Comparison of the efficacy between ultrasound measurement of cross-sectional area of the umbilical cord and Hadlock's formula in the prediction of neonatal birth weight at term gestation: cross-sectional study

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Abstract

The accurate calculation of birth weight at term gestation is critical in labor and delivery management. Hadlock's formula is the most commonly used ultrasonic approach, but it is still prone to error.

Aim: To evaluate the efficacy and accuracy of ultrasound assessment of umbilical cord cross-sectional area to Hadlock's formula in predicting birth weight at term gestation.

Patients and Methods: This cross-sectional study comprised 220 pregnant women with an uncomplicated, singleton pregnancy and a gestational age of 37 to 41 weeks + 6 days who were admitted with early labor or were scheduled for elective cesarean section. All women had EFW using Hadlock's formula (HC, BPD, AC, and FL), as well as measurement of the cross-sectional area of the umbilical cord, umbilical arteries, and umbilical vein within one cm of the umbilical cord's insertion into the fetal abdomen, and the results were compared to neonatal birth weight.

Results: There was a significant positive correlation between measurement of EFW using Hadlock's formula and umbilical cord and its components when compared to birth weight ($P = 0.001$). The correlation strength of the umbilical cord with the birth weight was higher than that by Hadlock's formula with the value of coefficient of determinant $R2 = 0.493$ for umbilical cord area versus $R2 = 0.274$ for Hadlock's.

Conclusion: The cross-sectional area of the umbilical chord predicted birth weight more accurately. This study's normalcy metrics can be used as a reference for future studies that may associate such characteristics with embryonic growth problems.

Keywords: umbilical cord, Hadlock's formula, estimated fetal weight, neonatal birth weight.

Introduction

Estimating songoraphic fetal weight is an important aspect of routine work in obstetric departments. Accurate fetal weight assessment would aid in the proper management of labor and delivery, as well as the avoidance of difficulties associated with both low and high fetal weight at the time of birth, as well as the reduction of perinatal morbidity and mortality (1).

In recent years, the prevalence of fetal macrosomia and the risks it poses to both mother and child has steadily increased. Prolonged second stage of labor, major maternal birth canal injuries, postpartum hemorrhage, and fetal delivery traumas such as shoulder dystocia, brachial plexus paralysis, and clavicular fracture are common concerns (2). On the other hand, identifying fetuses with growth restriction is critical in order to reduce perinatal hazards such as intrauterine fetal death (IUFD) and newborn morbidity (3).

In current obstetrics, the two main methods for predicting birth weight are: (a) clinical examination based on abdominal palpation of fetal body parts using Leopold's maneuver and calculation based on fundal height, and (b) ultrasound measurement of skeletal fetal parts that are then inserted into equations to calculate estimated fetal weight (1). Although the clinical approach is straightforward, easy, and inexpensive, it is the oldest method, and its utility has been questioned because it is subjective (1).

The accuracy of employing several ultrasound parameters to estimate fetal weight is receiving increasing attention. Multiple fetal parameters are used to predict fetal weight. Hadlock's formula, which includes fetal head circumference (HC), abdominal circumference (AC), and femur length (FL) (4), is the most widely used formula. Despite developments in ultrasound technology for acquiring fetal biometric data, there is still an error range of 6 to 11% depending on the factors collected and the equation employed for estimation (5,6).

Researchers have attempted to enhance ultrasound-based fetal weight prediction through a variety of ways, including evaluation of fat deposition at multiple places, the use of three-dimensional ultrasound equipment, and more advanced bioinformatics processing systems. None of them have gained traction, and ultrasound approaches that account for subcutaneous fat thickness have not been shown to increase our capacity to reliably estimate fetal weight using equations derived from standard biometric factors (5,6).

Improved ultrasound techniques for assessing the diameter of the umbilical cord and its components have resulted in more advanced perinatal diagnostics over the last decade. Heavier neonates have a bigger umbilical cord circumference at birth, according to research (7).

The umbilical cord is physiologically and genetically part of the fetus and contains two arteries and one vein buried within Wharton's jelly (8). It has been found that umbilical cord diameter has a linear association with fetal growth. However, situations such as prenatal and umbilical cord anomalies, polyhydraminos, and oligohydraminos may influence this measurement. Furthermore, maternal illnesses such as hypertension, diabetes, and anemia may influence umbilical cord diameter (9).

The diameter of the umbilical cord is determined by the amount of Wharton's jelly present; a short diameter is suggested by insufficient nutrition and a lack of glycogen in fetal tissues, as well as a tiny amount of Wharton's jelly. Males are said to have more Wharton's jelly than females, and excellent eating increases the amount. It tends to decrease with gestational age and may disappear in pregnancies that last longer than 40 weeks (10).

The hypothesis of this study is that the cross sectional area of the umbilical cord may provide an advantage over the usual Hadlock's formula for accurate estimation of real birth weight at term gestation, hence preventing a substantial number of maternal and newborn deaths and morbidities.

Patients and methods

This cross-sectional study has been registered on clinicaltrials.gov as NCT 05362175. From July 2021 to May 2022, it was held in the Obstetrics and Gynecology Department of Ain Shams University Maternity Hospital. This study comprised 220 women with an uncomplicated singleton pregnancy, term gestation (37 to 41+6 weeks), who were admitted to the hospital in early labor or for elective cesarean delivery. Intrauterine fetal death, structurally malformed fetus or umbilical cord, multiple pregnancies, oligohydramnios or polyhydramnios, uterine fibroid, abnormal Doppler flowmetry of umbilical artery, and presence of maternal diseases (Diabetes mellitus, Hypertensive disorders, renal diseases, ischemic heart diseases) were all exclusion criteria.

Before the study began, the Faculty of Medicine Ain Shams University Research Ethics Committee (FMASU REC) granted ethical permission with the following number MS 488/2021 and all subjects provided verbal agreement.

A comprehensive history is taken from each patient, followed by a computation of gestational age based on the last menstrual cycle if reliable or an early dating ultrasound, followed by a general and abdominal examination. Ain Shams University Hospital's Fetal Medicine unit performed obstetric ultrasonography utilizing a Samsung HS 60 ultrasound scanner with a 3.5 MHz convex probe. The ultrasound was performed first to discover any of the study's exclusion criteria.

Fetal weight estimation is done automatically by software in the ultrasound scanner using the standard Hadlock's formula. Aside from the cross sectional area of the umbilical cord, the umbilical arteries and veins were measured in a plane adjacent to the insertion into the fetal abdomen within a maximum distance of 1 cm. Using the image's greatest magnification, place the markers at its outer edges (Figures 1 and 2). Wharton's jelly surface cross sectional area was calculated by subtracting the cross sectional area of the vessels from that of the umbilical cord. Actual birth weight = 7.276X umbilical cord cross sectional area + 1785.996 (11).

Depending on the technique of delivery, the patients were directed to the labor ward or the operating theater. Following delivery, the following items were collected: neonatal birth weight assessed during the first hour using a digital weighted scale calibrated in kilos (LAICA PS3004), gender, Apgar score, and method of delivery.

Sample size justification:

The required sample size was estimated using NCSS, LLC's Power Analysis and Sample Size software (PASS) version 11.0.10 (Kaysville, Utah). The key outcome measure is the correlation between the anticipated fetal weight (EFW) or cross sectional area of the umbilical cord and the actual birth weight (ABW). According to (11), the expected correlation coefficient between cross sectional area of umbilical cord and neonatal birth weight (r) =0.44 and between Hadlock's formula and neonatal birth weight (r) =0.62 will require a sample size of 220 women to detect a difference between two correlation coefficients with power =80% and x- error =0.05 (12).

Statistical Methods

The Statistical Package for Social Sciences (SPSS) version 20 was used to analyze the data. The categorical data was provided in the form of frequency and percentage tables. The continuous variables were provided in the form of averages, standard deviations, medians, and ranges. Pearson's correlation test was performed to examine the relationship between fetal birth weight and According to earlier research, the link between fetal weight estimated by Hadlock's formula and umbilical cord area was weak when the coefficient of correlation (r) (0 - 0.3), moderate when (r= 0.3 - 0.7), and significant when (r>0.7) (11). Simple linear regression was used to compute regression formulas and the coefficient of determinant (R2). P-value: P>0.05 indicates nonsignificant (NS), P0.05 indicates significant (S), and P0.01 indicates highly significant (HS).

Figure 1 and 2: Measurement of the umbilical cord cross sectional area, umbilical arteries, and umbilical vein.
Fetal Medicine Unit, Ain Shams University Maternity Hospital.

RESULTS

A total of 250 women with uncomplicated singleton pregnancy were assessed for eligibility. Of those 30 were excluded due to diagnosis of fetal structural anomalies or single umbilical artery or presence of amniotic fluid abnormality. 220 were enrolled in the study.

Table (1): Initial Characteristics of the participants.

		Mean	±SD
Age (Yrs.)		28.66	7.51
Weight(kg)		85.25	12.37
Gestational age(weeks)		38.90	1.16
Parity	P0	52	23.6%
	P1-2	117	53.2%
	P>2	51	23.2%
Abortions	None	169	76.8%
	=<2	43	19.5%
	>2	8	3.6%
Prev. CS	None	117	53.2%
	=<2	78	35.5%
	>2	25	11.4%
Livings children	None	52	23.6%
	=<2	119	54.1%
	>2	49	22.3%

Conclusion

Patients' characteristics are summarized in Table (1) where the mean age of the participants was 28.6 ± 7.5 years, the mean weight was 85.3 ± 12.4 Kg, and the mean gestational age at delivery was 38.9 ± 1.2 weeks. About 24%, 77%, 53.2% and 24% of cases were P0, had no previous abortions, No previous caesarian and no children respectively.

Table (2): Description of US measurements of BPD, FL, AC, HC, and EFW (1) using Hadlock's formula and umbilical cord diameter, umbilical arteries, umbilical vein, Wharton's jelly and EFW (2) using regression equation.

	Mean	±SD	Minimum	Maximum
BPD (cm)	9.04	0.45	6.50	10.60
FL(cm)	7.29	0.38	6.39	8.80
AC(cm)	32.83	2.21	21.50	40.10
HC(cm)	32.52	1.74	27.90	39.30
EFW(1) kgs	3.16	0.41	2.20	4.57
A1(mm²)	179.63	45.24	106.00	310.00
A2 (mm²)	53.17	18.48	22.00	115.00
A3(mm²)	16.74	6.14	6.00	42.00
A4(mm²)	13.17	5.20	6.00	31.0
Wharton`s jelly area (mm²)	96.55	34.30	20.0	205.00
EFW(2) kgs	3.09	0.33	2.50	4.04

The estimation of fetal weight (EFW) is shown in Table (2) according to Hadlock's formula with average 3.19 kg ± 0.41 kg, through measuring of biparital diameter (BPD), femur length (FL), abdominal circumference (AC), and head circumference (HC) with mean values of 9.04 ± 0.45 cm, 7.29 ± 0.38 cm, 32.83 ± 2.21 cm, 35.52 ± 1.74 cm respectively. While according to the regression equation for the cross sectional area of the umbilical cord with average weight 3.09 ± 0.33 Kg, through measuring of umbilical cord cross sectional diameter, umbilical vein, umbilical arteries, and Wharton's jelly area with mean values of 179.63±45.24 mm²,53.17±18.48 mm²,16.74±6.14 mm²,13.17±5.20 mm²,96.55±34.30 mm² respectively.

Table (3): Description of neonatal birth weight, Apgar score, gender and mode of delivery among cases

		Mean	±SD	Minimum	Maximum
Actual birth weight		3.03	0.45	2.00	4.70
APGAR Score		7.82	0.81	3.70	9.10
Gender	Male	110	50.0%		
	Female	110	50.0%		
Delivery mode	A.V.D	6	2.7%		
	S.V.D	89	40.5%		
	LSCS	125	56.8%		

Table (3) summarizes the outcomes, where the mean birth weight was 3.03 ± 0.45 Kg with 50% were males and 50% females. 125 (56.8%) had been delivered by cesarean section, 89 (40.5%) delivered spontaneous vaginal delivery and 6 (2.7%) by assisted vaginal delivery. The mean APGAR score was 7.82 ± 0.81.

Table (4): Correlations between each of BPD, FL, AC, HC, EFW (1) using Hadlock's formula and actual birth weight and umbilical cord diameter, umbilical arteries, umbilical vein, Wharton's jelly, EFW (2) using regression equation and actual birth weight.

		Actual birth weight
BPD	R*	.407**
	P	0.0001
	Sig	HS
FL	R*	.356**
	P	0.0001
	Sig	HS
AC	R*	.456**
	P	0.0001
	Sig	HS
HC	R*	.410**
		0.0001
	Sig	HS
EFW1	R*	.524**
	P	0.0001
	Sig	HS
A1	R*	.701**
	P	0.0001
	Sig	HS
A2	R*	.450**
		0.0001
	Sig	HS
A3	R*	.320**
	P	0.0001
	Sig	HS
A4	R*	.350**
	P	0.0001
	Sig	HS
Wharton's jelly area	R*	.562
	P	0.0001
	Sig	HS
EFW2	R*	.702**
	P	0.0001
	Sig	HS

*Correlation coefficient

In correlation between the neonatal birth weight and prenatal EFW, Table (4) demonstrates a significant moderate positive correlation using BPD, FL, AC, HC, and Hadlock's formula r= 0.407, 0.356, 0.456, 0.410, 0.524 respectively (P< 0.001). While umbilical cord diameter and regression equation for calculation of EFW shows a significant strong correlation with neonatal birth weight r= 0.701, 0.702 respectively (P<0.001). But moderate correlation with umbilical arteries, umbilical vein and Wharton's jelly r= 0.450, 0.320, 0.562 (P<0.001).

Figure (3) illustrates the correlation of neonatal birth weight with their prenatal estimated body weight by Hadlock's formula. While Figure (4) illustrates the correlation using EFW by regression formula of umbilical cord.

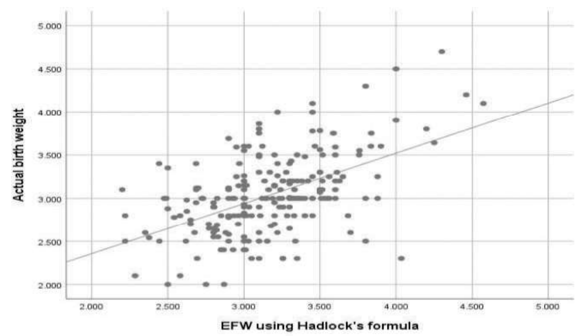

Figure (3): Correlation of neonatal birth weight with their prenatal estimated body weight by Hadlock's formula.

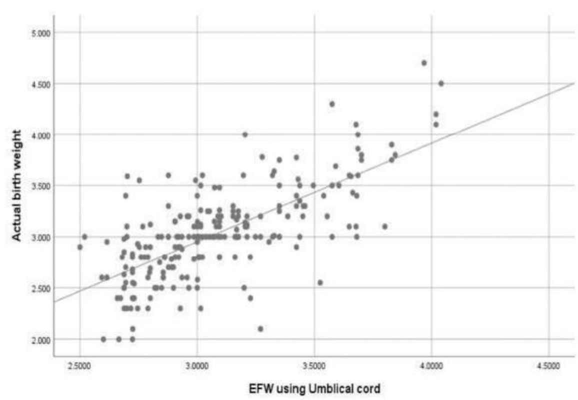

Figure (4): Correlation of neonatal birth weight with their prenatal estimated body weight by regression formula using umbilical cord.

Table (5): Correlations coefficients and Coefficient of determinant for each of BPD, FL, AC, HC, EFW(1) using Hadlock formula and umbilical cord diameter, umbilical arteries, umbilical vein, Wharton's jelly, EFW (2) using regression equation.

	Correlation coefficient (r)	Coefficient of determinant (R2)
BPD	0.407*	0.165*
FL	0.356*	0.127*
AC	0.456*	0.208*
HC	0.410*	0.168*
EFW(1)	**0.524***	0.274*
A0	0.701*	0.492*
A1	0.450*	0.202*
A2	0.320*	0.102*
A3	0.350*	0.122*
Wharton`s jelly area	0.555*	0.315*
EFW(2)	**0.702***	0.493*

*p<0.001

Table (5) shows that the correlation strength of the umbilical cord with the birth weight was higher than that by Hadlock's formula with the value of coefficient of determinant R2= 0.493 for umbilical cord that means 49% of the change in birth weight can be predicted using umbilical cord area versus R2= 0.274 for Hadlock's that's means that 27% of the change in birth weight can be predicted using Hadlock's formula.

DISCUSSION

One of the most important indicators of newborn survival is birth weight. Furthermore, the estimated fetal weight at term influences the timing and route of delivery. However, there is no agreement on acceptable clinical or acoustic measurements. As a result, researchers have tried a variety of strategies to enhance ultrasound-based fetal weight prediction (13).

Fetal biometric measures are the most often used approach for estimating birth weight. Despite extensive study into the most precise ultrasonography formula for determining estimated fetal weight, current evidence shows high error levels (14). Previously, sonographic examinations of the umbilical cord were confined to determining the number of arteries and assessing blood flow using Doppler. Heavier neonates have a bigger umbilical cord circumference at birth, according to research (11). The purpose of this study was to examine the effectiveness and accuracy of ultrasonography assessment of umbilical cord cross-sectional area with Hadlock's formula in predicting newborn birth weight at term gestation.

The current study found a significant moderate positive correlation of actual neonatal birth weight with prenatal EFW using Hadlock's formula (r=0.524, P 0.001), with the value of coefficient of determinant (R2) being 0.274, implying that Hadlock's formula can predict 27.4% of the actual birthweight. On the other hand, there was a significant strong positive correlation with EFW using the regression equation of umbilical cord area (r= 0.702, P0.001) with the value of the coefficient of determinant (R2) being 0.493, implying that umbilical cord area can predict 49.3% of the actual birth weight. That is, predicting birth weight using prenatal U/S measured umbilical cord cross sectional area is more accurate than Hadlock's algorithm.

This is consistent with other investigations. Henan et al. (11) studied 113 fetuses over 37 weeks and discovered that fetuses with umbilical cord areas less than the 10th percentile (lean umbilical cord) were more likely to have a low birth weight, confirming the existence of a correlation between umbilical cord area and fetal birth weight. Elghazaly et al. (10) shown a clear link between gestational age, fetal weight, and the amount of Wharton's jelly in the umbilical cord.

Furthermore, Morteza et al. (15), Rakesh et al. (16), and Sarah et al. (17) found a strong relationship between umbilical cord cross sectional area and birth weight. In contrast to small cords, large cords are connected with high birth weight. Because Wharton's jelly improves cord diameter and blood vessel size, which enhances blood flow and nutrients, fetal weight gain increases. on addition to Ghezzi et al. (18), who discovered that a lean umbilical cord, particularly when accompanied by diminished Wharton's jelly on ultrasound, was related with an increased chance of delivering a child that was undersized for gestational age at birth. According to Afroze et al. (19), umbilical cords with a short cross-sectional area or a sparse amount of Wharton's jelly may be associated with the occurrence of oligohydramnios and fetal distress during delivery, resulting in a higher incidence of Cesarean sections and low birth weight.

While Morteza et al. (15) discovered that a big umbilical cord cross sectional area on ultrasound examination was considerably higher in the macrocosmic fetus population than in the non-macrocosmic fetus population. In addition to Benjamin et al., (9), there is a strong association between a large cross-sectional area of umbilical cord and the presence of metabolic diseases such as diabetes and macrocosmic fetuses, and that a thin umbilical cord is associated with a higher incidence of low birth weight.

Unlike Barbieri et al. (20), who discovered that the umbilical cord cross sectional area is a poor predictor of actual body weight. This discrepancy could be attributed to differences in gestational age (20-40) weeks and criteria covered in this study of low-risk pregnancy; they also categorised the umbilical cord according to their percentile curve.

There was no significant relationship between maternal age, height, parity, and fetal gender with estimated body weight (EFW) by Hadlock's formula in the current study, but there was a significant relationship between fetal gestational age (r=0.32 p value 0.001) and maternal weight (r=0.40 p value 0.001) with EFW, which means that the EFW changes with the mother's weight and gestational age of pregnancy.

The same was true for the umbilical cord cross sectional area, where there was no significant relationship with maternal age, height, parity, or fetal gender, but a significant relationship with maternal weight (r=0.61 p value 0.001) and fetal gestational age (r=0.27 p = 0.003), indicating that the umbilical cord cross sectional area changes as the mother's weight and fetal gestational age change.

When compared to other research, Raio et al. (21) found no significant relationship between age, parity, and gestational age at time of delivery and umbilical cord parameter in an ultrasound investigation. Furthermore, Rakesh et al. (16) found a significant relationship between umbilical cord parameter and maternal age and fetal gestational age without taking into account maternal weight or fetal gender. In contrast to Afroze et al., 2017, who discovered a strong link between umbilical cord parameters in an ultrasonography research and maternal age, parity, and fetal gestational age.

The mean real neonatal birth weight and Apgar score in the current study were 3.030.45 and 7.82 0.81, respectively. This was consistent with Tahmasebi's (22) study, which found that the average birth weight was 3372.12440.7 g (range: 1950-4350 g). The majority of babies had normal 5-minute Apgar scores, with a range of 4:10.

According to Raio et al. (21), the diameter of the umbilical cord is altered by a decrease in Wharton jelly around the umbilical arteries in cases of segmental thinning. Furthermore, because the cross-section of the cord may not be precisely circular, a modest reduction in the quantity of Wharton jelly with no modification in the artery lumen may be underestimated when only diameter estimates are employed, according to these authors.

The current study's strength is the large sample size of the study population and the use of this new method, regardless of maternal decubitus, parities, fetal presentation, position, and lie, which can provide a more predictive method of estimating fetal weight than the standard Hadlock's formula. The link of the measurement with maternal medical problems like as diabetes mellitus or hypertension, in addition to amniotic fluid abnormalities, and correlation with earlier gestational age are areas for further research.

CONCLUSION

For the current sample, it is obvious that the umbilical cord area is a good predictor of birth weight at term gestation, which may provide support for future use of the umbilical cord formula for birth weight prediction. The current investigation demonstrates that measuring umbilical cord thickness and cross-sectional area in a free loop of umbilical chord is simple. The cross-sectional areas of the umbilical cord components can be determined to be crucial parameters to consider when evaluating fetal growth. This study's normalcy metrics might be used as a reference for future studies that may associate such characteristics with fetal growth abnormalities and pregnancy disorders such as diabetes mellitus and hypertension.

REFERENCES

1. Magdi El-Sayed, Badeea S, Mohamed M Z, Rehab El Shorbaji. Clinical and Ultrasound Estimation of Fetal Weight at Term and Its accuracy with Birth Weight". The Egyptian Journal of Hospital Medicine, 2020;81(7):2468-2475.
2. Moraitis AA, Shreeve N, Sovio U, Brocklehurst P, et al. Universal third-trimester ultrasonic screening using fetal macrosomia in the prediction of adverse perinatal outcome. 2020;13; 17(10):e1003190.
3. Jan-Simon L , Gabriele L , Cordula S , Kristina D. Ultrasound versus Clinical Examination to estimate Fetal Birth Weight at Term. Geburtshilfe Frauenheilkd. 2017; 77(3): 276-283.
4. Cajethan E, Patience O, Sylvestre A, Chinedu C, et al. Determination of Accuracy of Fetal Weight Using Ultrasound and Clinical Fetal Weight Estimations in Calabar South, South Nigeria. Internnational Scholarly Research Notices. 2014;6.
5. Pretscher J, Kehl S, Stumpfe FM, Mayr A, et al. Ultrasound Fetal Weight Estimation in Diabetic Pregnancies. J Ultrasound Med. 2020; 39(2):341-350.
6. Mazzone E, Dall'Asta A, Kiener AJ, Carpano MG, et al. Prediction of fetal macrosomia using two-dimensional and three-dimensional ultrasound Eur J Obstet Gynecol Reprod Biol. 2019;243:26-31.
7. Stanirowski PJ, Majewska A, Lipa M, Bomba-OD, et al. Ultrasound evaluation of the fetal fat tissue, heart, liver and umbilical cord measurements in pregnancies complicated by gestational and type 1 diabetes mellitus: potential application in the fetal birth-weight estimation and prediction of the fetal macrosomia. Diabetol Metab Syndr. 2021;18; 13(1):22.
8. Moore KP and Torchia MG. The Developing Human:Clinically Oriented Embryology. 9th ed. Philadelphia, PA, Elservier. 2013; 126-127.
9. Benjamin E, Akwa E, Ekanem A. Sonographic Assessment of Umbilical Cord Diameter as an indicator of Fetal Growth and Perinatal Outcome.Journal of Diagnostic Medical Sonography. 2021; 37(1): 41-45.
10. Elghazaly EA, Awad KA, Alghamdi J. Correlation between the measurement of the umbilical cord diameter and the birth weight outcome, in Sudanese neonates. Int J Health Sci Res. 2018; 8(11):97-101.
11. Henan DH Skheel .Cross sectional area of umbilical cord as a predictor for neonatal birth weight. Mustansiriya Medical Journal, [S.l.], 2018;14(2):2-6.

12. Bujang MA, Adnan TH. Requirements for Minimum Sample Size for Sensitivity and Specificity Analysis. J Clin Diagn Res. 2016;10(10):1-6.
13. Kang, L., Wu, Q. Q., Sun, L. J., Gao, F. Y., & Wang, J. J. Predicting fetal weight by three-dimensional limb volume ultrasound (AVol/TVol) and abdominal circumference. Chinese medical journal, 2021;134(9):1070–1078.
14. Milner, J., & Arezina, J. The accuracy of ultrasound estimation of fetal weight in comparison to birth weight: A systematic review. Ultrasound (Leeds, England), 2018;26(1), 32–41.
15. Morteza T and Reza A. Evaluation of umbilical cord thickness, cross-sectional area, and coiling index as predictors of pregnancy outcome. Indian Journal of Radiology and Imaging; 2011;21(3):195-198.
16. Rakesh, K. G., & Amit, M. Prognostic indices for pregnancy outcome on ultrasound: a prospective study. 78-83:(3)22;2012.
17. Sarah K D, Lindsay SC, John CK, Clare LW, et al. Wharton's jelly area and its association with placental morphometry and pathology 2020;94:3438.
18. Ghezzi, F., Raio, L., Di Naro, E., Franchi, M., Balestreri, D., & D'addario, V. Nomogram of Wharton's jelly as depicted in the sonographic cross section of the umbilical cord. Ultrasound in Obstetrics and Gynecology: The Official Journal of the International Society of Ultrasound in Obstetrics and Gynecology, 2001;18(2), 121-125.
19. Afroze KH, Prabha SL, Chandrakala V, Deepak M. Sonographic Estimation of Umbilical Cord Cross section Area and its Reference Value in Normal Pregnancy. J Clin Diagn Res. 2017;11(8):4-6.
20. Barbieri C, J. G. Cecatti, F. G. Surita, Sonographic measurement of the umbilical cord area and the diametersof its vessels during pregnancy. Journal of Obstet Gynaecol, 2012; 32: 230–236
21. Raio L, Ghezzi F, Di Naro E, Duwe DG, Cromi A, Schneider H. Umbilical cord morphologic characteristics and umbilical artery Doppler parameters in intrauterine growth-restricted fetuses. J Ultrasound Med 2003;22(12):1341–7.
22. Tahmasebi, M., & Alighanbari, R. Evaluation of umbilical cord thickness, cross-sectional area, and coiling index as predictors of pregnancy outcome. Indian Journal of Radiology and Imaging, 2011;21(03):195-198.