**Obstetrics;** *Maternal Fetal Medicine and Perinatology*

# Longitudinal Assessment of Fetal Ductus Arteriosus Morphometry: Establishing Gestational Age-Specific Reference Values

**Murat CAGAN[1], Umutcan KAYIKCI[1], Erdem FADILOGLU[1], Ayse Cigdem BAYRAK[1], Edip Alptug KIR[1], Hayrettin Hakan AYKAN[2], Ozgur DEREN[1]**

*Ankara, Türkiye*

## ABSTRACT

**OBJECTIVES:** To longitudinally evaluate fetal ductus arteriosus (DA) morphometric changes and establish normative reference values between 18 and 36 weeks of gestation.

**STUDY DESIGN:** This prospective cohort study included 29 pregnant women with structurally normal singleton fetuses and confirmed gestational ages. Each participant underwent serial standardized ultrasound examinations to evaluate DA length and proximal, mid, and distal diameters. We defined weekly growth trends using regression analyses and assessed correlations with fetal biometric parameters.

**RESULTS:** Due to missed examinations caused by intermittent withdrawals, a total of 99 prenatal and 29 postnatal ultrasound examinations were performed longitudinally. DA length increased linearly at approximately 0.63 mm/week ($R^2$=0.813). Proximal, mid, and distal diameters showed significant linear increases of 0.28 mm/week, 0.32 mm/week, and 0.16 mm/week, respectively ($R^2$=0.769, 0.681, and 0.541). DA length correlated strongly with fetal abdominal circumference ($R^2$=0.855). We established reference percentile tables and normative curves for DA dimensions across gestational ages (18-36 weeks).

**CONCLUSIONS:** This longitudinal study provides comprehensive reference values for fetal DA morphometric assessment between 18-36 gestational weeks. These nomograms support clinicians in identifying deviations suggestive of DA constriction, especially relevant given the expanded indications for maternal indomethacin administration. Further multicentre studies involving diverse populations are required to enhance the generalizability and clinical applicability of these reference standards.

**Keywords:** Ductus arteriosus; Fetal; Longitudinal; Morphometry; Ultrasonography

***Gynecol Obstet Reprod Med. 2026;32(2):70-76***

*[1] Hacettepe University Faculty of Medicine, Department of Obstetrics and Gynecology, Division of Maternal and Fetal Medicine, Ankara, Türkiye*
*[2] Hacettepe University Faculty of Medicine, Department of Pediatrics, Division of Pediatric Cardiology, Ankara, Türkiye*

*Address of Correspondence:* *Murat Cagan*
*Hacettepe University Faculty of Medicine,*
*Department of Obstetrics and Gynecology,*
*Division of Maternal and Fetal Medicine*
*06230 Ankara, Türkiye*
*drmuratcagan@gmail.com*

*Submitted for Publication: 27.07.2026. Revised for Publication: 08.08.2026*
*Accepted for Publication: 26.08.2026 Online Published: 28.08.2026*

*ORCID IDs of the authors:*
*UK: 0000-0003-3710-0462*
*ACB: 0000-0003-1547-3663*
*HHA: 0000-0001-5136-3977*
*MC: 0000-0003-0629-4401*
*EF: 0000-0001-7953-2517*
*EAK: 0000-0002-2293-3624*
*OD: 0000-0003-4735-2444*

| QR Code | Access this article online |
|---|---|
| | www.gorm.com.tr • gorm@medicalnetwork.com.tr<br>full magazin: https://mndijital.medicalnetwork.com.tr |
| | DOI:10.21613/GORM.2026.1755 |

***How to cite this article:*** *Cagan M. Kayikci U. Fadiloglu E. Bayrak AC. Kir EA. Aykan HH. Deren O. Longitudinal Assessment of Fetal Ductus Arteriosus Morphometry: Establishing Gestational Age-Specific Reference Values. Gynecol Obstet Reprod Med. 2026;32(2):70-76*

## Introduction

The ductus arteriosus (DA) connects the fetal pulmonary artery to the descending aorta, shunting most right ventricular output away from the high-resistance lungs toward the placenta for oxygen exchange (1). Only about 10% of right ventricular output passes through fetal lungs; the remainder bypasses via the ductus (2).

Embryologically, the DA arises from the distal left sixth pharyngeal arch and is characterized by spirally oriented smooth muscle with reduced elastin, enabling strong contractility (3). Prenatal ductal patency is maintained by low oxygen tension and vasodilators such as prostaglandin $E_2$ and nitric oxide. At birth, increased oxygen saturation and reduced prostaglandins trigger immediate ductal constriction, followed by anatomical obliteration (4,5). Abnormalities in DA closure can be life-threatening and cause significant morbidity, as persistent postnatal patency results in patent ductus arteriosus (PDA). In contrast, premature prenatal closure may lead to fetal heart failure (6).

Prenatal ultrasound assessment, particularly sagittal ductal arch and 3VT views, is a mandatory component of mid-trimester evaluation, allowing comprehensive assessment of

*Copyright© 2026. Gercik Arzik et al. This article is distributed under a Creative Commons Attribution 4.0 International License.*

ductal anatomy and flow (7). Echocardiographic findings such as aneurysmal dilation or increased Doppler flow velocities indicate potential pathology and require detailed evaluation (1,8,9). Existing normative ductal data largely derive from cross-sectional studies that measure diameters and flow velocities at different gestational ages to generate reference Z-scores and percentile charts (10). However, single-time-point measurements miss individual growth trajectories and subtle pathological changes. Compared with cross-sectional reference data, longitudinal reference values better characterize individual fetal growth trajectories and may improve the interpretation of serial fetal echocardiographic measurements in clinical practice. To address this gap, we conducted longitudinal serial ultrasounds in uncomplicated pregnancies to generate robust normative growth curves for the DA. This study aimed to establish gestational reference values for ductal dimensions, capture individualized growth trajectories, and enhance prenatal detection of deviations associated with congenital cardiac anomalies and fetal growth restriction (FGR).

## Material and Method

This prospective cohort study was conducted at the Division of Maternal Fetal Medicine, Department of Obstetrics and Gynecology, Hacettepe University Faculty of Medicine. We enrolled 29 pregnant women with structurally normal singleton fetuses and accurately known gestational ages confirmed in the late first trimester, after they provided informed consent. The Institutional Ethics Committee approved the study protocol under number SBA 24/804, and the study was conducted in accordance with the Declaration of Helsinki.

The study protocol included four ultrasound assessments per participant, which were to coincide with routine antenatal assessments as per national standards, depending on participant availability. When conducted, they were done at the following time points: first visit at 19-23 weeks of gestation, second at 24-28 weeks, third at 29-33 weeks, and fourth at 34-38 weeks.

All 29 subjects had an initial ultrasound assessment. Compliance with further visits, however, ranged: eight subjects missed their second investigation, three missed their third, and six missed their fourth examination. Missed examinations were intermittent rather than representing permanent withdrawal whenever applicable. Consequently, some participants who missed one scheduled visit attended subsequent examinations. A total of 99 antenatal and 29 postnatal ultrasound investigations were conducted. Timing for postnatal ultrasonographic assessment of DA patency varied from 24$^{th}$ 2472$^{nd}$ 72s. All patients underwent postnatal echocardiography to confirm normal cardiac morphology.

Biometric measurements were taken at each ultrasonography session. The fetal DA was identified in the upper part of the mediastinum, and precise measurements were made, including length and proximal, mid, and distal measurements of the DA (Figure 1). The measurement protocol was based on previously described fetal ductus arteriosus echocardiographic methodology with minor modifications adapted to the objectives of the present study (10). The length of the DA was measured from its proximal origin at the main pulmonary artery to its distal insertion into the descending aorta. This measurement was obtained in the transverse plane of the fetal thorax, clearly identifying the DA pathway from its origin just distal to the main pulmonary artery to its entry into the descending aorta. The proximal diameter of the DA was measured at its pulmonary end, precisely at its junction with the main pulmonary artery. The mid-diameter of the DA was measured at the midpoint between its proximal and distal ends. The distal diameter was measured immediately before the DA joins the descending aorta. All measurements were taken consistently at end-diastole, with the ultrasound beam perpendicular to the vessel walls to ensure accuracy and reproducibility. All two-dimensional measurements were obtained directly on-screen using the ultrasound machine's electronic calipers. All measurements were obtained with an enlarged region of interest occupying at least half of the screen. Images were documented digitally for subsequent verification and quality control. This systematic approach provided consistent, reproducible measurements of fetal DA dimensions, essential for establishing normative reference values. A single experienced operator (U.K.) performed all ultrasonographic examinations and measurements using a Mindray DC-80 device and a standardized measurement protocol to minimize measurement variability.

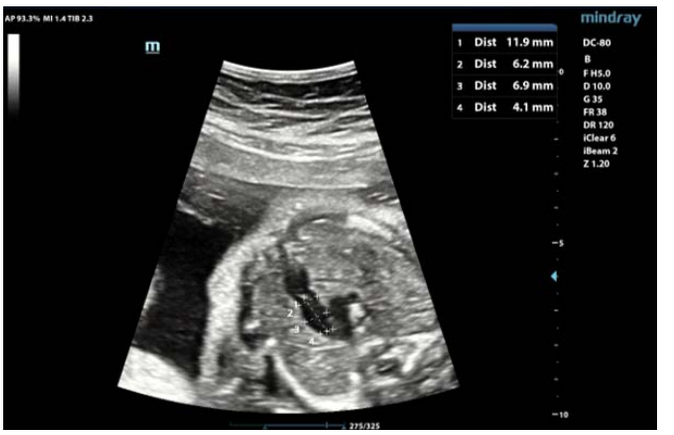


***Figure 1:*** *Length, and proximal, mid, and distal measurements of the Ductus Arteriosus. (1: Length, 2: Proximal Diameter, 3: Middle Diameter, 4: Distal Diameter).*

Echocardiography was performed in hein the early postnatal period by pediatric cardiologists to exclude morphological cardiac abnormalities or early ductal constriction.

We excluded patients with congenital abnormalities, increased nuchal translucency, or systemic diseases affecting placental perfusion. We also excluded patients with biometric measurements above the 90th percentile or below the 10th percentile. We obtained detailed written consent from each patient before the first visit.

Statistical analyses were performed using SPSS version 23 (IBM Corp., Armonk, NY, USA). We tested demographic data for normality using the Kolmogorov-Smirnov test. As the data were not normally distributed, results are presented as medians with interquartile ranges. We performed linear regression analyses to assess correlations between gestational age and DA measurements. Correlations were further illustrated with scatter plots, and regression equations were derived from fitted lines. Percentile values (5$^{th}$, 25$^{th}$, 50$^{th}$, 75$^{th}$, and 95$^{th}$) were derived from regression-based predictions, with residual distributions used to estimate variability around the fitted line.

Percentile estimates were calculated from the regression models using the full-precision coefficients, whereas the coefficients displayed in the figures and tables were rounded for presentation.

A p-value <0.05 was considered statistically significant.

## Results

Demographic and characteristic features are presented in Table I. Linear regression analyses demonstrated a positive correlation between all ductal measurements and gestational age (p<0.05 for all) (Table II). Among these, ductal length exhibited the strongest relationship ($R^2$=0.813; Figure 2), followed by proximal ($R^2$=0.769; Figure 3), mid ($R^2$=0.681; Figure 4), and distal diameters ($R^2$=0.541; Figure 5). All correlations were statistically significant (p<0.05). The DA length was also strongly correlated with fetal abdominal circumference (AC) ($R^2$=0.855; p<0.001) (Figure 6). Percentile tables for the length and diameters of the DA for each visit (Table III, IV, V, and VI) provide clinically applicable reference values. We also presented Figure 7 to show the correlation between gestational age and morphometric measurements. Postnatal echocardiographic evaluations confirmed ductal closure in all neonates, thereby supporting the reliability of the prenatal measurements.

***Table I:*** *Demographic and characteristic features of the participants.*

| | **Median (25p-75p)** |
|---|---|
| Maternal Age | 27 (25-31) |
| Gravida | 1 (1-2) |
| Parity | 0 (0-1) |
| Gestational week at 1st examination | 22 (21-23) |
| Gestational week at 2nd examination | 26 (25-26) |
| Gestational week at 3rd examination | 29 (29-31) |
| Gestational week at 4th examination | 36.5 (34.5-37) |

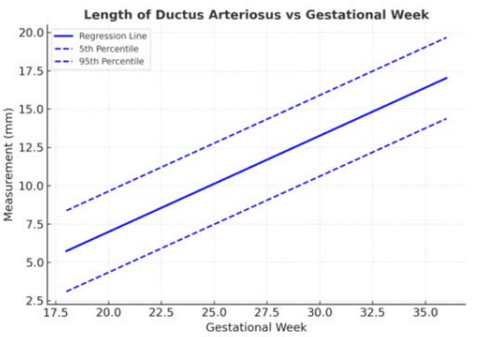


***Figure 2:*** *Relationship between gestational week and ductus arteriosus (DA) length. Solid line shows the fitted linear regression (y=0.627×GA−5.556; p <0.001; $R^2$ =0.813). Dashed lines indicate the 5$^{th}$ and 95$^{th}$ percentiles derived from the reference tables (Tables 3-6).*

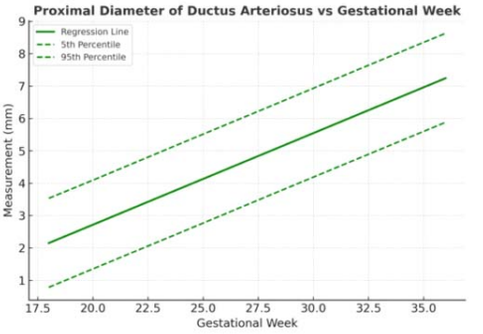


***Figure 3:*** *Relationship between gestational week and proximal ductus arteriosus (DA) diameter. Solid line shows the fitted linear regression (y=0.283×GA−2.946; p <0.001; $R^2$=0.769). Dashed lines indicate the 5$^{th}$ and 95$^{th}$ percentiles derived from the reference tables (Tables 3-6).*

***Table II:*** *Linear regression analysis for prediction of various measurements of the ductus arteriosus based on gestational week.*

| | | **Unstandardized Coefficients** | | **Standardized Coefficients** | | |
|---|---|---|---|---|---|---|
| **Dependent variable** | **Predictor** | **B** | **Std. Error** | **Beta** | **t** | **p** |
| Length of Ductus Arteriosus | (Constant) | -5.556 | 0.876 | 0.902 | -6.345 | <0.001 |
| | Gestational age (weeks) | 0.627 | 0.031 | | 20.409 | <0.001 |
| Proximal diameter of Ductus Arteriosus | (Constant) | -2.946 | 0.454 | 0.877 | -6.482 | <0.001 |
| | Gestational age (weeks) | 0.283 | 0.016 | | 17.777 | <0.001 |
| Middle diameter of Ductus Arteriosus | (Constant) | -3.704 | 0.648 | 0.825 | -5.717 | <0.001 |
| | Gestational age (weeks) | 0.324 | 0.023 | | 14.256 | <0.001 |
| Distal diameter of Ductus Arteriosus | (Constant) | -1.288 | 0.428 | 0.736 | -3.008 | 0.003 |
| | Gestational age (weeks) | 0.159 | 0.015 | | 10.600 | <0.001 |

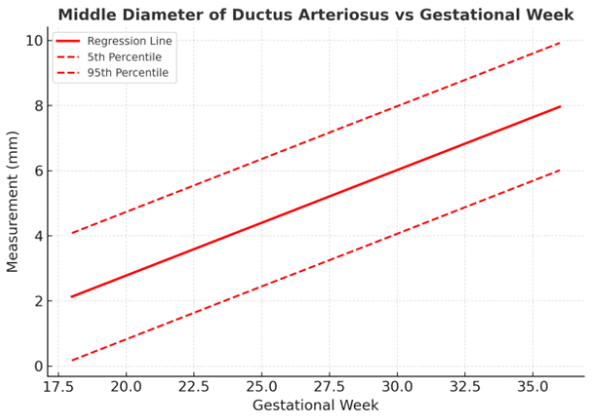


***Figure 4.*** *Relationship between gestational week and middle ductus arteriosus (DA) diameter. Solid line shows the fitted linear regression (y=0.324×GA-3.704; p <0.001; R²=0.681). Dashed lines indicate the 5th and 95th percentiles derived from the reference tables (Tables 3-6).*

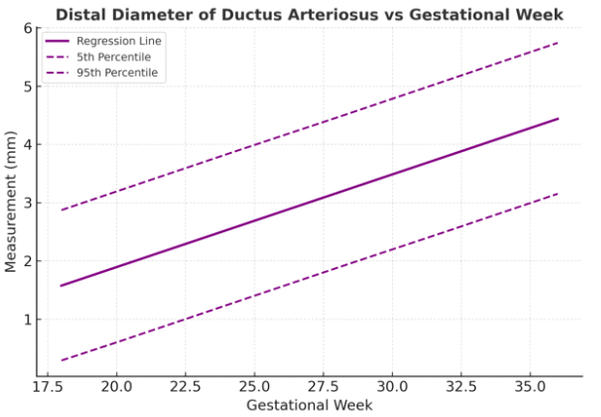


***Figure 5:*** *Relationship between gestational week and distal ductus arteriosus (DA) diameter. Solid line shows the fitted linear regression (y=0.159×GA−1.288; p <0.001; R²=0.541). Dashed lines indicate the 5th and 95th percentiles derived from the reference tables (Tables 3-6).*

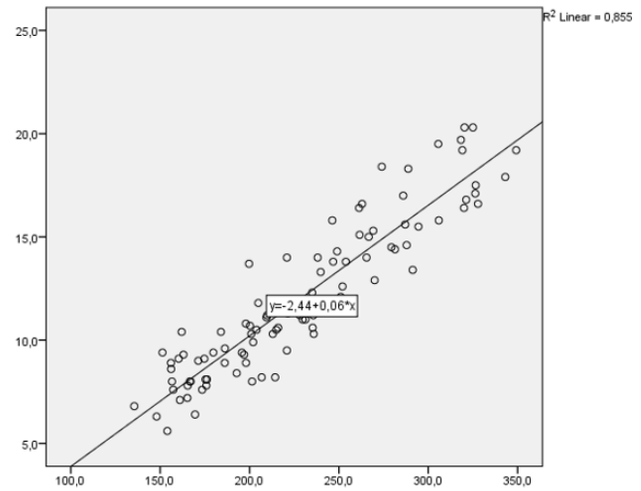


***Figure 6:*** *Scatter plot demonstrating the relationship between abdominal circumference and ductus arteriosus length. The solid line represents the linear regression fit (DA length = -2.44 +0.06×abdominal circumference; R²=0.855).*

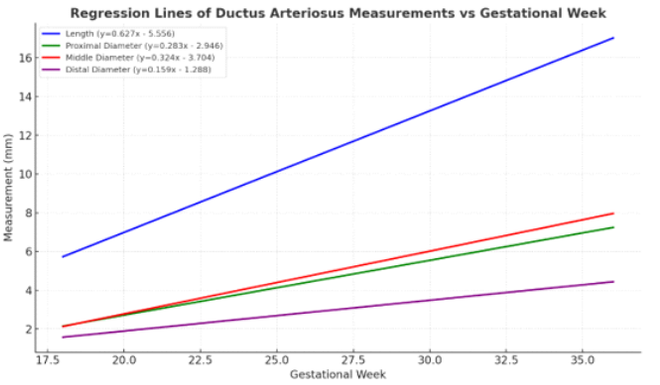


***Figure 7:*** *Regression lines illustrating the relationship between gestational age (18-36 weeks) and ductus arteriosus (DA) morphometric measurements: DA length (blue line), proximal diameter (green line), middle diameter (red line), and distal diameter (purple line).*

***Table III:*** *Percentiles for Length of Ductus Arteriosus (mm)*

| Gestational Week | 5th Percentile | 25th Percentile | 50th Percentile | 75th Percentile | 95th Percentile |
|---|---|---|---|---|---|
| 18 | 3.09 | 4.65 | 5.73 | 6.81 | 8.37 |
| 20 | 4.34 | 5.9 | 6.98 | 8.07 | 9.63 |
| 24 | 6.85 | 8.41 | 9.49 | 10.58 | 12.14 |
| 28 | 9.36 | 10.92 | 12.0 | 13.08 | 14.64 |
| 32 | 11.86 | 13.42 | 14.51 | 15.59 | 17.15 |
| 36 | 14.37 | 15.93 | 17.02 | 18.1 | 19.66 |

***Table IV****: Percentiles for Proximal Diameter of Ductus Arteriosus (mm)*

| Gestational Week | 5th Percentile | 25th Percentile | 50th Percentile | 75th Percentile | 95th Percentile |
|---|---|---|---|---|---|
| 18 | 0.78 | 1.59 | 2.16 | 2.72 | 3.53 |
| 20 | 1.35 | 2.16 | 2.72 | 3.29 | 4.09 |
| 24 | 2.48 | 3.29 | 3.86 | 4.42 | 5.23 |
| 28 | 3.62 | 4.43 | 4.99 | 5.55 | 6.36 |
| 32 | 4.75 | 5.56 | 6.12 | 6.69 | 7.5 |
| 36 | 5.88 | 6.69 | 7.26 | 7.82 | 8.63 |

***Table V:*** *Percentiles for Middle Diameter of Ductus Arteriosus (mm)*

| Gestational Week | 5th Percentile | 25th Percentile | 50th Percentile | 75th Percentile | 95th Percentile |
|---|---|---|---|---|---|
| 18 | 0.17 | 1.33 | 2.13 | 2.93 | 4.08 |
| 20 | 0.82 | 1.97 | 2.78 | 3.58 | 4.73 |
| 24 | 2.12 | 3.27 | 4.07 | 4.88 | 6.03 |
| 28 | 3.41 | 4.57 | 5.37 | 6.17 | 7.33 |
| 32 | 4.71 | 5.86 | 6.67 | 7.47 | 8.62 |
| 36 | 6.01 | 7.16 | 7.96 | 8.76 | 9.92 |

***Table VI.****:Percentiles for Distal Diameter of Ductus Arteriosus (mm)*

| Gestational Week | 5th Percentile | 25th Percentile | 50th Percentile | 75th Percentile | 95th Percentile |
|---|---|---|---|---|---|
| 18 | 0.29 | 1.05 | 1.58 | 2.11 | 2.87 |
| 20 | 0.6 | 1.37 | 1.9 | 2.43 | 3.19 |
| 24 | 1.24 | 2.0 | 2.53 | 3.06 | 3.83 |
| 28 | 1.88 | 2.64 | 3.17 | 3.7 | 4.46 |
| 32 | 2.51 | 3.28 | 3.81 | 4.34 | 5.1 |
| 36 | 3.15 | 3.91 | 4.44 | 4.97 | 5.74 |

## Discussion

In this study, we assessed fetal DA morphometric measurements and their relationship with advancing gestational age. Our results showed that DA length and diameters increased significantly with gestational age between 18 and 36 weeks. Specifically, DA length showed a strong linear relationship with gestational weeks ($R^2$=0.813), increasing by approximately 0.63 mm per week. Additionally, the proximal, mid, and distal diameters showed significant positive linear correlations with gestational age, with weekly increases of 0.28 mm, 0.32 mm, and 0.16 mm, respectively. DA length also showed a strong correlation with fetal abdominal circumference (AC) ($R^2$=0.855), indicating proportional growth with fetal size. We generated percentile reference tables for DA length and diameters from 18 to 36 gestational weeks, consistent with previously established fetal growth trends.

Our findings align closely with previous reports in the literature. Mielke and Benda demonstrated similar trends of increasing DA diameters and lengths across gestation in a comprehensive study involving 222 fetuses between 13 and 41 weeks of gestation, supporting our observations of proportional growth and tapering towards the distal DA (10). Vieira et al. similarly presented reference Z-scores and equations for various fetal cardiac structures, which showed a strong correlation with gestational age and aligned closely with our reported measurements, especially for proximal and middle ductal diameters (11).

The physiological significance of these morphometric changes has been extensively studied. Rasanen et al. described fetal cardiac output distribution via Doppler assessment, highlighting increased blood flow to pulmonary arteries and stable flow through the DA, supporting the critical role of the DA in fetal circulation (12). Sutton et al. reinforced these observations, noting significant increases in pulmonary blood flow and foramen ovale flow during gestation, indicating that despite increased pulmonary perfusion, the DA maintains its central role in fetal systemic circulation (13).

Fetal growth restriction also provides valuable context for interpreting DA measurements. Demircan et al. found that in early-onset FGR, aortic annulus-to-ductal diameter ratios were significantly reduced, suggesting relative dilation of the DA compared with other cardiac structures as an adaptation to chronic fetal hypoxia (14). This highlights the potential clinical utility of our reference values, especially when evaluating pregnancies complicated by FGR. The proposed reference values represent normative longitudinal data obtained from structurally normal fetuses. Further validation in independent cohorts including pathological pregnancies is required before their diagnostic application in clinical practice. These values may serve as preliminary normative data for future studies investigating ductus arteriosus morphometry in FGR and other pathological conditions. DA measurements outside expected norms could warrant physicians to consider a possible cardiovascular adaptation to compromised placental circulation.

Pasquini et al. explored the clinical importance of the aortic isthmus-to-DA diameter ratio, emphasizing its potential role in diagnosing fetal aortic coarctation. They reported that significant deviations from the normal ratio range (0.74-1.23) strongly suggest pathology, underscoring the diagnostic relevance of accurate DA reference ranges (15). Thus, our established norms could facilitate prenatal diagnosis of critical cardiac conditions by providing clear, reliable diagnostic thresholds.

Clinical application of these morphometric norms is broad. Accurate DA reference values are crucial for diagnosing DA constriction associated with maternal non-steroidal anti-inflammatory drug use or idiopathic constriction, both of which have significant clinical implications. Our nomograms allow

clinicians to quantify deviations from normal growth, enabling precise clinical decision-making. Weichert highlighted that any deviation in DA morphology or dimensions could significantly affect fetal circulation, emphasizing the clinical value of detailed morphological assessments (16). Furthermore, the role of routine echocardiographic screening for PDA in extremely low birth weight neonates remains a subject of debate in the literature (17). Our longitudinal reference values offer a prenatal framework that may inform such postnatal decisions by enabling early identification of fetuses with DA dimensions outside expected norms.

Constriction of the DA due to maternal exposures has been associated with impaired biventricular function and adverse hemodynamic changes (18). By providing robust normative growth trajectories, our study allows these pathological deviations to be recognized earlier and contextualized against physiologic development.

Our study has certain limitations. First, our analysis was limited to fetuses between 18-36 weeks, so applicability beyond these gestational ages requires further investigation. Second, the single-center and regionally specific population may limit generalizability. Future multicenter studies with diverse populations are warranted. Missing follow-up examinations may have introduced some degree of uncertainty into the longitudinal estimates. However, because most participants completed multiple examinations, we believe that the overall growth trends remain representative. The relatively small number of independent pregnancies may limit the precision of the estimated extreme percentile values. Therefore, interpret these reference values with caution until validated in larger multicenter cohorts.

Additionally, measuring DA dimensions is technically challenging, and operator-dependent variations can affect reproducibility. Furthermore, one pilot study emphasized the challenge of distinguishing statistically significant from clinically meaningful differences (19). In the present study, we did not evaluate formal intra-observer reproducibility using statistical methods such as the intraclass correlation coefficient or Bland-Altman analysis. Although a single experienced operator performed all measurements using a standardized protocol to minimize measurement variability, future studies should include reproducibility analyses to further validate the measurement technique. Another limitation is that we analyzed repeated measurements using conventional regression methods rather than mixed-effects models that account for within-fetus correlation. Although the present analyses demonstrated consistent associations between gestational age and ductus arteriosus measurements, future longitudinal studies with larger sample sizes should employ mixed-effects modeling to provide more robust estimates and reference centiles. Our longitudinal design, based on serial within-fetus measurements, overcomes this limitation by capturing true growth trajectories and yielding percentile curves with stronger clinical validity.

To our knowledge, this is one of the first studies to investigate DA diameters longitudinally in fetuses without cardiac abnormalities or fetal growth restriction. Strict inclusion criteria allowed us to generate robust, reliable outcomes. Importantly, postnatal confirmation of normal ductal closure and exclusion of cardiac malformations further strengthen the validity of our findings. Collectively, this study addresses a critical gap in the literature and may serve as a reference point for future research. Moreover, the normative data provided in this study may assist future clinical and research applications following further validation, potentially supporting the assessment and early identification of fetal ductus arteriosus abnormalities.

In conclusion, this study provides preliminary longitudinal reference values for morphometric measurement of fetal DA sizes in 18-36 gestational weeks. Our findings are highly consistent with available published work and are valuable diagnostic and evaluation tools in the clinic. These nomograms may provide normative reference data for future studies investigating fetuses with ductus arteriosus constriction, fetal growth restriction, or aortic coarctation. Future investigations in broader populations and pathological conditions will enhance the clinical validity and usefulness of these norms.

*Declarations*

*Ethics approval and consent to participate: All participants signed informed written consent before being enrolled in the study. The Hacettepe University Institutional Ethics Committee approved the study protocol under number SBA 24/804 (Date: 18 February 2025), and the study was conducted in accordance with the Declaration of Helsinki.*

*Availability of data and materials: The data supporting this study are available through the corresponding author upon reasonable request.*

*Competing interests: The authors declare no competing interests.*

*Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.*

*Authors' contributions: MC: Conceptualization, data curation, investigation, methodology, validation, writing-original draft, writing-review and editing; UK: Conceptualization, data curation, investigation, validation, visualization, writing-original draft, writing-review and editing; EF: Conceptualization, data curation, formal analysis, methodology, supervision, visualization, writing – original draft, writing-review and editing; ACB: Data curation, writing-original draft; EAK: Data curation, writing-original draft; HHA: Data curation, investigation, supervision, writing-original draft; OD: Conceptualization, formal analysis, methodology, supervision, writing-review and editing*

*Acknowledgment: The authors acknowledge the support of the clinical and research teams involved in this study and thank all participants for their valuable contribution.*

## References


1. Coceani F, Olley PM. The control of cardiovascular shunts in the fetal and perinatal period. Can J Physiol Pharmacol. 1988;66(8):1129-34. Doi: 10.1139/y88-185. PMID:305 c2747.
2. Heymann MA, Rudolph AM. Control of the ductus arteriosus. Physiol Rev. 1975;55(1):62-78. Doi: 10.1152/physrev.1975.55.1.62. PMID: 1088992.
3. May LA, Masand PM, Qureshi AM, Jadhav SP. The ductus arteriosus: a review of embryology to intervention. Pediatr Radiol. 2023;53(3):509-22. Doi: 10.1007/s00247-022-05518-0. PMID: 36221034.
4. Ovalı F. Molecular and mechanical mechanisms regulating ductus arteriosus closure in preterm infants. Front Pediatr. 2020;8:516. Doi: 10.3389/fped.2020.00516. PMID: 32984222, PMCID: PMC7477801.
5. Hung YC, Yeh JL, Hsu JH. Molecular mechanisms for regulating postnatal ductus arteriosus closure. Int J Mol Sci. 2018;19(7):1861. Doi: 10.3390/ijms19071861. PMID: 29941785, PMCID: PMC6073350.
6. Pugnaloni F, Doni D, Lucente M, Fiocchi S, Capolupo I. Ductus arteriosus in fetal and perinatal life. J Cardiovasc Dev Dis. 2024;11(4):113. Doi: 10.3390/jcdd11040113. PMID: 38667731, PMCID: PMC11050351.
7. Salomon LJ, Alfirevic Z, Berghella V, Bilardo CM, Chalouhi GE, Da Silva Costa F, et al. ISUOG Practice Guidelines (updated): performance of the routine mid-trimester fetal ultrasound scan. Ultrasound Obstet Gynecol. 2022;59(6):840-56. Doi: 10.1002/uog.24888. Erratum in: Ultrasound Obstet Gynecol. 2022 Oct;60 (4): 591. Doi: 10.1002/uog.26067. PMID: 3559 2929.
8. Ganesan S, Hutchinson DP, Sampson AJ. Prenatal diagnosis of ductus arteriosus aneurysm. Ultrasound. 2015;23(4):251-3. Doi: 10.1177/1742271X15587931. PMID: 27433265, PMCID: PMC4760603.
9. Tulzer G, Gudmundsson S, Sharkey AM, Wood DC, Cohen AW, Huhta JC. Doppler echocardiography of fetal ductus arteriosus constriction versus increased right ventricular output. J Am Coll Cardiol. 1991;18(2):532-6. Doi: 10.1016/0735-1097(91)90611-c. PMID: 1856423.
10. Mielke G, Benda N. Reference ranges for two-dimensional echocardiographic examination of the fetal ductus arteriosus. Ultrasound Obstet Gynecol. 2000;15(3):219-25. Doi: 10.1046/j.1469-0705.2000.00078.x. PMID: 10846778.
11. Vieira MF, Bravo-Valenzuela NJ, Carvalho FHC, da Rocha Amorim LA, Araujo Júnior E. Reference ranges and Z-score equations for 19 Fetal cardiac biometry structures from 18 to 34 weeks' gestation. J Ultrasound Med. 2025;44(3):467-82. Doi: 10.1002/jum.16609. Erratum in: J Ultrasound Med. 2026 Jul 20. Doi: 10.1002/jum.70329. PMID: 39436148.
12. Rasanen J, Wood DC, Weiner S, Ludomirski A, Huhta JC. Role of the pulmonary circulation in the distribution of human fetal cardiac output during the second half of pregnancy. Circulation. 1996;94(5):1068-73. Doi: 10.1161/01.cir.94.5.1068. PMID: 8790048.
13. Sutton MS, Groves A, MacNeill A, Sharland G, Allan L. Assessment of changes in blood flow through the lungs and foramen ovale in the normal human fetus with gestational age: a prospective Doppler echocardiographic study. Br Heart J. 1994;71(3):232-7. Doi: 10.1136/hrt.71.3.232. PMID: 8142191, PMCID: PMC483659.
14. Demircan T, Atakul BK, Güven B, Yıldız K, Karadeniz C, Emir B, et al. Ductus arteriosus diameters in fetuses with early- and late-onset fetal growth restriction. J Clin Ultrasound. 2024;52(8):1010-8. Doi: 10.1002/jcu.23737. PMID: 38830837.
15. Pasquini L, Mellander M, Seale A, Matsui H, Roughton M, Ho SY, et al. Z-scores of the fetal aortic isthmus and duct: an aid to assessing arch hypoplasia. Ultrasound Obstet Gynecol. 2007 Jun;29(6):628-33. Doi: 10.1002/uog.4021. Erratum in: Ultrasound Obstet Gynecol. 2007;30(3):366. PMID: 17476706.
16. Weichert J, Hartge DR, Axt-Fliedner R. The fetal ductus arteriosus and its abnormalities--a review. Congenit Heart Dis. 2010;5(5):398-408. Doi: 10.1111/j.1747-0803.2010.00424.x. PMID: 21087423.
17. Colak R, Ozdemir SA, Ergon EY, Kulali F, Kalkanli OH, Yildirim TG, et al. Should echocardiographic evaluation be performed routinely in the first 72 hours in extremely low birth weight babies? Gynecol Obstet Reprod Med. 2021;27(2):175-80. Doi: 10.21613/GORM.2021.1168.
18. Ma J, Cao H, Hong L, Liu J, Song X, Shi J, et al. Cardiac function assessment in fetuses with ductus arteriosus constriction: a two-dimensional echocardiography and FetalHQ study. Front Cardiovasc Med. 2022;9:868675. Doi: 10.3389/fcvm.2022.868675. PMID: 35958395, PMCID: PMC9360592.
19. Moon-Grady AJ, Lee H, Lopez L, Fatusin O, Freud LR, Hogan W, et al. Fetal echocardiographic Z score pilot project: study design and impact of gestational age and variable type on reproducibility of measurements within and across investigators. J Am Soc Echocardiogr. 2023;36(9):978-97. Doi: 10.1016/j.echo.2023.05.010. PMID: 37302438.