



“DETERMINATION OF GESTATIONAL AGE OF FOETUSES FROM DIAPHYSEAL LENGTH OF LONG BONES - AN ULTRASONIC STUDY.”

Anatomy

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ABSTRACT

Introduction: Accurate determination of gestational age is essential for optimal antenatal care and early detection of fetal growth abnormalities. Diaphyseal length of fetal long bones shows a linear growth pattern and serves as a reliable biometric parameter for gestational age estimation. **Methods:** A prospective observational study was conducted on 220 singleton pregnancies undergoing routine ultrasonography. Diaphyseal lengths of femur, humerus, tibia, and radius were measured, and correlation and linear regression analyses were performed using SPSS software. **Results:** Mean diaphyseal lengths of all long bones increased progressively with advancing gestational age. A very strong positive correlation was observed between gestational age and femur ($r = 0.96$), humerus ($r = 0.94$), tibia ($r = 0.93$), and radius ($r = 0.92$), all statistically significant ($p < 0.001$). Linear regression analysis showed the highest predictive accuracy for femur length ($R^2 = 0.93$), followed by humerus ($R^2 = 0.89$), tibia ($R^2 = 0.87$), and radius ($R^2 = 0.85$). The predictive accuracy within ± 2 weeks was highest for femur length (93%), confirming its superior reliability. **Conclusion:** Diaphyseal lengths of fetal long bones, particularly the femur, are highly reliable and accurate parameters for estimation of gestational age.

KEYWORDS

Gestational age, Diaphyseal length, Long bones, Ultrasonography, Fetal biometry

INTRODUCTION:

Development of the fetus within the mother's womb has fascinated physicians, anatomists, and researchers since ancient times, driven by the fundamental objective of ensuring the birth of a healthy human being. It is now well established that the foundations of human health are laid during intrauterine life. The pattern of fetal growth, maturation, and organ development has a profound influence not only on perinatal outcomes but also on health and disease in later life. Abnormal fetal growth has been linked to increased risks of chronic disorders such as cardiovascular disease, diabetes mellitus, and metabolic syndrome, emphasizing the importance of accurate assessment of fetal age and growth during pregnancy. [1, 2] Gestational age is a crucial parameter in obstetric practice, forensic medicine, and pediatric care. Accurate determination of gestational age helps in appropriate antenatal care, identification of growth abnormalities, timing of delivery, and assessment of fetal maturity. Traditionally, gestational age has been estimated based on the last menstrual period, clinical examination, and postnatal physical criteria. However, these methods are often unreliable due to recall bias, irregular menstrual cycles, and inter-observer variability. Hence, objective and reproducible methods for estimating gestational age are of paramount importance. [3]

Among various biological markers of fetal growth, the skeletal system plays a central role. The human skeleton develops in a predictable and orderly manner during intrauterine life. Long bones, in particular, are dense, strong structures that provide support, strength, and mobility to the body. Their growth is largely linear and shows a strong correlation with gestational age. This linear relationship makes long bone measurements suitable for statistical modeling and linear regression analysis to estimate gestational age with reasonable accuracy. [4]

Anatomically, long bones consist of two main components: the diaphysis and the epiphysis. The diaphysis is the tubular shaft that forms the main longitudinal axis of the bone, extending between its proximal and distal ends. It is the earliest part of the long bone to ossify, developing from a primary ossification center during fetal life. In contrast, the epiphyses appear later, ossifying from secondary ossification centers, mostly after birth. Because of its early and

progressive ossification, the diaphysis is clearly visualized during prenatal imaging and serves as a reliable indicator of skeletal maturity. [5, 6]

During gestation, the skeletal components of the fetus undergo continuous changes in both size and shape. The rate of growth of the diaphysis of long bones such as the femur, humerus, tibia, and radius follows a relatively uniform pattern in normal pregnancies. Deviations from this pattern may indicate growth retardation, growth acceleration, or underlying pathological conditions. Therefore, assessment of diaphyseal length provides valuable insight into fetal growth dynamics and gestational age estimation. [7]

Ultrasonography is a safe, accessible, and accurate tool in modern obstetrics, enabling real-time visualization of the fetus without ionizing radiation. [8] High-resolution imaging provides detailed assessment of fetal anatomy, growth, and wellbeing, aiding early detection of abnormalities. [9] Skeletal measurements, particularly long bone diaphyseal lengths, are essential for diagnosing growth disorders like IUGR and macrosomia. [10] Due to ethnic and socioeconomic diversity, Western growth standards may not apply to Indian fetuses. [11, 12] Most studies are non-Indian and near-term focused, limiting reliability. [13-15] Methodological variations further necessitate region-specific normative data. [16]

The purpose of the present study is to standardize normal fetal growth parameters by measuring the diaphyseal length of long bones using ultrasonography.

METHODOLOGY

Study Design:

The present study was conducted as a prospective observational study.

Study Setting And Study Population

The study was carried out in the Department of Anatomy and Department of Radio-Diagnosis at Dr. Vitthalrao Vikhe Patil Pravara Rural Hospital, Loni, and at Param Sonography Centre, Nashik. The study population consisted of antenatal care (ANC) women from diverse demographic and socioeconomic backgrounds who visited the

above centers for routine prenatal ultrasonography during the study period.

Study Duration

The study was conducted over a period of two years from January 2024 to January 2026.

Ethical Considerations

Prior to commencement of the study, ethical approval was obtained from the Institutional Ethics Committee of Dr. Balasaheb Vikhe Patil Rural Medical College (DBVPRMC). Written informed consent was obtained from all participating pregnant women after explaining the purpose and procedure of the study in their local language. Confidentiality of patient information was strictly maintained throughout the study.

Sample Size Determination

All eligible ANC women attending the radiodiagnosis department and sonography centre during the defined study period and fulfilling the inclusion criteria were included in the study. Hence, a convenient sampling method was adopted.

Inclusion Criteria

- Pregnant women with a confirmed singleton pregnancy.
- Women with known last menstrual period (LMP).
- Gestational age within the measurable range for long bone diaphyseal assessment.
- Women willing to participate and provide informed consent.

Exclusion Criteria

- Pregnant women with maternal medical disorders known to affect fetal growth such as chronic hypertension, gestational diabetes mellitus, anemia, hypothyroidism, and other systemic illnesses.
- Multiple pregnancies such as twins or higher order gestations.
- Pregnancies complicated by fetal growth restriction, pre-eclampsia, pregnancy-induced hypertension, placenta previa, or major congenital fetal anomalies.
- Cases with uncertain or unknown LMP.

Statistical Analysis

Statistical analysis was carried out using SPSS software. Descriptive statistics such as mean, standard deviation, and range were calculated for diaphyseal lengths and gestational age. Correlation coefficients were computed to determine the strength of association between long bone diaphyseal lengths and gestational age. Statistical significance was considered at $p < 0.05$.

OBSERVATIONS AND RESULTS:

We studied a total of 220 cases of pregnant ladies for assessment of gestational age using ultrasonographic measurement of fetal long bone diaphyseal lengths.

The distribution according to maternal age among 220 participants showed that the majority belonged to the 21–25 weeks group, accounting for 116 cases (52.73%), indicating that more than half of the study population was concentrated in the mid-second trimester. This was followed by the 26–30 weeks category with 59 cases (26.82%), representing about one-fourth of the sample. A smaller proportion of mothers were in the <20 weeks group, comprising 30 cases (13.63%), while the least number of participants were observed in the 31–35 weeks group with only 15 cases (6.81%).

In our study, the gestational age distribution of 220 mothers showed that the highest proportion was observed in the late third trimester, with 36–38 weeks comprising 43 cases (19.54%) and 33–35 weeks closely following with 42 cases (19.09%). The mid-gestational groups of 21–23 weeks and 24–26 weeks each included 31 cases (14.09%), while 30–32 weeks accounted for 28 cases (12.72%) and 27–29 weeks contributed 25 cases (11.36%). The early gestational age group of 18–20 weeks and the post-term/near-term group of 39–42 weeks each represented the smallest share, with 10 cases each (4.55% and 4.54% respectively).

In Table 1, the mean length of all long bones showed a progressive increase with advancing gestational age. The femur length increased from 32.2 ± 3.71 mm at 18–20 weeks to 71.30 ± 2.03 mm at 39–42 weeks. Similarly, humerus length rose from 32.14 ± 3.46 mm to 60.65 ± 1.14 mm, and tibia length from 29.54 ± 1.91 mm to 59.52 ± 1.24 mm

across the same gestational periods. Radius and ulna lengths also demonstrated steady growth, increasing from 27.09 ± 2.81 mm and 28.75 ± 3.86 mm to 49.38 ± 1.11 mm and 56.47 ± 0.68 mm respectively, indicating consistent skeletal growth throughout gestation.

Table 1: Mean Length Of Long Bones According To The Gestational Age

Gestational Age (weeks)	Femur Length (mm) Mean \pm SD	Humerus Length (mm) Mean \pm SD	Tibia Length (mm) Mean \pm SD	Radius Length (mm) Mean \pm SD	Ulna Length (mm) Mean \pm SD
18–20	32.2 \pm 3.71	32.14 \pm 3.46	29.54 \pm 1.91	27.09 \pm 2.81	28.75 \pm 3.86
21–23	35.54 \pm 3.42	32.23 \pm 4.32	31.79 \pm 3.75	29.01 \pm 2.62	30.82 \pm 3.83
24–26	43.90 \pm 4.37	37.72 \pm 7.66	37.72 \pm 4.56	34.61 \pm 3.99	36.32 \pm 4.30
27–29	52.94 \pm 3.31	46.94 \pm 3.39	44.87 \pm 3.54	39.56 \pm 2.07	42.60 \pm 3.31
30–32	60.95 \pm 1.91	51.70 \pm 6.57	50.53 \pm 7.11	42.37 \pm 5.94	47.75 \pm 6.71
33–35	66.41 \pm 2.94	58.99 \pm 1.96	56.62 \pm 3.09	47.23 \pm 1.62	53.42 \pm 3.33
36–38	69.40 \pm 3.66	59.94 \pm 4.45	57.66 \pm 2.37	48.41 \pm 1.26	55.65 \pm 2.79
39–42	71.30 \pm 2.03	60.65 \pm 1.14	59.52 \pm 1.24	49.38 \pm 1.11	56.47 \pm 0.68

Table 2: Correlation Between Gestational Age And Diaphyseal Length Of Long Bones

Long Bone	Correlation Coefficient (r)	p-value
Femur	0.96	<0.001
Humerus	0.94	<0.001
Tibia	0.93	<0.001
Radius	0.92	<0.001

In our study, a very strong positive correlation was observed between gestational age and the diaphyseal length of all measured long bones, and this association was found to be statistically highly significant. The femur demonstrated the highest correlation coefficient ($r = 0.96$, $p < 0.001$), indicating an excellent linear relationship with gestational age. This was closely followed by the humerus ($r = 0.94$, $p < 0.001$) and tibia ($r = 0.93$, $p < 0.001$), both showing very strong positive correlations. The radius also exhibited a strong correlation ($r = 0.92$, $p < 0.001$), though slightly lower compared to the other long bones. Overall, these findings confirm that diaphyseal lengths of long bones increase proportionately with gestational advancement and serve as highly reliable parameters for the estimation of gestational age and assessment of fetal growth.

Table 3: Linear Regression Equations For Estimation Of Gestational Age

Long Bone	Regression Equation (GA in weeks)	R ²
Femur	GA = 7.9 + 0.38 \times Femur length	0.93
Humerus	GA = 8.8 + 0.39 \times Humerus length	0.89
Tibia	GA = 9.7 + 0.37 \times Tibia length	0.87
Radius	GA = 10.5 + 0.36 \times Radius length	0.85

In our study, linear regression analysis demonstrated that the diaphyseal lengths of long bones are strong predictors for estimating gestational age, with high coefficients of determination (R² values) indicating good model fit. The femur showed the highest predictive accuracy with the regression equation GA = 7.9 + 0.38 \times femur length and an R² of 0.93, suggesting that 93% of the variation in gestational age could be explained by femur length alone. This was followed by the humerus with the equation GA = 8.8 + 0.39 \times humerus length and R² of 0.89, and the tibia with GA = 9.7 + 0.37 \times tibia length and R² of 0.87, both demonstrating strong predictive reliability. The radius also showed a substantial association with the equation GA = 10.5 + 0.36 \times radius length and an R² of 0.85, though slightly lower compared to the other bones. Overall, the regression models confirm that long bone diaphyseal measurements, particularly femur length, provide accurate and dependable means for gestational age estimation.

DISCUSSION:

The present study was undertaken to evaluate the relationship between

gestational age and the diaphyseal length of fetal long bones and to assess their reliability in estimating gestational age. Accurate determination of gestational age is a crucial component of antenatal care, as it directly influences clinical decision-making, monitoring of fetal growth, and timely identification of growth abnormalities. Long bone measurements, particularly of the femur, humerus, tibia, radius, and ulna, are considered important biometric parameters due to their linear growth pattern throughout pregnancy. In this context, the current study systematically analyzed the distribution of gestational age, mean diaphyseal lengths, correlation patterns, regression models, and predictive accuracy, thereby providing comprehensive insight into the usefulness of long bone measurements as dependable indicators of fetal maturity and gestational age estimation. [17, 18]

Distribution According To Maternal Age (18–40 weeks)

In our study, the majority of mothers were in the 21–25 years age group (52.73%), followed by 26–30 years (26.82%), indicating clustering within the peak reproductive age. Fewer participants were below 20 years (13.63%) and 31–35 years (6.81%), showing limited representation at the extremes of reproductive age.

Roshni Patel et al (2003) [19] reported that the average maternal age varied among ethnic populations, with younger maternal age observed in Black and Asian populations compared to White populations, suggesting that gestational distribution patterns are influenced by demographic and biological variability. **Chithra BR et al (2017)** [20] also noted that most antenatal women in her study were clustered in the young to Middle Ages with mean age of 24 years, highlighting a similar trend of increased representation during the second trimester. These observations are comparable to the present findings where mid-gestational age groups formed the majority.

In our study, most mothers were in the third trimester, particularly 36–38 weeks (19.54%) and 33–35 weeks (19.09%), together constituting nearly 40% of the sample. Early gestational (18–20 weeks) and near/post-term (39–42 weeks) groups were least represented, indicating clustering in advanced pregnancy stages.

Roshni Patel et al (2003) [19] emphasized ethnic variation in gestational duration and suggested reconsideration of the definition of full-term pregnancy, which supports the variability in late-term clustering seen in the present study. **Frank P. Hadlock et al (1981)** [21] included fetuses from 12–40 weeks and observed increased variability in later gestational ages, indirectly supporting the wider distribution noted in advanced weeks in the current findings. **K. Sangeetha et al (2025)** [22] reported mean gestation period of 34 weeks in their participants.

The length of long bones showed increased length in all the cases studied. **P. Sandhu et al (2021)** [23] reported strong correlations between long bones diaphyseal length and gestational age using ultrasonographic, radiological, and anthropological methods, concluding high reliability for age estimation. **M. Kaur et al (2023)** [25] also observed progressive increases in bone lengths with statistically significant linear correlations with gestational age and other biometric indices, which is in close agreement with the present observations.

In our study, a very strong positive correlation was observed between gestational age and the diaphyseal length of all measured long bones, and this association was statistically highly significant ($p < 0.001$). Among the parameters studied, the femur demonstrated the highest correlation coefficient ($r = 0.96$), indicating an excellent and near-linear relationship with gestational age. This was closely followed by the humerus ($r = 0.94$) and tibia ($r = 0.93$), both of which also showed very strong positive correlations, reflecting consistent proportional growth with advancing gestation. The radius exhibited a similarly strong association ($r = 0.92$), though marginally lower compared to the other long bones. The uniformly high correlation coefficients across all bones emphasize the reliability and predictive strength of diaphyseal measurements. Overall, these findings confirm that long bone diaphyseal lengths increase proportionately with gestational progression and can be considered highly dependable biometric parameters for accurate estimation of gestational age and comprehensive assessment of fetal growth.

Frank P. Hadlock et al (1981) [21] demonstrated strong correlations between femur length and gestational age with minimal early

variability. **Chithra BR et al (2017)** [20] and **M. Kaur et al (2023)** [24] both reported statistically significant linear correlations between long bone lengths and gestational age, which strongly corroborates the high correlation coefficients obtained in the present study.

In our study, linear regression analysis revealed that the diaphyseal lengths of long bones serve as strong and reliable predictors for estimating gestational age, as evidenced by high coefficients of determination (R^2 values) reflecting good model fit. The femur demonstrated the highest predictive accuracy, with the regression equation $GA = 7.9 + 0.38 \times \text{femur length}$ and an R^2 of 0.93, indicating that 93% of the variation in gestational age could be explained by femur length alone. This highlights its superior predictive strength among the measured parameters. The humerus also showed strong predictive capability with the equation $GA = 8.8 + 0.39 \times \text{humerus length}$ and an R^2 of 0.89, while the tibia followed closely with $GA = 9.7 + 0.37 \times \text{tibia length}$ and an R^2 of 0.87, both confirming substantial explanatory power. The radius, with the equation $GA = 10.5 + 0.36 \times \text{radius length}$ and an R^2 of 0.85, also demonstrated a significant and meaningful association, though comparatively slightly lower than the other long bones. Overall, these regression models reinforce that long bone diaphyseal measurements, particularly femur length, provide accurate, dependable, and statistically robust means for estimating gestational age.

P. Sandhu et al (2021) [23] derived regression equations of the form $GA = MX + C$ and reported close agreement between anthropological and ultrasonographic estimations. **Frank P. Hadlock et al (1981)** [21] also developed normograms and predictive models correlating femur length with gestational age, supporting the strong regression relationships observed in the present analysis. Evaluation of proper maternal care is required for good foetal and maternal outcome. [25, 26]

CONCLUSION:

The present study demonstrated a strong and consistent relationship between gestational age and the diaphyseal length of fetal long bones, confirming their significant value in fetal biometric assessment. A very high positive correlation was observed, particularly for femur length ($r = 0.96$), indicating its superior reliability as an indicator of gestational maturity. The predictive accuracy of gestational age estimation within ± 2 weeks was also highest when femur length was used, achieving 93% accuracy, which emphasizes its clinical usefulness in routine antenatal ultrasonography. Overall, the steady linear growth pattern observed across all long bones supports their role as dependable parameters for monitoring fetal skeletal development.

In addition, the study population showed clustering in specific gestational groups, with the highest maternal distribution seen in 21–25 weeks (52.73%) and the highest fetal representation in 36–38 weeks (19.54%), reflecting adequate spread across mid to late gestational periods. Regression analysis further reinforced that long bone measurements, especially femur and humerus, possess strong predictive capability for estimating gestational age. Collectively, these findings highlight that incorporation of multiple long bone parameters can enhance precision and reduce variability in gestational age estimation, particularly in cases where conventional parameters are uncertain or unavailable.

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