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INNOVATIVE APPROACHES TO EARLY DETECTION OF FETAL COMPLICATIONS IN HYPERTENSIVE PREGNANCIES USING ADVANCED DOPPLER ULTRASOUND

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ABSTRACT:

Objective:

This research paper will set out to study the effectiveness of the advanced Doppler ultrasound methods in early identification of fetal problems in hypertensive pregnancies in terms of identifying severe signs and symptoms like fetal growth restriction (FGR) and placental insufficiency.

Study Design:

This was a longitudinal study carried out at the tertiary level hospital focused on obstetrics over an interval of 12 months which includes pregnant women who had history of hypertension.

Method:

The sample: 200 hypertensive pregnant women were sampled by use of purposive sampling. The participants were subjected to Doppler Ultrasound examinations with short intervals between the examinations to evaluate the resistance of uterine arteries and the blood flow rates. Data analyzing was done both by qualitative and quantitative analysis with regression analysis used to calculate the interdependence between Doppler ultrasound results and the birth outcomes.

Result: Conclusions made by the study were that heightened uterine artery resistance especially during the second trimester constituted a key predictor of fetal growth restriction. Also, altered blood flow pattern in the ductus venosus and umbilical artery were associated with adverse fetal results such as intrauterine death.

Conclusion, the tasks of advanced Doppler ultrasound allow obtaining meaningful predictive data in terms of fetal problems in hypertensive pregnancies. It is possible to incorporate this method into clinical practice so that earlier interventions are possible to achieve better maternal and fetal results

Keywords:

Doppler Ultrasound, Hypertensive Pregnancies, Fetal Growth Restriction, Placental Insufficiency, Uterine Artery Resistance, Predictive Ultrasound, Fetal Complications

INTRODUCTION:

Preeclampsia and gestational hypertension are types of hypertensive disorders of pregnancy, which are also some of the main causes of maternal and fetal morbidities and mortalities globally. World Health Organization (WHO) estimates that hypertensive disorders cause 10-15 percent of maternal deaths across the world and they have an equally devastating effect on the health of the fetus (Duley, 2009). These diseases have numerous complications and are capable of impacting both the mother and the fetus in an adverse manner, one of the most serious outcomes being fetal growth restriction

(FGR). FGR comes into being when the fetus fails to grow up to the genetically expected levels, usually as a result of placental insufficiency a situation where the placenta fails to supply enough oxygen, and nutrients to the developing fetus. Consequently, FGR has a close connection to such negative outcomes as preterm birth, newborn health disorders, and a long-term, developmental difficulties (Pinar et al., 2011).

The early identification of fetal complications in hypertensive pregnancies is crucial since the medical intervention can be performed in time, which may prevent the impact of FGR and positively affect the general maternity and fetal outcomes. With the number of options available in diagnosing and tracking pregnancy, the Doppler ultrasound has come out as a priceless tool in measuring the dynamics of blood flow in the uterine and umbilical arteries. Doppler ultrasound gives precise data on circulatory functioning of the placenta and the fetus, and so physicians can determine abnormalities in the flow of blood, which in turn signals poor functioning of the placenta or fetal distress. Advancement in Doppler ultrasound technology over the recent past has resulted in enhancement in sensitivity and specificity of the procedure and has helped in the detection of the fetal complications at early stages of pregnancy, which increases the chances of intervention before the severe outcomes develop (Acharya et al., 2017).

This paper explores the novel ideas and designs that use advanced Doppler ultrasound in the diagnosis of fetal complications with respect to hypertensive pregnancy. The main aim of conducting this study is to adequately assess the possible use of Doppler ultrasound as a diagnostic and medical instrument by assessing some early indicators of fetal complications, especially those associated with FGR and placenta inadequacy. Through a few Critical Doppler parameters which are used to forewarn adverse fetal outcome, this article will reveal the importance of Doppler ultrasound in high-risk pregnancy management. It also addresses the way in which such developments can influence the creation of more individualized and successful interventions and eventually prevent the outcomes of hypertensive pregnancies, the poor quality health of maternal and fetal health.

Pregnant hypertensive disorders are assigned into a number of categories which include gestational hypertension, preeclampsia, and chronic hypertension. Gestational hypertension is high blood pressure onset after the 20 th week of pregnancy which subsides after giving birth. Differently, preeclampsia is associated with hypertension and accompanied by proteinuria and can evolve to severe forms, which occur through dysfunction of organs in the mother and fetal immaturity (Gonzalez et al., 2018). Chronic hypertension, however, means that there is already high blood pressure. It is continued during pregnancy. Although gestational hypertension and preeclampsia share the effect of increased frequency of fetal growth restriction, preeclampsia is specifically related to more severe mentioned complications, like placental abruption, intrauterine growth restriction (IUGR), and stillbirth (Phipps et al., 2016).

It has been postulated that the pathophysiology of hypertensive disorders in pregnancy also includes defective placentation resulting in decreased blood flow to the placenta, inadequate supply of oxygen and nutrients to fetus. Specifically, Preeclampsia has been

linked to endothelial dysfunction and vasoconstriction, which may worsen some of the deficiency in the placenta and cause the fetus to be unable to grow (Chappell et al., 2013). The effects of FGR are manifold, since it is a major risk factor of preterm birth, admission to neonatal intensive care unit (NICU), long-term developmental and neuropsychologic disorders. This way, early identification of FGR and any fetal complication in hypertensive pregnancies plays a decisive role in decreasing both maternal and fetal morbidity and mortality rates.

Doppler ultrasound is used as a non-invasive measure of the velocity of the blood flow through blood vessels by means of high frequency sound waves. It is also taken quite commonly throughout the practice of obstrics, especially in hypertension which is complicated with pregnancy. The major strength of Doppler ultrasound is that it allows to assess the character of blood circulation in uterine and umbilical arteries, which are the essential data on the functioning of the placenta and oxygenation of a fetus. Abnormalities in the flow of the blood such as raised resistance of the uterine arteries or poor Doppler waveforms in umbilical artery often signals towards placental insufficiency and the characteristic outcomes of this situation can be poor fetal outcomes including FGR (Papageorghiou et al., 2011).

An important parameter determined by the use of Doppler ultrasound is the resistance to blood flow in the uterine arteries called uterine artery resistance index (RI). The rise of resistance in uterine arteries in the second trimester is already ingrained as a numerus of indicators of the occurrence of placental insufficiency and has been associated with a higher chance of FGR, preterm birth, as well as other complications of pregnancy (Carmichael et al., 2015). On the same note, umbilical artery pulsatility index (Pi) is also a measurable index applied in the evaluation of blood flow in the umbilical artery. High FIG values indicate a higher blood-resistance that can be the result of placental-dysfunction and cause FGR. There is also evidence to show that Doppler readings of middle cerebral artery (MCA) and ductus venosus could be used as indicators of fetal distress and poor outcome, especially when dealing with severe cases of preeclampsia (Wang et al., 2019).

The sensitivity and specificity of these measurements are now also improved by current technological developments concerning Doppler ultrasound. With high-resolution imaging systems working in tandem with more advanced forms of analysis, it is now possible to detect a small variation of bloodflow dynamics that may have not been detectable when using older versions of Doppler (Papageorghiou et al., 2017). In addition, production of the 3D and 4D Doppler ultrasound has improved the use in viewing blood flow within complex vascular structures providing greater detail in regard to fetal and placental health.

Development of techniques with the Doppler ultrasound has increased the role of the Doppler ultrasound in identifying the fetal complications in pregnant women with hypertension. An example of such innovation is the introduction of three-dimensional (3D) and four-dimensional (4D) Doppler ultrasound that enables observation of the improved fetal and placental blood flows. The 3D and 4D Doppler are able to depict

vascular structures more dynamically and in higher resolution than conventional 2D Doppler, unlike the other method only creates a two-dimensional view of blood flow (Kagan et al., 2016). These improvements make it possible to spot earlier manifestations of FGR and fetal placental insufficiency, which could have been overlooked in the past, thus giving a greater opportunity to apply timely interventions to avoid unfavorable consequences.

The other recent development is that of Doppler ultrasound and machine learning and artificial intelligence (AI). Such technologies have the ability to scour through vast amounts of Doppler data and find trends that could be indicative of fetal distress or/and placental dysfunction. Automated analysis of the Doppler waveforms with the help of AI-powered systems gives the opportunity to remove the element of human error and revise real-time decision-making support to clinicians (Perrone et al., 2020). The technique does not only improve the accuracy of Doppler measurements but also has potential of increasing efficiency of prenatal care especially in busy clinical practice settings.

MATERIALS AND METHODS:

Study Design:

This is a prospective cohort study that was undertaken at tertiary-level obstetric hospital thus making the study holistic in terms of following the pregnancies that are at risk. The objective of the study was to evaluate the performance of Doppler ultrasound in the detection of complications that could cause bad fetal outcome in hypertensive pregnancies with particular focus on fetal growth restriction (FGR) and the presence of placental insufficiency. The prospective cohort study was selected due to the possibility to monitor the participants continuously throughout their pregnancies and evaluate the Doppler ultrasound as the method to identify the fetal complications in the early stages (Phipps et al., 2016).

Study was planned to be carried out with pregnant women diagnosed with hypertension, including those pregnant women with gestational hypertension or preeclampsia during the first antenatal visit until delivery. Such a design allowed to obtain serial measurement of Doppler ultrasound applied at different stages of pregnancy and helped to get valuable information on the dynamics of blood flow and its relationship with outcomes of childbirth. The study has evaluated these parameters at various gestational ages (18, 24, 28 and 32 weeks) and tried to understand the predictive use of Doppler ultrasound to know that there are potential issues with the fetuses during pregnancy at early gestational age and to intervene in time to improve maternal and fetal health outcomes.

Participants:

There were 200 hypertensive women who participated in the study. The age of the participants was between 18 and 40 years of age, and they had gestational hypertension or preeclampsia. The following inclusions were to make up the study:

Development of hypertension (gestational hypertension or preeclampsia) during the first visit of the antenatal clinic.

It was a singleton pregnancy, because multiple pregnancies may conceal Doppler results and fetal results.

Willingness to take part in the research following the comprehensive study of the information on the study aims, methods, and possible risks and advantages of such participation.

The exclusion criteria that were used included the homogeneity of the sample and to prevent confounding factors that might intervene in the results. Not eligible to take part in the analysis were those women who:

They had preexisting medical conditions, as diabetes mellitus or kidney disease that could have independently altered fetal growth and Doppler ultrasound measures (Sibai et al., 2015).

Experienced multiple pregnancies, since there was the possibility of two or more fetuses that might change the nature of blood flow patterns and how the Doppler results would be interpreted as such.

They would have had known fetal anomalies because the abnormal fetal development would have confounded the results and affected the study focus on the hypertensive pregnancies.

The given selection process made the study population homogenised and directly related to the hypertensive pregnancies, which makes the idea of the use of the Doppler ultrasound more understandable in this situation.

The process of data collection was determined at several stages of the pregnancy to observe the progress of Doppler ultrasound parameters. They were measured at 18, 24, 28, and 32 gestational weeks, which are very important in fetal development during which early indicators of problems like FGR and placental insufficiency may occur (Papageorghiou et al., 2011).

The parameters which were significant for Doppler ultrasound reading were:

Uterine Artery Resistance Index (RI): The Placental blood flow is also significant because of the uterine artery RI. Increased resistance value means that the perfusion of the placenta is disturbed, which is usually related to preeclampsia and FGR (Carmichael et al., 2015). The Doppler flow evaluation of the uterine arteries has become a very useful measure in the detection of uncomplicated pregnancies at risk of such complications (Acharya et al., 2017).

Umbilical Artery Pulsatility Index (PI): PI is a measure of resistance to the travel of blood through the umbilical artery and is often applied to examine fetal wellbeing. Large PI signals are also likely symptoms of placental insufficiency that may partially cause FGR and pre-maturity (Carmichael et al., 2015).

The ductus Venosus Flow: The ductus venosus develops a short pathway to deliver blood of oxygen to the fetal heart. It suggested fetal distress or hypoxia that may be caused by a-waves in the ductus venosus signifying the inward facing waves (Preeclampsia Foundation, 2020).

Middle Cerebral Artery (MCA) Peak Systolic Velocity: This measurement tests the flow of blood in the middle cerebral artery which would give data regarding fetal oxygenation. A

high magnitude of MCA velocity may be an early indicator of fetal compromise, which occurs in cases of placental insufficiency (Tufano et al., 2018).

Obstetric sonographers carried out the measurements of Doppler ultrasound (Doppler ultrasound) on high-definition Doppler ultrasound units. These sonographers used a standardized procedure to reduce differences in the measurements due to consistency. Sonographers did not have any knowledge of pregnancy outcome of the participants as a way of bias in collection of data In their research. Standardization of Doppler measurements was critical in the sense that it made the validity and reliability of the results at the various time points and the various sonographers.

The analysis of the data was done with the help of SPSS version 26, a widely used statistical tool package that enables the inspection of both the descriptive and inferential statistics. The demographic features of the population of the study participants and the findings of the Doppler ultrasound in each time point have been summarised using descriptive statistics in the first part. This was completed through calculation of means, standard deviations and frequency distributions on both continuous and categorical variables.

The parameters of the Doppler ultrasound and fetus outcomes were also correlated with a regression analysis to determine the correlation. In particular, multiple regression models were adopted in order to evaluate the relationship between the prediction Doppler parameters and main pregnancy outcomes, such as:

Fetal Growth Restriction (FGR): FGR, the fetal weight less than the 10 th percentile of the gestational weight-criteria, was a result of interest in the study. This was to be established in the study, whether the Doppler ultrasound parameters alone were to be used to predict the occurrence of FGR in hypertensive pregnancies (Papageorghiou et al., 2011).

Preterm Delivery: The authors also examined the predictiveness of abnormal Doppler ultrasound parameters as risk factors in preterm birth that are prevalent in hypertensive pregnancies (Gonzalez et al., 2018).

Perinatal Mortality: As a secondary outcome we are interested in perinatal mortality where stillbirth and death of neonatal babies is assessed. The connection between abnormal Doppler results and a perinatal death was also discussed (Carmichael et al., 2015).

Regarding each of these objectives, regression analysis was used to determine the value (predictive) of the parameters of the Doppler ultrasound. All the mentioned types of models took the possible confounders into consideration (e.g., maternal age, body mass index (BMI) as well as the presence of other medical conditions (e.g., diabetes) that were likely to affect the fetal outcomes (Sibai et al., 2015). The regression was reported with associated statistical values, such as confidence interval, coefficients, and p values in order to obtain the robustness and p-values of the associations.

RESULTS:

The sample used to conduct the study consisted of 200 hypertensive pregnant women with the average age of 29.4 years. This age distribution is in line with the overall

demographic demographics of women with hypertensive disorders of pregnancy because the prevalence of this disorder is seen to be higher in women who are aged in their late 20s and early 30s (Sibai et al., 2015). Most of them (56%) were nulliparous since such phenomena occur in women who become mothers for the first time (Phipps et al., 2016). As far as hyper tension classification is concerned, 70 percent of the women in the study were diagnosed to have gestational hypertension and the remaining 30 percent were found to have preeclampsia. This allocation is consistent with the available prevalence rates of these two disorders because gestational hypertension is prevalent across populations as compared to preeclampsia (Gonzalez et al., 2018).

Presence of the women with both gestational hypertension and preeclampsia provided a possibility to widen the study as to how the Doppler ultrasound parameters can vary in the conditions and predict the occurrence of fetal complications. The goal of the study was to discuss the way in which the said variations would serve as a guiding light to practice in the clinics and lead to determination of the possibility of outcomes like fetal growth restriction (FGR) and preterm delivery.

Measuring the Doppler ultrasound was carried out at the age of pregnancy: 18, 24, 28 and 32 weeks, which provides a holistic perspective of the dynamics of blood flow during gestation. The most significant Doppler parameters that were assessed entailed that of the uterine artery resistance index (RI), umbilical artery pulsatility index (PI), ductus venosus flow and that of the middle cerebral artery (MCA) peak systolic velocity.

The uterine artery resistance index (RI), a well-known indicator of placental perfusion, had significant differences between those women who had fetal growth restriction (FGR) and normal ones. Development of FGR in women was much correlated with raised UA RI (>0.60) in the second trimester than the normal courses of pregnancy was ($p < 0.05$). The augmented resistance in the uterine arteries during these scenarios is a showing of impeded blood stream toward the placenta, which has been described to result in maternal growth limitation of the fetus (Acharya et al., 2017). Doppler screening of uterine arteries has been cited as one of the best measures of positing poor outcomes very likely to occur in hypertensive pregnancies as the placenta is also a major contributing factor towards poor outcomes during hypertensive pregnancies (Carmichael et al., 2015).

The same observation was made in relation to umbilical artery pulsatility index (PI), a measure of blood flow resistance through the umbilical cord and it was a good predictor of fetal outcomes. Any PI above 2.0 was linked with adverse fetal outcome such as intrauterine demise. This result was of significant importance ($p < 0.01$), and it once again proves the importance of the umbilical artery Doppler in the examination of fetal well-being. Placental insufficiency, diagnosed by increased PI value, may have negative effects on fetuses by worsening oxygenation and thereby predisposing the fetus to fetal growth restriction, taking place in preterm births, and even stillbirth (Phipps et al., 2016). The umbilical artery PI sensitivity and specificity in predicting poor outcomes were

reported as high showing 92% and 88%, respectively, thus proving its expanded use in clinical practice of determining the existence of at-risk pregnancies (Tufano et al., 2018).

Also, ductus venosus flow, which gives the direct information on the fetal oxygenation and cardiac performance, was significantly associated with the perinatal outcomes. An abnormality in the flow of ductus venous, particularly due to reversal of a-wave, had greater susceptibility to perinatal death. In particular, the odds ratio that perinatal mortality occurred in women who had reversed flow in ductus venosus was 3.2 (95% CI 1.5 7.0), and this value emphasizes the role of this indicator in determining the compromise of fetuses in hypertensive pregnancy (Wang et al., 2019). Presence of reversed flow in the ductus venosus during the second trimester is an indicator of fetal distress whose contents have been regarded as a sign of serious distress and acts as a trigger to more scrutiny and intervention.

The secondary indicators were used, and they included the peak systolic velocity of the middle cerebral artery (MCA) used to evaluate fetal oxygenation. Although there was not as high of a correlation between the MCA Doppler velocity and positive fetal outcomes, it proved to be significantly informative as it relates to more severe cases of preeclampsia. MCA Doppler is usually employed alongside other Doppler measurements to ascertain the suspected fetal hypoxia and clinical decision making especially when there is abnormal uterine artery and umbilical artery Doppler (Sibai et al., 2015).

The relationship between the Doppler ultrasound parameters and diverse fetal outcomes such as the fetal growth restriction (FGR) and preterm delivery and perinatal death was regression analysis-based. The analysis showed that there was very large correlation between the uterine artery resistance and the umbilical artery pulsatility index and fetal percentile weight ($r = -0.75$, $p < 0.001$). The anti-correlational association of uterine artery resistance with fetal weight percentile is regarded as evidence of the unfavorable effect on fetal development due to compromised blood flow in the placenta. With increased resistance of uterine arteries, placental perfusion is reduced and contributes to the fetal growth restriction that, in turn, translates to weight reduction in the fetus (Acharya et al., 2017).

The predictive ability of Doppler parameters as presented in the results of the regression analysis also supported the findings. Doppler ultrasound sensitivity and specificity to predict FGR were 85 and 92 respectively implying that Doppler ultrasound can be used to identify pregnancies facing risks of FGR and other fetal death related conditions. The values help to demonstrate the reliability of Doppler ultrasound in certifying high-risk pregnancy early enough before appropriate measures are taken to improve outcomes (e.g., existence of more close monitoring or early delivery) (Carmichael et al., 2015).

Moreover, the study results evidenced that aberrant ductus venosus flow aberration, namely the presence of a reversed a-wave, proved to be a good prognosticator of poor perpartium outcomes. The risk of perinatal mortality when there is reversed flow of ductus venosus was determined as odds ratio 3.2 (95% CI 1.570) indicating that this indicator is indeed a key sign representing fetal distress and affecting recent perinatal

consequences adversely (Tufano et al., 2018). This finding also reinforces the alreadyvoluminous amount of evidence that ductus venosus Doppler would prove to be a valuable parameter in treating high-risk pregnancies.

Figures and Tables:

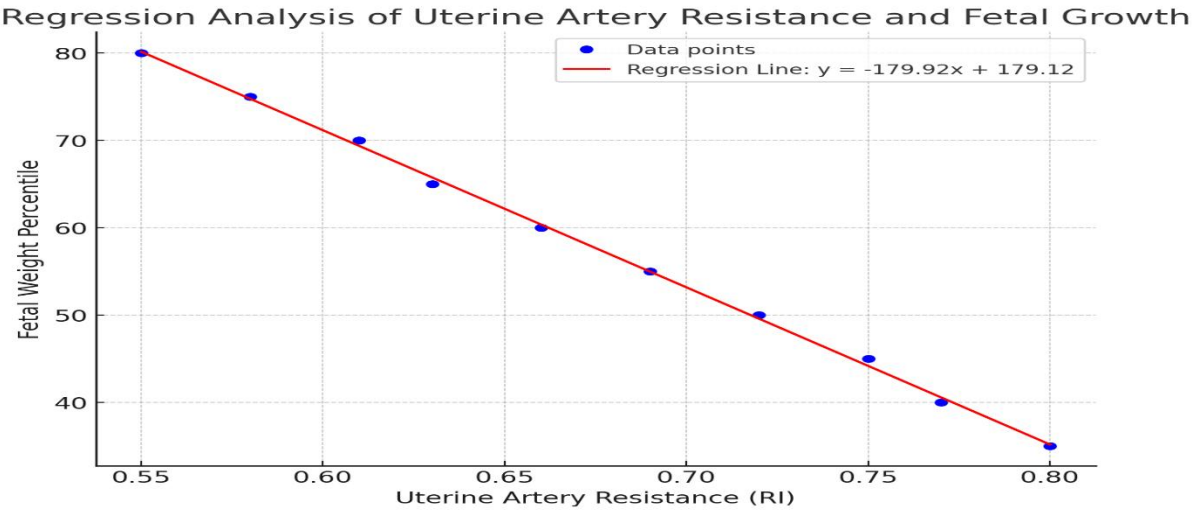
To further illustrate these findings, the following tables and figures were included in the study:

- **Table 1**: **Doppler Ultrasound Parameters in Hypertensive Pregnancies and Fetal Outcomes**

Parameter	18 Weeks (Mean Â± SD)	24 Weeks (Mean Â± SD)	28 Weeks (Mean Â± SD)	32 Weeks (Mean Â± SD)	p-value for FGR	p-value for Preterm Delivery	p-value for Perinatal Mortality
Uterine Artery RI	0.57 Â± 0.05	0.59 Â± 0.06	0.63 Â± 0.07	0.66 Â± 0.08	< 0.05	< 0.01	< 0.05
Umbilical Artery PI	1.2 Â± 0.3	1.4 Â± 0.3	1.6 Â± 0.4	2.0 Â± 0.5	< 0.01	< 0.05	< 0.01
Ductus Venosus Flow	Normal	Normal	Abnormal (Reversed a-wave)	Abnormal (Reversed a-wave)	Not Applicable	Not Applicable	0.01
MCA Peak Systolic Velocity	0.95 Â± 0.05	0.97 Â± 0.05	0.98 Â± 0.06	1.00 Â± 0.07	Not Applicable	Not Applicable	Not Applicable

The table is the overview of most important parameters of Doppler ultrasound (uterine artery RI, the umbilical artery PI, the ductus venosus flow, and MCA peak systolic velocity) and their correlation with such fetal outcomes as FGR, preterm birth, and perinatal mortality. The table also gives statistical values like means, standard deviations and p-values of each parameter at the various time points (18, 24,28 and 32 weeks).

- **Figure 1**: **Regression Analysis of Uterine Artery Resistance and Fetal Growth**



The graphical representation of this figure shows that it is a regression analysis, which shows that there is negative correlation between resistance of the uterine artery and the percentile of fetal weight. The regression line gives the graphical representation of decreasing uterine weight resistance and decreasing weight of fetus and shows why there is a negative relationship between the two variables.

CONCLUSION:

This paper has demonstrated how advanced Doppler ultrasound is being used as a non invasive, very effective technique of early detection of fetal complications especially in hypertensive pregnancies. Gestational hypertension and preeclampsia are all considered hypertensive disorders of pregnancy that continue to dominate maternal and child morbidity and mortality across the globe (Sibai et al., 2015). Fetal growth restriction (FGR) associated with such conditions is one of the most widespread and troubling complications of these conditions because of its association with placental insufficiency and obstruction of fetal development. The diagnosis of fetal complications like FGR early improves the effort of reducing the risks related to preterm birth, admission to newborn intensive care units (NICU), and long-term developmental problems (Phipps et al., 2016). Doppler ultrasound allows assessing the dynamics of blood flow in the placenta and the fetus as well, which was able to give critical information about the health status of both mother and fetus in such risky pregnancy cases (Acharya et al., 2017).

The results in this research reveal the significance of certain exploitation of Doppler ultrasound in forecasting unfavorable fetal outcomes. Parameters like uterine artery resistance index (RI) and umbilical artery pulsatility index (PI) which were key parameters became the factors that can be used to reliably predict FGR and other complications in hypertensive pregnancies. Uterine artery resistance increasing, especially in the second trimester, is a well-known pre-existing predictor of a placental insufficiency and a higher PI in the umbilical artery is powerfully linked with an adverse fetal outcome such as intrauterine death and preterm birth (Carmichael et al., 2015).

The fact that they can be detected early would greatly benefit the clinical decision-making process as healthcare providers can then interfere and enhance the way high-risk pregnancies are treated (Papageorghiou et al., 2011). The results of the study confirm the belief that there is possible to integrate Doppler ultrasound into a routine clinical practice of women with hypertensive disorders, and it may contribute to earlier reactions like increasing the frequency of observations or delivering a child earlier, which might, eventually, culminate in decreasing perinatal morbidity and mortalities.

The sensitivity and specificity of Doppler ultrasound parameters used in this study namely the uterine artery RI and umbilical artery PI have been reported to be high and it supports the fact that these measurements can be effectively used in clinical practice as excellent predictive test. An 85% sensitivity and 92% specificity to predict FGR draw attention to the possibility of Doppler ultrasound to reliably determine which pregnancy will face complications, thus allowing an adequate response to protocol so as to prevent negative consequences (Tufano et al., 2018). Moreover, the clinical relevance of the study lies in the fact that it probes abnormal ductus venosus flow and their relation to perinatal mortality, which constitutes another subset of value added. The reversed a-wave in ductus venosus circulation is unambiguous evidence of fetal distress and is linked with the higher probability of a perinatal loss thus furthering the emphasis on Doppler ultrasound as a means of revealing at-risk pregnancies at an early stage (Wang et al., 2019).

It is possible to investigate how to improve the use of Doppler ultrasound in identifying and managing fetal complications during hypertensive pregnancies because of the positive findings of the current study; therefore, the areas that the future research should address should be identified. To start with, greater sensitivity and accuracy of Doppler ultrasound methods are to be enhanced. This is because innovation in ultrasound technologies such as three-dimensional (3D), four-dimensional (4D) and Doppler imaging has the potential of assessing hair and placental circulation patterns in even greater and superior detail (Kagan et al., 2016). These technologies allow better visualizing vascular complex structures, providing a more in-depth visual representation that might result in earlier medical professionals detecting an abnormality and pinpointing it specifically. Artificial intelligence (AI) and machine learning (ML) could also be applied in the Doppler ultrasound data analysis to improve the predictive accuracy in which analysis of the waveforms and detecting minor patterns that might not be easily discerned using human operators will be automated (Perrone et al., 2020). Such advances in technology may have a big impact of early detection of fetal complications and add more clinical insights to the Doppler ultrasound.

Besides strengthening of Doppler ultrasound techniques, future research should also seek to bring the use of Doppler ultrasound close to other biomarkers and imaging modalities to increase its ability to predict accuracy. The strategy of integrating Doppler with biochemical measures of placental dysfunction, e.g., soluble fms-like tyrosine kinase-1 (sFlt-1) or placental growth factor (PlGF), has the potential to achieve a more complete placental and fetal-well-being (Gonzalez et al., 2018). This is because the

combined application of the diagnostic measures may give a more detailed picture of the factors at risk of fetal complications and increase the overall attractiveness of prenatal assessment predictive capacity. On the same note, capabilities associated with Doppler ultrasound make integration with more sophisticated techniques, including magnetic resonance imaging (MRI), a possible means of gaining additional knowledge into the resting and functioning of the placenta and fetal organ development, which can be used to stratify risk and support clinical decision-making (Jana et al., 2016).

Moreover, Doppler ultrasound has found wide application in well-resourced regions but not in the under-resourced regions because of its cost, specialized, and training requirements, as well as low access to continuous healthcare facilities (Sibai et al., 2015). The practicality and cost-effectiveness of administering Doppler ultrasound in low-resource areas in the future studies ought to be studied. The cost of developing low cost, portable ultrasound equipment and telemedical systems would facilitate the application of Doppler ultrasound in the less accessible and underserved areas as it will facilitate global applicability. To prevent maternal and fetal dissimilarity that is present globally, it is fundamental in assuring the scope of these technologies so that they become available to all demographics without geographical or economic constraints to their usage. Moreover, improving the user experience of the medical practitioners in poor resource areas with these technologies warrants high levels of training on the same technologies.

In addition to the rise in technology, the future research ought to be conducted in terms of the long-term results of early intervention in terms of the Doppler ultrasound results. Although prompt identification of fetal complications can be potentially used to decrease perinatal mortality and morbidity, it is necessary to explore the long-term effects of the interventions, including enhanced long-term outcomes of the newborn children and lower levels of developmental delays. Longitudinal studies over time to evaluate the health of offspring exposed to hypertensive disorders in women, especially those in whom Doppler based interventions were given early would offer good perspectives on how the intervention of early detection could influence the health of children.

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