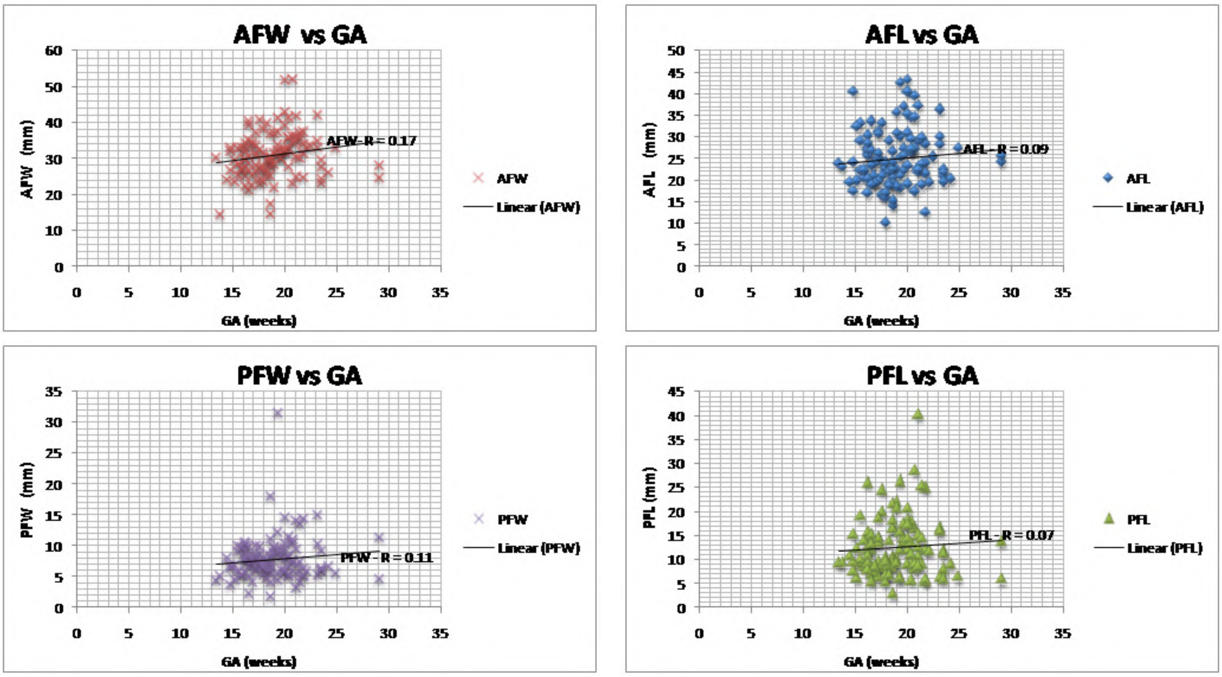

Fig. 6.- Linear regression analysis using the full set of data of fontanelle measurements. A- Anterior fontanelle width against gestational age; B- Anterior fontanelle length against gestational age; C- Posterior fontanelle width against gestational age; D- Posterior fontanelle length against gestational age.

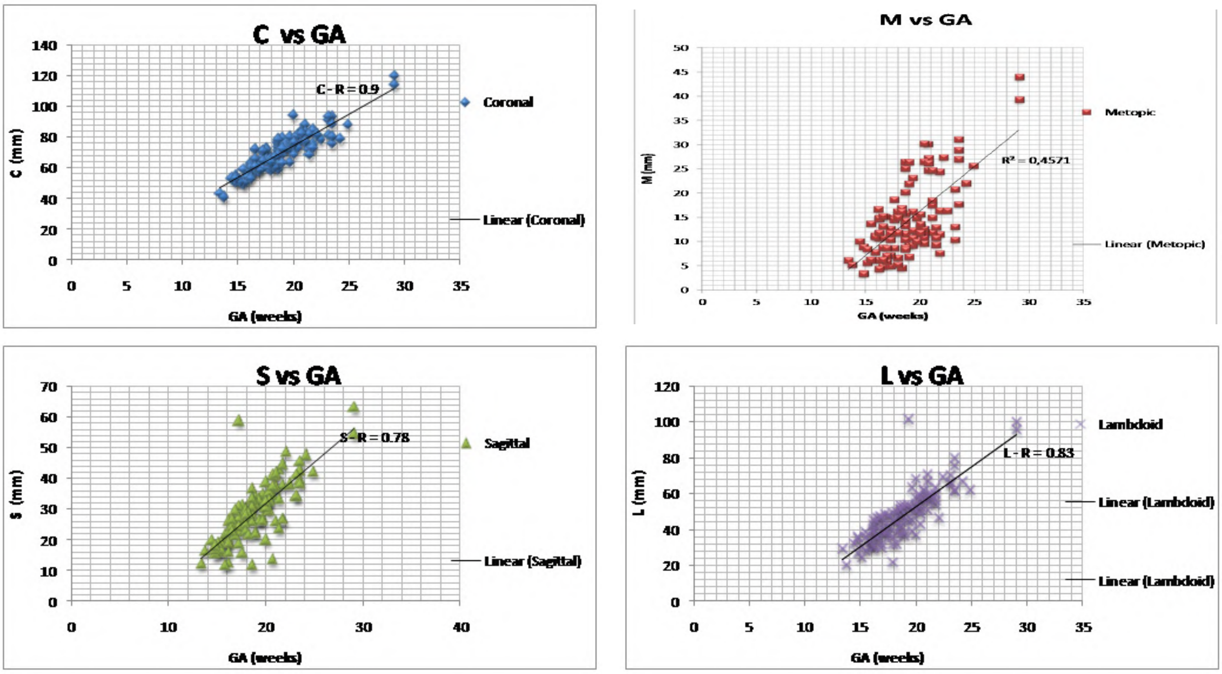

Fig. 7.- Linear regression analysis using the full set of data of suture measurements. A- Coronal suture length against gestational age; B- Metopic suture length against gestational age; C- Sagittal suture length against gestational age; D- Lambdoid suture length against gestational age.

Table 3. Correlation of all measurements with gestational age and growth rates

		r	SE	95% CI	Growth Rates (mm/week)
Standard measurements	HC	0.85	0.03	0.79 – 0.91	9.64 ± 0.03
	G-EOP	0.91	0.02	0.87 – 0.95	6.11 ± 0.02
	BPD	0.89	0.02	0.85 – 0.93	2.61 ± 0.02
	BPL	0.9	0.02	0.86 – 0.94	3.3 ± 0.02
	BTL	0.94	0.01	0.92 – 0.96	6.31 ± 0.01
Fontanelle measurements	AFW	0.17	0.09	0 – 0.35	0.38 ± 0.09
	AFL	0.09	0.09	0 – 0.27	0.21 ± 0.09
	PFW	0.07	0.09	0 – 0.25	0.13 ± 0.09
	PFL	0.11	0.09	0 – 0.29	0.14 ± 0.09
Suture measurements	C	0.9	0.02	0.86 – 0.94	4.12 ± 0.02
	M	0.68	0.05	0.58 – 0.78	1.84 ± 0.05
	S	0.78	0.04	0.7 – 0.86	2.69 ± 0.04
	L	0.83	0.03	0.77 – 0.89	4.42 ± 0.03

Key: r= correlation; SE= standard error; CI= confidence interval

the individual fontanelle parameters (length and width) and those of Groups A and C are likely due to the fact that fontanelles are two-dimensional structures, and growth is, therefore, dependent on two separate measures, i.e., length and width, which grow independently. In fact, it appears that the fontanelles do not appear to 'truly' grow, but rather, the bones that form their boundaries grow (Pedroso et al., 2008; D'Antoni et al., 2017). The AF is reliant on the frontal and parietal bones, and the PF is dependent on the surrounding parietal and occipital bones. Since the bones increase in size proportionately and the fontanelles do not, they are, therefore, not very useful for determining GA. Further, with regard to both the AF and the PF, a small change in any of their boundaries may cause a substantial difference in the length and/or width. Due to all these findings, fontanelle measurements may not be very useful in calculating GAs.

For sutural measurements, the length of C is the largest of all the sutures (C>L>S>M). This study found that C and L are very strongly correlated with GA. The growth rate of the C and L (4.12 mm and 4.42 mm/week) was almost twice the rate of the S and M (2.69 mm and 1.84 mm/week). Their correlation with the GA also appears in the same order of descending reliability (C>L> S>M). The poor correlation between M and GA may possibly be due to M being a temporary suture and could also be a point for further study.

Following the findings from this study, it is, therefore, possible to make a very reasonable estimation of the GA of a fetus given an isolated skull fragment with an intact suture line. Therefore, using the sets of parameters investigated in this study, it is possible to determine the fetal age using linear regression analysis, with the following progression of accuracy: BTL (0.94), G-EOP (0.91), C (0.9), BPL (0.9), BPD (0.89), HC (0.85), L (0.83), S (0.78) and M (0.68).

CONCLUSIONS

This study investigated the correlation between GA and the standard fontanelle, and suture measurements taken on the surface of a fetal skull. There was a very strong correlation with the GA ($r > 0.8$) for standard measurements. The fontanelle parameters in this study, i.e., the AFL, AFW, PFL, and PFW (all $r < 0.2$), appear unsuitable for GA calculations (weak correlations). In the sutural measurements, the C was found to be the most accurate measure of GA when compared to the other sutures. Findings from this study will assist forensic anthropologists in age determination, especially when skull fragments are only available. It will also assist clinicians in spotting possible skull anomalies in fetuses.

Limitations

Fetal specimens used for this study were between the age range of 13 to 29 weeks IUG age, which could possibly limit all measurements, inferences, and calculations of growth rates to be valid for fetal ages 13-29/52 IUG age. Also, the information regarding the sex and population groups of the specimens was not documented; hence, the specimens were neither classified nor analyzed based on sex or population group. Therefore, the authors would like to allude to future studies on fetal specimens up to 52 weeks of GA that would include classification by sex and population group to enhance the comprehensiveness and applicability of findings.

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