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Fetal Umbilical-Porto-Ductal Venous System: Standardized 3D Evaluation Using RealisticVue™/CrystalVue™ – A Step-by-Step Technique

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Introduction

Anomalies of the fetal intrahepatic venous system are likely more frequent than current prenatal diagnostic rates suggest [1,2].

Detailed sonographic assessment of the fetal umbilical-porto-ductal venous system (UPDVS) presents a considerable challenge for many sonographers. Nonetheless, its evaluation is essential when congenital heart defects, structural malformations, signs of fetal compromise, or suspected hepatic vascular anomalies are present. Accurately identifying the specific type of anomaly is crucial for providing appropriate prenatal counseling, guiding individualized management strategies, and planning postnatal follow-up.

Over recent decades, prenatal evaluation of the fetal hepatic venous system has progressed significantly with the advent of high-resolution ultrasound equipment, advances in Doppler techniques (including bidirectional color and power Doppler), and the introduction of volumetric imaging modalities. These innovations have enabled clearer visualization of small-caliber vessels with low-velocity flow, which is characteristic of the fetal venous system [3].

Despite the increasing availability of ultrasound systems with advanced applications, their systematic integration into clinical workflows remains limited. One key reason for this gap is the lack of practical training in the technical aspects of the examination—the “how to” component [4].

Therefore, this article aims to provide a clear and detailed review of the anatomy and physiology of fetal UPDVS and to introduce a standardized three-dimensional (3D) technique for its sequential assessment using volumetric ultrasound and bidirectional color Doppler. This approach is designed to be easily learned and reproduced, serving as a training tool, a diagnostic aid, and a support in clinical practice.

Normal Anatomy of the Fetal Hepatic Venous System

The fetal hepatic venous system comprises two main components:

· **Afferent system**, which includes the umbilical vein, the portal sinus, the left and right portal branches, and the main (extrahepatic) portal vein, responsible for delivering blood to the liver.

· **Efferent system**, consisting of the ductus venosus, the inferior vena cava (IVC), and the hepatic veins (suprahepatic), which drain into the systemic circulation [5,6].

Umbilical Vein (UV) and Portal Sinus (PS)

After a short extrahepatic course, the umbilical vein (UV) enters the fetal liver through the porta hepatis. Within the hepatic parenchyma, its intrahepatic portion empties into a larger-caliber, thin-walled vessel known as the portal sinus (PS), which exhibits a characteristic L-shaped configuration.

The portal sinus extends from the origin of the inferior branch of the left portal vein to the origin of the right portal vein, the latter identified at the anastomosis with the main portal vein (MPV) at the transverse portion of the PS (Figure 1-2).

Following the physiological direction of fetal blood flow, the PS gives rise to the inferior, middle, and superior branches of the left portal vein, as well as the ductus venosus (DV). At its transverse segment, the PS receives blood from the MPV [7,8].

Ductus Venosus (DV)

The ductus venosus is a small-caliber vessel with a trumpet-like morphology, approximately one-third the diameter of the umbilical vein. Its ostium originates in the portal sinus, aligned with the axis of the intrahepatic umbilical vein. From there, the DV courses posterosuperiorly toward the subdiaphragmatic venous vestibule, establishing a direct shunt into the systemic circulation.

Main Portal Vein (MPV)

The main (extrahepatic) portal vein forms from the confluence of the superior mesenteric vein and the splenic vein. It runs a nearly horizontal course from left to right toward the hepatic hilum, where it anastomoses with the transverse portion of the portal sinus.

Intrahepatic Portal Veins

· **Right portal vein**: Divides into anterior and posterior branches, which supply the right hepatic lobe. These branches often exhibit anatomical variants.

· **Left portal vein**: Gives rise to inferior, middle, and superior branches, which primarily supply the left lobe of the fetal liver.

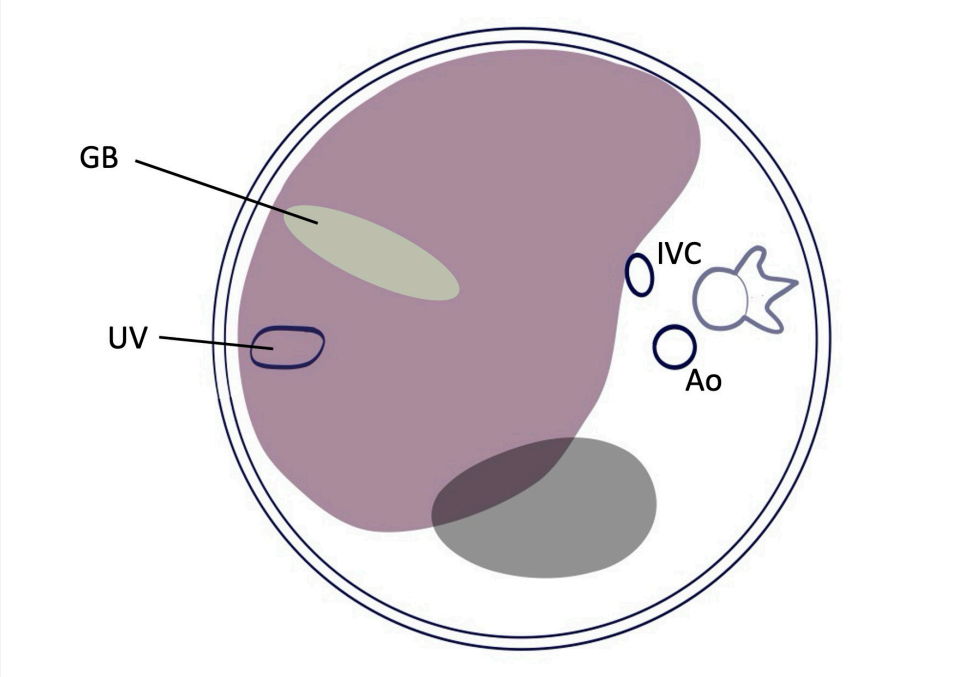

Figure 1. Schematic representation of the anatomy of the hepatic venous system in the inferior axial plane (Level 1). UV: intrahepatic portion of the umbilical vein, GB: gallbladder, Ao: abdominal aorta, IVC: inferior vena cava.

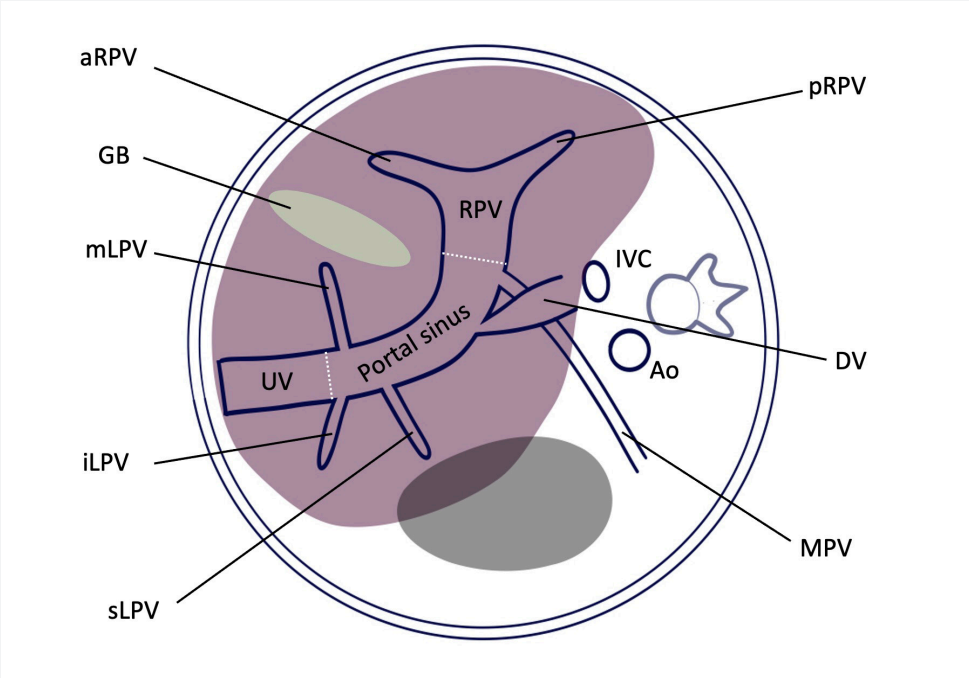

Figure 2. Schematic representation of the anatomy of the hepatic venous system in the middle axial plane (Level 2). UV: umbilical vein, PS/LPV: portal sinus/left portal vein, RPV: right portal vein, DV: ductus venosus, MPV: main portal vein/extrahepatic portal vein, aRPV: anterior branch of the right portal vein, pRPV: posterior branch of the right portal vein, iLPV: inferior branch of the left portal vein, mLPV: middle branch of the left portal vein, sLPV: superior branch of the left portal vein, GB: gallbladder.

Hepatic Veins (Suprahepatic)

The right, middle, and left hepatic veins form the efferent venous system of the fetal liver (Figure 3). Located in the upper plane of the liver, they typically exhibit a trident configuration.

The right hepatic vein runs parallel to the inferior vena cava (IVC), whereas the middle and left hepatic veins follow a path parallel to the ductus venosus, facilitating their identification in sagittal views used to assess the DV.

Inferior Vena Cava (IVC)

The IVC is readily identified in the transverse view of the upper fetal abdomen. It lies to the right of the spine and the abdominal aorta, ascending along the posterior surface of the liver until it reaches the subdiaphragmatic venous vestibule. This structure, shaped like an inverted funnel, is the confluence site of the IVC, ductus venosus, and the three hepatic veins before entering the right atrium of the fetal heart [9].

Topographically, the hepatic veins lie in the upper plane, while the umbilical-portal system occupies the middle and lower planes. The ductus venosus traverses all three levels.

Understanding this spatial arrangement is essential for conducting a systematic and accurate examination of the fetal hepatic venous system.

The combined use of 3D volumetric ultrasound and color Doppler allows for detailed characterization of the spatial distribution of each component of the UPDVS.

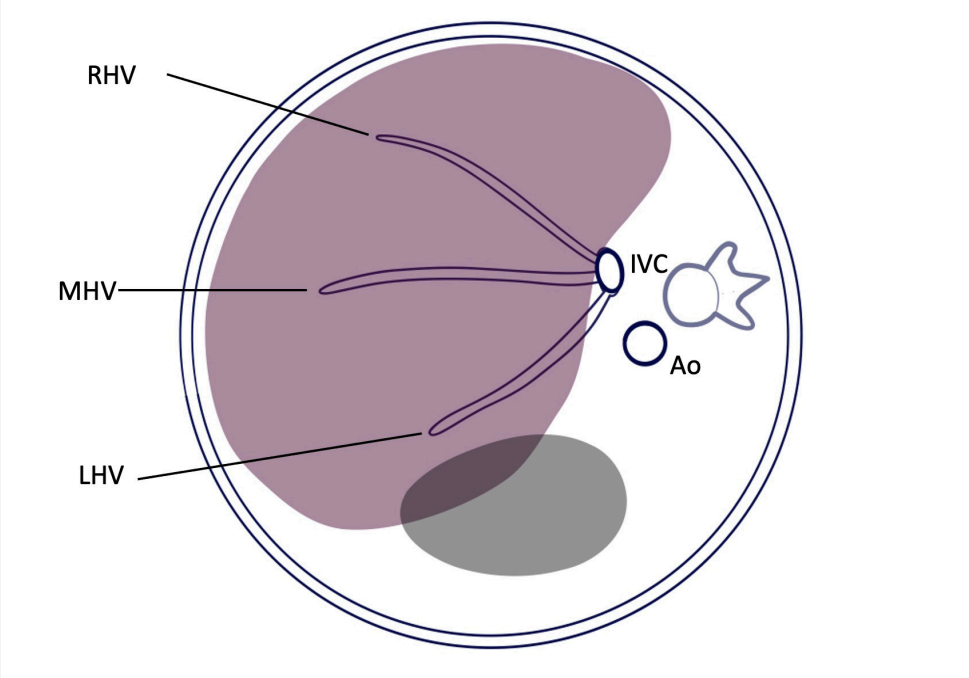

Figure 3. Schematic representation of the fetal hepatic venous system at the superior axial plane, showing the hepatic veins (Level 3). RHV: right hepatic vein, MHV: middle hepatic vein, LHV: left hepatic vein, IVC: inferior vena cava, Ao: aorta.

Physiology

Oxygenated blood from the placenta enters the fetus through the umbilical vein (UV). Upon reaching the portal sinus, this blood follows three main pathways: one portion is directed toward the branches of the left portal vein, predominantly perfusing the left hepatic lobe. Another fraction is diverted through the ductus venosus, bypassing the hepatic parenchyma and channeling directly into the systemic circulation. The remaining flow continues through the transverse portion of the portal sinus, where it mixes with blood from the main (extrahepatic) portal vein before being distributed via the branches of the right portal vein to perfuse the right hepatic lobe (see Figure 4).

During fetal life, the greater perfusion and higher oxygen content in the left hepatic lobe explain its relatively larger size compared to the right lobe [11]. After birth, functional closure of the umbilical vein and ductus venosus reverses this asymmetry (see Figure 5).

From a hemodynamic perspective, two main flow patterns can be distinguished in the hepatic veins: a continuous antegrade flow in the afferent venous system and a pulsatile (triphasic) flow in the efferent hepatic veins, with waveforms that reflect events of the fetal cardiac cycle. These flows can be evaluated using pulsed Doppler imaging, providing functional characterization complementary to anatomical assessment.

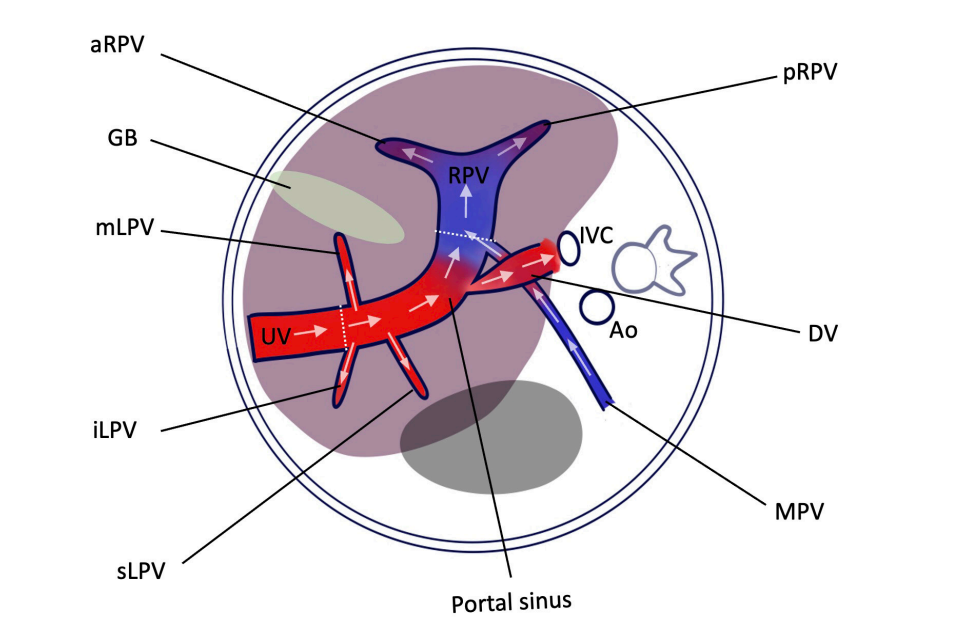

Figure 4. Detailed depiction of normal blood flow direction within the umbilical–portal–ductus venous system (UPDVS) during the prenatal period.
UV: umbilical vein; portal sinus/left portal vein, RPV: right portal vein, DV: ductus venosus, MPV: main portal vein/extrahepatic portal vein, aRPV: anterior branch of the right portal vein, pRPV: posterior branch of the right portal vein, iLPV: inferior branch of the left portal vein, mLPV: middle branch of the left portal vein, sLPV: superior branch of the left portal vein, GB: gallbladder.

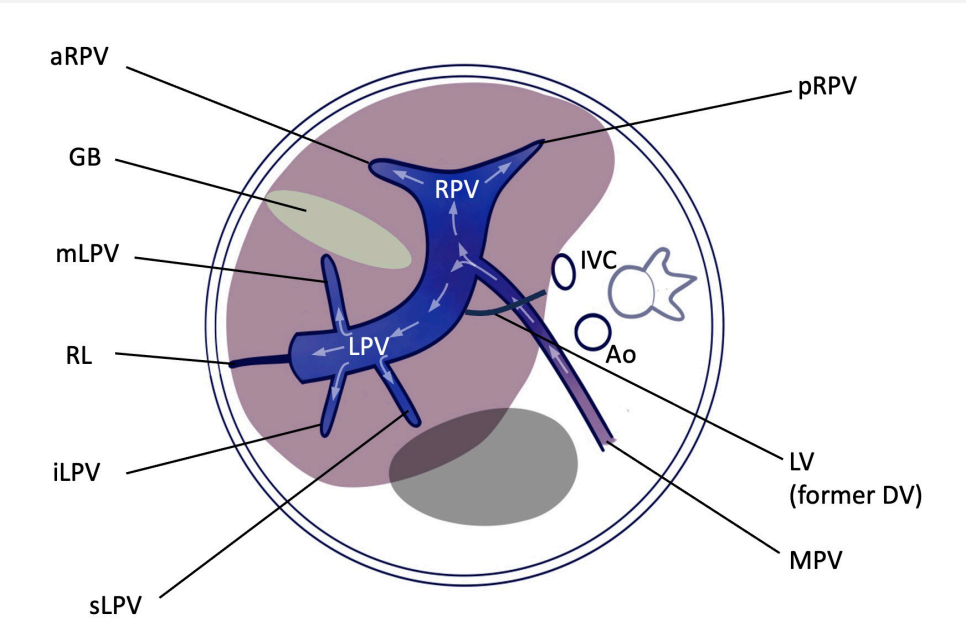

Figure 5. Direction of blood flow in the hepatic venous system during the postnatal period. Note how, following the closure of the ductus venosus and the umbilical vein, blood flow reverses within the left portal vein (referred to as the portal sinus during the prenatal stage).
RL: round ligament of the liver, LPV: left portal vein, RPV: right portal vein, LV: ligamentum venosum, MPV: main portal vein/extrahepatic portal vein, aRPV: anterior branch of the right portal vein, pRPV: posterior branch of the right portal vein, iLPV: inferior branch of the left portal vein, mLPV: middle branch of the left portal vein, sLPV: superior branch of the left portal vein, GB: gallbladder.

Step-by-step method for volumetric acquisition and analysis of the fetal hepatic venous system during the second and third trimesters

The use of standardized sonographic planes for evaluating the fetal heart and great vessels is well established. Within this context, sequential ultrasound algorithms based on a set of predefined planes have been developed to standardize and simplify the comprehensive evaluation of the fetal venous system[12-14]. These algorithms facilitate a clear and systematic interpretation of findings, improving clinical communication and reporting [15-18].

In 2019, a simplified 2D ultrasound technique for the assessment of the fetal precardiac venous system was proposed, based on three essential planes: two axial and one sagittal [19].

We present a modification of the plane-based technique originally proposed by Yagel[19], incorporating three-dimensional (3D) ultrasound combined with bidirectional color Doppler to enhance both the anatomical and functional characterization of the fetal venous system.

For comprehensive fetal anatomical evaluation—particularly of the hepatic-venous system—we employ Samsung V8 ultrasound systems equipped with a convex volumetric abdominal transducer (CV1-8A; frequency range 1.0–8.0 MHz) and advanced 2D and volumetric imaging technologies, which enable high-resolution visualization and enhanced spatial orientation essential for detailed vascular mapping.

Volume acquisition

Given that the branches of the hepatic venous system lie at different anatomical levels and exhibit low-velocity flow, appropriate visualization requires a combination of two-dimensional ultrasound (preset for the second trimester) and bidirectional power Doppler (S-Flow™). This combination allows for vascular architecture mapping and color encoding of both flow direction and velocity.

Fetal lie, presentation, and laterality must be determined in advance. Volume acquisition is performed from a transverse upper abdominal plane, the same used for abdominal circumference measurement [20]. It is essential to orient the transducer so that the gastric chamber is located on the opposite side of the transducer (farthest away), thereby optimizing visualization of the hepatic venous system—particularly the course of the extrahepatic portal vein. Standardized fetal positioning facilitates later optimization and interpretation of the acquired volume (see Figure 6-A).

Once 3D mode is activated, the region of interest (ROI) is defined, extending slightly beyond the borders of the abdominal circumference. A high-quality setting (High 1) is recommended, with a sweep angle between 30° and 40°. To reduce motion artifacts, the patient is asked to briefly hold her breath during acquisition.

Volume manipulation

Following the acquisition, multiplanar reconstruction (MPR) is accessed, and the B-plane is selected as the reference. Fine-tuning of the ROI is performed by minimizing its width as much as possible (Figure 6-B). For three-dimensional rendering, the presets RealisticVue™ or CrystalVue™ are applied, allowing for detailed visualization of vascular structures.

Volume analysis

Subsequently, the X, Y, and Z axes are adjusted to optimize anatomical alignment. Progressive cranial displacement of the cutting plane enables sequential evaluation of the fetal hepatic venous system components in terms of presence, origin, trajectory, caliber, anatomical relationships, anastomoses, and flow direction.

Anatomical evaluation is performed at three axial levels:

· **Level 1 (inferior)**: Allows assessment of visceral situs, visualizing the ascending course of the umbilical vein, transverse sections of the abdominal aorta and inferior vena cava, as well as the emergence of the celiac trunk and the sinuous course of the splenic artery (Figure 7).

· **Level 2 (middle)**: Represents the key plane for hepatic venous system assessment. The intrahepatic portion of the umbilical vein, the gallbladder, the portal sinus/left portal vein and its branches, the origin of the ductus venosus, the right portal vein and its branches, and the site of anastomosis between the extrahepatic portal vein and the portal sinus are identified (Figure 8).

· **Level 3 (superior)**: Displays the three hepatic veins (left, middle, and right) and their convergence into the subdiaphragmatic vestibule directed toward the right atrium (Figure 9).

Volume storage

To facilitate deferred analysis and remote consultation, volumetric ultrasound data must be stored in a format that preserves the full three-dimensional dataset. Immediately after acquisition, volumes were saved using the system's **"Save Volume"** function, generating files in the .**UZD format**, which is Samsung's proprietary format for volumetric imaging.

For post-processing and visualization, the acquired volumes were opened using **Samsung SonoView**, the manufacturer's dedicated software for viewing and basic manipulation of 3D/4D datasets. This platform allowed for an integrated image management and facilitated export to standardized formats when required for further analysis.

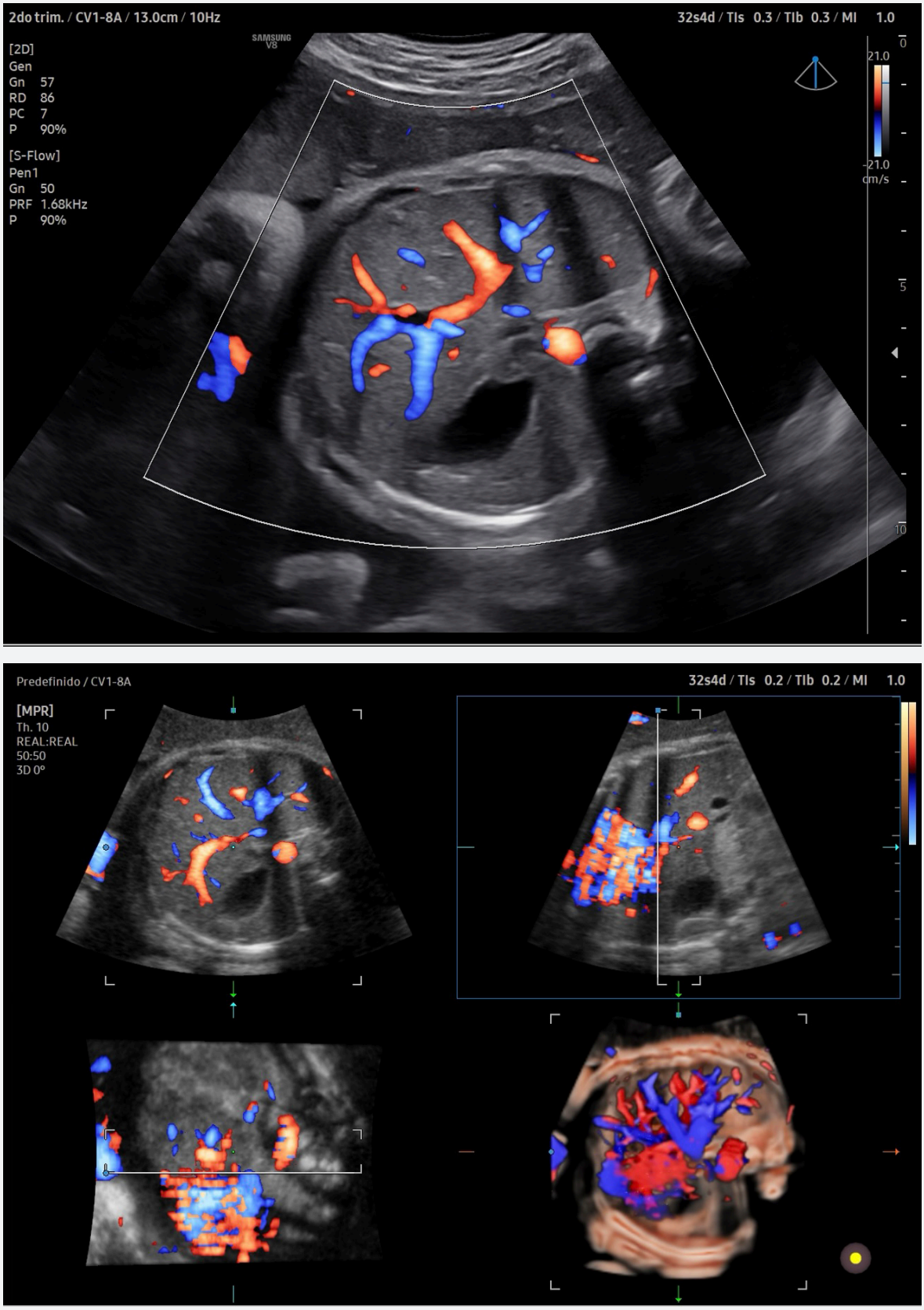

Figure 6.

A: Recommended 2D plane for image acquisition. Note the transducer orientation, with the gastric chamber positioned in the far field (opposite to the transducer), optimizing visualization of the hepatic venous system.

B: Multiplanar reconstruction (MPR) with selection of plane B as the reference plane, adjusting the region of interest (ROI) to the minimum necessary thickness in this view.

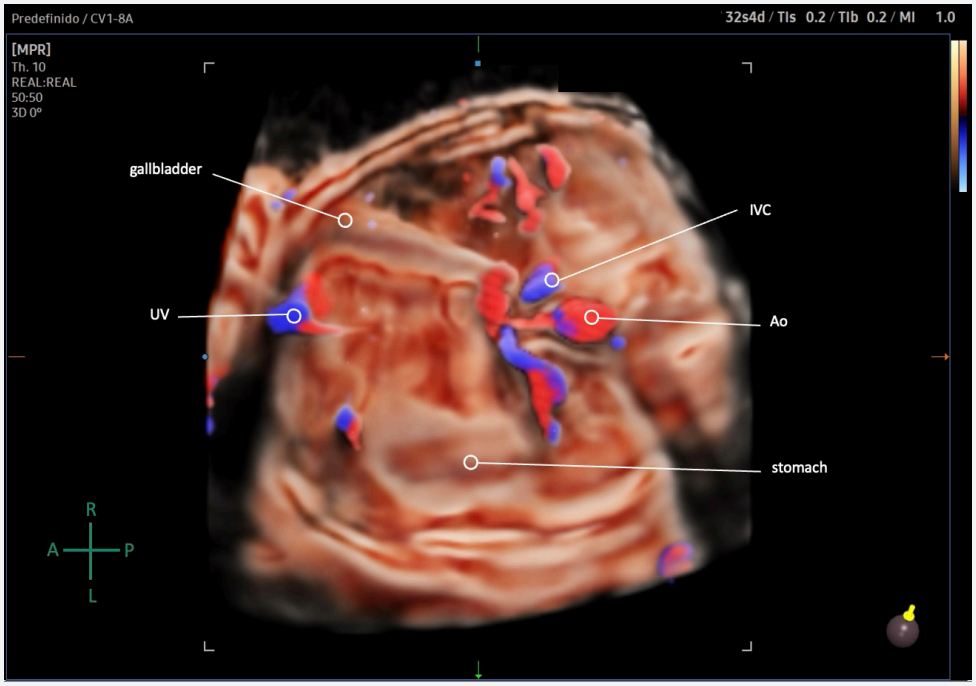

Figure 7. 3D rendering (RealisticVue™/CrystalVue™ with S-Flow™) of the inferior plane of the fetal hepatic venous system (visceral situs).
UV: umbilical vein, gallbladder, IVC: inferior vena cava, Ao: abdominal aorta, stomach.

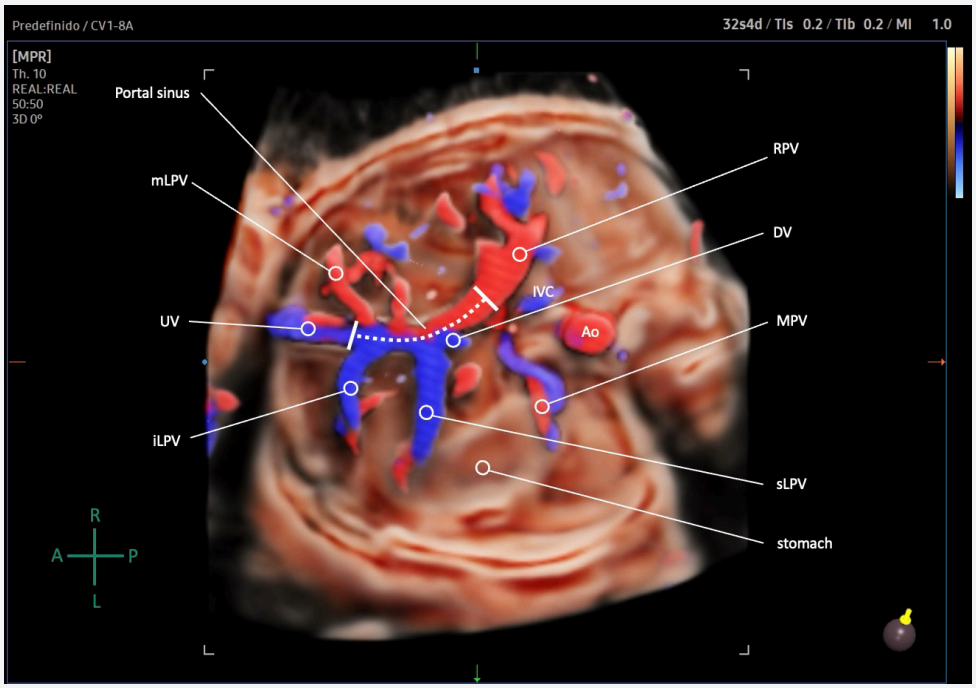

Figure 8. 3D Rendering (RealisticVue™/CrystalVue™ with S-Flow) of the Midplane of the Fetal Hepatic Venous System.
UV: umbilical vein, LPV: Portal sinus/left portal vein, RPV: right portal vein, DV: ductus venosus, MPV: main portal vein or extrahepatic portal vein, sLPV: superior branch of the left portal vein, mLPV: middle branch of the left portal vein, iLPV: inferior branch of the left portal vein, IVC: inferior vena cava, Ao: abdominal aorta, stomach.

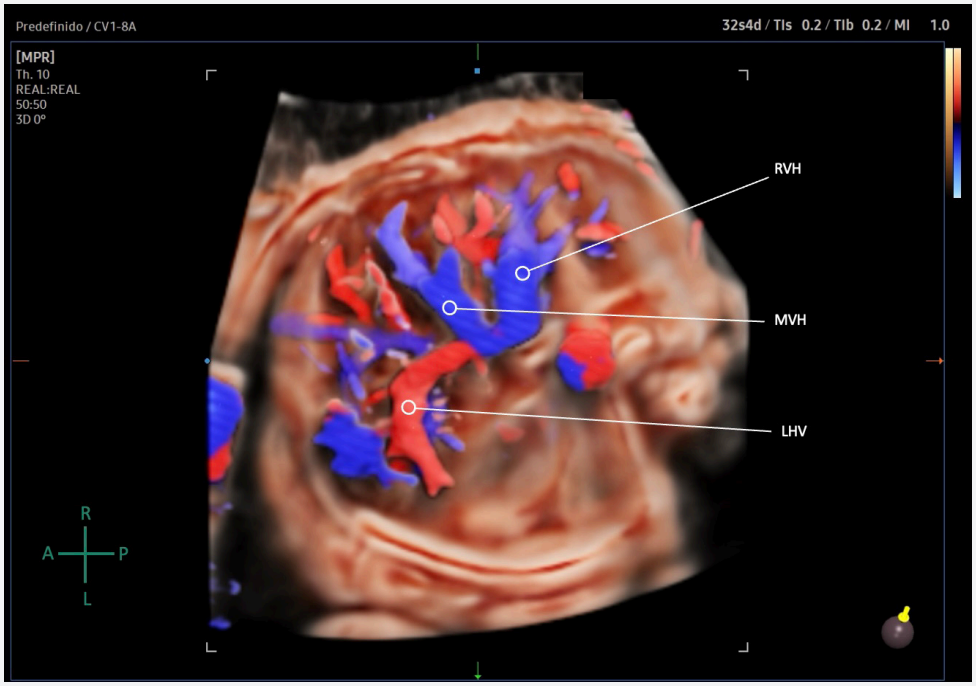

Figure 9. 3D Rendering (RealisticVue™/CrystalVue™ with S-Flow™) of the Superior Plane of the Fetal Hepatic Venous System.
RHV: right hepatic vein, MHV: middle hepatic vein, LHV: left hepatic vein.

Clinical value of volumetric analysis

Sequential three-dimensional evaluation, level by level, of the components of the fetal umbilico-porto-ductal venous system (UPDVS) provides a comprehensive understanding of its architecture, identification of normal anatomical variants, and, when suggestive findings are present, supports clinical assessment and classification of potential anomalies.

This methodology can be particularly useful for trainees, offering a structured guide for the anatomical and functional assessment of the fetal venous system. Although proper volume acquisition and manipulation require a certain level of skill, the technique becomes familiar and reproducible with practice.

Conclusion

This article reviews the normal anatomy and physiology of the fetal hepatic venous system and describes a standardized three-dimensional technique for its acquisition, optimization, manipulation, and sequential evaluation across three axial planes. The method is reproducible and can be easily integrated into routine clinical practice.

The incorporation of advanced rendering technologies such as CrystalVue™ and RealisticVue™, along with high-sensitivity Doppler techniques like S-Flow™, significantly enhances both anatomical and functional interpretation. These tools complement two-dimensional imaging by adding a crucial spatial dimension for prenatal assessment.

Finally, the ability to store volumes from both normal and pathological cases enables retrospective analysis, remote second opinions, and specialized consultations. This contributes significantly to education, professional training, and diagnostic standardization. Moreover, the described methodology lays the groundwork for future research in fetal medicine.

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