Original

Fetal Middle Cerebral Artery Systolic-Diastolic Ratio at 12-41 weeks of gestation and clinical application in a Tertiary Hospital in Jos, North Central Nigeria

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ABSTRACT

Background: Studies on fetal Middle Cerebral Artery (MCA) Systolic-Diastolic ratio reflecting resistance to blood flow in the MCA and its changes over gestation in response to fetal distress are well documented in literatures, however, there is paucity of local data in this regard. The study aimed to determine normal ranges for fetal MCA Doppler S/D ratio at 12 to 41 weeks of gestation and their pattern in normal pregnancies at Jos University Teaching Hospital, Jos, Nigeria.

Methods: A cross-sectional, convenient sampling was used to recruit 456 pregnant women who were non-smokers and had no clinical history of autoimmune conditions. They were scanned using ultrasound and Doppler to establish fetal gestational age (GA), Doppler indices and also to determine the suitability of subjects for inclusion into the study. Descriptive statistics was used to determine mean waveform values of percentile curves for S/D ratio. Pearson's correlation determined the relationship between the variables, $p< 0.05$.

Results: The mean (±SD) age of subjects was 27.93±5.17 years. The S/D ratio was demonstrated as follows: 3.47±0.43 at 12 weeks, 3.95±1.07 at 28 weeks and 2.19±0.21 at 40 weeks. The relationship between S/D ratio and fetal GA yielded a regression curve equation: S/D ratio=4.591GA-0.036

Conclusion: This study established percentile curves and normative values of the fetal MCA S/D ratio of fetuses aged between the 12th to 41st weeks of gestation. A regression curve equation was established which could serve as prediction model together with the normative values, help to discriminate between a normal fetal situation and disease.

Keywords: Doppler sonography, flow velocity, middle cerebral artery, systolic to diastolic ratio, low risk pregnancy

How to cite this article

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INTRODUCTION

Infant and maternal mortality rates remain critical indicators of population health and are unacceptably high in many low- and middle –income countries, including Nigeria. Globally, the infant mortality rate is estimated at 49.4 deaths per 1000 live births, while Nigeria's rate is approximately 55.2 deaths per 1000 live births as of 2025, ranking the country among those with the highest infant mortality worldwide. A substantial proportion of these deaths are attributable to complications arising from fetal haemodynamic compromise, intrauterine growth restriction and prematurity. The tragedy of these preventable deaths, high maternal and infant mortality comes with a high cost to the rest of the society, a public health concern.[1-4]

Assessment of fetal wellbeing is therefore central to reducing perinatal morbidity and mortality. Traditional invasive techniques such as amniocentesis, although informative, expose the fetus to the risk of infection, feto-maternal haemorrhage, preterm labour and miscarriages. Application of Doppler in pediatrics are increasing day by day; gray scale ultrasound is often routinely performed to evaluate high risk pregnancies. Although this provides anatomic information, it lacks the ability to provide physiologic data. In contrast, Doppler velocity waveform analysis has the provide physiologic information concerning the middle cerebral artery blood flow and resistance as it is non-invasive, safe and repeatable means assessing fetal haemodynamics.[5-6]

The middle cerebral artery (MCA) is a major branch of the internal carotid, plays a key role in cerebral perfusion as it supplies parts of the lateral cerebral cortex and supplies blood to the anterior temporal lobes and the insular cortices.[7]

Several studies have demonstrated that MCA Doppler indices are superior to conventional biometric parameters in predicting fetal compromise and adverse perinatal outcomes. Furthermore, pooled evidence suggests s that the use of fetal Doppler velocimetry, when combined with appropriate obstetric intervention, can significantly reduce perinatal mortality by 29 % [RR 0.71, 95 % CI 0.52-0.98].[8]

In contrast to the umbilical artery and other arterial Doppler indices, the middle cerebral arterial Doppler indices demonstrate a consistent relation with fetal hypoxia as the human fetal cerebral circulation is uniquely sensitive to a decline in oxygen and a rise in carbon dioxide. As hypoxia develops, vasodilatation and a concomitant fall in the middle cerebral arterial Doppler index occur. When hypoxia becomes severe, the Doppler index tends to rise suggesting increasing cerebral vascular impedance which is probably caused by cerebral edema. It is clinically important to determine whether given middle cerebral arterial Doppler indices are normal or not. Therefore, normal middle cerebral artery Doppler indices must be defined for each week of gestational age. Since these parameters may be varied among different population, population –specific nomogram is important (Maulik, 2005).[6]

Favre et al (1991) studied the fetal cerebral vessels and the correlation between their flow velocity waveforms and fetal acidosis and found that all cerebral vessels react with a vasodilatation in the group with acidosis, but with different intensities. They observed that the middle cerebral artery appeared to be the most predictive for acidosis of all fetal cerebral arteries. Favre suggested that cerebral flow velocity seem to be an encouraging method for the obstetrical management of high-risk pregnancies especially its ability to detect impending antenatal fetal acidosis at a fairly early stage.[7]

In a study to establish reference ranges and standard percentile-curves for Doppler indices resistance index(RI) and systolic /diastolic ratio of the fetal middle cerebral artery color Doppler measurements in a perinatal centre, Meyberg et al (2000) showed that the increase in the diastolic component in the middle cerebral artery of the last third of the pregnancy demands reference ranges by using percentile curves; and further stressed that knowledge of the reference range helps to discriminate between a normal fetal situation and disease. Meyberg (2000) and his team therefore, recommended that because of the different absolute range values shown in literature, each perinatal centre should develop their data.[9]

The surveillance of fetus at high risk usually requires serial Doppler measurements (longitudinal study) including that of the middle cerebral artery. Middle cerebral arterial (MCA) Doppler measurement is a well-known modality for detecting fetal compromise. Some studies showed that MCA blood flow abnormalities were associated with hypoxia, adverse perinatal outcome and suboptimal neurodevelopment.[10-11]The use of parameters like the peak systolic velocity, systolic-diastolic ratio, pulsatility index, and resistivity index depends on appropriate reference ranges and these vary among populations, according to literatures.[12-117]

Despite extensive international literature, there remains paucity if locally derived normative data for fetal middle

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cerebral artery Doppler systolic to diastolic ratio and fetal gestational age for Nigerian population. The objectives of the study were to establish cross-sectional reference values and pattern of the fetal middle cerebral artery systolic to diastolic ratios in Nigeria, particularly across a wide gestational age range. Develop a regression model describing the relationship between gestational age and MCA S/D ration and provide population-specific normative data to aid clinical surveillance of high-risk pregnancies in Nigeria.

METHODOLOGY

Study Design and Setting: This was a prospective cross-sectional study conducted at the Radiology Department of Jos University Teaching Hospital, (JUTH). JUTH is a Federal Tertiary Referral Centre located in Lamingo, Jos North Local Government Area of Plateau State, Nigeria was established in 1981. It is a major Referral Centre in North-Central Nigeria, with a capacity of over 670 beds, 29 clinical departments, and comprehensive diagnostic capabilities.

Study Population and eligibility: The study population consisted of pregnant women with singleton, low pregnancies between 12 and 41 weeks of gestation who were referred for routine obstetric ultrasound. Inclusion criteria comprised normal fetal anatomy, normal fetal heart rate, absence of maternal medical conditions and Nigerian nationality. Multiple gestations, fetal structural anomalies, and high-risk pregnancies were excluded.

Sample Size and Sampling Technique: The sample size was determined using the Taro Yamane formula, based on an estimated population of 2,050 pregnant women attending the facility during the study period.

$$n = \frac{N}{1 + Ne^2}$$

Where n = Minimum Sample Size

N = Total Population (2050)

e = Acceptable Error Limit (0.05)

Sample Size = 335 Subjects. However, the sample size was increased to 456 subjects to include both high and low risk pregnancies; this was to improve the strength and sensitivity of results.

A convenience sampling technique was used to recruit eligible participants consecutively until the desired sample size was reached.

Study variables.

1. Independent variables: Gestational ages (weeks)
2. Dependent variables: Fetal MCA systolic-diastolic (S/D) ratio
3. Covariates: Maternal age, fetal biometric parameters (BPD FL, AC)

Data Collection Procedure: Participants underwent real-time gray scale Ultrasound examinations and Doppler velocimetry using standard obstetric protocols. Fetal biometric parameters such as the biparietal diameter (BPD), femur length (FL), abdominal circumference (AC) were measured to estimate gestational age. Fetal Middle Cerebral Artery (MCA) Doppler waveforms were obtained at the proximal third of the vessel with an insonation angle less than 30 degrees, and at least five uniform waveforms were recorded. Doppler variables measured for each fetal gestation included: the peak systolic velocity (PSV), the end diastolic velocity (EDV). These were used to calculate the systolic-diastolic ratio. The calculated values of the Doppler systolic-diastolic ratio were constructed and presented as 5th, 35th, 50th and 95th percentiles (90% reference range) according to fetal gestational age and displayed in tabular form. The 95th percentile values were considered as the cut-off levels or the upper border of normal and 5th percentile considered as low normal. A value of $p < 0.05$ was considered statistically significant.

Data Analysis: Data were analysed using statistical packages for social sciences (SPSS) version 17.0. Descriptive statistics were used to determine age distribution of subjects, generate mean values and standard deviations and frequencies of the fetal gestational age, fetal middle cerebral artery (MCA) peak systolic velocity, fetal MCA end diastolic velocity and percentile curves. Pearson's correlation was used to determine the relationship between gestational age and MCA S/D ratio. A p-value less than 0.05 was considered statistically significant.

Ethical Considerations: Approval for the study was obtained from Jos University Teaching Hospital Ethics committee with reference: JUTH/DCS/ADM/127/XIX/5306. Informed consent was obtained from every participant.

RESULTS

Table 1: Age distribution of subjects

Age of subjects (Years)	**Number of subjects**	**Percentage (%)**
15-20	85	18.6

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Age of subjects (Years)	**Number of subjects**	**Percentage (%)**
21-25	98	21.5
26-30	151	33.1
31-35	85	18.6
36-40	36	7.9
41 and above	1	0.22
Total	456	100

Table 1 shows the age distribution of subjects. The data shows that 33.1% of subjects were between the age range of 26 and 30 years. Subjects above 41 years of age represent 0.22% of study population.

Table 2: Variation of fetal biometrics with systolic diastolic ratio.

Serial Number	Fetal Gestational Age(weeks)	No of Subject	Age of Subjects (years)	Systolic-Diastolic ratio
1	12	3	27.00±9.89	3.47±0.43
2	13	6	28.00±4.77	4.29±1.39
3	14	9	27.89±4.86	4.36±2.73
4	15	10	27.40±4.25	3.69±1.63
5	16	11	28.50±3.89	4.08±0.93
6	17	24	27.52±5.02	3.48±0.83
7	18	13	28.92±4.96	3.79±0.76
8	19	15	27.26±5.42	3.73±0.75
9	20	13	26.66±7.10	3.23±0.67
10	21	15	26.38±4.23	3.55±0.86
11	22	18	27.81±5.12	3.64±0.92
12	23	23	27.77±5.95	3.83±0.85
13	24	19	27.89±5.62	4.13±1.06
14	25	25	28.50±4.74	3.88±1.19
15	26	20	28.56±4.44	3.89±1.66
16	27	8	26.75±4.30	4.39±1.36
17	28	23	27.38±5.64	3.95±1.07
18	29	15	27.00±5.30	3.95±0.90
19	30	12	28.08±5.40	3.63±1.91
20	31	18	28.17±5.14	4.27±1.81
21	32	13	27.61±5.26	3.43±0.61
22	33	11	27.18±4.24	3.81±1.47
23	34	10	29.70±6.46	3.45±0.51
24	35	15	25.92±5.74	3.58±1.03
25	36	6	30.50±1.87	2.75±0.37
26	37	11	28.36±5.73	2.72±1.13
27	38	13	31.69±5.02	2.60±0.93
28	39	12	26.75±5.49	2.49±0.32
29	40	4	31.00±5.41	2.19±0.21
30	41	4	30.00±7.34	2.50±0.074

Table 2 shows the number of subjects according to gestational age in weeks, patients' characteristics; mean±standard deviation (SD) for the MCA S/D ratio. Fetal gestational age evaluated are from the 12th weeks of gestation to the 41st weeks of gestation with a sample size of an average of 14 subjects (range of 9- 25) for each week of gestation.

The mean (±SD) age of subjects was 27.93±5.17 years Results from the study show the systolic-diastolic ratio demonstrating a parabolic pattern, increasing from: 3.47±0.0.43 at 12 weeks of gestation, to 4.13±1.06 at 24 weeks of gestation, and decreasing to 2.19±0.21 at 40 weeks of gestation.

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Table 3: Nomogram of Systolic-Diastolic ratio at various percentiles for each gestational age.

GA (weeks)	5th Percentile	35th Percentiles	50th percentile	95th percentile	Suggested	
					Lower limit	Upper limit
12	3.17	3.21	3.27	3.977.96	3.01	3.99
13	1.40	1.76	2.30	2.94	1.30	3.01
14	1.40	3.30	3.86	6.68	1.33	6.71
15	1.57	2.91	3.09	5.68	1.44	5.87
16	2.37	3.58	4.39	5.40	2.23	5.55
17	2.13	3.99	4.45	6.93	2.08	6.95
18	2.52	4.18	4.39	6.35	2.17	6.97
19	2.91	3.70	4.69	6.94	2.57	6.99
20	3.56	3.97	4.81	6.65	3.40	7.01
21	2.52	4.23	5.09	7.60	2.08	7.65
22	2.73	4.21	4.70	7.30	2.69	7.80
23	2.95	4.46	4.30	6.43	2.74	6.45
24	3.06	3.85	4.56	8.40	3.00	8.42
25	2.79	4.07	4.45	7.96	2.52	7.98
26	2.26	4.27	3.73	6.87	2.08	6.90
27	2.14	3.05	4.78	8.76	2.11	8.80
28	2.36	4.29	5.01	10.19	3.30	10.21
29	3.23	4.51	5.09	8.13	3.20	8.80
30	2.79	3.85	4.82	11.75	2.51	11.81
31	2.02	4.31	6.32	10.05	2.00	10.12
32	3.23	5.45	5.61	10.00	2.97	10.06
33	3.03	4.13	5.67	8.07	2.77	7.97
34	3.86	4.77	5.40	6.59	3.01	2.52
35	3.15	4.63	5.51	5.90	2.95	5.70
36	4.09	4.57	2.56	6.81	4.00	6.86
37	1.37	2.02	2.57	4.95	1.30	4.97
38	1.62	2.35	2.49	4.70	1.60	4.71
39	2.02	2.04	2.15	3.31	2.00	3.35
40	2.00	2.44	2.52	2.49	1.98	2.50
41	2.39	2.44	2.52	2.56	2.20	2.60

Table 3: shows nomogram of systolic-diastolic ratio at 5th, 35th, 50th, and 95th percentiles for each gestational age for low-risk pregnancies and suggested limits of normal. The 95th percentile values are considered as the cut-off level or the upper border of normal and 5th percentile considered as low normal as proposed by Mari G et al 1997.[5]

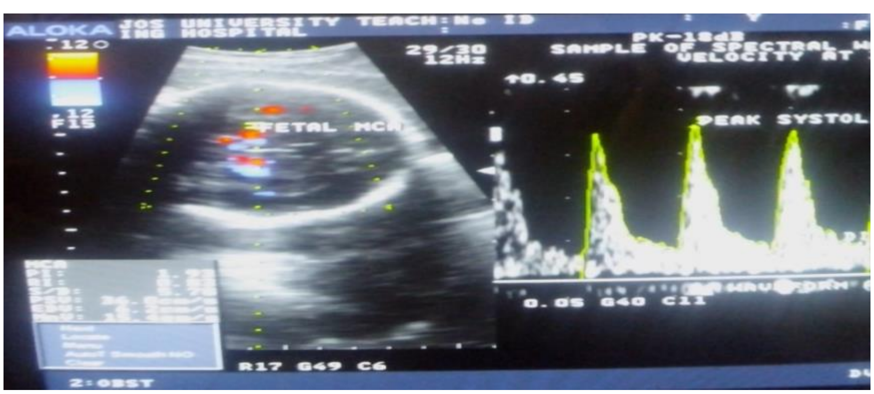

Fig 1: Normal flow velocity waveforms of the middle cerebral artery (MCA) in the third trimester.

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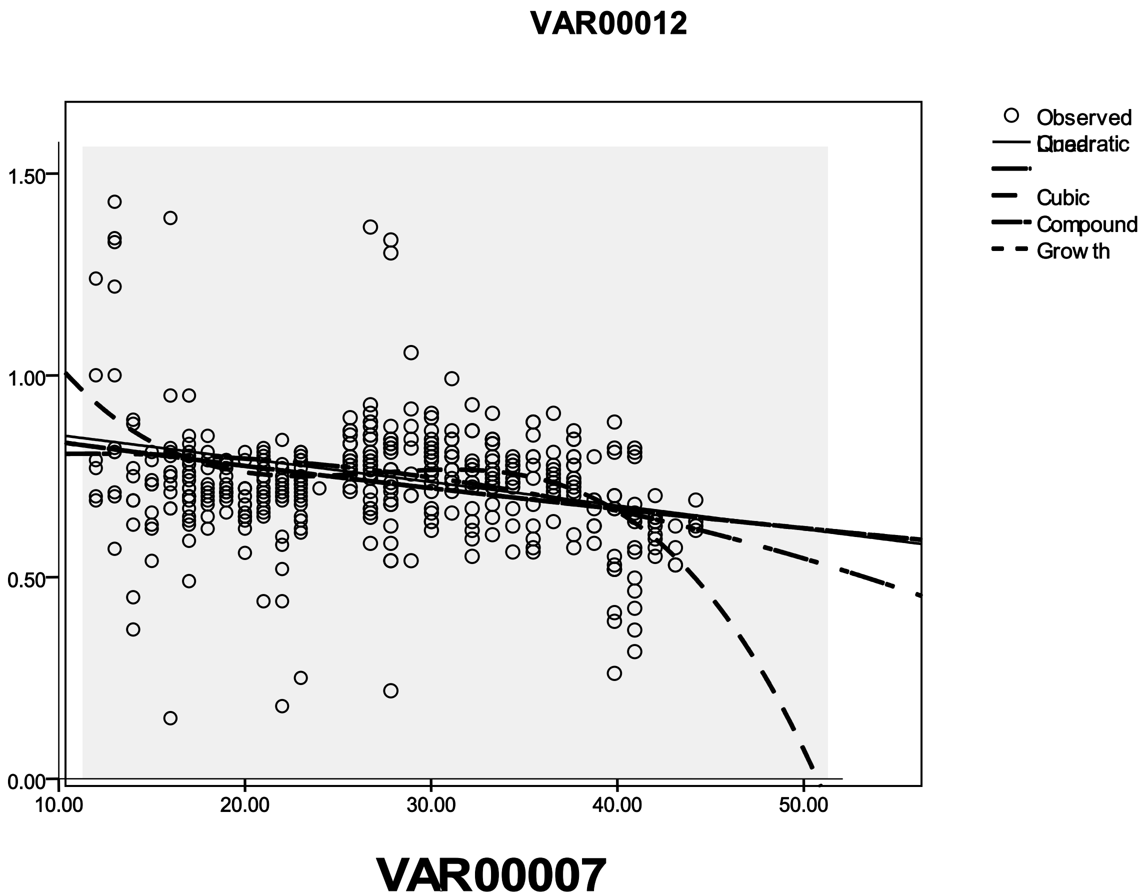

Figure 2 shows the regression curve of MCA systolic-diastolic ratio of subjects. It demonstrates an inverse relationship of systolic-diastolic ratio with gestational age. It shows a parabolic pattern, peak systolic-diastolic ratio increased from: 3.47±0.0.43 at 12 weeks of gestation, to 4.13±1.06 at 24 weeks of gestation and decreased to 2.19 ±0.21 at 40 weeks of gestation. This relationship yielded a regression curve equation: systolic-diastolic ratio=4.591GA-0.03

DISCUSSION

Infant and maternal mortality rates in Nigeria are high[1] and most causes are attributable to fetal haemodynamic challenges and complications of prematurity, a public health concern.

The fetal middle cerebral arterial (MCA) Doppler measurement is a well-known modality for detecting fetal compromise. Studies by Vyas et al., Gaary et al., and Bilardo et al., showed that ultrasonographic fetal biometric measurements are weaker predictors of fetal conditions than Doppler measurements; and surprisingly, that the symmetry and asymmetry of growth patterns do not improve the condition.[7-9]

Empirical studies have shown a gradual abandonment of serial amniocentesis for delta OD 450 in favor of serial MCA Doppler assessment which usually expose the fetus to the risk of boosting antibody concentration which has led to miscarriage and pre-term labour.[10] Doppler wave form velocity analysis of selected organs is valuable in detecting haemodynamic rearrangements that occur in response to hypoxemia in pregnancy. The use of parameters like the peak systolic-diastolic velocity ratio, peak systolic velocity among others for fetal surveillance depends on appropriate reference ranges as these vary among populations, according to literatures.[11] Fetal gestational age evaluated are from the 12th weeks of gestation to the 41st weeks of gestation with a sample size of an average of 14 subjects (range of 9- 25) for each week of gestation with the mean (±SD) age of subjects at 27.93±5.17 years. These values are in consonant with other studies in the literature.[12-15,]

This study demonstrated a S/D ratio of 4.27±1.81 at 20 weeks, 2.50±0.07 at 30 weeks and 2.19±0.21 at 40 weeks of gestation with peak values between the 30th to 34th weeks of gestation and then decreasing towards the end of pregnancy.

When compared with studies from other populations, the absolute fetal MCA S/D ratio values and percentile curves generated in this study were slightly lower than those reported by Tarzamni et al. in an Iranian cohort and Meyberg et al. in European populations. Several factors may account for these differences. First, variation in sample size and study design may influence percentile estimation; many previous studies employed larger cohorts or longitudinal designs, whereas the present study was cross-sectional. Second, population-specific factors such as genetic diversity, maternal anthropometry, socioeconomic status, and environmental conditions may influence fetal haemodynamics. Differences in ultrasound machine, Doppler angler correction, and statistical modeling techniques may also contribute to iner-study variability. These findings reinforce recommendations in the literature that Doppler reference ranges should ne population-specific rather than universally applied.[16,19]

Our study established systolic-diastolic ratio at 5th, 35th, 50th, and 95th percentiles for each gestational age for low-risk pregnancies with suggested limits of normal. The 95th percentile values are considered as the cut-off level or the upper border of normal and 5th percentile considered as low normal as proposed by Mari G et al.[17] Though our percentile curves of S/D with fetal gestations at 5th through the 95th were slightly lower than those reported by Tarzamni et at., and Ertan et al., the parabolic pattern were similar.The differences in values and percentile curves could be due to the larger sample size of 1037 adopted by Tarzamni et al , 602 by Ertan et al and the serial Doppler measurements whereas our sample size was 461 and cross-sectional in approach. Other plausible reasons could be the differences in the socioeconomic, statistical methods adopted by the different studies. These support the need for a population specific reference value.[14,16]

The parabolic trend observed in this study is consistent with findings reported by Ertan et al., Gagnon et al., and Tarzamni et al., all of whom documented a rise in MCA Doppler indices during mid-gestation followed by a decline in late pregnancy. This pattern is largely attributable to progressive maturation of the fetal cardiovascular system and a reduction in cerebral vascular resistance as pregnancy advances. In early gestation, relatively high vascular impedance results in high S/D ratios, whereas increases diastolic flow in the third trimester shows enhanced cerebral perfusion necessary to meet the metabolic needs of rapid brain growth. [13,14,16]

The inverse correlation between gestational age and MCA S/D ratio observed in this study further confirm the sensitivity of the fetal MCA to changes in fetal oxygenation and haemodynamic status. As gestation progresses, improved placental efficiency and cerebral autoregulation contribute to declining resistance indices. These physiological adaptations underpin the clinical utility of fetal MCA Doppler indices in identifying fetuses at risk of hypoxia, intrauterine growth restriction, and anaemia, conditions in which abnormal cerebral vasodilatation may occur.[15,17,19]

Pearson's correlation between peak systolic-end diastolic velocities ratio and fetal gestational age showed inverse relationship; the regression curve demonstrates a parabolic pattern. This relationship yielded a prediction model: systolic-diastolic ratio=4.591GA-0.036. This regression further highlights the unique haemodynamic profile of this study. Although the parabolic nature of the regression curve is similar to those reported in other studies, the coefficients differ, supporting the assertion that no two populations share identical Doppler regression models. This underscores the limitation of applying foreign reference standards to local clinical practice and emphasizes the importance of our locally derived normograms in improving diagnostic accuracy.[18-25]

Clinically, the establishment of 5th and 95th percentile thresholds for fetal MCA S/D ratio provides practical cut-off values for identifying abnormal cerebral blood flow patterns. Values below the 5th percentile may indicate cerebral vasodilatation associated with hypoxia or fetal anemia, while values above the 95th percentile may suggest increased vascular resistance.[17] These reference limits may enhance the early detection of fetal compromise, guide timely intervention, and ultimately improve perinatal outcomes, particularly in resource-limited settings where access to advanced fetal monitoring modalities may be restricted.

The **strengths** of this study include its prospective design, relatively large sample size, detailed fetal

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biometric assessment, the multiple Doppler indices, and robust statistical analysis. However, certain limitations should be acknowledged. The cross-sectional nature of the study precludes assessment of longitudinal changes within individual fetuses. In addition, the number of subjects in some gestational weeks was relatively small, which may affect the precision of percentile estimates. A larger, multicentre longitudinal would provide more robust normative data and enhance the generalization of the findings.

Implications of findings.
Despite these limitations, this study provides valuable baseline data on fetal MCA S/D ratio in a Nigerian population and contributes to the growing body of evidence supporting the role of Doppler velocimetric fetal surveillance. The reference values and normograms established herein may serve as a practical clinical tool for obstetricians and other clinicians in differentiating normal from pathological fetal conditions and in optimizing the management of high-risk pregnancies.

Conclusion: This study established gestational age-specific reference values and percentile curves for the fetal middle cerebral artery (MCA) systolic-diastolic(S/D) ration in a low-risk Nigerian population. The findings demonstrated clear inverse, parabolic relationship between gestational age and MCA S/D ratio, characterized by a gradual increase during early gestation, peak values in the late second trimester to early third trimester, and a progressive decline towards term. The physiological pattern reflects the evolving fetal cerebral hemodynamics and supports the clinical relevance of MCA Doppler assessment in the fetal surveillance. Although the parabolic nature of the regression curve is similar to those reported in other studies, the coefficients differ, supporting the assertion that no two populations share identical Doppler regression models. This underscores the limitation of applying foreign reference standards to local clinical practice and emphasizes the importance of our locally derived normograms in improving diagnostic accuracy

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