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Review Article

Radiological Modalities for the Assessment of Fetal Growth Restriction: A Comprehensive Review

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ABSTRACT

Fetal growth restriction is a significant contributor to fetal morbidity and mortality. In addition, there are heightened maternal risks associated with surgical operations and their accompanying dangers. Monitoring fetal development is a crucial objective of prenatal care and effective methods for early diagnosis of Fetal growth restriction, allowing prompt management and timely intervention to improve the outcomes. Screening for Fetal growth restriction can be achieved via many modalities; it can be medical, biochemical, or radiological. Some recommended combining more than one for better outcomes. Currently, there is inconsistency about the best method of Fetal growth restriction screening.

In this review, a comprehensive evaluation of the current radiological methods used for Fetal growth restriction, including serial growth scan, Doppler velocimetry, and biophysical profile is offered. Limitations, and potential enhancements area were specifically analyzing the effectiveness. Moreover, recently developed experimental radiological techniques were presented and how to integrate them into practice to enhance follow-up performance and results.

Introduction

Obstetrical care aims to provide a healthy journey for the mother that ends with the delivery of a safe and healthy baby (1,2). Fetal growth restriction (FGR) or "intrauterine growth restriction" is when a fetus fails to reach its genetically determined weight lacks a common definition, and it can occur due to several factors (3). It could be maternal, placental, or fetal causes or it can be a combination of more than one. On the other hand, a small for gestational age fetus (SGA) is the case when the fetus weight is below the 10th percentile of the norms for that community (4). Table 1. Summarize the main points that distinguish both terms (5).

FGR is a significant contributor to fetal and neonatal morbidity and death. For that, many screening strategies have been adopted to halt its complications on feto-maternal outcomes (6). Screening for fetal growth restriction can be medical, biochemical, and physiological.

Table.1 A comparison between FGR and SGA

Parameter	Small for Gestational Age	Fetal Growth Restriction
Definitions	A baby is considered small for its gestational age (SGA) if its birth weight is less than the tenth percentile, which is two standard deviations below the mean for that community	. Is diagnosed if physical growth is slow, with an estimated fetal weight is less than the third percentile, with compromised umbilical/cerebral blood flow
Recently revised	--	• Placenta Biochemical marker for placental compromise • Maternal inflammatory biomarkers • Fetal biomarkers as skin folds
Incidence	10-15 percent	3-8 percent
Interpretation	May not always be pathological	always be pathological
An etiology	Constitutional, genetically determined	Placental, maternal, and fetal diseases such as hypertension, infections,….etc.
Impact on fetus	Increased risk, respiratory problems, prematurity, low birth weight	May have a risk or not, depending on the underlying etiology

- **Medical screening** involves Fundal height measurement (FHM)

It is a simple and cost-effective procedure that is currently included in prenatal screening for pregnant mothers(7). Yet, it is impeded by its lack of precision due to its subjective to the examiner. FHM is influenced by maternal factors such as body weight and size. More importantly, it may fail to detect FGR indicators in its early stages, resulting in delayed diagnosis when options for fetal intervention are limited. The test may yield false-positive results in the case of twins and thus requires confirmation from another test, indicating its limited diagnostic utility(8).

- **Biochemical screening**

Several biomarkers and inflammatory cytokines(9) were analyzed as Pregnancy-Associated Plasma Protein-A, alpha-1 antitrypsin, and placental growth factor (10)(11). Usually, there is a delay or time lag before the fetal measurements show signs of FGR. Biochemical screening has a higher likelihood of detecting FGR early, however it has poor detection rate and there is no agreement in determining the best time for intervention(12).

- **Biophysical screening**

Currently, this is the most popular way, including a 2-dimensional ultrasound (US), Doppler study, and biophysical profiling. These tests need serial measurement and repetitions so patient compliance is crucial in the diagnosis (13). These tests are also examiner-dependent, so the inter-observer disparity cannot be excluded. Biophysical is coasty, time-consuming, and can lead to higher operative intervention due to their high false positive and negative rates(14).

To date, there are no gold test that could spot FGR, for that utilizing one way of screening alongside other clinical data and maternal risk factors is essential for precise diagnosis and proper management of pregnancies with suspected FGR(15), see Figure 1. To avoid the complications that come with intrauterine growth restriction, it is crucial to take comprehensive steps:

- Accurate dating establishment is the first step in diagnosing a fetus with growth restriction, which could be obtained by either LMP or by early US within the 1st trimester (16).
- Identify the cause; an extensive medical background.
- Control Maternal illnesses that are not well managed, such as hypertension, kidney disease, chronic pre-gestational diabetes with vasculopathy, and other systemic diseases, can have a major effect on fetal growth (17).
- To maintain good uteroplacental and fetoplacental circulations, it is necessary to continue a normal pregnancy which can be achieved via controlling maternal risk factors such as blood pressure diabetes, renal disease, etc. and adequate fetal circulation is necessary for normal fetal growth (18)
- Close monitoring of the fetus:
- Take appropriate action if the fetus is in distress by instituting appropriate surveillance and termination of pregnancy (19).

FGR management is a complex dilemma. A critical choice between preventing fetal harm or death by prolonging the pregnancy and the potential risks associated with terminating the pregnancy. This must be grounded on a delicate equilibrium between maternal and family risk factors and the anticipated benefits for the overall feto-maternal outcome (20).

In this review, we will address biophysical screening for FGR, including the ultrasonic parameters, and we will supply a comprehensive appraisal and critique of up-to-date breakthroughs in this rapidly growing field.

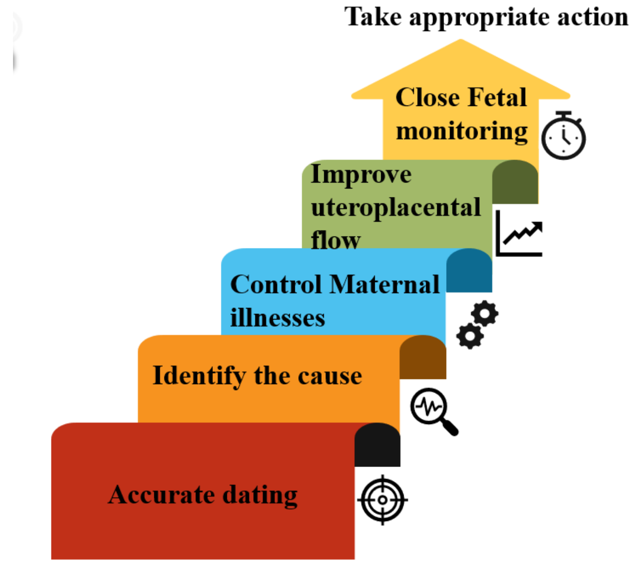

Figure 1. Steps for managing cases with FGR

Methods

The purpose of this review was to bring together data on FGR screening with radiological methods. To ensure a full study of the released work, the methods used a simplified approach that included the steps below:

A plan was used to find relevant papers using digital libraries, which include databases like Scopus, Web of Science, and Google Scholar.

A mix of terms and subject titles was used to find articles about fetal growth, fetal growth restriction, intrauterine growth retardation, Doppler, biophysical profile, radiological screening, and babies that are small for their gestational age. To improve the search results, Boolean operators like "AND" and "OR" were used to join keywords. The search looked for papers that were published till 1/2/2024. Fig.2 shows the study's process and the factors for who was included and who was not included.

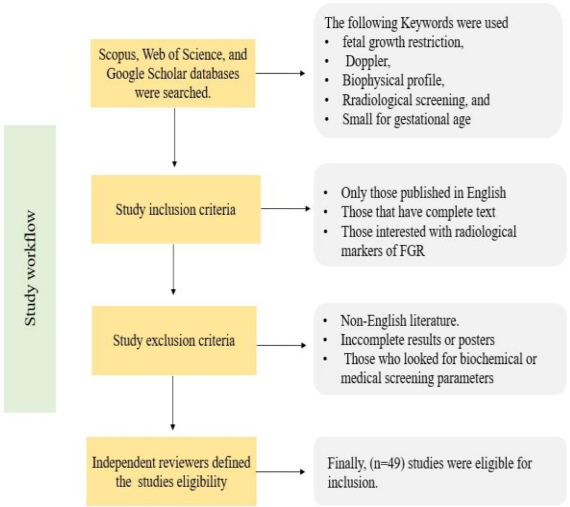

Figure2. The study workflow, inclusion, exclusion, and analysis

Biophysical screening includes Serial growth scan, Doppler, biophysical profiles (BPP), and modified BBP.

Serial growth scan

In basic terms, the weight of the fetus is assessed at a particular moment using conventional measurements such as biparietal profile (BPD), femoral length (FL), head circumference (HC), and abdominal circumference (AC). On the other hand, fetal growth is a dynamic process that involves changes in fetal weight over time. Therefore, at least two ultrasound scans conducted at different intervals are necessary to track this progression (21) (22)

Fetuses with an estimated fetal weight below the 10th percentile, according to the trajectory model, should undergo serial ultrasound scans every 3-4 weeks following diagnosis. This will allow the supervising clinician to periodically evaluate the fetus's viability perinatal risk and determine the appropriate timing for delivery (23). When dealing with pregnancies that have no date or have been poorly dated, accurately diagnosing the incorrect size of the fetus presents a distinct issue. Several specialists recommend scheduling a follow-up ultrasound examination within a period of 3-5 weeks to verify that the development of the pregnancy is progressing in accordance with the predicted pattern, particularly if the fetus seems smaller than anticipated by a difference of more than 21 days based on the last menstrual period (24) . Serial ultrasound is an indispensable instrument in identifying growth-restricted fetuses and minimizing the risk of incorrectly diagnosing healthy fetuses as small for their gestational age in high-risk pregnancies. This procedure is both time-consuming and cost-effective. Therefore, Hiersch et al. recommended conducting additional studies to establish the most accurate timing and intervals for performing ultrasound exams(25).

Doppler US:

The Doppler technique is a noninvasive method that utilizes sound waves to quantify the speed and direction of blood flow in different vessels, it provides real-time evaluations, allowing the continuous monitoring of blood flow fluctuations throughout pregnancy (26). It is frequently employed to examine the umbilical artery blood flow in addition to other arteries during pregnancy; see Figure 3, 4 and Table 2, especially for assessing FGR.

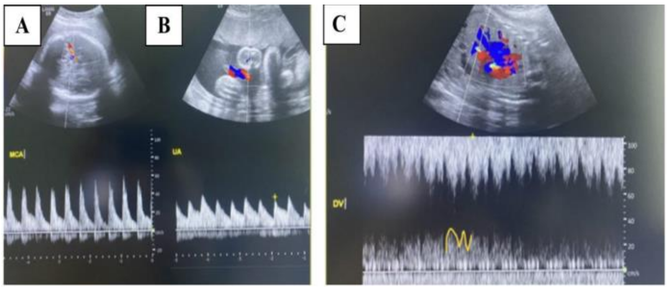

Figure 3: A) middle cerebral artery Doppler waveform B). umbilical artery Doppler waveform, C) ductus venosus Doppler waveform (DV) showing the typical waveforms during 34 weeks of gestation

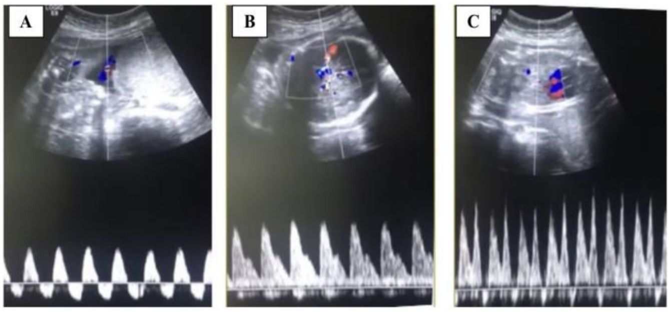

Figure 4: A 30 weeks pregnant lady known to be hypertensive; present with decreased fetal movement for 2 days, US confirmed a FGR baby, severe oligohydramnios AFI =2 cm, Doppler indices showed grade III placental Insufficiency: reversed end diastolic flow within the umbilical artery as shown in Fig. (A), MCA RI =0.7 shown in Fig. (B) , reversed A wave of the ductus venosus shown in Fig. (C).

Doppler's role in FGR can be summarized into:

Identify FGR:

Doppler results, in conjunction with other clinical and ultrasound characteristics, can assist in diagnosing FGR. Furthermore, it enables the categorization of FGR risk for moms exhibiting abnormal Doppler results, thus empowering obstetricians to identify pregnancies with a heightened risk and adopt suitable management techniques. Timely detection of FGR optimizes treatment and enhances outcomes(35) .

Evaluate FGR severity:

Doppler indices abnormality frequently corresponds to the severity of insufficient placental supply and fetal jeopardy. Giving valuable guidance for treatment decisions and optimal timing for interventions(36).

Table 2. The main vessels used in screening for FGR alongside Doppler parameters used and supporting references

vessel/Artery; Function/Role	Doppler Indices	Significance in FGR	Supporting references/study findings
Umbilical Artery Transports oxygenated blood from the placenta to the fetus	Pulsatility Index (PI), Systolic/Diastolic (S/D) ratio	Increased resistance indicates placental insufficiency, a common cause of FGR.	• Frusca et al. said in low-risk pregnancies, UA Doppler adds no prognostic criteria (27) • Figueras recommended predictive value in high-risk pregnancies, especially if those complicated by preeclampsia or FGR(28)
Middle Cerebral Artery Provides blood to the brain	Absence or reversal of end-diastolic flow	Abnormal Doppler waveforms may suggest fetal hypoxia and the risk of brain damage in cases of FGR.	• Anjum et al. said if a normal umbilical artery Doppler is present, a reduced pulsatility index in the middle cerebral artery suggests fetal adaptation(29). • Oyekale et al. There is a dispute over the reliance on CPR as an indication for FGR (30)
Ductus venosus Connects umbilical vein to inferior vena cava, bypassing liver	Aberrant Doppler waveforms	It may indicate fetal cardiac dysfunction and impairment, potentially associated with FGR.	• Seravalli et al. said that although the ductus venosus waveform lacks precise specificity, its association with arterial Doppler gives it significance in evaluating and follow up on FGR fetuses (31) • It plays a crucial role in guiding the therapeutic treatment of fetuses who are at risk of experiencing a decline in cardiovascular health
Uterine Artery Supplies blood to the uterus	Resistance Index (RI), Pulsatility Index (PI)	Increased RI or PI may indicate impaired blood flow, suggesting potential placental issues and an elevated risk of FGR.	• Pedroso et al. concluded UtA Doppler is not a very accurate predictive test for PE and FGR when used alone. Yet more accurate in detecting preterm PE, its combined use in predictive models is encouraging (32) • Kwok-Yin Leung concluded by his metanalysis that's abnormal UtA Doppler in the third trimester is useful in predicting perinatal death in suspected SGA fetus (33)
Umbilical Vein transport oxygenated and nutrient-rich blood from the placenta to the fetus	Monophasic, non-pulsatile flow (10-15 cm/s)	Assessing risk of perinatal death in FGR	• Farsetti et al confirmed that UV Doppler were significantly low in FGR ; it was able to distinguish SGA from FGR babies with good discrimination power(34)

Assess fetal health and well-being:

Serial Doppler tests can monitor alterations in blood flow patterns over a period of time, offering crucial insights into the fetus's reaction to treatments and possible decline (37).

Predict unfavorable consequences:

Aberrant Doppler results, namely the absence or reversal of end-diastolic flow in the umbilical artery (UA) or middle cerebral artery (MCA), are linked to a higher likelihood of perinatal problems such as stillbirth, newborn acidemia, and neurodevelopmental disability (38).

Doppler has its limitations; to begin with, it is reliant on the operator's skill in both acquiring and interpreting images. It cannot conclusively determine the underlying cause of FGR in every instance. Consequently, its predictive value is restricted (39). It is influenced by a broad range of variables since the normal levels vary across different ethnicities. The accuracy of the system is influenced by technical challenges such as movement and location. Furthermore, placental pathology may not be adequately seen by Doppler (40).

There were some concerns that prolonged exposure to the US practically Doppler may have harmful effects on the growing fetuses. Some animal studies reported increased cellular apoptosis however that effect was never reported in humans. Others suggested unwanted thermal effects by Doppler. All these are inconclusive and need further research (41).

To summarize, Doppler ultrasonography is an invaluable technique for evaluating blood circulation in FGR babies. It has a crucial impact on the diagnosis, evaluation of severity, monitoring, and prediction of unfavorable results, eventually leading to enhanced pregnancy outcomes for both women and their infants.

Biophysical profile:

The biophysical profile (BPP) is a 30-minute US examination that evaluates the well-being of the fetus and monitors its cardiac activity. The components consist of a fetal non-stress test, an amniotic fluid index evaluation, fetal breathing movements, full body movements, and limb tone (42), it was explained in details in Table 3.

Table 3. The component of biophysical profile and how is the score giving

Parameters	Time	Score giving
Fetus breathing movement	Thirty minutes	2 points for active breathing 1 point for slow or minimal breathing 0 points ; NO movement throughout thirty minutes
Gross fetus body movement	Thirty minutes	2 points for Vigorous movement involving Three 3 body parts 1 point for less 0 points ; No movement at all
Muscles tone	Thirty minutes	2 points for active trunk and limb movement that involves flexion &extension 1 points for less than that 0 points for No movement
The volume of Amniotic fluid	--	2 points for normal volume 1 point for reduced amount 0 for absent liquor
Non-stress test	Twenty minutes	2 points for normal heart rate tracing in response to fetus movement; i.e. 15 beat acceleration for 15 seconds. 1 point for absent acceleration 0 point for fetal heart decertation in response to movement.

The modified Biophysical Profile (MBPP) consists of two components: the Amniotic Fluid Index and the Non-Stress Test (43)

In cases of fetal distress, as in FGR, a decrease in oxygen levels necessitated the implementation of targeted adaptation strategies to provide adequate oxygen supply to various organs. This led to vasodilation in some organs, such as the brain and heart, and constriction in others, such as the kidney and liver(44)

BPP scores should be promptly repeated if the BPP Score is 6 and all of the deducted points are associated with fetal movement. A score ranging from 2-4 is considered disconcerting, and it is recommended to proceed with pregnancy termination.

A score of 0 indicates that fetal asphyxia and death are imminent, and urgent delivery is required(45)

Further testing is required in cases when the AFI examination reveals oligohydramnios, which is an indirect indication of fetal renal perfusion, despite if other parameters appear normal(46)

The BPP possessed the benefit of being very accessible, secure, non-intrusive, and easily obtainable. The evaluation encompasses several characteristics of the fetus's well-being, resulting in a more comprehensive assessment compared to individual tests (47).

BPP Predicts unfavorable outcomes: An atypical BPP score might suggest an elevated likelihood of problems such as stillbirth, whereas a normal BPP score has a strong positive predictive value for favorable fetal health.

BPP data assist obstetricians in implementing more vigilant surveillance, intervention, or potentially even delivery.

The main drawback of this test is its time-consuming nature, taking around thirty minutes. It exhibits intra-observer variance, meaning that different observers may interpret the results differently. Furthermore, the exam can be influenced by certain medicines such as opiates, magnesium sulfate, corticosteroids, and tocolytics, which can slow down the heart rate and lead to non-reactive cardiac patterns (48).

False positive findings might arise from the infant's deep sleep cycles. Maternal weight might impair visual clarity, necessitating adjustments to the ultrasound's depth and gain (49).

Borade and Sharma discussed that the modified Biophysical Profile is a simple, cost-effective, and time-saving method. It can be utilized as the main antepartum fetal surveillance test to predict perinatal outcomes and offer timely intervention in high-risk pregnancies. However, it does not adequately evaluate fetal breathing, muscular tone, and power (50) Moreover, few studies have been done to validate its use so it currently has low reliability.

Newer radiological markers for FGR evaluation

Shear wave elastography:

Shear wave elastography (SWE) is a developing imaging method that uses US to quantify the tissue stiffness. Recently it gained attention for its possible uses in medicine as FGR(51).

The fact that this technology is noninvasive and radiation-free adds value to its safety for usage in pregnant women and fetuses. The advantage of this procedure that's it could be carried out in the same session and by the same device for fetal and Doppler scan (52).

The test provides a quantitative assessment of tissue stiffness, enabling the evaluation of maturity and development of several fetal organs.

SWE can detect complications at an earlier stage compared to traditional ultrasound and identify FGR babies at a greater risk of experiencing complications, enabling early intervention and enhancing results(53).

It can follow FGR progress and assess the effectiveness of treatment (54).

The end organ damage seen in FGR newborns is also seen, including Liver fibrosis, which is an indicator of long-term liver damage in newborns with growth restriction, and intestinal inflammation, which is a major contributor to perinatal morbidity and death. Finally, it can predict infants who are susceptible to neurodevelopmental issues (55,56)

SWE is a comparatively novel technology that has not yet been extensively implemented in all healthcare settings, and it needs further study to substantiate its therapeutic applicability in FGR. Being operator-dependent makes its precision affected by the proficiency and expertise of the operator. Having a posterior placenta increases the interference with shear wave propagation.

Flow Mediated Dilatation (FMD) and Flow-mediated slowing (FMS)

Studies on flow-mediated dilatation (FMD) and flow-mediated slowing (FMS) in newborns with FGR are scarce. Although these methods are widely accepted for evaluating vascular well-being in adults and older kids, their application in newborns, particularly in FGR, is still nascent (57).

Ultrasonic assessment of FMD of the brachial artery is the standard method to assess endothelial function, and it can proceed with the onset of clinical symptoms(58).

FMS is equivalent to FMD, yet it has not been tested in pregnant moms. Flow Mediated Slowing FMS is calculated by VICORDER® electronically, and it retrieves results for clinical screening and follow-up care and allows interventional strategies to be made (59).

Lößner et al. conducted a pilot study among high-risk pregnancies. The study recommended its use for standard care during pregnancy and predicting accurate clinical outcomes with the advantage of being a straightforward, automated, and operator-independent test technique.

The study compared the findings of FMD and FMS, showing convergence in all 9 cases and suggesting normal endothelium function with a specificity of 100% and a sensitivity of 72.7% (60) .

However, it is important to note that the study had limitations, and further extensive investigations are required. Despite that research in this technique is in its infancy state; this technique can provide valuable insights into:

Assessments and evaluation of blood vessel endothelium function, thus providing insights into cardiovascular risks in FGR infants, who are prone to such complications. Anomalous FMD and FMS may suggest initial vascular impairment and maybe forecast forthcoming cardiovascular problems so they can spot a complication (61).

Implementing FMD and FMS in practice, especially for neonates with FGR, presents; technical challenges while doing the measurements owing to the newborns' tiny stature and their tendency to move (62). Currently, there is a lack of standardized techniques and reference values for neonates, especially for FGR. Further investigation and comprehension are needed to interpret the data within the framework of FGR and its possible influence on vascular health.

Artificial intelligence and machine learning:

One area where artificial intelligence (AI) shows great promise is in the field of illness detection and treatment, which is fast becoming an integral part of healthcare. Algorithms powered by artificial intelligence can sift through mountains of medical data, find insights and trends that human physicians would miss, and then propose tailored treatments(63),(64)

Rescinito et al. systemic review and meta-analysis examined using AI/ML models to forecast FGR. The parameters tested in enrolled studies were the fetal heart rate variability, screening of biochemical markers, DNA profiling data, Doppler velocimetry, MRI, and maternal physiological, clinical, or socioeconomic variables (65).

Artificial intelligence and machine learning techniques were effective in accurately predicting and identifying fetuses that are at risk of FGR during pregnancy. The sensitivity of these techniques is 0.84; the specificity is 0.87. The diagnostic odds ratio is 30.97 (95% CI 19.34–49.59), indicating the strength of the association between the AI/ML techniques and risk identification of FGR. The most accurate prediction of FGR was fetal heart rate (FHR) characteristics measured by cardiotocography(66).

AI/ML can enhance the optimization of pregnancy outcomes, but it requires appropriate algorithmic improvement and refinement, which is further emphasized (67). (68).

Early pregnancy imaging via MRI indices

Lee et al. conducted a prospective study examining the MRI technique as early as the 14th to 16th week of gestation to forecast the probability of FGR.

They assessed the placenta's ability to maintain a sufficient blood supply to the fetus. When compared to the usual placental ultrasound approach, which may identify decreases in placenta blood flow between 20 to 24 weeks. MRI indices appear to have earlier detection of ischemic placenta. Timely detection of fetal growth restriction and neonates who are undersized for their gestational age at delivery may lead to the formulation of therapeutic strategies for these disorders (69).

Pulmonary vein Doppler ultrasonography:

Pham et al. determined that growth-restricted fetuses have a significantly elevated average pulsatility index (PI) in the pulmonary vein. There is a direct relationship between the pulsatility index (PI) of the pulmonary vein and the PI of the umbilical vein in FGR fetuses. Additionally, there is an inverse relationship between the pulmonary vein's PI and the umbilical artery's pH(70) .

Early first-trimester pregnancy with contrast-enhanced ultrasound and 3D power Doppler angiography

Bertholdt et al. designed a study protocol to recruit pregnant women currently at different stages of pregnancy. These women will be divided into three groups based on their gestational ages, Which will be 8, 11, and 13 weeks. A 3-dimensional power Doppler and contrast-enhanced ultrasound techniques will be utilized to collect data on perfusion kinetics and construct 3-D indices to be compared both within and across different gestational ages(71).

Conclusion and Future Perspective

The vast emerging technique that arose recently while offering promising results introduces challenges. There is a need for longitudinal studies to validate early promising results—integration of results via multicentric collaborative study. Examine new approaches for understanding the placental function to unravel newer, more efficient interventions, applying AI/ML in screening programs and integrating it into other screening modes.

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Conflict of Interest

Authors declare no conflict of interest.

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References

[1] Hassan WNM, Shallal F, Roomi AB. Prediction of Successful Induction of Labor using Ultrasonic Fetal Parameters. Current Women s Health Reviews. 2021 Jan 6;18(1). http://dx.doi.org/10.2174/1573404817666210105151803

[2] Cook K, Loomis C. The Impact of Choice and Control on Women's Childbirth Experiences. J Perinat Educ [Internet]. 2012 Jan 1 https://doi.org/10.1891/1058-1243.21.3.158

[3] Berghella V. Maternal-Fetal Evidence Based Guidelines, Third Edition. Maternal-Fetal Evidence Based Guidelines, Third Edition. 2017 Jan 27;1–571.

[4] Schlaudecker EP, Munoz FM, Bardají A, Boghossian NS, Khalil A, Mousa H, Nesin M, Nisar MI, Pool V, Spiegel HM, Tapia MD. Small for gestational age: Case definition & guidelines for data collection, analysis, and presentation of maternal immunisation safety data. Vaccine. 2017 Dec 12;35(48Part A):6518. https://doi.org/10.1016/j.vaccine.2017.01.040

[5] Zeve D, Regelmann MO, Holzman IR, Rapaport R. Small at birth, but how small? The definition of SGA revisited. Hormone research in paediatrics. 2016 Sep 30;86(5):357-60. https://dx.doi.org/10.1159/000449275

[6] Wilcox AJ, Cortese M, McConnaughey DR, Moster D, Basso O. The limits of small-for-gestational-age as a high-risk category. European Journal of Epidemiology. 2021 Oct;36:985-91. https://doi.org/10.1007/s10654-021-00810-z

[7] Peter JR, Ho JJ, Valliapan J, Sivasangari S. Symphysial fundal height (SFH) measurement in pregnancy for detecting abnormal fetal growth. Cochrane Database of Systematic Reviews. 2015(9). https://doi.org/10.1002/14651858.CD008136.pub3

[8] Whelan R, Schaeffer L, Olson I, Folger LV, Alam S, Ajaz N, Ladhani K, Rosner B, Wylie BJ, Lee AC. Measurement of symphysis fundal height for gestational age estimation in low-to-middle-income countries: A systematic review and meta-analysis. Plos one. 2022 Aug 25;17(8):e0272718. https://doi.org/10.1371/journal.pone.0272718

[9] Murad AM, Majeed MJ, Al-Ameri RB, AL-Haidari AS. Serum Myelin Oligodendrocyte Glycoprotein and Myelin Protein Zero as Diagnostic Biomarkers in Diabetic Neuropathy. Al-Kindy College Medical Journal. 2023 Apr 30;19(1):42-7. https://doi.org/10.47723/kcmj.v19i1.859

[10] Nori W, Hamed RM, Roomi AB, Akram W. Alpha-1antitrypsin in pre-eclampsia; from a clinical perspective. J Pak Med Assoc. 2021 Dec 1;71(12):S53-56.

[11] Hurrell A, Sparkes J, Duhig K, Seed PT, Myers J, Battersby C, Clark K, Green M, Hunter RM, Shennan AH, Chappell LC. Placental growth fActor Repeat sampling for Reduction of adverse perinatal Outcomes in women with suspecTed pre-eclampsia: study protocol for a randomised controlled trial (PARROT-2). Trials. 2022 Sep 2;23(1):722. https://doi.org/10.1186/s13063-022-06652-8

[12] Górczewski W, Górecka J, Massalska-Wolska M, Staśkiewicz M, Borowski D, Huras H, Rybak-Krzyszkowska M. Role of First Trimester Screening Biochemical Markers to Predict Hypertensive Pregnancy Disorders and SGA Neonates—A Narrative Review. In Healthcare 2023 Sep 1 (Vol. 11, No. 17, p. 2454). MDPI. https://doi.org/10.3390/healthcare11172454

[13] Wang B, Zhang C. Risk evaluation of fetal growth restriction by combined screening in early and mid-pregnancy. Pakistan Journal of Medical Sciences. 2020 Nov;36(7):1708. https://doi.org/10.12669%2Fpjms.36.7.1988

[14] Intrauterine Growth Restriction. Obstetric Ultrasound: Artistry in Practice [Internet]. 2007 Nov 6 [cited 2024 Feb 6];35–43. Available from: https://onlinelibrary.wiley.com/doi/full/10.1002/9780470696231.ch5

[15] Rizzo G, Mappa I, Bitsadze V, Słodki M, Khizroeva J, Makatsariya A, D'antonio F. Role of Doppler ultrasound at time of diagnosis of late-onset fetal growth restriction in predicting adverse perinatal outcome: prospective cohort study. Ultrasound in Obstetrics & Gynecology. 2020 Jun;55(6):793-8. https://doi.org/10.1002/uog.20406

[16] Sharma D, Shastri S, Sharma P. Intrauterine growth restriction: antenatal and postnatal aspects. Clinical medicine insights: pediatrics. 2016 Jan;10:CMPed-S40070. https://doi.org/10.4137/CMPed.S40070

[17] Vayssière C, Sentilhes L, Ego A, Bernard C, Cambourieu D, Flamant C, Gascoin G, Gaudineau A, Grangé G, Houfflin-Debarge V, Langer B. Fetal growth restriction and intra-uterine growth restriction: guidelines for clinical practice from the French College of Gynaecologists and Obstetricians. European journal of obstetrics & gynecology and reproductive biology. 2015 Oct 1;193:10-8. https://doi.org/10.1016/j.ejogrb.2015.06.021

[18] Hu X, Zhang L. Uteroplacental circulation in normal pregnancy and preeclampsia: functional adaptation and maladaptation. International journal of molecular sciences. 2021 Aug 11;22(16):8622. https://doi.org/10.3390/ijms22168622

[19] Ayres-de-Campos D, Spong CY, Chandraharan E. FIGO consensus guidelines on intrapartum fetal monitoring: Cardiotocography. International Journal of Gynecology & Obstetrics. 2015 Oct 1;131(1):13-24. https://doi.org/10.1016/j.ijgo.2015.06.020

[20] Lees CC, Romero R, Stampalija T, Dall'Asta A, DeVore GR, Prefumo F, Frusca T, Visser GH, Hobbins JC, Baschat AA, Bilardo CM. The diagnosis and management of suspected fetal growth restriction: an evidence-based approach. American journal of obstetrics and gynecology. 2022 Mar 1;226(3):366-78. https://doi.org/10.1016/j.ajog.2021.11.1357

[21] Salomon LJ, Alfirevic Z, Da Silva Costa F, Deter RL, Figueras F, Ghi TA, Glanc P, Khalil A, Lee W, Napolitano R, Papageorghiou A. ISUOG Practice Guidelines: ultrasound assessment of fetal biometry and growth. Ultrasound in obstetrics & gynecology. 2019 Jun;53(6):715-23. https://doi.org/10.1002/uog.20272

[22] Ohuma EO, Altman DG, International Fetal and Newborn Growth Consortium for the 21st Century (INTERGROWTH-21st Project). Design and other methodological considerations for the construction of human fetal and neonatal size and growth charts. Statistics in medicine. 2019 Aug 30;38(19):3527-39. https://doi.org/10.1002/sim.8000

[23] Debbink MP, Son SL, Woodward PJ, Kennedy AM. Sonographic assessment of fetal growth abnormalities. RadioGraphics. 2021 Jan;41(1):268-88. https://doi.org/10.1148/rg.2021200081

[24] Caradeux J, Martinez-Portilla RJ, Peguero A, Sotiriadis A, Figueras F. Diagnostic performance of third-trimester ultrasound for the prediction of late-onset fetal growth restriction: a systematic review and meta-analysis. American journal of obstetrics and gynecology. 2019 May 1;220(5):449-59. https://doi.org/10.1016/j.ajog.2018.09.043

[25] Hiersch L, Melamed N. Fetal growth velocity and body proportion in the assessment of growth. American journal of obstetrics and gynecology. 2018 Feb 1;218(2):S700-11. https://doi.org/10.1016/j.ajog.2017.12.014

[26] Oglat AA, Matjafri MZ, Suardi N, Oqlat MA, Abdelrahman MA, Oqlat AA. A review of medical doppler ultrasonography of blood flow in general and especially in common carotid artery. Journal of medical ultrasound. 2018 Jan 1;26(1):3-13. https://doi.org/10.4103/jmu.jmu_11_17

[27] Frusca T, Todros T, Lees C, Bilardo CM, Hecher K, Visser GH, Papageorghiou AT, Marlow N, Thilaganathan B, van Wassenaer-Leemhuis A, Marsal K. Outcome in early-onset fetal growth restriction is best combining computerized fetal heart rate analysis with ductus venosus Doppler: insights from the Trial of Umbilical and Fetal Flow in Europe. American journal of obstetrics and gynecology. 2018 Feb 1;218(2):S783-9. https://doi.org/10.1016/j.ajog.2017.12.226

[28] Figueras F, Caradeux J, Crispi F, Eixarch E, Peguero A, Gratacos E. Diagnosis and surveillance of late-onset fetal growth restriction. American journal of obstetrics and gynecology. 2018 Feb 1;218(2):S790-802. https://doi.org/10.1016/j.ajog.2017.12.003

[29] Anjum S, Lakshmi TS. US Doppler Indices in Umbilical and Fetal MCA in Diagnosis of IUGR Fetuses. IAIM. 2019 Jan 1;6(1):118-27.

[30] Oyekale OI, Bello TO, Ayoola O, Afolabi A, Alagbe OA, Oyekale OT, Akinyoade ON. The cerebroplacental ratio: association with maternal hypertension and proteinuria. Radiologia Brasileira. 2021 Nov 26;54:381-7. https://doi.org/10.1590/0100-3984.2021.0026

[31] Seravalli V, Miller JL, Block-Abraham D, Baschat AA. Ductus venosus Doppler in the assessment of fetal cardiovascular health: an updated practical approach. Acta obstetricia et gynecologica Scandinavica. 2016 Jun;95(6):635-44. https://doi.org/10.1111/aogs.12893

[32] Pedroso MA, Palmer KR, Hodges RJ, Costa FD, Rolnik DL. Uterine artery Doppler in screening for preeclampsia and fetal growth restriction. Revista brasileira de ginecologia e obstetricia. 2018;40:287-93. https://doi.org/10.1055/s-0038-1660777

[33] Leung KY. Applications of advanced ultrasound technology in obstetrics. Diagnostics. 2021 Jul 6;11(7):1217. https://doi.org/10.3390/diagnostics11071217

[34] Farsetti D, Pometti F, Tiralongo GM, Lo Presti D, Pisani I, Gagliardi G, Vasapollo B, Novelli GP, Valensise H. Distinction between SGA and FGR by means of fetal umbilical vein flow and maternal hemodynamics. The Journal of Maternal-Fetal & Neonatal Medicine. 2022 Dec 12;35(25):6593-9. https://doi.org/10.1080/14767058.2021.1918091

[35] Rizzo G, Mappa I, Bitsadze V, Słodki M, Khizroeva J, Makatsariya A, D'antonio F. Role of Doppler ultrasound at time of diagnosis of late-onset fetal growth restriction in predicting adverse perinatal outcome: prospective cohort study. Ultrasound in Obstetrics & Gynecology. 2020 Jun;55(6):793-8. https://doi.org/10.1002/uog.20406

[36] Malhotra A, Allison BJ, Castillo-Melendez M, Jenkin G, Polglase GR, Miller SL. Neonatal morbidities of fetal growth restriction: pathophysiology and impact. Frontiers in endocrinology. 2019 Feb 7;10:433458. https://doi.org/10.3389/fendo.2019.00055

[37] Stampalija T, Gyte GM, Alfirevic Z. Utero-placental Doppler ultrasound for improving pregnancy outcome. Cochrane Database of Systematic Reviews. 2010(9). https://doi.org/10.1002/14651858.CD008363.pub2

[38] Uquillas KR, Grubbs BH, Prosper AE, Chmait RH, Grant EG, Walker DK. Doppler US in the evaluation of fetal growth and perinatal health. Radiographics. 2017 Oct;37(6):1831-8. https://doi.org/10.1148/rg.2017170020

[39] Alfirevic Z, Stampalija T, Dowswell T. Fetal and umbilical Doppler ultrasound in high-risk pregnancies. Cochrane database of systematic reviews. 2017(6). https://doi.org/10.1002/14651858.CD007529.pub4

[40] Sánchez-Fernández M, Corral ME, Aceituno L, Mazheika M, Mendoza N, Mozas-Moreno J. Observer influence with other variables on the accuracy of ultrasound estimation of fetal weight at term. Medicina. 2021 Feb 27;57(3):216. https://doi.org/10.3390/medicina57030216

[41] Quarato CM, Lacedonia D, Salvemini M, Tuccari G, Mastrodonato G, Villani R, Fiore LA, Scioscia G, Mirijello A, Saponara A, Sperandeo M. A review on biological effects of ultrasounds: key messages for clinicians. Diagnostics. 2023 Feb 23;13(5):855. https://doi.org/10.3390/diagnostics13050855

[42] Practice bulletin no. 145: Antepartum fetal surveillance. Obstetrics and Gynecology [Internet]. 2014 ;124(1):182–92. https://doi.org/10.1097/01.aog.0000451759.90082.7b

[43] Bardakci M, Balci O, Acar A, Colakoglu MC. Comparison of modified biophysical profile and doppler ultrasound in predicting the perinatal outcome at or over 36 weeks of gestation. Gynecologic and obstetric investigation. 2010 Jan 12;69(4):245-50. https://doi.org/10.1159/000274488

[44] MANNING, FRANK A. MD. Fetal Biophysical Profile: A Critical Appraisal. Clinical Obstetrics and Gynecology 45(4):p 975-985, December 2002. https://doi.org/10.1097/00003081-200212000-00004

[45] Zelop CM, Javitt MC, Glanc P, Dubinsky TJ, Harisinghani MG, Harris RD, Khati NJ, Mitchell DG, Pandharipande PV, Pannu HK, Podrasky AE. ACR Appropriateness Criteria® growth disturbances—risk of intrauterine growth restriction. Ultrasound Quarterly. 2013 Sep 1;29(3):147-51. https://doi.org/10.1097/ruq.0b013e31829ea221

[46] Bamfo JE, Odibo AO. Diagnosis and management of fetal growth restriction. Journal of pregnancy. 2011;2011. https://doi.org/10.1155/2011/640715

[47] Sapoval J, Singh V, Carter RE. Ultrasound Biophysical Profile. StatPearls. 2023 Jan 16 https://www.ncbi.nlm.nih.gov/books/NBK539866/

[48] Voormolen-van Munster DN. *Novel insights into the management of diabetes in pregnancy* (Doctoral dissertation, Utrecht University).

[49] Sapoval J, Singh V, Carter RE. Ultrasound Biophysical Profile. StatPearls [Internet]. 2023 Jan 16 [cited 2024 Feb 6]; https://www.ncbi.nlm.nih.gov/books/NBK539866/

[50] Borade JS, Sharma SP. The role of modified biophysical profile in predicting perinatal outcome in high risk pregnancies. Int J Reprod Contracept Obstet Gynecol. 2018 May 26;7(6):2287-94. https://doi.org/10.18203/2320-1770.ijrcog20182337

[51] Wang J, Zhang Z, Xu X, Lu X, Wu T, Tong M. Real-time shear wave elastography evaluation of the correlation between brain tissue stiffness and body mass index in premature neonates. Translational Pediatrics. 2021 Dec;10(12):3230. https://doi.org/10.21037%2Ftp-21-513

[52] Ahmed AM, Elsammak A, Refaat MM, Abd Ellatif OE. Radiological Features Of Pre-Eclampsia And Its Complications. Journal of Pharmaceutical Negative Results. 2023 Feb 7:2112-26. https://doi.org/10.47750/pnr.2023.14.S02.251

[53] El-Ali AM, Subramanian S, Krofchik LM, Kephart MC, Squires JH. Feasibility and reproducibility of shear wave elastography in pediatric cranial ultrasound. Pediatric radiology. 2020 Jun;50:990-6. https://doi.org/10.1007/s00247-019-04592-1

[54] Malhotra A, Ditchfield M, Fahey MC, Castillo-Melendez M, Allison BJ, Polglase GR, Wallace EM, Hodges R, Jenkin G, Miller SL. Detection and assessment of brain injury in the growth-restricted fetus and neonate. Pediatric research. 2017 Aug;82(2):184-93. https://doi.org/10.1038/pr.2017.37

[55] Bruce M, Kolokythas O, Ferraioli G, Filice C, O'Donnell M. Limitations and artifacts in shear-wave elastography of the liver. Biomedical engineering letters. 2017 May;7:81-9. https://doi.org/10.1007/s13534-017-0028-1

[56] Mentzel HJ, Glutig K, Gräger S, Krüger PC, Waginger M. Ultrasound elastography in children—nice to have for scientific studies or arrived in clinical routine?. Molecular and Cellular Pediatrics. 2022 Jun 6;9(1):11. https://doi.org/10.1186/s40348-022-00143-1

[57] Marôco JL, Pinto M, Santa-Clara H, Fernhall B, Melo X. Flow-mediated slowing shows poor repeatability compared with flow-mediated dilation in non-invasive assessment of brachial artery endothelial function. PLoS One. 2022 May 24;17(5):e0267287. https://doi.org/10.1371/journal.pone.0267287

[58] Rodriguez-Miguelez P, Seigler N, Harris RA. Ultrasound assessment of endothelial function: a technical guideline of the flow-mediated dilation test. JoVE (Journal of Visualized Experiments). 2016 Apr 27(110):e54011. https://dx.doi.org/10.3791/54011

[59] Mućka S, Miodońska M, Jakubiak GK, Starzak M, Cieślar G, Stanek A. Endothelial function assessment by flow-mediated dilation method: A valuable tool in the evaluation of the cardiovascular system. International journal of environmental research and public health. 2022 Sep 7;19(18):11242. https://doi.org/10.3390/ijerph191811242

[60] Lößner C, Multhaup A, Lehmann T, Schleußner E, Groten T. Sonographic Flow-Mediated Dilation Imaging versus Electronic EndoCheck Flow-Mediated Slowing by VICORDER in Pregnant Women—A Comparison of Two Methods to Evaluate Vascular Function in Pregnancy. Journal of Clinical Medicine. 2023 Feb 21;12(5):1719. https://doi.org/10.3390/jcm12051719

[61] Pereira T, Almeida A, Conde J. Flow-mediated slowing as a methodological alternative to the conventional echo-tracking flow-mediated dilation technique for the evaluation of endothelial function: a preliminary report. Mayo Clinic Proceedings: Innovations, Quality & Outcomes. 2018 Jun 1;2(2):199-203. https://doi.org/10.1016/j.mayocpiqo.2018.02.002

[62] Lopes van Balen VA, Van Gansewinkel TA, De Haas S, Van Kuijk SM, Van Drongelen J, Ghossein-Doha C, Spaanderman ME. Physiological adaptation of endothelial function to pregnancy: systematic review and meta-analysis. Ultrasound in Obstetrics & Gynecology. 2017 Dec;50(6):697-708. https://doi.org/10.1002/uog.17431

[63] Bertini A, Salas R, Chabert S, Sobrevia L, Pardo F. Using machine learning to predict complications in pregnancy: a systematic review. Frontiers in bioengineering and biotechnology. 2022 Jan 19;9:780389. https://doi.org/10.3389/fbioe.2021.780389

[64] Holzinger A, Langs G, Denk H, Zatloukal K, Müller H. Causability and explainability of artificial intelligence in

medicine. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery. 2019 Jul;9(4):e1312. https://doi.org/10.1002/widm.1312

[65] Rescinito R, Ratti M, Payedimarri AB, Panella M. Prediction models for intrauterine growth restriction using artificial intelligence and machine learning: a systematic review and meta-analysis. InHealthcare 2023 Jun 1 (Vol. 11, No. 11, p. 1617). MDPI. https://doi.org/10.3390/healthcare11111617

[66] Farhan FS, Nori W, Al Kadir IT, Hameed BH. Can fetal heart lie? Intrapartum CTG changes in COVID-19 mothers. The Journal of Obstetrics and Gynecology of India. 2022 Dec;72(6):479-84. https://doi.org/10.1007/s13224-022-01663-6

[67] Al-Ameri LT, Hameed EK. Artificial Intelligence: Current Challenges and Future Perspectives. Al-Kindy College Medical Journal. 2023;19(1):3–4. https://jkmc.uobaghdad.edu.iq/index.php/MEDICAL/article/view/1017

[68] Javaid M, Haleem A, Singh RP, Suman R, Rab S. Significance of machine learning in healthcare: Features, pillars and applications. International Journal of Intelligent Networks. 2022 Jan 1;3:58-73. https://doi.org/10.1016/j.ijin.2022.05.002

[69] Lee B, Janzen C, Aliabadi AR, Lei MY, Wu H, Liu D, Vangala SS, Devaskar SU, Sung K. Early pregnancy imaging predicts ischemic placental disease. Placenta. 2023 Sep 7;140:90-9. https://doi.org/10.1016/j.placenta.2023.07.297.

[70] Pham MS, Tran DV, Pham CK, Truong TL, Nguyen VQ. Added value of the pulmonary vein pulsatility index and its correlation to neonatal umbilical artery pH in fetal growth restrictions: a Vietnamese matched cohort study. BMC Pregnancy and Childbirth. 2023 Aug 30;23(1):625. https://doi.org/10.1186/s12884-023-05910-0.

[71] Bertholdt C, Eszto ML, Tournier M, Hossu G, Mellouki N, Cherifi A, Morel O. Assessment of uteroplacental vascularisation in early first-trimester pregnancy with contrast-enhanced ultrasound and 3D power Doppler angiography: protocol for a prospective, cross-sectional, multicentre and non-randomised open study ("HOPE Study"). BMJ open. 2019 Sep 1;9(9):e030353. https://doi.org/10.1136/bmjopen-2019-030353

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