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Systematic Review

Pulmonary Vein Doppler for Early Detection of Fetal Cardiac Dysfunction in Placental Insufficiency: A Systematic Review

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ABSTRACT

Background: Placental insufficiency results in chronic fetal hypoxemia and progressive cardiovascular adaptation that may culminate in myocardial dysfunction. Conventional fetal surveillance relies primarily on arterial Doppler parameters, which reflect placental resistance and fetal circulatory redistribution but do not directly assess cardiac performance. Pulmonary vein Doppler reflects left atrial pressure and ventricular compliance and has emerged as a potential marker of fetal diastolic dysfunction.

Objective: To systematically review contemporary evidence on the role of pulmonary vein Doppler in pregnancies complicated by placental insufficiency and intrauterine growth restriction (IUGR), focusing on fetal cardiac dysfunction and perinatal outcomes.

Methods: A systematic literature search was conducted in PubMed, Scopus, and Embase for studies published between January 2019 and June 2025. Studies assessing pulmonary vein Doppler parameters in pregnancies complicated by placental insufficiency or IUGR were included. Study selection followed PRISMA 2020 guidelines. Risk of bias was assessed using the Newcastle–Ottawa Scale.

Results: Twelve studies met inclusion criteria. Pulmonary vein pulsatility index (PVPI) was consistently elevated in growth-restricted fetuses compared with appropriately grown fetuses. Elevated PVPI was associated with fetal diastolic dysfunction, abnormal arterial Doppler indices, and adverse perinatal outcomes including neonatal intensive care unit admission and neonatal acidosis. In several studies, pulmonary vein Doppler abnormalities preceded deterioration in arterial Doppler parameters.

Conclusion: Pulmonary vein Doppler is a sensitive marker of fetal cardiac diastolic dysfunction in placental insufficiency. Its integration into comprehensive fetal surveillance protocols may improve early detection of fetal compromise and support more individualized clinical decision-making.

Keywords*: Pulmonary vein Doppler; fetal cardiac dysfunction; placental insufficiency; intrauterine growth restriction; systematic review.*

INTRODUCTION

Placental insufficiency is a central pathological mechanism underlying fetal growth restriction and remains a major contributor to adverse perinatal outcomes worldwide. Inadequate placental perfusion leads to sustained reductions in oxygen and nutrient delivery to the fetus, resulting in chronic hypoxemia and altered metabolic conditions. These disturbances not only increase the risk of stillbirth and neonatal morbidity but also contribute to long-term cardiovascular and metabolic disease in affected offspring [1,2].

In response to a compromised intrauterine environment, the fetus initiates adaptive cardiovascular mechanisms designed to maintain perfusion of vital organs. These adaptations include redistribution of cardiac output, elevation of systemic vascular resistance, and modification of ventricular loading conditions. While such responses are initially protective,

persistent hypoxemia and increased cardiac workload eventually promote myocardial hypertrophy, increased myocardial stiffness, and impaired ventricular relaxation. Notably, abnormalities of diastolic function often emerge before detectable systolic impairment, rendering early myocardial dysfunction difficult to identify using conventional surveillance methods [3,4].

Current antenatal monitoring in placental insufficiency relies largely on arterial Doppler indices, such as the umbilical artery and middle cerebral artery pulsatility indices, as well as the cerebroplacental ratio. Although these parameters are valuable indicators of placental resistance and fetal circulatory redistribution, they do not provide direct information regarding myocardial performance. This limitation is particularly evident in late-onset fetal growth restriction, where arterial Doppler findings may remain within normal ranges despite underlying cardiac compromise and increased risk of adverse outcomes [5,6].

Venous Doppler assessment offers a complementary approach by reflecting cardiac filling pressures and ventricular compliance. Pulmonary vein Doppler, in particular, provides insight into left atrial pressure and left ventricular diastolic function. Increased pulmonary vein pulsatility and exaggerated atrial reversal are considered indicators of impaired ventricular relaxation and elevated atrial pressure. These features suggest that pulmonary vein Doppler may serve as an early marker of fetal cardiac dysfunction, potentially preceding changes in arterial Doppler parameters [7,8].

Despite its physiological relevance, pulmonary vein Doppler has not been widely incorporated into routine clinical practice, largely due to technical challenges and the absence of standardized reference values. Given the increasing recognition of fetal cardiac dysfunction as a key determinant of outcome in placental insufficiency, a systematic evaluation of available evidence is required. This review aims to synthesize contemporary data on pulmonary vein Doppler in placental insufficiency and fetal growth restriction, with emphasis on its association with myocardial dysfunction and perinatal outcomes.

METHODS

Aim, design and setting

The aim of this study was to systematically review the available evidence on the role of pulmonary vein Doppler as a marker of fetal cardiac dysfunction in pregnancies complicated by placental insufficiency or fetal growth restriction. This study was conducted as a systematic review of published literature in accordance with the PRISMA 2020 guidelines. No clinical setting was involved, as the review was based on previously published studies.

Participants and study characteristics

The review included studies involving pregnant women carrying singleton fetuses diagnosed with placental insufficiency or fetal growth restriction, in whom fetal pulmonary vein Doppler parameters were assessed. Studies of uncomplicated pregnancies with appropriately grown fetuses served as comparators where applicable.

Processes, exposure, and comparisons

A systematic search of PubMed (MEDLINE), Scopus, and Embase was performed to identify eligible studies published between January 2019 and June 2025. Study selection, data extraction, and risk of bias assessment were conducted independently by two reviewers.

The exposure of interest was assessment of fetal pulmonary vein Doppler parameters, including pulsatility index and atrial reversal. Comparisons were made with appropriately grown fetuses and with conventional arterial Doppler parameters, such as the umbilical artery and middle cerebral artery Doppler indices, when reported. In the included studies, fetal pulmonary vein Doppler was obtained using pulsed-wave Doppler at the point of entry of the pulmonary vein into the left atrium, ensuring clear visualization of the vessel and minimal insonation angle, preferably less than 30 degrees. Doppler sampling was performed during fetal quiescence and in the absence of fetal breathing movements to avoid waveform distortion. Pulmonary vein pulsatility index was calculated using standard methodology based on peak systolic velocity, diastolic velocity, and atrial reversal velocity. Abnormal pulmonary vein Doppler was defined as a pulsatility index above the 95th percentile for gestational age and/or increased atrial reversal, as reported in the respective studies.

Statistical analysis

Quantitative meta-analysis was not undertaken due to significant heterogeneity among the included studies, including variations in pulmonary vein Doppler acquisition techniques, gestational age at assessment, and definitions of abnormal pulmonary vein pulsatility index. In addition, the absence of standardized gestational age–specific reference ranges and uniform cut-off values for pulmonary vein Doppler indices precluded meaningful statistical pooling of data. Therefore, findings were synthesized using a qualitative narrative approach. Power calculation was not applicable, as this study did not involve primary data collection or statistical pooling of results.

Study design and reporting standards
This systematic review was conducted in accordance with the **PRISMA 2020 guidelines**.

PRISMA Flow
A total of 164 records were identified through database searching (PubMed n = 56, Scopus n = 58, Embase n = 50). After removal of 32 duplicates, 132 records were screened by title and abstract. Of these, 108 records were excluded for irrelevance. Twenty-four full-text articles were assessed for eligibility, and twelve studies met the inclusion criteria and were included in the final qualitative synthesis.

PRISMA Flow Diagram Structure

- **Identification**
  - Records identified: 164
  - Duplicates removed: 32
- **Screening**
  - Records screened: 132
  - Records excluded: 108
- **Eligibility**
  - Full-text articles assessed: 24
  - Full-text articles excluded: 12
    - Wrong population (n = 4)
    - No pulmonary vein Doppler (n = 3)
    - Review/editorial (n = 3)
    - Structural heart disease (n = 2)
- **Included**
  - Studies included in qualitative synthesis: **12**

Search strategy
PubMed, Scopus, and Embase were searched for studies published between January 2019 and June 2025 using combinations of the terms *pulmonary vein Doppler*, *placental insufficiency*, *fetal growth restriction*, *fetal cardiac dysfunction*, and *venous Doppler*.

Eligibility criteria
Inclusion criteria

- Original research studies
- Human pregnancies
- Assessment of pulmonary vein Doppler parameters
- Pregnancies complicated by placental insufficiency or IUGR

Exclusion criteria

- Case reports or series (<10 subjects)
- Reviews, editorials, conference abstracts
- Structural congenital heart disease

Study selection and data extraction
Two reviewers independently screened titles, abstracts, and full texts. Disagreements were resolved by consensus. Extracted data included study design, sample size, gestational age, pulmonary vein Doppler findings, and perinatal outcomes. A large language model (ChatGPT, OpenAI) was used to assist with language editing and structuring of the manuscript. The authors take full responsibility for the content

Risk of bias assessment
Risk of bias was assessed using the Newcastle–Ottawa Scale for observational studies. Overall, six studies were rated as low risk of bias and six as moderate risk, primarily due to sample size limitations and heterogeneity of outcome definitions**.**

RESULTS
Study selection
A total of 164 records were identified. After removal of 32 duplicates, 132 records were screened. Twenty-four full-text articles were assessed for eligibility, and twelve studies met inclusion criteria.

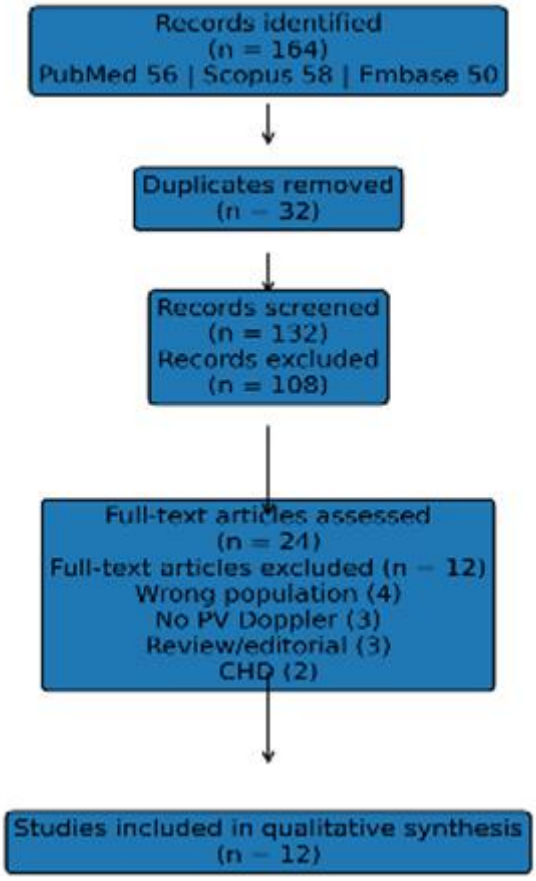

Figure 1. PRISMA 2020 flow diagram.
Flow diagram showing identification, screening, eligibility, and inclusion of studies.

Study characteristics

Table 1. Characteristics of studies included in the systematic review

Author (Year)	Country	Study design	Sample size	Gestational age (weeks)	Key pulmonary vein Doppler findings	Main outcomes
Crispi et al. (2019)	Spain	Prospective cohort	96	28–37	Elevated PVPI in IUGR	Diastolic dysfunction
Hernandez-Andrade et al. (2020)	Mexico	Observational	82	26–38	Increased PVPI, atrial reversal	Impaired compliance
Miranda et al. (2021)	Spain	Cohort	110	30–40	High PVPI predicted adverse outcome	NICU admission
Bhide et al. (2022)	UK	Prospective	74	28–36	Venous Doppler abnormal before arterial	Early compromise
Acharya et al. (2023)	Norway	Cross-sectional	68	32–38	Elevated PVPI	Cardiac remodeling
Rizzo et al. (2019)	Italy	Case-control	90	28–37	Higher PVPI in IUGR	Diastolic dysfunction
Gardiner et al. (2020)	UK	Prospective	62	24–36	Altered pulmonary venous flow	Filling abnormalities
Figueras et al. (2020)	Spain	Observational	78	30–38	PVPI associated with low CPR	Adverse outcome
Baschat et al. (2019)	USA	Cohort	84	26–34	Venous Doppler predicted deterioration	Preterm delivery
Lees et al. (2021)	Multicenter	Prospective	102	32–39	Elevated PVPI in late IUGR	NICU admission

Gordijn et al. (2020)	Netherlands	Cross-sectional	71	28–36	PVPI correlated with placental disease	CV stress
Hernandez-Andrade et al. (2022)	Multicenter	Prospective	88	26–38	Reproducible PVPI abnormalities	Neonatal morbidity

Pulmonary vein Doppler findings

Across all studies, pulmonary vein pulsatility index was significantly higher in growth-restricted fetuses compared with controls. Abnormal pulmonary vein Doppler findings were reported even when UA and MCA Doppler indices were normal.

Table 2. Clinical significance of pulmonary vein Doppler abnormalities

Doppler findings	Clinical Implications
Elevated PVPI (>95th percentile)	Diastolic dysfunction
Increased atrial reversal	Elevated atrial pressure
Elevated PVPI	Low CPR
Elevated PVPI	NICU admission
Elevated PVPI	Neonatal acidosis

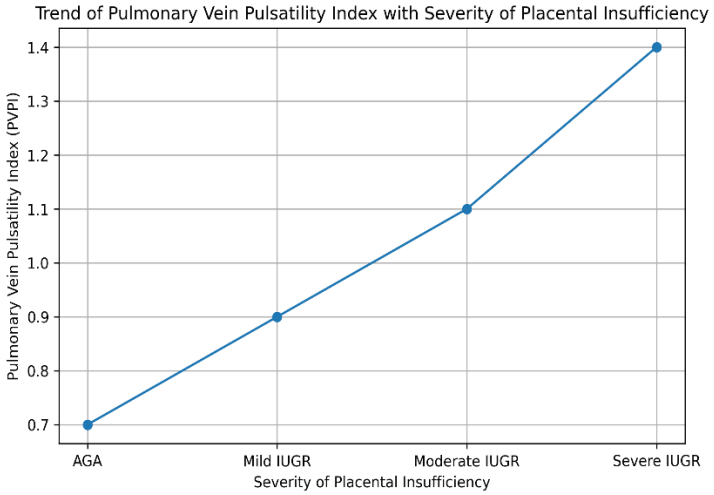

Figure 2. Trend of pulmonary vein pulsatility index with severity of placental insufficiency.
Progressive increase in PVPI from appropriately grown fetuses to severe IUGR.

Association with perinatal outcomes

Elevated pulmonary vein pulsatility index and increased atrial reversal were associated with adverse perinatal outcomes, including neonatal intensive care unit admission, neonatal acidosis, and preterm delivery. Several studies reported pulmonary vein Doppler abnormalities preceding deterioration in conventional arterial Doppler parameters.

DISCUSSION

The findings of this systematic review indicate that pulmonary vein Doppler abnormalities are consistently observed in fetuses affected by placental insufficiency and growth restriction. Elevated pulmonary vein pulsatility index was reported across multiple study designs and gestational age ranges and was frequently associated with indicators of adverse perinatal outcome. These observations support the concept that pulmonary vein Doppler reflects clinically relevant alterations in fetal cardiac function.

The pathophysiological basis for altered pulmonary venous flow lies in chronic fetal hypoxemia and increased cardiac afterload. Prolonged exposure to these conditions promotes myocardial hypertrophy and reduces ventricular compliance, leading to impaired diastolic filling and elevated left atrial pressure. Pulmonary vein Doppler directly captures these changes, as increased pulsatility and atrial reversal reflect resistance to ventricular filling during diastole [9,10].

An important observation from several included studies is that pulmonary vein Doppler abnormalities may be detected before deterioration of conventional arterial Doppler indices. This temporal sequence suggests that myocardial dysfunction can develop independently of, or earlier than, overt placental hemodynamic compromise. Such findings are particularly relevant in late-onset placental insufficiency, where clinical decision-making regarding timing of delivery remains challenging due to apparently reassuring arterial Doppler findings [11].

Compared with other venous Doppler parameters, pulmonary vein Doppler appears to provide distinct information. While ductus venosus Doppler is a well-established marker of advanced fetal compromise, its abnormalities typically occur late in the disease course. Pulmonary vein Doppler, by contrast, seems to reflect earlier stages of myocardial involvement, potentially allowing earlier identification of fetuses at increased risk [12].

Despite its promise, several limitations must be acknowledged. The included studies were predominantly observational and varied in methodology, Doppler acquisition techniques, and outcome definitions. In addition, the absence of universally accepted gestational age-specific reference ranges limits clinical implementation. Future research should focus on large prospective studies to standardize measurement protocols and evaluate whether pulmonary vein Doppler-guided management improves perinatal outcomes.

CONCLUSION

Pulmonary vein Doppler assessment provides valuable insight into fetal cardiac diastolic function in pregnancies complicated by placental insufficiency. Elevated pulmonary vein pulsatility index reflects impaired ventricular compliance and increased atrial pressure and is consistently associated with fetal growth restriction and adverse neonatal outcomes.

The evidence summarized in this review suggests that pulmonary vein Doppler abnormalities may precede deterioration in conventional arterial Doppler parameters, highlighting its potential role in early identification of fetal myocardial compromise. Incorporation of pulmonary vein Doppler into advanced fetal surveillance strategies may enhance risk stratification and support more individualized clinical management.

Further well-designed prospective studies are required to establish standardized reference values and determine the clinical impact of pulmonary vein Doppler-guided surveillance. As understanding of fetal cardiovascular adaptation continues to evolve, pulmonary vein Doppler may become an important component of comprehensive fetal assessment in placental insufficiency**.**

List of Abbreviations

FGR – Fetal growth restriction
IUGR – Intrauterine growth restriction
PVPI – Pulmonary vein pulsatility index
UA – Umbilical artery
MCA – Middle cerebral artery
CPR – Cerebroplacental ratio
NICU – Neonatal intensive care unit

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable**.**

Availability of data and materials
All data supporting the findings of this study are derived from published literature**.**

Competing interests
The authors declare that they have no competing interests**.**

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Authors' contributions
All authors contributed to study conception and design. Literature search, data extraction, and analysis were performed collaboratively. All authors contributed to drafting and revising the manuscript and approved the final version.

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Registration: Research Registry (reviewregistry2072)

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