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# THE MORPHOMETRY OF THE FOOT IN FETAL HUMAN CADAVERS

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**Abstract:** Foot and associated formations have important functions in the musculoskeletal system. Recognition of normal parameter values related to the fetus in fetal development is important for the derivation of fetal growth curves, as each society determines its own normal values for its own population. There are limited number of studies on foot morphology in particular. Therefore, the aim of our study was to determine the measurements of morphological characteristics in human fetuses depending on gestational age, gender and side. Our study was carried out on 30 fetuses. Bilateral acropodian-pternion measurement (AP), the pternion measurement of 2nd, 3rd, 4th, 5th fingers (2P, 3P, 4P, 5P), metatarsaltibia-metatarsalfibula measurement (MT-MF), lengths of the 1., 2., 3rd, 4th, 5th toes (1TL, 2TL, 3TL, 4TL, 5TL), malleolus width (MW), proximal metatarsal width (PMW), distal metatarsal width (DMW), lateral forefoot length ( LFL), the length of the sole of the foot with the medial malleol (MMFL), the length of the sole of the foot (LMFL) with the lateral malleol, and the length of the lower leg (LLL) were measured on all fetuses. Furthermore, the foot index (FI), lower limb length (LL), and leg index (LI) values were also calculated. The difference between trimesters was found statistically significant for all parameters measured except bilateral AI, and right BI measurements. All parameters except left LMFL at 2nd trimester and PMW at 3rd trimester were higher in female fetuses. However, the difference between genders was not statistically significant ($p>0.05$). The difference between trimesters was significant for all measurements. Furthermore, a correlation was detected between many parameters. In our study, it was found that foot measurements in fetal cadavers did not change with gender, but increased as the week of gestation increased. It was concluded that the data obtained from our study would be useful for further studies as well as recognition of fetal foot anatomy in obstetrics, perinatology, fetopathology, and pediatric surgery.

**Keywords:** Foot, Aborted fetus, Gestational age

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## 1. Introduction

The structure of the foot which has important tasks in carrying out body weight-bearing, walking, and running displacement functions is special. The process of embryonic development is completed and the fetal period begins at the end of the 8th week. In embryological development, developments such as the musculoskeletal system originating from the mesoderm layer, the formation of fingers and toes with the beginning of fetal circulation, and ossification in the 3rd month are observed (Whirworth et al., 2015; Dudek, 2016; Rhades, 2017). The foot which completes its development during fetal period like other organs creates a wide support surface with vertical shape of the legs and higher number of bones on the distal side. The foot fulfills many biomechanical functions in the musculoskeletal system such as carrying body weight, absorbing shocks, walking, balancing, standing on one or both feet jumping, and squatting due to this anatomical and morphological order (Dere, 2018). A complex and excellent anatomic formation appears in order to fulfill these functions. In fact, it is obvious how complex it is, considering that 25% of the bones that make up the foot human skeleton, called pedis are considered. However, the foot provides integrity with 26 bones, 33 joints, 33 muscles, as well as many tendons, ligaments, blood vessels, nerves, skin, and soft tissues (Xiao et al., 2012).

The skeleton forming the foot is divided into three parts the tarsal bone, the metatarsal bone, and the digital bone. According to another classification, the foot is divided into three parts: the hindfoot consisting of talus and calcaneus bones, the midfoot consisting of the navicular bone, the cuboid bone, and the cuneiform bone, and the forefoot consisting of the metatarsal bone and the phalangeal bone (Snell, 2004; Akman et al., 2017).

The defects and imbalances of these structures would lead to deterioration of the foot structure and stability. The morphometry of the foot and foot-related formations

always maintains this importance in terms of surgery and physical therapy, as well as the branch of anatomy due to important functional features. Furthermore, the foot morphometry during the fetal period would be useful for further studies and also provide additional information to the procedures of obstetricians, perinatologists, fetopathologists, and pediatric surgeons (Canbaloğlu, 2019). However, there is a number of studies on feet of fetal cadavers in the literature. Therefore, the aim of this study was to determine the measurements of morphological characteristics in human fetuses depending on gestational age, gender, and side.

## 2. Materials and Methods

Fetal cadavers were fixed by immersion method in 10% formalin solution, and their ages (in weeks) were determined according to the (Hensinger, 1992) Crown-Rump Length (CRL) peak-to-rump distance lengths of the fetuses according to the age determination method of Polin and Fox.

The study was performed on 23 fetal cadavers the 3rd trimester ($26^{th}$ to $37^{th}$ gestational weeks) and 7 fetal cadavers in the 2nd trimester ($12^{th}$ to $25^{th}$ gestational weeks) without any morphological malformations, by examining the dysmorphic features of all fetuses in the collection. Measurements performed were obtained through an electronic caliper (Mitutoyo; Japan). Morphometric measurements were done after dissection with the same electronic caliper and the measurement sites were photographed through a camera (Canon D1000; Tokyo, Japan) during the study. Bilateral acropodian-pternion measurement (AP), the pternion measurement of $2^{nd}$, $3^{rd}$, $4^{th}$, $5^{th}$ fingers (2P, 3P, 4P, 5P), metatarsaltibia-metatarsalfibula measurement (MT-MF), lengths of the 1., 2 ., $3r^{d}$, $4^{th}$, $5^{th}$ toes (1TL, 2TL, 3TL, 4TL, 5TL), malleolus width (MW), proximal metatarsal width (PMW), distal metatarsal width (DMW), lateral forefoot length ( LFL), the length of the sole of the foot with the medial malleol (MMFL), the length of the sole of the foot (LMFL) with the lateral malleol, and the length of the lower leg (LLL) were measured on all fetuses. Furthermore, the foot index (FI), lower limb length (LL), and leg index (LI) values were also calculated (Figure 1-3).

### 2.1. Statistical Analysis

The data obtained were assessed through SPSS 21.0 (IBM, New York, USA) package program. Data were analyzed descriptively (mean, standard deviation, maximum and minimum values, percentages) and quantitatively. "Independent Sample T Test" was used to compare fetal cadavers according to gender, and "Paired Sample T Test" was used to compare right and left sides. Furthermore, the association between the parameters was detected through the correlation test. A regression analysis was also done between the measurements. The significance level was taken as $P<0.05$ for statistical analysis.

## 3. Results

In our study, morphometric measurements were taken and evaluated by a total of 30 fetal cadavers including 19 (63.3%) males and 11 (36.7%) females with bilateral foot measurements. Fetal cadavers including 23 fetuses (13 males, 10 females) between $14^{th}$ and $26^{th}$ gestational age at $2^{nd}$ trimester and 7 fetuses (6 males, 1 female) between $27^{th}$ and $40^{th}$ gestational age at $3^{rd}$ trimester were included in our study according to the crown-rump lengths (CRLs).

In this present study, the measurement parameters of the $2^{nd}$ and $3^{rd}$ trimesters were shown bilaterally. A statistically significant difference was detected between trimesters in the authors of this study measurement parameters except bilateral AI measurement and right BI measurement ($P<0.05$) (Table 1).

The distribution of the measurements of the $2^{nd}$ and $3^{rd}$ trimesters by gender is shown in our study. All parameters except left LMFL in the $2^{nd}$ trimester and PMW the $3^{rd}$ trimester were higher in female fetuses. However, the difference between the genders was not statistically significant ($P>0.05$). A statistically significant difference was found between trimesters in all measurements ($P<0.05$) (Table 2).

Correlation of the right and left data was done. Furthermore, a correlation was detected between many parameters (Tables 3 and 4). AP, MT-MF and height reference intervals were determined through simple regression analysis (Figure 4, 5). Equations are presented below (equation 1, 2, 3 and 4).

$$LAP\ (mm) = 1.552 \times Length - 2.484 \quad (1)$$

$$RAP\ (mm) = 1.486 \times Length - 0.992 \quad (2)$$

$$RMT\text{-}MF\ (mm) = 0.645 \times Length - 1.754 \quad (3)$$

$$LMT\text{-}MF\ (mm) = 0.676 \times Length - 1.946 \quad (4)$$

**Table 1.** Comparison of left / right 2nd and 3rd trimester

| | 2.Trimester(n=23) | | | 3.Trimester(n=7) | | | |
|---|---|---|---|---|---|---|---|
| Parameters | Min. | Max. | Mean±SD | Min. | Max. | Mean±SD | P |
| | 130 | 304 | 214.2±42 | 300 | 410 | 371.7±34.9 | 0.000 |
| LAP/RAP | 18.87/20.51 | 45.55/45.5 | 30.64±6.91/30.47±6.1 | 43.16/41.11 | 64.82/63.9 | 55.57±7.31/55.41±7.63 | 0.000/0.000 |
| L2P/R2P | 19.95/21.32 | 45.63/44.57 | 30.65±6.64/30.77±5.62 | 43.85/40.09 | 62.64/63.04 | 55.22±6.41/55.32±7.8 | 0.000/0.000 |
| L3P/R3P | 11.01/20.3 | 45.72/43.18 | 28.58±7.5/29.63±5.49 | 43.07/40.34 | 61.77/60.9 | 53.86±6.33/53.85±6.9 | 0.000/0.000 |
| L4P/R4P | 19.2/19.61 | 43.75/41.36 | 28.55±6.27/28.51±5.33 | 41.4/39.34 | 59.49/58.95 | 51.35±6.27/51.64±6.48 | 0.000/0.000 |
| L5P/R5P | 16.94/18.14 | 41.63/39 | 26.49±6.05/26.59±5.09 | 23.82/35.91 | 57.82/55.88 | 45.03±11.2/47.99±6.71 | 0.004/0.000 |
| LMTMF/RMTMF | 8.02/7.5 | 21.37/17.74 | 12.44±3/11.9±2.41 | 17.7/16.48 | 31.09/29.23 | 23.42±4.92/22.7±4.04 | 0.001/0.000 |
| LFI/RFI | 29.80/32.15 | 49.43/45.63 | 40.78±4.43/39.18±3.73 | 28.84/30.69 | 48.742/49.31 | 42.3±7.14/41.19±6.26 | 0.611/0.444 |
| LMW/RMW | 5.57/5.22 | 17.2/16.18 | 9.63±2.62/9.29±2.56 | 16.17/15.14 | 23.47/20.95 | 18.32±2.44/17.31±1.97 | 0.000/0.000 |
| LPMW/RPMW | 6.35/6.31 | 18.99/17.27 | 10.67±2.9/9.53±2.39 | 16.03/15.2 | 25.44/23.43 | 19.1±4.07/18.88±3.32 | 0.001/0.000 |
| LDMW/RDMW | 7.12/6.65 | 19.85/18.68 | 12.1±3.16/11.66±2.58 | 17.8/17.36 | 29.33/27.06 | 23.3±4.02/20.88±3.62 | 0.000/0.000 |
| LLFL/RLFL | 13.39/13.51 | 33.7/34.58 | 21.84±5.17/22.47±4.77 | 36.8/32.36 | 48.88/49.07 | 42.46±5.19/40.38±6.62 | 0.000/0.000 |
| LMFL/RMFL | 16.5/16 | 41.14/39.57 | 25.78±6.43/25.16±5.54 | 36.57/33.14 | 54.67/50.9 | 45.47±6.54/44.53±6.77 | 0.000/0.000 |
| LMLFL/RMLFL | 5.28/4.69 | 15.57/16.72 | 9.12±2.91/9.02±3.15 | 12.26/12.75 | 26.43/23.05 | 19.56±4.58/16.99±4.77 | 0.001/0.004 |
| LMMFLRMMFL | 5.62/5 | 16.68/17.53 | 9.57±2.74/9.5±3.14 | 11.87/10.42 | 25.04/24.32 | 19.04±4.39/16.49±5.3 | 0.001/0.012 |
| L1TL/R1TL | 4.71/4.66 | 12.96/11.33 | 7.81±2.05/7.29±1.62 | 11.12/9.2 | 20.47/16.7 | 15.02±3.45/13.83±2.59 | 0.001/0.000 |
| L2TL/R2TL | 4.63/5.07 | 11.2/11.21 | 7.29±1.66/7.22±1.45 | 9.85/7.5 | 16.17/14.87 | 12.97±2.36/12.13±2.5 | 0.000/0.001 |
| L3TL/R3TL | 4.47/4.4 | 9.48/11.38 | 6.53±1.46/6.6±1.52 | 8.63/7.34 | 15.25/13.73 | 11.94±2.36/11.14±1.99 | 0.001/0.000 |
| L4TL/R4TL | 4.16/4.32 | 9.16/10.37 | 6.09±1.37/6.16±1.36 | 8.63/7.26 | 13.45/13.73 | 11.29±1.95/10.4±1.91 | 0.000/0.001 |
| L5TL/R5TL | 3.02/3.37 | 8.38/9.82 | 5.28±1.3/5.5±1.34 | 6.79/5.44 | 12.7/82.39 | 9.39±1.89/9.17±2.39 | 0.001/0.006 |
| LLLRLL | 3.26/24.77 | 54.73/55.16 | 35.38±10.37/37.77±7.45 | 55.5/53.16 | 75.81/169.22 | 64.69±8.02/67.82±9.91 | 0.000/0.000 |
| LFL/RFL | 39.86/56.73 | 110.59/115.35 | 79.21±17.53/80.97±15 | 115.21/108.13 | 152.62 | 135.2±14.13/135.96±19.52 | 0.000/0.000 |
| LLI/RLI | 8.18/42.63 | 49.49/49.27 | 43.89±8.54/46.57±2.01 | 44.70/47.70 | 50.32 | 47.79±1.72/49.88±1.82 | 0.050/0.002 |

R= right, L= left, N= number of individuals, AP= bilateral acropodian-pternion measurement, 2P= the pternion measurement of 2nd, 3P= the pternion measurement of 3rd, 4P= the pternion measurement of 4th, 5P= the pternion measurement of 5th, MT-MF= metatarsal tibia-metatarsal fibula measurement, 1TL= lengths of the 1, 2TL= lengths of the 2nd, 3TL= lengths of the 3rd, 4TL= lengths of the 4th, 5TL= lengths of the 5th, MW= malleolus width, PMW= proximal metatarsal width, DMW= distal metatarsal width, LFL= lateral forefoot length, MMFL= the length of the sole of the foot with the medial malleol, LMFL= the length of the sole of the foot with the lateral malleol, LLL= the length of the lower leg; FI= the foot index, LL= lower limb length, LI= leg index.

**Table 2.** Distribution of the measurements of the 2nd and 3rd trimesters by gender

| | 2.Trimester(n=23) | | | 3.Trimester(n=7) | | | |
|---|---|---|---|---|---|---|---|
| Parameters | Min. | Max. | Mean±SD | Min. | Max. | Mean±SD | P |
| | 13.00 | 29.50 | 21.33±4.63 | 18 | 30.4000 | 21.53±3.8 | 0.911 |
| Length | 18.87/20.51 | 44.92/43.31 | 29.47±7.03/29.59±5.72 | 21.92/21.95 | 45.55/45.5 | 32.16±6.8/31.62±6.69 | 0.366/0.453 |
| LAP/RAP | 19.95/21.32 | 44.66/43.15 | 29.8±6.91/29.86±5.43 | 22.33/22.86 | 45.63/44.5700 | 31.76±6.46/31.94±5.93 | 0.493/0.398 |
| L2P/R2P | 19.95/20.30 | 43.06/41.30 | 28.2±6.29/28.76±5.3 | 11.01/21.51 | 45.7200/43.1800 | 29.08±9.18/30.77±5.79 | 0.798/0.403 |
| L3P/R3P | 19.20/19.61 | 41.67/39.59 | 27.68±6.4/27.73±5.11 | 21.07/19.80 | 43.7500/41.3600 | 29.67±6.26/29.52±5.71 | 0.464/0.445 |
| L4P/R4P | 16.94/18.14 | 38.06/36.99 | 25.58±5.99/25.75±4.86 | 19.53/18.44 | 41.6300/39.0000 | 27.66±6.24/27.67±5.43 | 0.430/0.391 |
| L5P/R5P | 8.02/7.50 | 17.18/16.54 | 11.84±2.61/11.35±2.15 | 9.03/8.01 | 21.3700/17.7400 | 13.23±3.42/12.62±2.65 | 0.299/0.233 |
| LMTMF/RMTMF | 29.802/32.15 | 49.431/45.63 | 40.61±5.21/38.55±4.13 | 35.85/35.79 | 46.91500/44.6000 | 41±3.44/39.99±3.16 | 0.834/0.355 |
| LFI/RFI | 5.57/5.22 | 13.21/14.10 | 9.15±2.17/8.79±2.17 | 5.60/5.47 | 17.2000/16.1800 | 10.25±3.11/9.94±2.97 | 0.356/0.318 |
| LMW/RMW | 6.35/6.31 | 14.27/13.23 | 10.08±2.43/8.58±1.88 | 6.69/8.23 | 18.9900/17.2700 | 11.45±3.4/10.77±2.51 | 0.295/0.035 |
| LPMW/RPMW | 7.12/6.65 | 19.75/16.86 | 11.8±3.25/11.03±2.37 | 8.96/9.00 | 19.8500/18.6800 | 12.5±3.17/12.48±2.73 | 0.609/0.200 |
| LDMW/RDMW | 13.39/17.38 | 32.14/31.46 | 21.34±5.14/22.14±4.26 | 14.97/13.51 | 33.7000/34.5800 | 22.49±5.42/22.89±5.57 | 0.612/0.727 |
| LLFL/RLFL | 16.50/17.94 | 41.14/33.10 | 25.59±6.64/24.89±4.54 | 18.66/16.00 | 39.5600/39.1700 | 26.04±6.5/25.5±6.87 | 0.874/0.811 |
| LMFL/RMFL | 5.33/4.69 | 13.80/13.92 | 9.19±2.81/8.73±2.62 | 5.28/6.00 | 15.5700/16.7200 | 9.03±3.18/9.4±3.85 | 0.901/0.644 |
| LMLFL/RMLFL | 5.62/5.00 | 14.34/15.02 | 9.33±2.62/9.24±2.79 | 5.89/5.77 | 16.6800/17.5300 | 9.88±2.99/9.85±3.67 | 0.648/0.669 |
| LMMFL/RMMFL | 4.71/4.66 | 11.02/11.33 | 7.48±1.9/7.17±1.68 | 5.13/4.97 | 12.9600/11.1100 | 8.24±2.26/7.44±1.62 | 0.407/0.695 |
| L1TL/R1TL | 4.63/5.07 | 10.38/10.72 | 6.8±1.57/7.1±1.41 | 5.66/5.40 | 11.2000/11.2100 | 7.93±1.64/7.37±1.56 | 0.111/0.680 |
| L2TL/R2TL | 4.65/5.02 | 9.48/9.36 | 6.15±1.38/6.51±1.32 | 4.47/4.40 | 9.2500/11.3800 | 7.04±1.47/6.71±1.82 | 0.157/0.766 |
| L3TL/R3TL | 4.32/4.74 | 9.16/8.45 | 5.74±1.28/6±1.2 | 4.16/4.32 | 8.5100/10.3700 | 6.54±1.43/6.37±1.58 | 0.184/0.545 |
| L4TL/R4TL | 3.02/4.17 | 6.46/7.76 | 4.96±1.15/5.24±0.99 | 3.65/3.37 | 8.3800/9.8200 | 5.69±1.42/5.84±1.7 | 0.199/0.338 |
| L5TL/R5TL | 3.26/24.77 | 54.73/53.03 | 33.9±12.63/36.7±7.47 | 26.39/26.52 | 48.6300/55.1600 | 37.29±6.57/39.17±7.58 | 0.416/0.446 |
| LLL/RLL | 39.86/56.73 | 110.59/112.71 | 77.89±21.1/78.6±14.94 | 59.56/62.21 | 101.8900/115.3500 | 80.94±12.34/84.05±15.28 | 0.670/0.402 |
| LFL/RFL | 8.18/43.66 | 49.49/49.27 | 42.32±11.18/46.59±1.9 | 42.15/42.62 | 48.2809/48.9039 | 45.94±1.88/46.53±2.25 | 0.272/0.946 |
| LLI/RLI | 13.00 | 29.50 | 21.33±4.63 | 18 | 30.4000 | 21.53±3.8 | 0.911 |

R= right, L= left, N= number of individuals, AP= bilateral acropodian-pternion measurement, 2P= the pternion measurement of 2nd, 3P= the pternion measurement of 3rd, 4P= the pternion measurement of 4th, 5P= the pternion measurement of 5th, MT-MF= metatarsal tibia-metatarsal fibula measurement, 1TL= lengths of the 1, 2TL= lengths of the 2nd, 3TL= lengths of the 3rd, 4TL= lengths of the 4th, 5TL= lengths of the 5th, MW= malleolus width, PMW= proximal metatarsal width, DMW= distal metatarsal width, LFL= lateral forefoot length, MMFL= the length of the sole of the foot with the medial malleol, LMFL= the length of the sole of the foot with the lateral malleol, LLL= the length of the lower leg; FI= the foot index, LL= lower limb length, LI= leg index.

**Table 3.** Correlation of left measurement data in and all fetal cadavers

| | | Lenght | LAP | L2P | L3P | L4P | L5P | LMTMF | LFI | LMW | LPMW | LDMW | LLFL | LMFL | LMLFL | LMMFL | LLL | LFL | LLI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LLI | r | .345 | .330 | .341 | .309 | .355 | .343 | .321 | .093 | .296 | .276 | .319 | .347 | .344 | .253 | .334 | .588** | .405* | 1 |
| | p | .062 | .075 | .065 | .096 | .054 | .063 | .084 | .624 | .112 | .139 | .086 | .060 | .063 | .178 | .071 | .001 | .027 | |
| LFL | r | .940** | .945** | .950** | .900** | .950** | .814** | .846** | -.032 | .911** | .824** | .901** | .919** | .941** | .873** | .893** | .971** | 1 | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .867 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | |
| LLL | r | .926** | .933** | .940** | .888** | .943** | .824** | .845** | .000 | .898** | .819** | .890** | .920** | .934** | .864** | .901** | 1 | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .999 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | | |
| LMMFL | r | .908** | .961** | .959** | .916** | .958** | .820** | .889** | .047 | .947** | .890** | .936** | .941** | .952** | .970** | 1 | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .807 | .000 | .000 | .000 | .000 | .000 | .000 | | | | |
| LMLFL | r | .897** | .953** | .945** | .912** | .942** | .810** | .873** | .015 | .932** | .881** | .910** | .934** | .945** | 1 | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .937 | .000 | .000 | .000 | .000 | .000 | | | | | |
| LMFL | r | .938** | .970** | .970** | .948** | .966** | .811** | .839** | -.106 | .939** | .842** | .894** | .964** | 1 | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .576 | .000 | .000 | .000 | .000 | | | | | | |
| LLFL | r | .948** | .952** | .958** | .937** | .957** | .816** | .876** | .050 | .949** | .865** | .916** | 1 | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .791 | .000 | .000 | .000 | | | | | | | |
| LDMW | r | .950** | .953** | .954** | .905** | .960** | .882** | .966** | .256 | .954** | .960** | 1 | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .172 | .000 | .000 | | | | | | | | |
| LPMW | r | .885** | .917** | .910** | .864** | .922** | .905** | .975** | .323 | .948** | 1 | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .082 | .000 | | | | | | | | | |
| LMW | r | .936** | .967** | .965** | .932** | .969** | .903** | .950** | .156 | 1 | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .410 | | | | | | | | | | |
| LFI | r | .107 | .014 | .035 | .058 | .071 | .291 | .391* | 1 | | | | | | | | | | |
| | p | .572 | .940 | .856 | .759 | .711 | .119 | .032 | | | | | | | | | | | |
| LMTMF | r | .909** | .917** | .919** | .885** | .933** | .941** | 1 | | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | | | | | | | | | | | | |
| L5P | r | .872** | .872** | .887** | .847** | .903** | 1 | | | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | | | | | | | | | | | | | |
| L4P | r | .969** | .993** | .998** | .950** | 1 | | | | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | | | | | | | | | | | | | | |
| L3P | r | .933** | .947** | .948** | 1 | | | | | | | | | | | | | | |
| | p | .000 | .000 | .000 | | | | | | | | | | | | | | | |
| L2P | r | .968** | .995** | 1 | | | | | | | | | | | | | | | |
| | p | .000 | .000 | | | | | | | | | | | | | | | | |
| LAP | r | .958** | 1 | | | | | | | | | | | | | | | | |
| | p | .000 | | | | | | | | | | | | | | | | | |
| Lenght | r | 1 | | | | | | | | | | | | | | | | | |
| | p | | | | | | | | | | | | | | | | | | |

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed). R= right, L= left, N= number of individuals, AP= bilateral acropodian-pternion measurement, 2P= the pternion measurement of 2nd, 3P= the pternion measurement of 3rd, 4P= the pternion measurement of 4th, 5P= the pternion measurement of 5th, MT-MF= metatarsal tibia-metatarsal fibula measurement, 1TL= lengths of the 1, 2TL= lengths of the 2nd, 3TL= lengths of the 3rd, 4TL= lengths of the 4th, 5TL= lengths of the 5th, MW= malleolus width, PMW= proximal metatarsal width, DMW= distal metatarsal width, LFL= lateral forefoot length, MMFL= the length of the sole of the foot with the medial malleol, LMFL= the length of the sole of the foot with the lateral malleol, LLL= the length of the lower leg; FI= the foot index, LL= lower limb length, LI= leg index.

**Table 4.** Correlation of right measurement data in and all fetal cadaver

| | | Lenght | RAP | R2P | R3P | R4P | R5P | RMTMF | RFI | RMW | RPMW | RDMW | RLFL | RMFL | RMLFL | RMMFL | RLL | RLI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RLI | r | .559** | .596** | .608** | .616** | .623** | .612** | .549** | .143 | .574** | .473** | .528** | .638** | .671** | .441* | .425* | .662** | 1 |
| | p | .001 | .001 | .000 | .000 | .000 | .000 | .002 | .450 | .001 | .008 | .003 | .000 | .000 | .015 | .019 | .000 | |
| RLL | r | .932** | .978** | .983** | .985** | .985** | .986** | .937** | .111 | .950** | .908** | .926** | .979** | .971** | .871** | .846** | 1 | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .558 | .000 | .000 | .000 | .000 | .000 | .000 | .000 | | |
| RMMFL | r | .816** | .817** | .831** | .827** | .832** | .835** | .816** | .158 | .843** | .793** | .799** | .860** | .829** | .926** | 1 | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .406 | .000 | .000 | .000 | .000 | .000 | .000 | | | |
| RMLFL | r | .825** | .863** | .872** | .864** | .861** | .862** | .841** | .136 | .837** | .824** | .791** | .876** | .880** | 1 | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .473 | .000 | .000 | .000 | .000 | .000 | | | | |
| RMFL | r | .899** | .956** | .963** | .964** | .963** | .959** | .886** | .034 | .915** | .860** | .855** | .964** | 1 | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .856 | .000 | .000 | .000 | .000 | | | | | |
| RLFL | r | .923** | .960** | .966** | .970** | .973** | .974** | .934** | .134 | .941** | .896** | .909** | 1 | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .481 | .000 | .000 | .000 | | | | | | |
| RDMW | r | .923** | .939** | .938** | .942** | .945** | .951** | .969** | .286 | .964** | .965** | 1 | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .125 | .000 | .000 | | | | | | | |
| RPMW | r | .915** | .938** | .936** | .939** | .941** | .944** | .959** | .253 | .943** | 1 | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .177 | .000 | | | | | | | | |
| RMW | r | .940** | .951** | .949** | .953** | .958** | .960** | .956** | .224 | 1 | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | .000 | .234 | | | | | | | | | |
| RFI | r | .203 | .059 | .080 | .097 | .119 | .117 | .376* | 1 | | | | | | | | | |
| | p | .282 | .757 | .675 | .609 | .530 | .540 | .041 | | | | | | | | | | |
| RMTMF | r | .936** | .942** | .944** | .949** | .955** | .958** | 1 | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | .000 | | | | | | | | | | | |
| R5P | r | .948** | .995** | .997** | .998** | .999** | 1 | | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | .000 | | | | | | | | | | | | |
| R4P | r | .952** | .993** | .997** | .999** | 1 | | | | | | | | | | | | |
| | p | .000 | .000 | .000 | .000 | | | | | | | | | | | | | |
| R3P | r | .948** | .995** | .998** | 1 | | | | | | | | | | | | | |
| | p | .000 | .000 | .000 | | | | | | | | | | | | | | |
| R2P | r | .939** | .996** | 1 | | | | | | | | | | | | | | |
| | p | .000 | .000 | | | | | | | | | | | | | | | |
| RAP | r | .937** | 1 | | | | | | | | | | | | | | | |
| | p | .000 | | | | | | | | | | | | | | | | |
| Lenght | r | 1 | | | | | | | | | | | | | | | | |
| | p | | | | | | | | | | | | | | | | | |

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed). R= right, L= left, N= number of individuals, AP= bilateral acropodian-pternion measurement, 2P= the pternion measurement of 2nd, 3P= the pternion measurement of 3rd, 4P= the pternion measurement of 4th, 5P= the pternion measurement of 5th, MT-MF= metatarsal tibia-metatarsal fibula measurement, 1TL= lengths of the 1, 2TL= lengths of the 2nd, 3TL= lengths of the 3rd, 4TL= lengths of the 4th, 5TL= lengths of the 5th, MW= malleolus width, PMW= proximal metatarsal width, DMW= distal metatarsal width, LFL= lateral forefoot length, MMFL= the length of the sole of the foot with the medial malleol, LMFL= the length of the sole of the foot with the lateral malleol, LLL= the length of the lower leg; FI= the foot index, LL= lower limb length, LI= leg index.


**Figure 1.** 1-5. Acropodian-pternion measurements (AP1= 1st finger acropodian-pternion measurement, AP2= 2nd 1st finger acropodian-pternion measurement, AP3= 1st finger acropodian-pternion measurement, AP4: 1st finger acropodian-pternion measurement, AP5= 1st finger acropodian-pternion measurement).


**Figure 2.** 1-5. finger-pternion measurement (F1= 1st finger length, F2= 1st finger length, F3= 1st finger length, F4= 1st finger length, F5= 1st finger length).

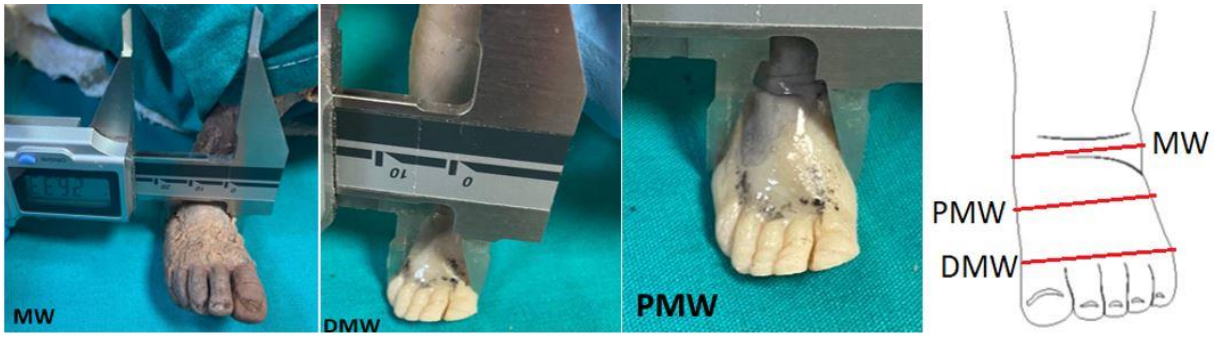


**Figure 3.** Foot widths (MW= malleolus width, PMW= proximal metatarsal width, DMW= distal metatarsal width).

## 4. Discussion

The morphological structure of 30 fetal cadavers were assessed in our study, and the differences between morphological measurements were investigated depending on the gestational age, gender, and side.

The foot also plays an important role in supporting the body statically in addition to being a basic structure that contributes to movements dynamically. Climate changes, hereditary factors, physical activity level, and nutrition affect the shaping and development of the foot. (Bek, 2018). Evaluation of fetal development is important in prenatal diagnosis for pediatricians in order to perform the surgical procedures required by providing information about skeletal system anomalies and estimating the length of the gestation period (Wyk, 2016; Wong, 2017; Geldenhuys et al., 2017). When we searched the literature, there was a limited number of studies on the foot morphology of the fetus; therefore, we evaluated the foot morphology of the fetus in our study.

It has been reported that investigated the association between the foot length and gestational age on 5,372 single fetuses between 15$^{th}$ and 27$^{th}$ gestational age (Meirowitz et al., 2000). Three hundred and fifty-five fetuses were detected below the 10th percentile among 586 fetuses which are smaller for gestational age. In the foot length nomogram, it was determined that 219 of 744 fetuses were above the 90$^{th}$ percentile in the growth curve in the foot lengths taken from fetuses larger for gestational age. It was emphasized in the study above that fetal foot length may be affected especially in rapid growth situations. Similar to the study conducted by Meirowitz et al. (2000) showed correlation between the foot length and gestational age in our study.

It has been reported that used early ultrasonography and fetal foot length in 69 fetal autopsies in their study and compared the duration of pregnancy (Geldenhuys et al., 2017). A higher correlation was detected between the gestation period calculated in the first ultrasonography scan and the calculation made on the fetal foot length. The evaluation of the foot morphology on fetal cadavers (except for left PMW, left DMW in male fetuses, left LLL, left 1 TL, left PMW, and left MW in female fetuses) of our study revealed no statistically significant difference as a result of the evaluation of fetal foot measurements according to gender. There was a significant difference between 2$^{nd}$ (the 2$^{nd}$) and 3$^{rd}$ trimesters when we evaluate according to the gestational age.

It has been reported that evaluated fetal measurements related to foot length at 10$^{th}$ to 16$^{th}$ gestational age under antenatal ultrasound (Wong, 2017). Forty-seven scans were performed in the study above; fetal measurements of women between the 10$^{th}$ and 16$^{th}$ gestational age who had their routine antenatal care were examined and fetal measurements and measurement rates, and their association with foot length were examined. Wong (2017) stated that the correlation between fetal foot length and fetal bi-parietal diameter, head circumference, abdominal circumference, femur length was better than the correlation between head-rump measurement. Consequently, Wong (2017) determined that fetal foot length is a precise estimation of early gestational age and the correlation between foot length and other fetal measurements is better when compared to head-rump measurement. It has been aimed to evaluate the correlation between fetal foot length and gestational age, to develop a nomogram, and the association between fetal foot length and femur length (Joshi et al., 2011). The fetal foot length was taken from the skin margin above the calcaneus to the distal tip of the longest toe (first or second toe) at the plantar or sagittal view. Joshi obtained a nomogram for fetal foot length. Joshi et al., (2011) found a positive correlation between foot length and gestational age, and between foot length and femur length. A positive correlation was found in our data detected in the study similar to the studies of Wong (2017).

It has been aimed to obtain the normal values of the development and morphology of the foot (Tuncer, 2017). Tuncer (2017) used a total of 107 human fetuses including 50 males and 57 females between 6 and 7 gestational age without any anomaly or pathology. Tuncer (2017) divided the fetuses into three different trimester groups and found significant differences between these groups. However, it was stated that there was no significant difference between the genders in all foot measurements ($P>0.05$), and there was a significant positive correlation between the gestational age and foot measurements ($P<0.001$). It has been aimed to determine

fetal age according to head-rump distance, head circumference, biparietal diameter, femur length and foot length during the fetal period (Malas et al., 2007). Malas et al. (2007) found a positive correlation between gestational age and parameters. It has been aimed to determine the growth rates between the upper and lower extremities in human fetuses during the fetal period (Malas et al., 2005). The shoulder width, arm, forearm, and hand length in the upper extremity, intertrochanter distance, thigh, leg and foot length in the lower extremity were measured in the study on 161 human fetuses at 9th to 40th gestational weeks. Malas et al. (2005) detected a significant correlation between the bi-acromial width, arm length, forearm length, and) hand length of the upper extremity, bi-trochanter distance of the lower extremity, thigh length, leg length, and foot length parameters, and the week of gestation in their study ($P<0.001$).

It has been reported that scanned 100 pregnant with ultrasound in the 2nd and 3rd trimesters (Gameraddin et al., 2014). Gameraddin et al. (2014) reported a strong positive correlation between foot length and gestational age, and between foot length and femur length. It has been reported that performed foot length measurements on 462 healthy pregnant individuals during the 15$^{th}$ to 42 gestational weeks (Yuksel et al., 2006). Yuksel et al. (2006) concluded that there is a correlation between fetal foot length and gestational age, and the majority of fetal foot measurements only provide precise information about fetal growth and can also reliably assess gestational age. A positive correlation was found between measurement parameters and gestational age in our study. As the gestational age increases, our measurement parameters increase.

## 5. Conclusion

A thorough understanding of foot anatomy and morphology is essential for increasing the success of ligament reconstructions and minimizing iatrogenic risks. We believe that the data obtained from our study would be useful for further studies as well as recognition of fetal foot anatomy in obstetrics, perinatology, fetopathology, and pediatric surgery.

It is thought that the results obtained from fetal cadavers in the specified trimesters in our study would provide developmental data about fetal cadavers within these trimesters. The knowledge about the measurements made on the foot, the gender, and height during fetal development would contribute to the branches of science working on the fetus in terms of the functioning of the gestational process.

**Author Contributions**

Percentages of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

| % | I.D. | M.S. | D.A.S. | M.T.Y. | M.A.D. |
|---|---|---|---|---|---|
| C | 20 | 40 | 20 | 20 | |
| D | 20 | 20 | 20 | 20 | 20 |
| S | | 100 | | | |
| DCP | 30 | | 30 | 30 | 10 |
| DAI | 20 | 20 | 20 | 20 | 20 |
| L | 20 | 20 | 20 | 20 | 20 |
| W | 20 | 20 | 20 | 20 | 20 |
| CR | 20 | 20 | 20 | 20 | 20 |
| SR | 20 | 20 | 20 | 20 | 20 |
| PM | 20 | 20 | 20 | 20 | 20 |
| FA | 20 | 20 | 20 | 20 | 20 |

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

**Conflict of Interest**

The authors declared that there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

**Ethical Approval/Informed Consent**

The present study was carried out on fetuses without any external pathology and abnormality that exist in fetal cadaver collection in Anatomy Department of Meram Faculty of Medicine after approval of Ethical Committee for Researches Except Drug and Medical Devices of Meram Faculty of Medicine within Necmettin Erbakan University (approval date: May 15, 2015, protocol code: 2015/55).

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