Original Article

http://dergipark.org.tr/en/pub/anatomy
Received: January 21, 2024; Accepted: July 3, 2024
doi:10.2399/ana.24.1506392

anatomy
An International Journal of Experimental and Clinical Anatomy

Correlation between morphometry of fetal foot and gestational age: a cadaver study

Abdurrahim Eyüp Canbaloğlu[1], Ahmet Dursun[2], Kenan Öztürk[3], Yadigar Kastamoni[3]

[1]*Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, İstinye University, Istanbul, Türkiye*
[2]*Department of Anatomy, Faculty of Medicine, Karamanoğlu Mehmetbey University, Karaman, Türkiye*
[3]*Department of Anatomy, Faculty of Medicine, Süleyman Demirel University, Isparta, Türkiye*

Abstract

Objectives: This study was conducted on a collection of fetal cadavers to describe the relationship between gestational age and foot parameters specifically in the Turkish population.

Methods: The study involved 83 fetal cadavers (45 males, 38 females) ranging from 13 to 40 weeks of gestation, without external anomalies or pathologies. Various foot parameters were measured, including foot width (FW), heel width (HW), foot length (FL), heel-metatarsophalangeal fold (HMF), bimalleolar width (BW), foot dorsum length (FDL), ankle-metatarsophalangeal fold (AMF), malleolus medialis height (MMH), malleolus lateralis height (MLH), and finger length (FiL). These parameters were measured using a digital caliper with a precision of 0.01 mm. The fetuses were grouped by gestational month, and morphometric measurements were taken.

Results: A strong and positive correlation was found between all foot parameters and gestational age (months). All parameters increased consistently throughout the fetal period. No significant differences were observed based on gender or side comparisons for any of the parameters. Linear regression equations were developed to estimate gestational age using fetal foot parameters. These parameters explained 72% to 90% of the variation in gestational age.

Conclusion: Fetal foot length and related foot parameters can reliably be used to estimate gestational age. Due to the simplicity of these measurements, fetal foot parameters can be utilized to estimate age for babies born outside a hospital setting without the need for specialist equipment. Additionally, for premature babies receiving treatment in neonatal units, foot measurements offer a practical and easily accessible method for age estimation.

Keywords: fetus; foot length; gestational age; morphometry

Anatomy 2024;18(2):51–60

Introduction

Accurate assessment of gestational age is essential for the effective management of any obstetric case. The most precise fetal age estimates are typically obtained from measurements of crown-rump length (CRL) in early pregnancy. In later stages of pregnancy, gestational age estimates tend to be less accurate; however, using multiple body measurements can provide an overall estimate that is approximately 93% accurate in determining the true gestational age.[1] Multiple anatomical parameters, such as fetal biparietal diameter, head circumference, crown-rump length, abdominal circumference, foot length, and femur length, are commonly used to assess gestational age. Historically, pathologists and obstetricians have relied on fetal foot length measurements following spontaneous abortion to estimate gestational age and assist in diagnosing certain fetal anomalies. Today, the combination of ultrasound assessment and the date of the last menstrual period is considered the most accurate method for pregnancy dating.[2] In areas where prenatal ultrasound is not routinely available, measuring fetal foot length after delivery is a viable method for estimating gestational age.[3] Assessing gestational age can also be challenging in fetuses with conditions such as anencephaly, hydrocephalus, and short limb dysplasia. A review of the literature shows that the fetal foot has a characteristic normal growth pattern, making it an easily measurable parameter that can be used to estimate gestational age.[4]

Over the past 90 years, several studies have reported reference intervals for fetal foot length in relation to gestational age.[5,6] While all studies indicated a linear relationship between fetal foot length and gestational age, none confirmed the generalizability of their models to the populations studied. Some studies reported differences in data collection methods, such as measurements from fresh versus formalin-fixed specimens, while others suggested that racial and population variances may affect fetal size measurements.[7]

Accurate assessment of gestational maturity in newborns, especially those requiring intensive care, can be challenging. However, the foot is usually easily accessible for measurement, even in an incubator. Measuring foot length has proven particularly valuable in premature infants who are too ill for traditional anthropometric measurements due to the constraints of intensive care apparatus. Clinicians typically rely on a combination of prenatal and postnatal indicators—such as ultrasound and the last menstrual period—to determine gestational age. There are also scoring systems that use various neurological and physical criteria for this purpose. While these scoring methods are convenient for physicians, they can be cumbersome for allied health personnel to use. In contrast, measuring foot length is simple and requires minimal expertise.[8]

This study was conducted to explore the relationship between gestational age and fetal foot length, as well as other foot-related parameters such as foot dorsum length, foot width, heel width, toe lengths, bimalleolar width, and the heights of the medial and lateral malleoli. Additionally, the study aimed to establish reference ranges for these fetal foot parameters in our population.

Materials and Methods

The study was a clinical investigation conducted in the Laboratory of the Department of Anatomy, Faculty of Medicine, involving 83 fetuses (45 males, 38 females) aged between 13 and 40 weeks of gestation, without external anomalies or pathologies. The fetuses were obtained from the Obstetrics and Gynaecology Hospital, with the consent of their families. The causes of death of the fetal cadavers were unknown.

All fetal cadavers were preserved using arterial injections of 10% formaldehyde solution and stored in pools containing the same solution. For fetal embalming, the common carotid and femoral arteries were used for arterial injection. In cases where arterial injection was not feasible or insufficient, partial embalming was performed.

Gestational age of the fetuses was determined using crown-rump length, biparietal diameter, head circumference, and femur length.[9–12] The fetuses were then grouped by gestational month as; fetuses between 13 and 16 weeks were categorized as being in the 4th month, 17 to 20 weeks in the 5th month, 21 to 24 weeks in the 6th month, 25 to 28 weeks in the 7th month, 29 to 32 weeks in the 8th month, 33 to 36 weeks in the 9th month, and 37 to 40 weeks in the 10th month.

Morphometric measurements were performed using a digital caliper with a precision of 0.01 mm. The following parameters were analyzed for each foot.[13–16] (**Figures 1** and **2**). Marked parameters indicate measurements unique to this study.

- **Foot width (FW):** The distance between the medial endpoint of the first metatarsophalangeal joint and the lateral endpoint of the fifth metatarsophalangeal joint.
- **Heel width (HW):** The distance between the widest points of the heel.
- **Foot length (FL):** The distance from the pternion (heel endpoint, Pte) to the longest toe's endpoint.
- **Heel-metatarsophalangeal fold (HMF)*:** The distance between the pte and the anterior endpoint of the metatarsophalangeal fold between the second and third digits.
- **Bimalleolar width (BW):** The distance between the endpoints of the malleolus medialis and malleolus lateralis.
- **Foot dorsum length (FDL)*:** The distance between the midpoint of the ankle and the tip of the longest toe.
- **Ankle-metatarsophalangeal fold (AMF)*:** The distance between the midpoint of the ankle and the anterior endpoint of the metatarsophalangeal fold between the second and third toes.
- **Malleolus medialis height (MMH)*:** The distance between the apex of the malleolus medialis and the heel.
- **Malleolus lateralis height (MLH)*:** The distance between the apex of the malleolus lateralis and the heel.
- **Finger length (FiL):** The distance from the metatarsophalangeal joint to the distal end of the toe.

Statistical analysis was conducted using SPSS for Windows, version 20.0 (IBM, Armonk, NY, USA). For each parameter, the minimum, maximum, mean, and standard deviations were calculated according to gestational age (in months), gender, and sides. The data were normally distributed for gender and side comparisons, so an inde-

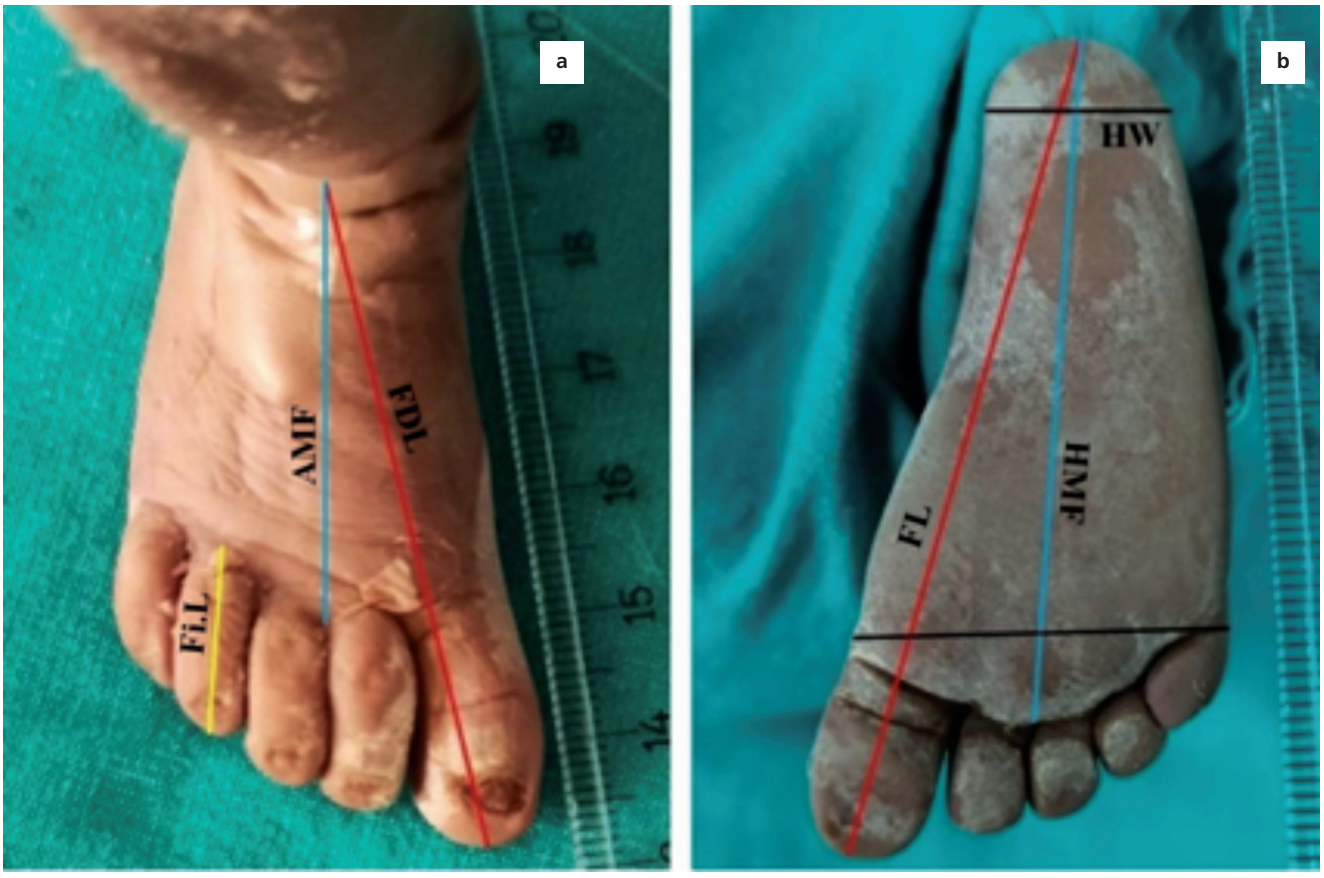

Figure 1. Fetal foot measurement parameters on a 40-week-old male fetus. (**a**) dorsal view; (**b**) plantar view. **AMF:** distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the second and third toes; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel.

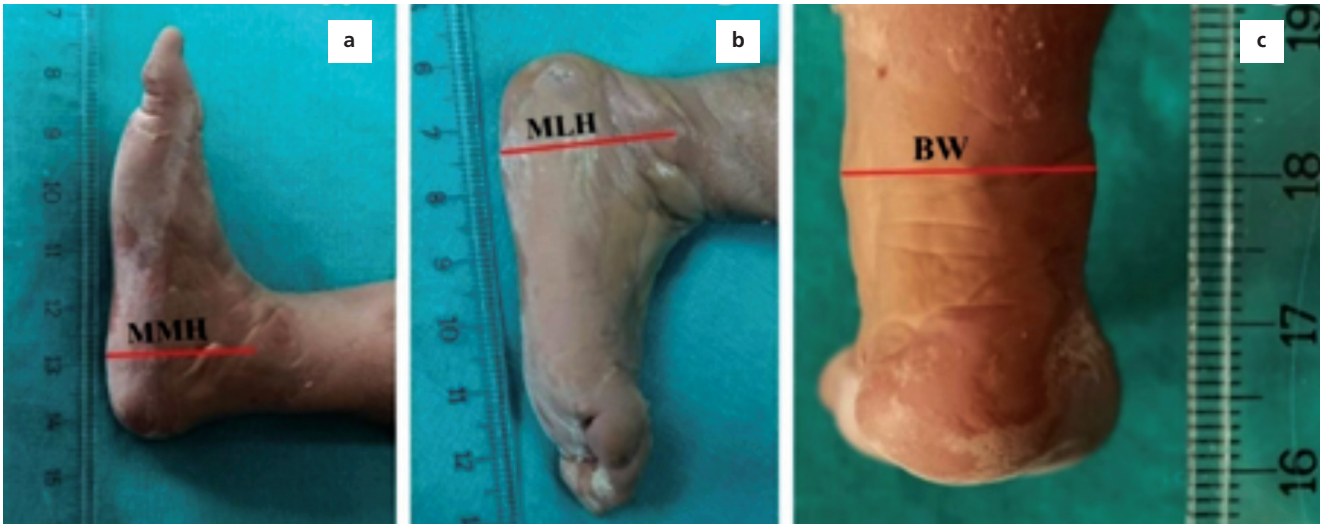

Figure 2. Fetal foot measurement parameters on a 40-week-old male fetus. (**a**) Medial view; (**b**) lateral view; (**c**) posterior view. **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

pendent t-test was used. For comparisons across gestational months, where the data were not normally distributed, the Kruskal-Wallis test was applied for multiple comparisons. Since significant differences were identified, post-hoc analysis was performed. Pearson's correlation analysis was used to assess the relationships between variables. A significance level of $p<0.05$ was considered statistically significant.

Simple linear regression analysis was also performed, using the following equation:

$$y = c + mx$$

where "y" represents the dependent variable (gestational age), "c" is the regression coefficient constant, "m" is the regression coefficient for the independent variable, and "x" represents the independent variable.

Results

In our study, morphometric data were evaluated from 166 fetal feet of 83 human cadaveric fetuses. The mean and standard deviations of the results were calculated according to sex, side, and gestational age (in months). Statistical comparisons were made across these categories (**Tables 1** and **2**). The measured foot parameters showed consistent growth with increasing gestational age (**Figures 3** and **4**). No significant differences were found between consecutive months for any of the parameters, but significant differences were observed between more distant months as fetal growth progressed (**Table 1**). All foot parameters had a strong positive correlation with gestational age, showing continuous improvement throughout the fetal period (**Table 3**). Additionally, no significant differences were observed in comparisons between sex or side for any of the parameters (**Table 2**).

Gestational age was estimated using the fetal foot parameters according to the linear regression equation. As shown in **Table 4**, fetal foot parameters explained between 72% and 90% of the variation in gestational age. This suggests that gestational age can be reliably estimated with a high degree of accuracy when multiple fetal foot parameters are used together.

Table 1
Monthly comparison of fetal foot parameters.

Parameters (mm)	Gestational age (months)							
	4 (n=8)	5 (n=18)	6 (n=24)	7 (n=32)	8 (n=32)	9 (n=24)	10 (n=26)	p-value
FL	21.10±1.47	29.18±4.16	40.34±6.24	47.82±3.97	59.37±5.36	65.31±5.82	75.16±5.23	<0.001
HMF	18.16±1.02	25.29±4.02	34.59±5.30	41.42±3.43	50.93±4.34	55.76±5.58	64.51±5.02	<0.001
FW	7.96±1.04	11.43±2.28	15.44±2.54	19.62±2.41	23.72±2.16	26.89±3.48	30.94±3.18	<0.001
BW	5.87±0.40	8.49±1.37	12.0±1.72	14.05±1.19	17.43±1.58	19.47±2.02	22.24±2.29	<0.001
HW	4.71±0.57	7.01±1.61	9.33±1.95	11.50±1.13	13.41±1.42	14.31±1.69	17.41±1.88	<0.001
MLH	5.09±0.82	6.18±1.23	10.16±2.21	11.81±1.49	14.71±2.58	16.73±2.90	18.23±3.65	<0.001
MMH	5.28±0.42	7.15±1.19	11.74±2.50	13.19±1.43	17.19±2.97	18.98±3.53	21.15±4.10	<0.001
FDL	15.56±1.97	22.05±3.44	30.83±5.65	37.07±3.52	47.66±3.80	51.81±5.55	57.15±3.95	<0.001
AMF	11.47±1.46	15.35±2.46	22.35±4.43	26.56±3.04	34.58±3.25	37.29±5.07	40.56±3.10	<0.001
FiL 1	4.79±0.48	6.99±1.31	9.89±1.82	11.50±1.21	14.47±1.91	16.17±2.11	17.96±1.93	<0.001
FiL 2	4.71±0.51	7.40±1.05	10.16±1.70	12.16±1.07	14.38±1.57	16.40±1.85	17.83±1.59	<0.001
FiL 3	4.26±0.51	6.45±1.12	9.21±1.76	10.60±0.93	12.73±1.46	14.12±1.45	15.85±1.41	<0.001
FiL 4	3.89±0.47	5.96±1.25	8.18±1.32	9.99±0.93	11.95±1.33	12.93±1.66	15.01±1.54	<0.001
FiL 5	3.41±0.46	5.21±1.02	7.41±1.29	8.89±1.01	10.95±1.21	12.27±1.47	13.75±1.72	<0.001

AMF: distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the first and second toes; **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

Table 2
Mean and standard deviation values of fetal foot parameters with comparisons by gender and side.

Parameters (mm)	Side			Gender		
	Right (n=83)	Left (n=83)	p-value	Female (n=38)	Male (n=45)	p-value
FL	52.72±16.47	52.55±16.30	0.947	54.23±16.36	50.79±16.22	0.180
HMF	45.43±14.09	45.01±13.99	0.848	46.53±14.08	43.71±13.84	0.198
FW	21.27±7.27	21.11±7.14	0.888	22.01±7.25	20.25±7.04	0.116
BW	15.58±5.0	15.48±4.93	0.894	15.99±5.11	15.0±4.74	0.201
HW	12.12±3.81	12.09±3.77	0.956	12.59±3.67	11.54±3.84	0.075
MLH	12.85±4.77	13.04±4.69	0.801	13.39±4.51	12.43±4.93	0.193
MMH	14.80±5.46	14.96±5.47	0.849	15.41±5.28	14.27±5.62	0.184
FDL	40.97±13.10	40.97±13.10	0.998	41.86±12.86	39.94±13.30	0.349
AMF	29.38±9.70	29.45±9.45	0.963	30.07±9.26	28.66±9.87	0.346
FiL 1	12.76±4.18	12.76±4.17	0.989	13.14±4.32	12.32±3.95	0.213
FiL 2	12.96±3.97	13.01±3.92	0.941	13.33±4.02	12.58±3.82	0.230
FiL 3	11.33±3.46	11.51±3.51	0.748	11.69±3.47	11.11±3.48	0.292
FiL 4	10.59±3.32	10.65±3.37	0.920	10.93±3.28	10.26±3.38	0.202
FiL 5	9.60±3.19	9.76±3.25	0.755	9.94±3.17	9.37±3.26	0.258

AMF: distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the first and second toes; **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

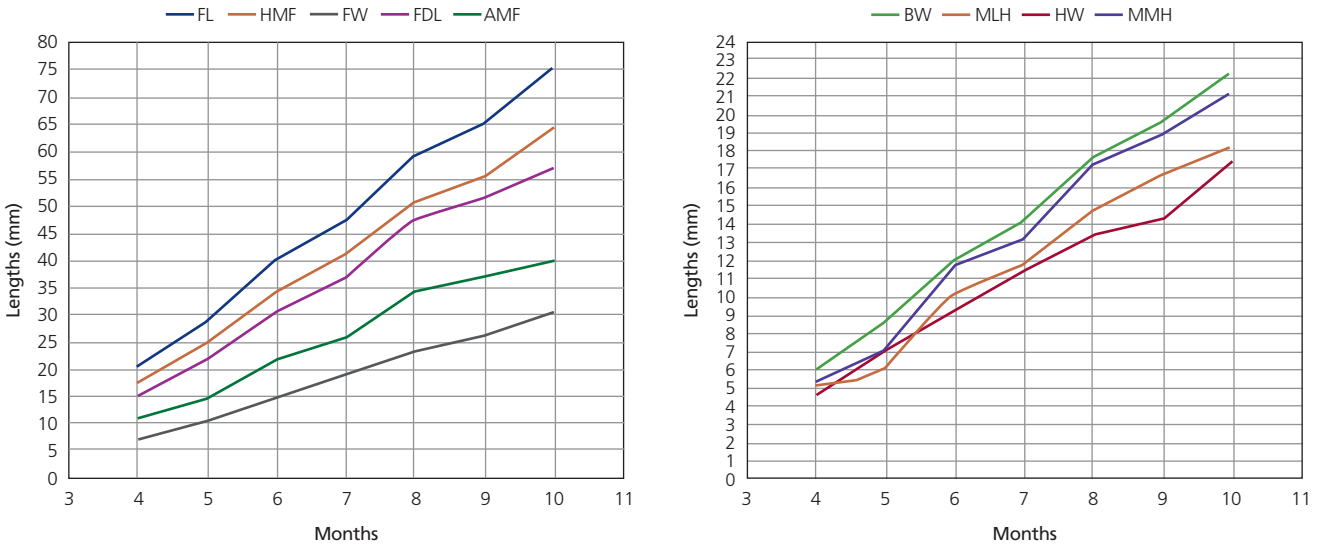

Figure 3. Relationship between fetal foot parameters and gestational age (months). **AMF:** distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the first and second toes; **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

Discussion

Gestational age is a critical factor in the management, decision-making, prognosis, and follow-up of newborns, particularly preterm infants. Neonatal scoring systems, such as the modified Ballard and Dubowitz scores, are commonly used to determine gestational age based on standardized postnatal assessments of physical and neurological maturity.[3,17] However, applying these scores to assess fetal age can be challenging due to the specialized training and clinical skills required for accurate use. In contrast, measuring foot length with a caliper is a simpler, faster method that requires minimal training and can be used by all levels of healthcare professionals. Moreover, unlike neonatal scoring systems, foot length measurements cause minimal discomfort to the infant.

The World Health Organization's 2012 "Born Too Soon" report emphasized the need for simplified approaches, such as foot measurement, to identify and

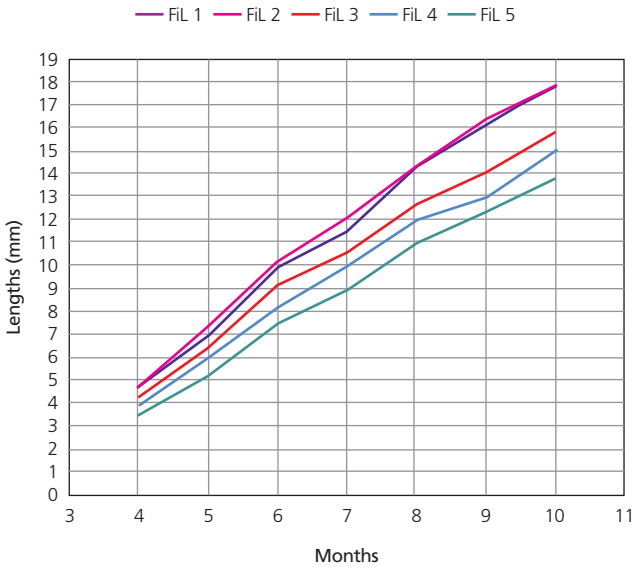

Figure 4. Relationship between fetal finger lengths (FiL) and gestational age (months).

Table 3
Correlation of fetal foot parameters with gestational age (in months).

		FL	HMF	FDL	AMF	FW	HW	BW	MMH	MLH	FiL1	FiL2	FiL3	FiL4	FiL5
Corelation coefficient	Months	0.954	0.952	0.939	0.948	0.911	0.890	0.888	0.939	0.921	0.922	0.934	0.921	0.928	0.923
	FL	1	0.997	0.979	0.958	0.975	0.931	0.985	0.927	0.925	0.972	0.971	0.970	0.973	0.971
	HMF		1	0.977	0.959	0.976	0.930	0.985	0.927	0.925	0.967	0.966	0.962	0.969	0.970
	FDL			1	0.991	0.957	0.900	0.965	0.920	0.921	0.954	0.964	0.959	0.968	0.961
	AMF				1	0.936	0.873	0.943	0.900	0.905	0.932	0.943	0.937	0.945	0.937
	FW					1	0.936	0.964	0.917	0.908	0.953	0.951	0.950	0.958	0.968
	HW						1	0.934	0.870	0.855	0.909	0.905	0.913	0.916	0.920
	BW							1	0.914	0.911	0.961	0.956	0.956	0.957	0.961
	MMH								1	0.962	0.915	0.908	0.903	0.905	0.926
	MLH									1	0.922	0.903	0.899	0.904	0.912
	FiL 1										1	0.967	0.968	0.956	0.954
	FiL 2											1	0.974	0.967	0.959
	FiL 3												1	0.977	0.956
	FiL 4													1	0.972
	FiL 5														1
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	N	166	166	166	166	166	166	166	166	166	166	166	166	166	166

AMF: distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the first and second toes; **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

Table 4
Simple linear regression equation for estimating gestational age (in months) using fetal foot anthropometric measurements*.

Parameters (mm) (y)	Regression coefficient constant (c)	Regression coefficient for independent variable (m)	r^2	p-value
FL	2.194	0.101	0.904	<0.001
HMF	2.195	0.116	0.896	<0.001
FW	2.691	0.224	0.868	<0.001
BW	2.389	0,327	0.886	<0.001
HW	2.457	0.413	0.824	<0.001
MLH	3.394	0.314	0.727	<0.001
MMH	3.420	0.272	0.739	<0.001
FDL	2.385	0.124	0.883	<0.001
AMF	2.579	0.166	0.845	<0.001
FiL 1	2.644	0.378	0.832	<0.001
FiL 2	2.225	0.404	0.860	<0.001
FiL 3	2.252	0.456	0.848	<0.001
FiL 4	2.428	0.474	0.845	<0.001
FiL 5	2.685	0.493	0.842	<0.001

*The equation y = c + mx was used in the regression analysis. In the equation, "y" represents the dependent variable (gestational age), "c" represents the regression coefficient constant, "m" represents the regression coefficient for the independent variable, and "x" represents the independent variable itself. **AMF:** distance between the midpoint of the ankle and the anterior end point of the metatarsophalangeal fold between the first and second toes; **BW:** distance between the end points of malleolus medialis and malleolus lateralis; **FDL:** distance between the midpoint of the ankle and the tip of the longest toe; **FiL:** distance between the metatarsophalangeal joint and the distal end of the finger; **FL:** distance between Pternion (Pte; heel end point) and the longest toe end point of the foot; **FW:** distance between the medial end point of the first metatarsophalangeal joint and the lateral end point of the fifth metatarsophalangeal joint; **HMF:** distance between Pte and the anterior end point of the metatarsophalangeal fold between the second and third fingers; **HW:** distance between the widest points of the heel; **MLH:** distance between the top of the malleolus lateralis and the heel; **MMH:** distance between the top of the malleolus medialis and the heel.

manage preterm infants early.[3] Several studies have reported ranges for fetal foot length at different gestational ages. For example, Tuncer[16] found foot length ranging from 7.4 to 75.7 mm, Chavan et al.[8] reported foot lengths between 50 and 82.9 mm in fetuses aged 27 to 40 weeks, Majmudar et al.[4] found foot lengths between 50 and 71 mm in fetuses aged 25 to 36 weeks, Stevens et al.[6] reported lengths between 16.13 and 39.86 mm in fetuses aged 14 to 22 weeks, and Shah et al.[18] found foot lengths ranging from 24 to 67 mm in fetuses aged 16 to 39 weeks.

In our study, fetal foot length was measured between 20.01 and 78.3 mm in fetuses aged 13 to 40 weeks, with results consistent with the existing literature (**Table 5**). While there is no comprehensive morphometric data on the fetal foot in the literature, some studies conducted on children or adults have shown that males tend to have significantly longer foot lengths than females. Other studies, however, have reported no significant gender differences. These findings vary between populations.[19–25] Similarly, some studies on adults and children have reported differences in foot length between the right and left sides, though results have varied.[25,26] In our study, no significant differences were found between genders or between the right and left sides.

Ultrasonography is a safe imaging method with no evidence of harm to the fetus and is widely used in studies for fetal measurements. Fetal foot length is an easily measurable parameter, particularly useful when parameters such as head-butt distance, biparietal diameter, head circumference, and femur length cannot be used to determine gestational age. Fetal foot length increases in a normally developing fetus and provides a reliable indicator for gestational age estimation.

In a prospective study conducted by Borgohain and George[27] on 334 Indian pregnant women using antenatal ultrasonography, the correlation coefficients of fetal foot length with head circumference, biparietal diameter, femur length, and abdominal circumference were 0.989, 0.985, 0.994, and 0.808, respectively. This demonstrates a high correlation between fetal foot length and these parameters, with all values being statistically significant

Table 5
Fetal studies on foot length (heel-to-long toe) measurements (mm).

Weeks	Our study (fetal cadaver)	Tuncer[16] (fetal cadaver)	Shah et al.[18] (ultrasound)	Chavan et al.[8] (ultrasound)	Majmudar et al.[4] (ultrasound)	Stevens et al.[6] (ultrasound)	Borgohain and George[27] ultrasound)	Sharma et al.[28] (ultrasound)
8		7.4±0						
9		8.55±0.21						
10		10.45±0.64						
11		14.3±2.69						
12		17.53±4.91						
13	21.6±0.6	22.28±10.32						
14	-	22.95±2.27				16.13	14.8±0	
15	20.6±0.52	26.98±1.98				18.95	20.25±2.9	
16	21.1±2.1	31.69±8.49	24			21.76	-	21.50±2.59
17	20.1±0.1	31.61±2.99	24.8			25.51	25.15±1.81	24.50±1.29
18	28.7±0.6	31.55±4.12	22			29.10	28.25±1.81	26.88±0.83
19	28.6±2	39.06±0.99	28.5			33.62	31.32±1.58	28.16±2.39
20	32±2.5	42.47±5.7	32			36.78	33.69±1.89	33.83±1.94
21	34.2±5.5	46.75±3.46	34			39.12	37.57±1.65	36.33±1.53
22	41.2±1.3	42.93±4.1	37			39.86	40.18±0.91	37.50±0.84
23	36.9±0.1	44.43±9.23	41				42.73±2.05	41.00±4.06
24	44.9±3.1	53.8±0	44				48.35±1.20	41.67±0.58
25	46.2±2.6	50.55±5	44		50		49.23±2.40	48.40±5.18
26	44.4±4.7	-	47		-		53.99±4.50	48.67±2.31
27	50.8±3.5	60.55±2.76	53	50±0	50		51.53±2.12	51.33±1.86
28	50.5±1.7	57.24±2.01	54	55±0	56		57.17±1.60	52.86±2.12
29	55.8±1.3	-	50	56.5±1.7	65		58.66±2.72	57.63±1.92
30	58.1±2.5	70.9±5.8	56	58.8±2.9	59		60.67±3.31	56.86±2.73
31	58.5±3.4	-	60	60±0	58		62.76±2.66	62.29±0.76
32	63.2±7.6	62.5±10.61	62	60.6±2	66		65.78±2.18	61.70±3.27
33	62±2.9	71.7±3.96	61	64.7±1.1	66		66.72±2.52	64.50±4.70
34	63.1±6.1	-	65	65.4±2.4	66		68.98±2.67	67.60±2.30
35	64.5±2.6	78±0	67	70±0	66		70.86±1.19	67.50±3.21
36	70.7±5.6	-	69	70±0	71		71.83±1.49	71.49±1.00
37	67.9±4.5	75.7±0	70	74.5±1.3			73.20±0.84	76.70±0.67
38	75.4±4.3		73	77±2.2				79.00±0.63
39	75.7±4.3		67	80±0.6				80.17±0.75
40	78.3±4.1			82.9±0.8				78.50±7.04

($p<0.001$). Similarly, in a prospective study by Sharma et al.,[28] conducted on 150 pregnant Indian women with gestational ages between 16 and 40 weeks (2020–2021), regression analysis was performed between known gestational age and fetal foot length using ultrasound. The study reported a strong correlation ($r=0.985$, $p<0.001$) between fetal foot length and gestational age, based on simple linear regression analysis.

A systematic review conducted in 2022, which analyzed 20 studies across Asia, North America, Africa, and

Pakistan, found that fetal foot length was highly correlated with gestational age in all included studies.[29] Additionally, Tuncer[16] and Shah et al.[18] demonstrated a strong correlation between foot length and gestational age in their studies on fetuses. Wong[30] reported that foot length showed a linear correlation with gestational age and other parameters, such as biparietal diameter, head circumference, femur length, abdominal circumference, and head-butt length, in fetuses between 10 and 16 weeks. Agnihotri et al.[1] also found a strong correlation between foot length and fetal age in a study conducted on fetal cadavers, with an r^2 value of 0.948 from linear regression analysis. In our study, we observed a similarly strong correlation between foot length and fetal age, with an r^2 value of 0.904. In addition to fetal foot length, we found that other foot parameters, such as toe length, toe and heel width, bimalleolar width, and the heights of the medial and lateral malleoli, also showed a strong correlation with gestational age (**Table 3**). The significant results of these additional foot parameters, along with fetal foot length, suggest that they can be used alongside foot length for more accurate gestational age estimation.

Our study has several limitations. Firstly, the small sample size is a notable limitation, which led to the use of a regression equation for gestational age in months rather than weeks. Additionally, the use of formaldehyde to fix the fetal cadavers, as well as storing them in formaldehyde, may have caused some tissue shrinkage. This factor should be considered when interpreting the study results. Furthermore, data collection was performed by a single observer, and intraobserver and interobserver reliability were not assessed. However, the parameters showed statistically significant correlations ($p<0.001$), and our results were consistent with findings from other studies. Our study is pioneering in its analysis of foot-related parameters beyond just fetal foot length. We presented more comprehensive data on fetal foot morphometry than previous studies, demonstrating that additional foot parameters, such as toe length, heel width, and bimalleolar width, can also be useful for estimating gestational age. This correlation between fetal foot morphometric data and gestational age can be particularly helpful in cases involving anomalies, such as fragmentation during abortion, anencephaly, hydrocephalus, and short limb dysplasia, where traditional measurements like head-butt length, head circumference, and femur length cannot be used. It is also valuable for determining gestational age after spontaneous abortion. Moreover, our findings suggest that foot and foot-related parameters can be useful for age assessment in premature babies and those receiving treatment in neonatal units, offering a practical and accessible method for age determination. The simple measurement of foot and related parameters could also be used to estimate gestational age for babies born outside of hospitals, without requiring a specialist. We suggest that the data obtained from our study will contribute significantly to future research in fields such as anatomy, radiology, obstetrics, perinatology, and fetopathology.

Acknowledgement

The authors sincerely thank those who donated their bodies to science so that anatomical research and teaching could be performed.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

AEC: project development, data collection, data analysis, manuscript writing; AD: project development, manuscript writing; KÖ: data analysis, manuscript editing; YK: manuscript editing.

Ethics Approval

Fetuses were obtained from the Obstetrics and Gynaecology Hospital with the permission of their families. Approval was obtained from the Süleyman Demirel University Faculty of Medicine Clinical Research Ethics Committee before the study (05/03/2019-86). All procedures performed in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Funding

None.

References

1. Agnihotri D, Dubey A, Singh D, Jethani SL. A study of correlation between anthropometric measurements of fetal limbs and gestational age of the fetus. National Journal of Clinical Anatomy 2019;8:27–31.
2. Pettker CM, Goldberg JD, El-Sayed YY, Copel JA. Methods for estimating the due date. Obstet Gynecol 2017;129:967–8.
3. Wyk LV, Smith J. Postnatal foot length to determine gestational age: a pilot study. J Trop Pediatr 2016;62:144–51.
4. Majmudar DK, Vaidya CV, Sanghrajka VJ. Accuracy of foetal foot length and femur/foot length ratio in usg estimation of gestational age. International Journal of Contemporary Medicine and Radiology 2019;4:B111–3.

5. Drey EA, Kang MS, McFarland W, Darney PD. Improving the accuracy of fetal foot length to confirm gestational duration. Obstet Gynecol 2005;105:773–8.
6. Stevens K, Elia J, Kaneshiro B, Salcedo J, Soon R, Tschann M. Updating fetal foot length to gestational age references: a chart review of abortion cases from 2012 to 2014. Contraception 2020; 101:10–3.
7. Kwon JY, Park IY, Wie JH, Choe S, Kim CJ, Shin JC. Fetal biometry in the Korean population: reference charts and comparison with charts from other populations. Prenat Diagn 2014;34:927–34.
8. Chavan N, Kothari R, Mhaske SN, Aher G. The correlation of foot length and gestational age. VIMS Health Science Journal 2019;6:74–6.
9. Adhvaryu M, Adhvaryu A, Rathod SP, Chauhan PR. A study of sonographic evaluation of fetal femur length for estimation of gestational age. International Journal of Anatomy and Research 2019; 7:6621–6.
10. Malas M, Desticioğlu K, Cankara N, Evcil E, Özgüner G. Fetal dönemde fetal yaşın belirlenmesi. Süleyman Demirel Üniversitesi Tıp Fakültesi Dergisi 2009;14:20–4.
11. Kalish RB, Thaler HT, Chasen ST, Gupta M, Berman SJ, Rosenwaks Z, Chervenak FA. First- and second-trimester ultrasound assessment of gestational age. Am J Obstet Gynecol 2004; 191:975–8.
12. Ziylan T, Murshid KA. An assessment of femur growth parameters in human fetuses and their relationship to gestational age. Turk J Med Sci 2003;33:27–32.
13. Domjanic J, Seidler H, Mitteroecker P. A combined morphometric analysis of foot form and its association with sex, stature, and body mass. Am J Phys Anthropol 2015;157:582–91.
14. Krauss I, Grau S, Mauch M, Maiwald C, Horstmann T. Sex-related differences in foot shape. Ergonomics 2008;51:1693–1709.
15. Mauch M, Grau S, Krauss I, Maiwald C, Horstmann T. Foot morphology of normal, underweight and overweight children. Int J Obes (Lond) 2008;32:1068–75.
16. Tuncer I. The development of the extremities of Turkish fetuses during the fetal period. International Journal of Medical and Health Research 2017;70–3.
17. Gebeşçe A, Uslu H, Keleş E, Demirdöven M, Tonbul A, Baştürk B, Yazgan H. Evaluation of very low birth weight infants in the neonatal intensive care unit of a university hospital. Dicle Medical Journal 2015;42:137–42.
18. Shah A, Lakshmi, Mallikarjunappa, Arafat H, Rb R, Magaluri P. Fetal gestational age estimation by fetal foot length measurement and fetal femur to foot length ratio in South Indian population-a prospective study. International Journal of Scientific Research 2019;8:56–8.
19. Xu M, Li JX, Hong Y, Wang L. Foot morphology in Chinese adolescents aged between 13 to 18 years varies by gender and age. Med Sci Monit 2019;25:938–45.
20. Tomassoni D, Traini E, Amenta F. Gender and age related differences in foot morphology. Maturitas 2014;79:421–7.
21. Chiroma SM, Philip J, Attah OO, Dibal NI. Comparison of the foot height, length, breadth and foot types between males and females Ga'anda people, Adamawa, Nigeria. IOSR Journal of Dental and Medical Sciences 2015;14:89–93.
22. Krishan K, Kanchan T, Passi N, DiMaggio JA. Sexual dimorphism in foot length ratios among North Indian adolescents. J Forensic Leg Med 2015;36:96–101.
23. Saghazadeh M, Kitano N, Okura T. Gender differences of foot characteristics in older Japanese adults using a 3D foot scanner. J Foot Ankle Res 2015;8:29.
24. Lee YC, Wang MJ. Taiwanese adult foot shape classification using 3D scanning data. Ergonomics 2015;58:513–23.
25. Kağnıcıoğlu CH, Altay E. Türkiye'de ayakkabı tasarımında kullanılan ölçüler ile Türk insanının antropometrik ayak ölçülerinin karşılaştırılması: 0–3 yaş bireyler üzerinden bir analiz. Fırat University Journal of Science 2013;25:77–85.
26. Asadujjaman M, Al Noman SN, Molla MBA. Stature estimation from foot anthropometric measurements in Bangladeshi population. Ir J Med Sci 2020;189:365–72.
27. Borgohain L, George CRA. Ultrasonographic correlation of fetal foot length and gestational age (GA) in Indian population. International Journal Dental and Medical Sciences Research 2021; 3:1622–31.
28. Sharma V, Saxena R, Gaur P. Fetal foot length for assessment of gestational age: a cross sectional study. International Journal of Reproduction, Contraception, Obstetrics and Gynecology 2021; 10:3153–7.
29. Rubab N, Anjum, MN, Ahmed M, Fatima M. Estimation of gestational age from fetal foot length measurement. Pakistan Biomedical Journal 2022;5:380–4.
30. Wong HS. A revisit of the fetal foot length and fetal measurements in early pregnancy sonography. Int J Womens Health 2017;9:199–204.

ORCID ID:
A. E. Canbaloğlu 0000-0002-7560-7865;
A. Dursun 0000-0003-4568-8761;
K. Öztürk 0000-0002-5552-8684;
Y. Kastamoni 0000-0002-3504-5853

Correspondence to: Abdurrahim Eyüp Canbaloğlu
Department of Physiotheraphy and Rehabilitation,
Faculty of Health Sciences, Istinye University, Istanbul, Türkiye
Phone: +90 534 649 23 22
e-mail: abdurrahim.eyup@gmail.com

Conflict of interest statement: No conflicts declared.

 How to cite this article: Canbaloğlu AE, Dursun A, Öztürk K, Kastamoni Y. Correlation between morphometry of fetal foot and gestational age: a cadaver study. Anatomy 2024;18(2):51–60.