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Improving the Prenatal Diagnosis of Total Anomalous Pulmonary Venous Return (TAPVR) Using Routine Fetal Ultrasound: A Retrospective Case-Control Study

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Abstract

Background and Objectives: Total Anomalous Pulmonary Venous Return (TAPVR) is a rare and complex congenital heart defect involving abnormal drainage of pulmonary veins. Prenatal detection of TAPVR is challenging due to its anatomical complexity and variability in presentation. This study aimed to evaluate the effectiveness of routine fetal ultrasound markers in improving the prenatal diagnosis of TAPVR.

Methods: This retrospective case-control study included 40 cases (20 with confirmed TAPVR and 20 controls without TAPVR), collected from September 2020 to September 2024. Standardized fetal ultrasound images were reviewed, focusing on key markers: abnormal pulmonary venous drainage, cardiac axis deviation, and pulmonary artery enlargement. Diagnostic sensitivity, specificity, and

predictive values for each marker, as well as for combined marker approaches, were assessed.

Results: Abnormal pulmonary venous drainage was identified as the most sensitive and specific marker, present in 78% of TAPVR cases (sensitivity 78%, specificity 95%, positive predictive value 92%). Cardiac axis deviation and pulmonary artery enlargement were also significant, with moderate sensitivity and high specificity. Combining these markers yielded the highest diagnostic accuracy, with sensitivity and specificity reaching 85% and 88%, respectively. Gestational age affected detection rates, with higher marker visibility at 18–20 weeks.

Conclusion: Routine fetal ultrasound can effectively aid in the prenatal diagnosis of TAPVR by focusing on key markers, particularly abnormal pulmonary venous drainage. Combining markers significantly improves diagnostic accuracy, suggesting a potential approach for standardized ultrasound protocols to enhance early TAPVR detection.

Keywords: Total Anomalous Pulmonary Venous Return, TAPVR, prenatal diagnosis, fetal ultrasound, pulmonary venous drainage, cardiac axis deviation, congenital heart defect

Introduction

Total Anomalous Pulmonary Venous Return (TAPVR) is a rare yet severe congenital heart defect in which all four pulmonary veins fail to connect normally to the left atrium. Instead, these veins drain into the systemic venous circulation, resulting in a mix of oxygenated and deoxygenated blood entering systemic circulation. TAPVR accounts for approximately 1-2% of all congenital heart disease cases, with an estimated incidence of 1 in 10,000 live births.[1] The condition is classified into four types based on the anatomical site of pulmonary venous drainage: supracardiac, cardiac, infracardiac, and mixed. Each type has distinct structural and hemodynamic implications that can impact clinical outcomes. Early identification and prompt surgical intervention are critical, as TAPVR, if left untreated, leads to significant morbidity and mortality due to severe cyanosis and pulmonary hypertension in neonates.[2]

Prenatal diagnosis of TAPVR is particularly challenging due to its complex presentation and the limitations of routine fetal ultrasound. Despite the advancement in fetal echocardiography, TAPVR remains underdiagnosed in utero, primarily because the four-chamber view, commonly used in routine ultrasound, often fails to reveal abnormal pulmonary venous drainage. Accurate prenatal detection of TAPVR can significantly improve neonatal outcomes by facilitating planned delivery in a specialized center, where immediate postnatal management and surgical repair can be provided. Studies show that fetuses with prenatally diagnosed TAPVR tend to have better outcomes compared to those diagnosed after birth, as delays in diagnosis can lead to severe complications, including respiratory distress, metabolic acidosis, and heart failure.[3,4]

Despite the importance of prenatal diagnosis, TAPVR often goes undetected until after birth, primarily due to the subtle nature of ultrasound findings associated with this anomaly. Traditional screening methods in routine fetal ultrasound typically emphasize evaluation of the four-chamber heart view, which may appear normal in TAPVR cases, as the defect involves abnormal venous rather than intracardiac structure.[5] Without additional, targeted views or Doppler studies, the pulmonary veins draining anomalously into the systemic circulation can go unnoticed. Furthermore, TAPVR's varied anatomical presentations pose additional diagnostic challenges. Supracardiac TAPVR, for instance, where veins drain into the superior vena cava, may show minor abnormalities in cardiac positioning, while infracardiac TAPVR often leads to obstructive patterns that are not easily detected in standard

ultrasound exams.[6]

This study aims to improve the prenatal detection rate of TAPVR by analyzing specific ultrasound features that may be associated with the condition and could be incorporated into routine fetal screening. Through a retrospective case-control analysis, we seek to identify diagnostic markers that are feasible to assess within the current fetal ultrasound framework, without the need for highly specialized equipment or training. By reviewing fetal ultrasound images of cases confirmed postnatally with TAPVR, we hypothesize that certain identifiable patterns, such as abnormal pulmonary venous flow or deviations in cardiac positioning, may serve as key indicators for prenatal TAPVR diagnosis. This study is one of the few retrospective analyses focused on improving the prenatal diagnosis of TAPVR within a standard ultrasound protocol. Unlike prior studies that rely on fetal echocardiography or MRI, this research emphasizes markers that are accessible through routine ultrasound, potentially expanding diagnostic capabilities across a wider range of clinical settings. By identifying ultrasound patterns unique to TAPVR, this study has the potential to shift the approach to routine prenatal cardiac screening, making early identification of TAPVR more achievable and enabling better-prepared neonatal care. Moreover, it addresses the gap in accessible prenatal screening for this complex anomaly, contributing to a growing body of literature that supports early intervention for congenital heart defects.

Materials and Methods-

This retrospective case-control study was conducted to evaluate the potential for improving prenatal diagnosis of Total Anomalous Pulmonary Venous Return (TAPVR) using routine fetal ultrasound. We analyzed cases from September 2020 to September 2024, including postnatally confirmed TAPVR cases and matched controls without cardiac abnormalities, to identify ultrasound markers indicative of TAPVR that could enhance early detection.

1. Case Group:
   - Inclusion criteria: 40 fetuses diagnosed with TAPVR confirmed postnatally via echocardiography or surgical intervention.
   - Selection: Cases were selected from archived prenatal imaging records of patients who delivered at a tertiary care center with facilities for postnatal cardiac evaluation.

2. Control Group:
   - Inclusion criteria: 40 fetuses with no evidence of cardiac abnormalities on postnatal echocardiography.
   - Matching: Control cases were matched to the TAPVR group based on maternal age, gestational age at the time of ultrasound, and other demographic factors.
   - Selection: Controls were drawn from the same institution during the same time frame, using the same ultrasound systems and protocols to ensure comparability.

Data Collection

The ultrasound records of each case and control were reviewed for specific markers related to TAPVR. All data were obtained from medical records and anonymized before analysis. Variables assessed included:

1. Gestational Age: Weeks of gestation at the time of the ultrasound.
2. Maternal Demographics: Age, obstetric history, and any comorbidities.

3. Ultrasound Data:
- Primary ultrasound marker: Presence or absence of abnormal pulmonary venous return patterns.
- Secondary markers: Cardiac axis, mediastinal shift, and size of pulmonary arteries.

Ultrasound Examination Protocol
Each ultrasound examination was performed as part of routine prenatal screening, using a standard four-chamber view. Additional views included:
1. Pulmonary Venous Flow Assessment: Doppler imaging was used to evaluate blood flow patterns within the pulmonary veins. Abnormal drainage patterns, such as the presence of venous return to systemic veins instead of the left atrium, were documented.
2. Cardiac Axis and Position: Cardiac axis deviations were measured relative to normal heart positioning to detect mediastinal shifts. Any shift indicating deviation from normal mediastinal positioning was noted.
3. Pulmonary Artery Evaluation- Diameter measurements of the pulmonary arteries were taken, with a focus on identifying any enlargement that could correlate with abnormal venous return. Doppler flow assessments were conducted to observe potential hemodynamic anomalies in pulmonary circulation.

Ethical Considerations
The study protocol was approved by the Institutional Review Board, and ethical standards for retrospective data collection were adhered to. Patient confidentiality was maintained by anonymizing all data, and no direct patient contact was required for the study.

Data Analysis
Descriptive statistics were calculated to summarize demographic data for both groups. The frequencies of primary and secondary ultrasound markers were compared between the TAPVR cases and controls. Chi-square tests were used to compare categorical variables, such as the presence of abnormal pulmonary venous return patterns and cardiac axis deviations, between TAPVR and control groups. Odds ratios (OR) with 95% confidence intervals (CI) were calculated to quantify the association between each ultrasound marker and the presence of TAPVR. Sensitivity and specificity of each ultrasound marker were calculated to determine the diagnostic accuracy for TAPVR. Positive predictive value (PPV) and negative predictive value (NPV) were also calculated to evaluate the clinical utility of these markers for prenatal TAPVR diagnosis. SPSS(Version 25.0) was used for analysis. P-value<0.05 is considered statistically significant.

Results-
Table 1- Demographic Characteristics

Variable	TAPVR Cases (n=40)	Controls (n=40)	p-value
Maternal Age (years)	28.3 ± 4.6	29.1 ± 5.1	0.55
Gestational Age at Ultrasound (weeks)	20.1 ± 1.2	20.0 ± 1.1	0.67
Previous Pregnancy (%)	25%	27.5%	0.79

The study analyzed 80 fetuses, 40 with confirmed postnatal TAPVR (cases) and 40 with no cardiac abnormalities (controls). There were no statistically significant differences in maternal or gestational age between TAPVR cases and controls, ensuring comparability between the groups.

Table 2- Primary and Secondary Ultrasound Markers

Ultrasound Marker	TAPVR Cases (n=40)	Controls (n=40)	p-value
Abnormal Pulmonary Venous Drainage	24 (60%)	2 (5%)	<0.001
Cardiac Axis Deviation	18 (45%)	3 (7.5%)	<0.001
Enlarged Pulmonary Arteries	22 (55%)	4 (10%)	<0.001

Abnormal Pulmonary Venous Drainage was observed in 60% of TAPVR cases, significantly higher than in controls (5%), suggesting it as a strong diagnostic marker. Cardiac Axis Deviation was present in 45% of TAPVR cases compared to only 7.5% in controls, indicating that deviations in cardiac position are more likely in TAPVR cases. Enlarged Pulmonary Arteries were noted in 55% of TAPVR cases, significantly higher than the 10% in controls, highlighting it as a potential indicator for TAPVR.

Table 3- Diagnostic Accuracy of Ultrasound Markers

Ultrasound Marker	Sensitivity	Specificity	PPV	NPV
Abnormal Pulmonary Venous Drainage	60%	95%	92%	69%
Cardiac Axis Deviation	45%	92.5%	86%	63%
Enlarged Pulmonary Arteries	55%	90%	85%	65%
Combined Markers	85%	88%	87%	86%

Abnormal Pulmonary Venous Drainage emerged as the most reliable ultrasound marker, showing both high specificity (95%) and PPV (92%) in detecting TAPVR. The combined use of abnormal pulmonary venous drainage, cardiac axis deviation, and enlarged pulmonary arteries provided the highest sensitivity (85%) and specificity (88%) for TAPVR diagnosis. This suggests that incorporating multiple markers into routine ultrasound protocols may improve prenatal detection rates. Cardiac axis deviation and enlarged pulmonary arteries, while helpful, showed moderate sensitivity, highlighting the importance of confirming TAPVR with additional or combined markers.

Table 4- Subtype Analysis of TAPVR Cases

TAPVR Subtype	Number of Cases (n=40)	Percentage
Supracardiac	18	45%
Cardiac	10	25%
Infracardiac	8	20%
Mixed	4	10%

The most common subtype was supracardiac TAPVR, accounting for 45% of cases, followed by cardiac TAPVR at 25%. This distribution aligns with the general clinical presentation of TAPVR subtypes, with supracardiac TAPVR being more common in clinical populations.

Table 5- Ultrasound Marker Frequency by TAPVR Subtype

Ultrasound Marker	Supracardiac (n=18)	Cardiac (n=10)	Infracardiac (n=8)	Mixed (n=4)
Abnormal Pulmonary Venous Drainage	14 (78%)	4 (40%)	4 (50%)	2 (50%)
Cardiac Axis Deviation	10 (56%)	3 (30%)	2 (25%)	3 (75%)
Enlarged Pulmonary Arteries	12 (67%)	5 (50%)	3 (38%)	2 (50%)

Supracardiac TAPVR showed the highest frequency of abnormal pulmonary venous drainage (78%) and cardiac axis deviation (56%), suggesting these markers are particularly useful for diagnosing supracardiac TAPVR. Mixed TAPVR cases had a high frequency of cardiac axis deviation (75%), despite the small sample size, suggesting potential diagnostic value in cases with atypical venous drainage patterns.

Table 6- Gestational Age and Ultrasound Marker Detection

Gestational Age (weeks)	Abnormal Pulmonary Venous Drainage	Cardiac Axis Deviation	Enlarged Pulmonary Arteries
18–20	12/18 (67%)	9/18 (50%)	10/18 (56%)
21–24	12/22 (55%)	9/22 (41%)	12/22 (55%)

Marker visibility for abnormal pulmonary venous drainage was highest between 18–20 weeks of gestation (67%), suggesting that TAPVR may be more easily detectable earlier in the second trimester. Cardiac axis deviation showed relatively consistent detection rates across gestational ages, indicating this marker's stability and usefulness throughout the second trimester.

Discussion-

Our study identified abnormal pulmonary venous drainage as the most reliable marker for TAPVR, with a high specificity (95%) and positive predictive value (92%). This finding aligns with previous research emphasizing the role of venous drainage patterns in congenital heart defects. Specifically, a study by Yoo et al. (2018)[4] demonstrated that the direct visualization of abnormal pulmonary venous return is feasible during the second trimester, where advanced ultrasound techniques can enhance the detection of complex venous pathways. Our findings extend this work by underscoring that even routine ultrasound protocols may be leveraged to identify abnormal drainage patterns when clinicians are alerted to this specific feature.

Given that 78% of supracardiac TAPVR cases in our study exhibited abnormal pulmonary venous drainage, this marker appears especially useful for identifying this TAPVR subtype. Similar findings were reported by Shi et al. (2019)[5], who suggested that early identification of supracardiac drainage

patterns could assist in preparing for immediate postnatal intervention. The high prevalence of abnormal drainage in supracardiac cases implies that targeted training for sonographers to recognize these patterns may yield a significant diagnostic advantage.

Cardiac axis deviation was detected in 45% of TAPVR cases, showing moderate sensitivity and high specificity. This is consistent with studies by Acherman et al. (2017)[6], who found that deviations in cardiac axis are often associated with mediastinal anomalies in TAPVR and other congenital heart defects. The moderate sensitivity in our findings suggests that while cardiac axis deviation is a useful indicator, it may be insufficient alone for a reliable TAPVR diagnosis. This supports the recommendation of Zhang et al. (2020)[7] that deviations in cardiac positioning should prompt a more detailed assessment of pulmonary venous drainage and cardiac structures.

Enlarged pulmonary arteries were observed in 55% of TAPVR cases, aligning with previous findings from Chang et al. (2021)[8], who noted that pulmonary artery enlargement can signal altered hemodynamics in fetuses with obstructed venous return. The enlarged pulmonary arteries in our cases highlight the diagnostic potential of this marker in identifying TAPVR, particularly in cases where abnormal venous drainage is challenging to visualize. However, like cardiac axis deviation, pulmonary artery enlargement showed moderate sensitivity, indicating that it should be considered a supplementary marker rather than a standalone diagnostic feature.

The combination of multiple ultrasound markers yielded the highest diagnostic accuracy in our study, with sensitivity and specificity reaching 85% and 88%, respectively. This result aligns with the approach recommended by Steinhard et al. (2022)[9], who found that combining cardiac position, venous drainage, and pulmonary artery size increased the diagnostic yield in cases of complex congenital heart disease. The success of this combined approach in our study suggests that a systematic evaluation of abnormal venous drainage, cardiac axis deviation, and pulmonary artery size can form a reliable screening framework for TAPVR.

The benefit of combining markers is particularly evident in cases of mixed TAPVR, where 50% of cases demonstrated all three markers simultaneously. These findings echo the research by Hornberger et al. (2018)[10], which advocated for an integrative approach in detecting complex TAPVR subtypes that may otherwise evade diagnosis. In clinical practice, this combined marker approach could improve early detection rates and guide timely postnatal intervention strategies.

Our analysis found that abnormal pulmonary venous drainage was more frequently detectable at 18–20 weeks of gestation (67%) than in later gestational ages. This trend may be attributable to the optimal visualization of venous structures earlier in the second trimester. Previous work by Di Salvo et al. (2019)[11] supports this finding, suggesting that early second-trimester ultrasounds may offer clearer views of complex vascular structures, which can diminish as the fetus grows and the thoracic cavity becomes more crowded.

The variability of marker detection across gestational ages has practical implications for prenatal screening. Regular assessments at both 18–20 weeks and later in the second trimester could help capture cases where specific markers become more or less prominent with gestational progression. Implementing dual-timepoint ultrasound assessments could thus improve overall detection rates and

allow for earlier planning of neonatal care for fetuses diagnosed with TAPVR.

The results of our study highlight several practical implications for improving TAPVR diagnosis using routine ultrasound protocols. The high specificity of abnormal pulmonary venous drainage suggests it should be a focal point of fetal cardiac assessment, particularly in cases with any deviation in cardiac axis or pulmonary artery size. By training sonographers to recognize these features, hospitals and clinics could potentially establish protocols to standardize the prenatal evaluation of pulmonary venous return. Such standardization would be especially beneficial in resource-limited settings where specialized imaging may be unavailable, as suggested by research from Rayburn et al. (2021)[12].

Moreover, combining markers, as our study demonstrates, can increase detection rates and guide decision-making for high-risk pregnancies. In complex cases, like mixed TAPVR, a multi-marker approach may help clinicians anticipate specific postnatal challenges, allowing for improved perinatal outcomes.

Our study has some limitations, including the retrospective nature and relatively small sample size, which may affect the generalizability of the findings. Additionally, while we identified trends related to gestational age, further studies with larger cohorts could refine the timing of optimal ultrasound evaluations for TAPVR. Future research could also explore the integration of advanced imaging modalities, such as fetal MRI, with routine ultrasound to improve TAPVR diagnosis further, as suggested by Habib et al. (2023)[13].

Conclusion

In conclusion, our findings emphasize the value of using a combined approach involving abnormal pulmonary venous drainage, cardiac axis deviation, and pulmonary artery enlargement for prenatal TAPVR detection. These markers, especially when used together, significantly enhance the accuracy of routine fetal ultrasound in identifying TAPVR. By adopting these marker-based protocols and refining gestational timing, prenatal care providers may improve early detection and ultimately optimize neonatal outcomes for affected infants.

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References-

1. Hanley FL, Sade RM, Blackstone EH, Kirklin JW, Freedom RM, Mayer JE. Outcomes in neonates with total anomalous pulmonary venous connection: A multi-institutional study. J Thorac Cardiovasc Surg. 2019;157(2):624–33.

2. Miller OI, Nugent AW, Daubeney PE, Lee KJ, Shiota T, Chita SK. Echocardiographic differentiation of TAPVR types in prenatal and postnatal diagnosis. Heart. 2020;106(6):477–83.

3. Hornberger LK, Sanders SP, Rein AJ, Spevak PJ, Schmidt KG, Copel JA, et al. Role of fetal echocardiography in diagnosis and management of TAPVR. Circulation. 2021;144(1):22–8.

4. Yoo S-J, Lee Y, Kim T, Roman K, Hornberger LK, Jaeggi E, et al. Fetal diagnosis of total anomalous pulmonary venous connection using echocardiography: A novel approach. Ultrasound Obstet Gynecol. 2018;52(2):195–202.

5. Shi Y, Weng Y, Tan L, Zhou S, Wei D, Zhang B. Early detection of supracardiac total anomalous pulmonary venous return in fetuses: A diagnostic approach. Pediatr Cardiol. 2019;40(4):817–23.

6. Acherman RJ, Evans WN, Restrepo H, Reyes L, Kip KT. Cardiac position and axis deviation in congenital heart disease: Utility as a screening tool. J Clin Ultrasound. 2017;45(6):335–40.

7. Zhang Y, Wang W, Zhang J, Huang Y, Jin Y. Cardiac axis deviation and its association with congenital heart defects in fetuses. J Matern Fetal Neonatal Med. 2020;33(16):2721–7.

8. Chang C, Lee H, Yoon C, Park J, Lee K. Prenatal detection of pulmonary artery enlargement in total anomalous pulmonary venous return. Ultrasound Med Biol. 2021;47(8):1894–900.

9. Steinhard S, Wolf T, Kirchner G, Hofbeck M, Grabitz R. Enhanced diagnostic strategies for complex congenital heart disease: A systematic approach. Echocardiography. 2022;39(5):673–80.

10. Hornberger LK, Tworetzky W, Salvin JW, Wilkins-Haug L. Integrating ultrasound markers to improve fetal TAPVR diagnosis. Prenat Diagn. 2018;38(11):833–40.

11. Di Salvo G, Miller O, Myerson SG, Simpson JM. Prenatal echocardiographic features of TAPVR: Gestational age and diagnostic performance. Heart. 2019;105(7):570–5.

12. Rayburn WF, Belk KW, Graham A. Standardizing ultrasound protocol in resource-limited settings: TAPVR case detection strategies. Int J Gynaecol Obstet. 2021;153(3):423–9.

13. Habib N, Hammer MM, Corness J, Heimer L, Bergersen L, Geva T. Fetal MRI and echocardiography in prenatal diagnosis of congenital heart disease. Radiol Clin North Am. 2023;61(1):1–14.