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Simplifying Imaging of the Abdominal Fetal Precordial Venous System

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The fetal precordial veins comprise a complex system of vessels delivering oxygenated blood from the placenta through the umbilical vein to the developing fetus. This system draws most of its nomenclature from the adult venous system. However, the direction of flow, as well as the relative size and prominence of the component vessels, differ from those in the postnatal circulation. Understanding the unique characteristics of the fetal circulation and its differences from the postnatal system can aid the sonographer in identifying normal[1] and anomalous[2] anatomy (Figure 1). The system can be challenging to image partly because of these differences, and partly because of individual variations in anatomy. Using a systematic approach may assist the operator to obtain these planes and target vessels confidently. Our aim here is to present our approach to imaging the fetal precordial venous system, based on three successive imaging planes.

In the fetus, the umbilical vein delivers oxygen- and nutrient- rich blood from the placenta to the left portal vein; the ductus venosus shunts this blood away from the portal system to the IVC and onward to the right heart. The proximal portion of the left portal vein, known also as the pars transversa or portal sinus (PS), extends to the point of bifurcation of the main portal vein to the right portal vein. This blood flows into the main portal vein and from there to the right portal vein and the hepatic circulation. In our opinion, therefore, the intra-abdominal portion of the umbilical vein should be termed the left portal vein from the bifurcations of the LPV (Figure 1a).

The blood flow direction in the left portal vein, therefore, is reversed from that in the adult (Figure 1b). This shunt system at the left portal vein, situated between the main portal vein junction and the ductus venosus, is known as the watershed of the fetal circulation[3, 4]. It has been shown to be a sensitive gauge of hemodynamic changes in the fetus. The greater volume and higher oxygen content of blood flowing through the left lobe of the liver as compared to the right may result in the relatively larger left than right lobe during fetal life[5]. Shortly following delivery the umbilical vein and ductus venosus atrophy and form the

ligamentum teres (round ligament) and the ligamentum venosum, respectively, and the proportional sizes of the liver lobes is reversed.

While most anomalies of the venous system are rare, and some isolated anomalies may be innocuous, such as persistent right umbilical vein[6-11], others may have serious consequences. Agenesis of the ductus venosus or abnormal development of the portal system[12-18] for example, may have grave prognoses. Indeed, it would appear that some malformations of the venous system are not as rare as formerly believed, and that more will be diagnosed if practitioners are cognizant of their sonographic appearance and associated anomalies[1, 2, 19]. Whenever anomalies of the cardinal, vitelline, or umbilical systems are diagnosed, they should prompt thorough investigation of the other segments of the cardiovascular system. When a cardiac defect is suspected, venous system examination is essential to identify or exclude possible associated lesions. Pulse Doppler scanning of the venous system can be a sensitive tool in obstetric management of intra-uterine growth restriction or other fetal distress[20-29], as well as assisting in gauging the impact of any anomaly on the system[11, 14-16, 30, 31].

When the fetal precordial venous system is examined, whether in the context of suspected anomaly in one of its component veins, or a cardiac or other malformation, or compromised fetal well-being, the examination should include the course of the umbilical vein, the ductus venosus, left and right portal veins and portal sinus, the splenic vein, hepatic veins, and the inferior vena cava (IVC). The examiner should be able to confirm normal anatomy and rule out anomalies[13, 19, 32].

The three planes approach to the fetal venous system

We recently described[19] a systematic approach to scanning the fetal venous system, based on 2DUS color Doppler scanning of the fetal abdomen in three planes: two transverse and one longitudinal (Figure 2A-C). The more caudal plane (A) is a ventral or lateral

transverse plane through the fetal abdomen at the level of the left portal sinus. This plane shows the umbilical vein, left portal vein, portal sinus, anterior right portal vein, posterior right portal vein, main portal vein, and splenic vein and artery. The latter was included because it is always seen with the splenic vein. Configuration of the target vessels may show slight individual variation. Tilting the transducer slightly to capture the main portal vein may assist in orienting the scan.

To obtain the second plane (B), the transducer is moved cephalad to a ventral or slightly lateral transverse plane that images the trident: the right, middle, and left hepatic veins where they drain into the IVC, and the IVC itself.

The third plane (C), is obtained by rotating the transducer toward a longitudinal anterior-posterior plane, in order to image the umbilical vein, left portal vein, ductus venosus, IVC, and left hepatic vein where they converge proximal to the right atrium. Acquiring it may require the operator to adjust the rotation and tilt of the transducer by a few degrees, to visualize all of the target vessels. This plane corresponds to the classic sagittal ductus venous plane proposed by Kiserud[33]. Using these successive planes the operator can systematically image the elements of the fetal precordial venous system. The component veins can be investigated with pulse Doppler, as described below. Color and power Doppler settings should be optimized according to the vascularity and flow velocity in the region of interest.

Anomalies diagnosed in the scanning planes

Anomalies may be encountered in all of the component veins of the precordial venous system. We present six cases (Figure 3a-f), showing the anomalous appearance of each of the three scanning planes that led to their diagnosis. Figure 3a-b show two anomalies diagnosed in the A Plane (compare Figure 2A). Figure 3a is a case of complete agenesis of the portal venous system (CAPVS). The figure shows the absence of the usual constellation

of vessels, except for the remnant of the system (arrow). Figure 3b is a case of portal sinus varix anomaly.

The normal B Plane shows the trident of the hepatic veins (Figure 2b); Figure 3c-d show shunt anomalies from the portal system to the hepatic veins. Figure 3c shows two shunts to the left and middle hepatic veins; Figure 3d shows a left porto-hepatic shunt, with the left portal vein flowing into the left hepatic vein.

Figure 3e-f show cases of agenesis of the ductus venosus, visualized in the C Plane. Figure 3e is a right porto-hepatic shunt, with blood shunted directly from the left portal vein to the right hepatic vein. Figure 3f shows another case of agenesis of the ductus venosus with a wide shunt draining into the IVC.

Doppler waveforms of the normal fetal venous system

The pulse Doppler waveforms of the fetal precordial veins reflect the heart cycle. Their typical three-peak form mirrors the ventricular systolic phase (s), passive diastolic phase (d), and active diastolic phase (a). DV blood flows forward throughout the entire heart cycle, differing from the IVC and hepatic veins and thus assuring constant high quality blood supply to the heart. A venous system preload index[34-37], similar to that devised for the arterial system, has been proposed. It was consistently shown to gradually decrease with progression of pregnancy[35, 38]. Doppler sampling sites are shown in Figure 2c, and normal waveforms of the most commonly investigated vessels are shown in Figure 4.

The umbilical vein is evaluated in the intra-abdominal portion of the vein (Figure 2). Pulsatile flow may be considered a normal feature until 15 weeks' gestation, before the low resistance placental vascular bed is established by the second trophoblast invasion[39] and even later. In addition, the waveform characteristics are influenced by the diameter and stiffness of the vessel. In the second half of pregnancy, UV pulsations are associated with fetal breathing movements. The sampling site will also impact the appearance of pulsations.

Moving from the free loop UV to the intrahepatic, porto–umbilical connection, the retrograde atrial contraction waveform propagation becomes more pronounced and the incidence of pulsations markedly increases[40].

The ductus venosus forms a direct shunt between the left portal vein and the inferior vena cava. The DV can be sampled at its inlet in a near-sagittal scan, with a large sample volume at a low angle of insonation[33] or in an oblique transverse section of the fetal abdomen (Figure 2). Changes in DV flow are seen in hypoxia and hypovolemia in experimental animal models and in human fetuses[25, 41-45]. (Figure 3) Venous compensatory mechanisms aim to improve the placental supply to the heart by increasing the proportion of DV shunting from the portal sinus. Normally at 20 weeks' gestation about 30% of blood is shunted through the DV, while at 30 weeks about 20% of blood is shunted[29, 46-48]. In small-for-gestational age fetuses a much higher proportion of blood is shunted through the DV, and earlier placental compromise will show a more pronounced shunt and distension of the DV[20, 29]. The degree of shunting in IUGR fetuses is positively correlated with the severity of placental insufficiency as reflected by the UA diastolic flow. Ductus venosus anomalies can be characterized by their pulse Doppler waveforms. This is beyond the scope of this paper; the reader is referred to our review[2] and other work[14, 30, 49, 50].

The IVC is usually sampled in the fetal abdomen, caudal to the hepatic confluence and DV outlet, to avoid interference from neighboring vessels (Figure 2). It is normal to observe a negative a-wave in the IVC because of the vessel's normally lower velocities[51-54]. Since the IVC is familiar to pediatricians as the preferred vessel for postnatal evaluation of SGA neonates, it is often sampled in the fetus[29].

The trident-shaped hepatic veins (Figure 2b), although readily available for Doppler investigation, have not been widely studied[27, 55-59]. The signs of cardiac compromise observed in the hepatic vein are similar to those apparent in the DV and IVC[29, 57]. Hepatic venous Doppler has been shown to differentiate between types of extrasystoles[27].

Because of its position at the focal point of oxygenated blood flow from the umbilical vein toward the liver and the ductus venosus, the left portal vein has been described as the watershed of the fetal venous circulation and suggested as a simple marker of circulatory compromise[4, 46, 60-62]. The vessel is sampled in the left portal branch between the ductus venosus inlet and the junction with the main portal stem (Figure 2). In the compromised fetus, flow in the LPV is reduced, and may become pulsatile, bi-directional, or reversed. In hemodynamically compromised fetuses, Kiserud et al[4] showed that accentuation of LPV peak velocity mirrored the DV a-wave. Reverse flow in the LPV shows significant correlation with increased RI in the UA[3].

For more extensive discussion of the etiology and appearance of altered venous system Doppler waveforms in IUGR and other cardiovascular compromise, we refer the reader to our review[2] and other work[12, 20, 22, 49, 50].

In summary, we provide here a simple approach to evaluating the fetal precordial venous system. Visualization of the described planes may require some finesse on the part of the operator, but acquisition of these planes readily becomes familiar. Anomalies of this system may be less rare than previously believed, and familiarity with the normal configuration of these veins is imperative to reach a diagnosis. In addition, Doppler investigation of the component veins provides important information on the well-being of fetuses with IUGR or other cardiac compromise.

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LEGENDS TO FIGURES

Figure 1:

Schematics of the precordial venous system in the fetus (A) and the adult (B), modified from Kiserud et al.[63] UV, umbilical vein; LPV, left portal vein; DV, ductus venosus; MPV, main portal vein; RPV, right portal vein; St, stomach; Sp, spine. Arrows indicate direction of blood flow.

Figure 2:

The fetal precordial venous system in three planes.

Frame A: Lateral transverse plane through the fetal abdomen from right to left. The splenic artery is shown (SA, blue jet) as it is always observed with the splenic vein. (ARPV, anterior

right portal vein; PRPV, posterior right portal vein; MPV, main portal vein; LPVs, left portal veins; Ao, aorta; SV, splenic vein; SA, splenic artery; St, stomach; Rt, right; Lt, left; Sp, spine.
Frame B: Anterior-posterior transverse plane through the upper fetal abdomen showing the normal "trident sign" of the hepatic veins. LHV, left hepatic vein; MHV, middle hepatic vein; RHV, right hepatic vein; Ao, aorta; Rt, right; Lt, left; Sp, spine.
Frame C: Typical longitudinal plane showing the umbilical vein (UV); left portal vein (LPV); left hepatic vein (LHV); right portal vein (RPV); ductus venosus (DV); and inferior vena cava (IVC). The DV is best seen in this plane, where it arises from the left portal vein. Doppler sample sites are marked with gates.

Figure 3:

Examples of anomalies diagnosed at plane A of the venous system:

a) Complete absence of the portal venous system having only a remnant vessel. Compare with normal A plane, inset.
b) Portal sinus varix (PSV) with significantly dilated portal sinus (SV, splenic vein).

Examples of anomalies diagnosed at plane B of the venous system:

c) Porto-hepatic shunts: arrows indicate two anomalous vessels draining into the hepatic veins (LHV, left hepatic vein; MHV middle hepatic vein; RHV, right hepatic vein). These anomalies may also be referred to as intrahepatic porto-systemic shunts (IPS).
d) Left porto-hepatic shunt (arrow) arising from the left portal vein draining into the hepatic vein (HV) at the junction with the IVC.

Examples of anomalies diagnosed at plane C of the venous system:

e) Right porto-hepatic shunt showing the left portal vein (LPV) draining into the right hepatic vein (RHV).

f) Agenesis of the ductus venosus anomaly with the umbilical vein (UV) draining directly into the inferior vena cava (IVC) with wide shunt.

Figure 4:

Characteristic Doppler waveforms of the studied vessels. (a) umbilical vein; (b) splenic artery and vein (note that the arterial and venous waves appear together: as mentioned, the splenic artery and vein are always imaged together); (c) ductus venosus; (d) left hepatic vein; (e) inferior vena cava. Reprinted with permission from reference[19]

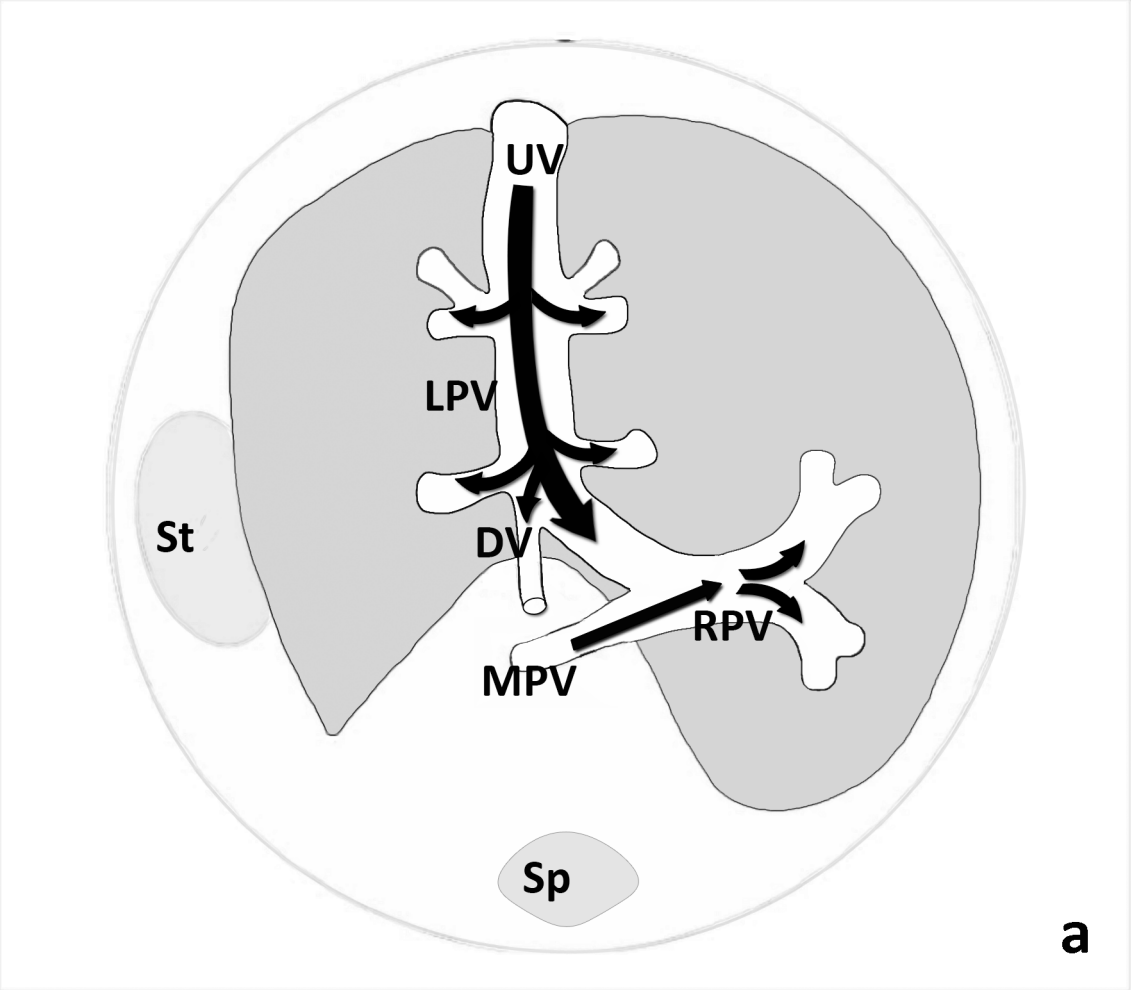

Figure 1a fetal circulation schematic.tif

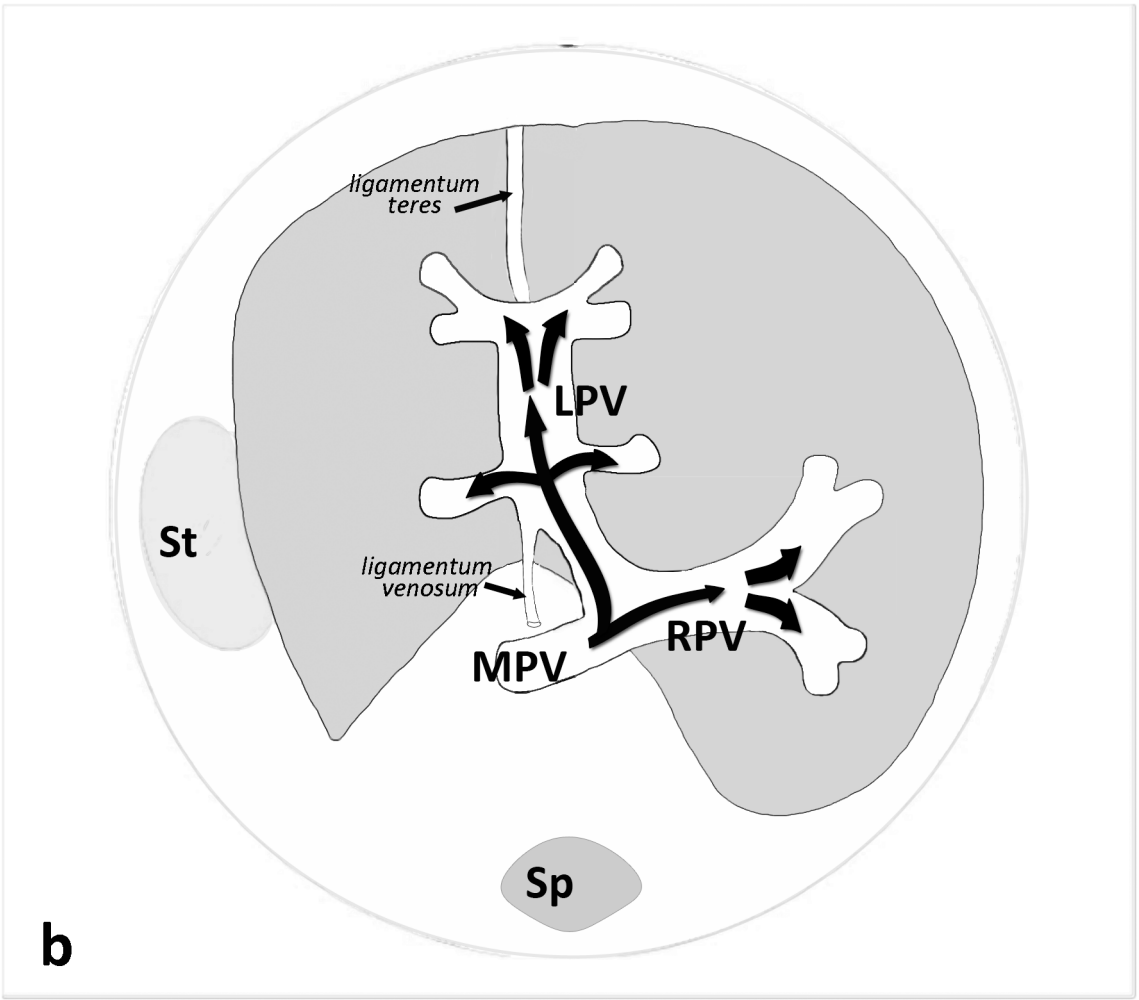

Figure 1b adult circulation schematic.tif

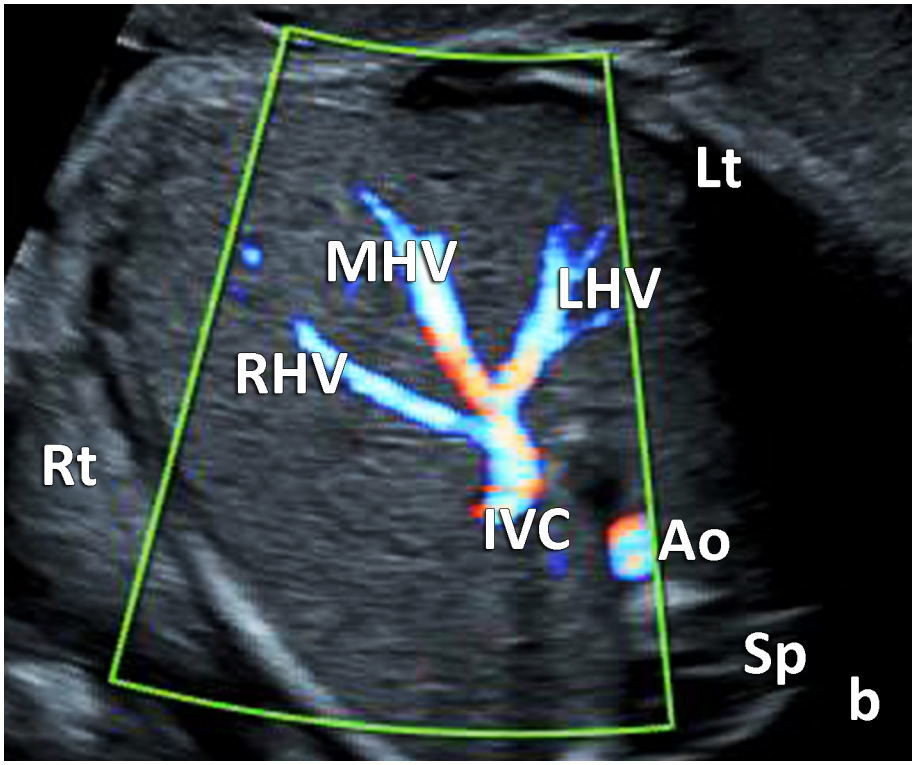

Figure 2 frame B trident normal rt lt.tif

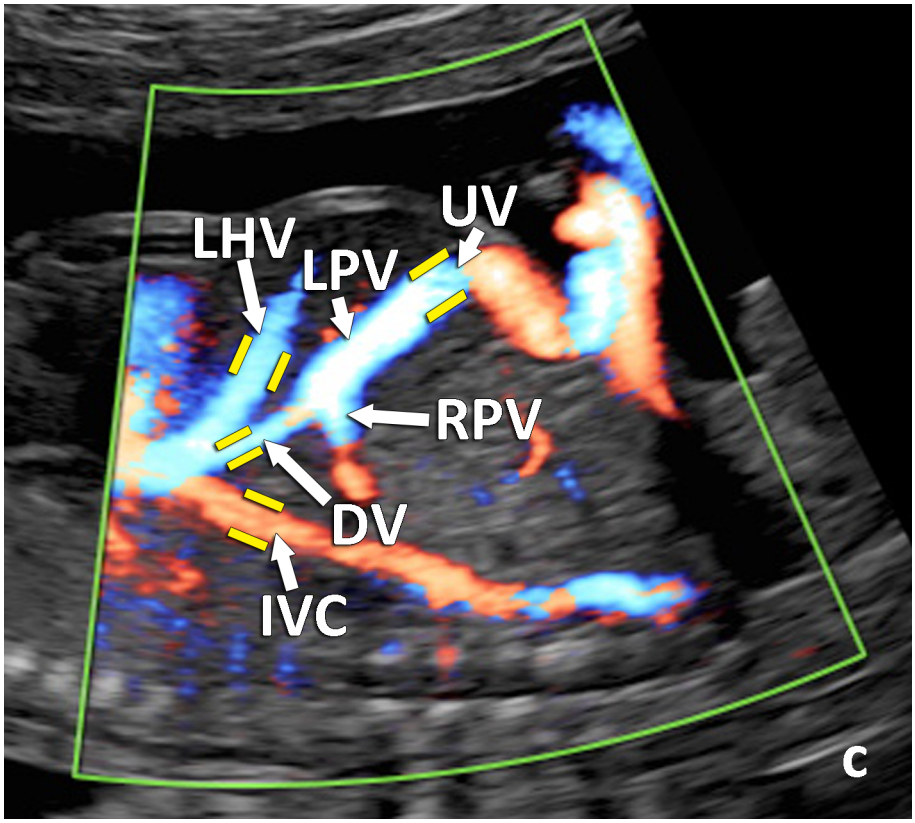

Figure 2 normal plane C longitudinal new.tif

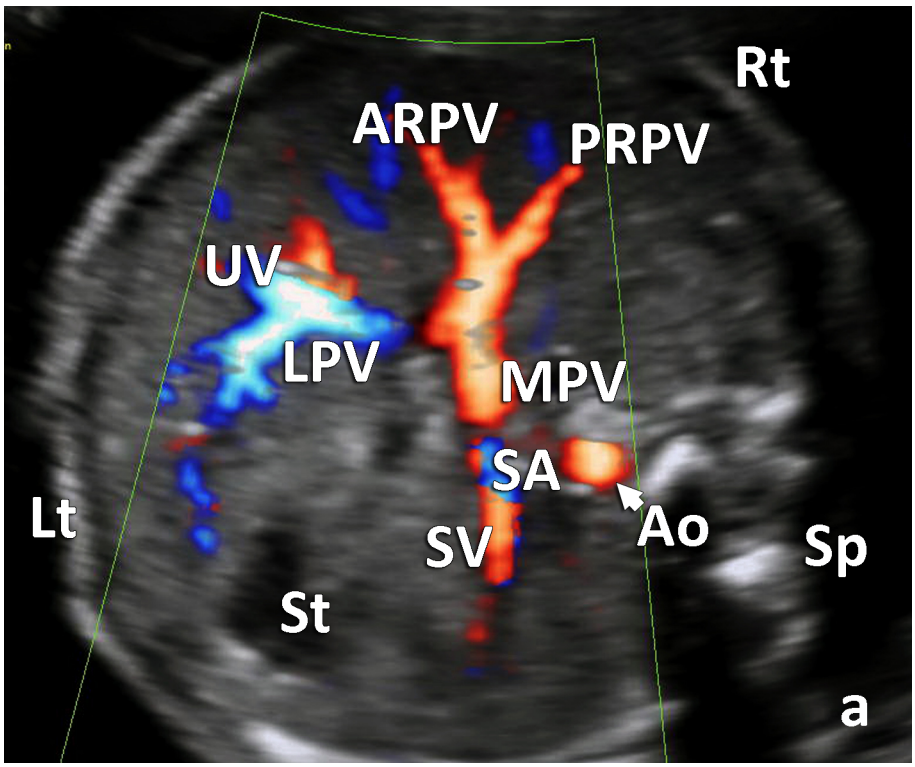

Figure 2 Plane A normal labelled rt lt.tif

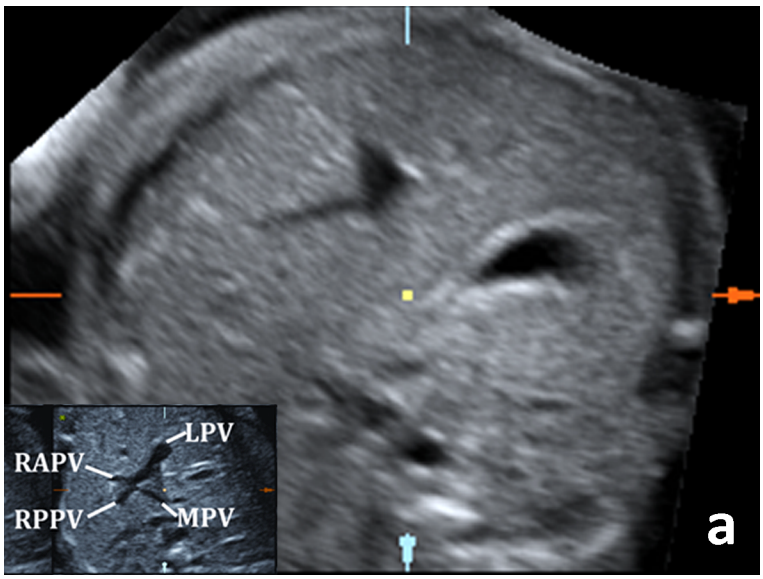

Figure 3A plane A - CAPVS inset.tif

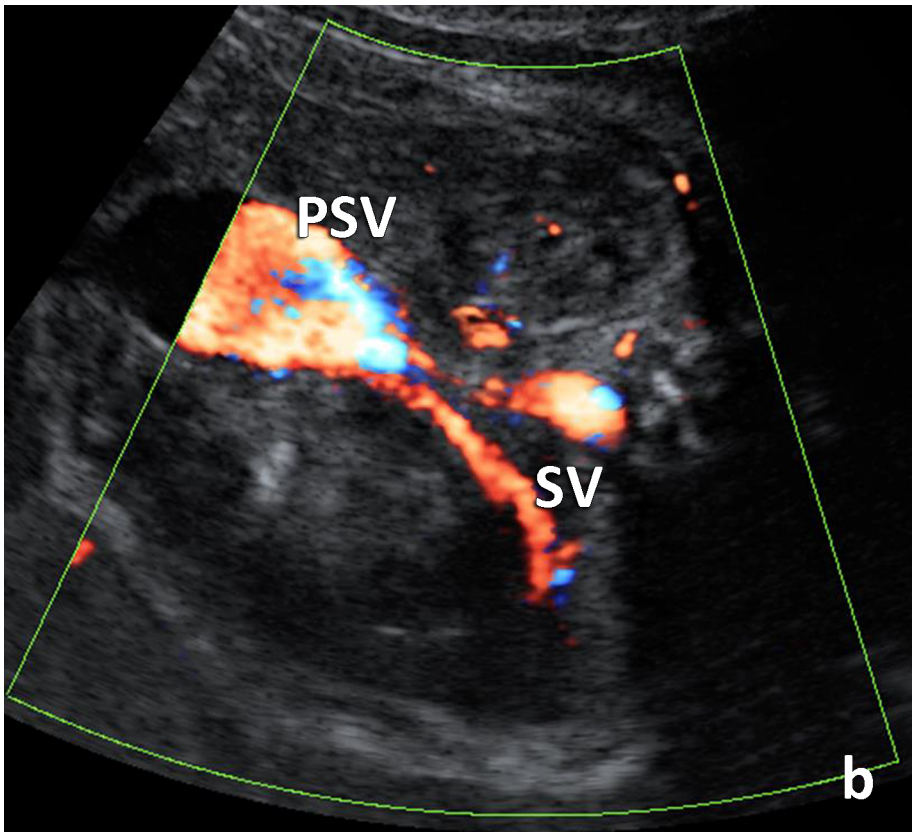

Figure 3b Plane A PSV anomaly.tif

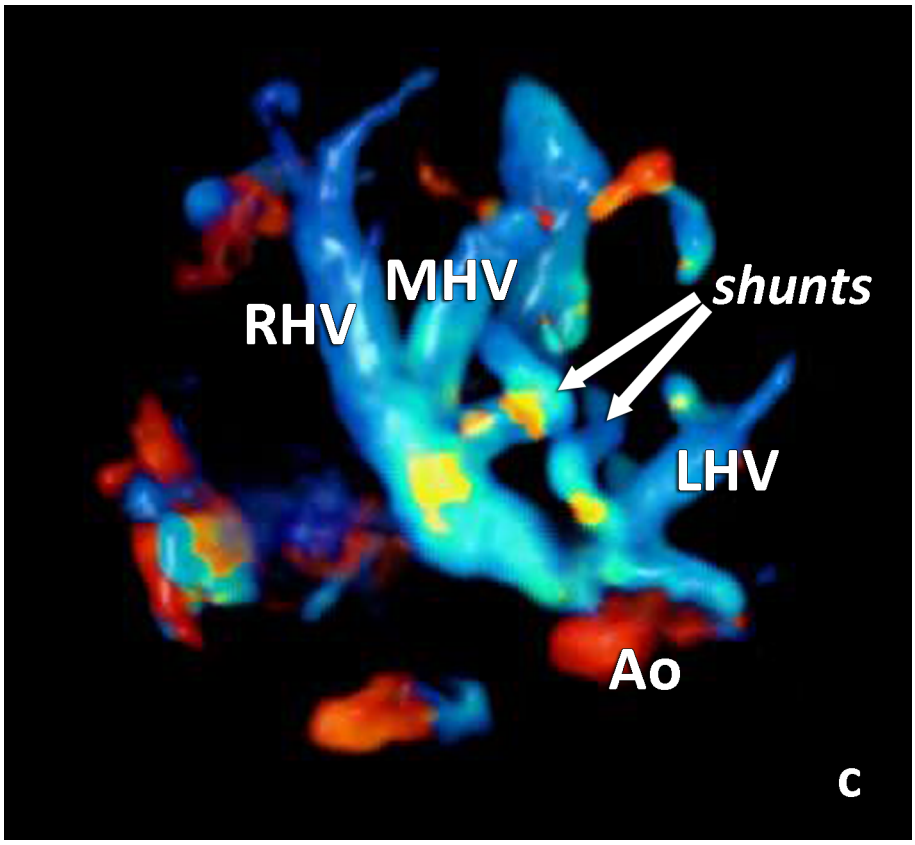

Figure 3c plane B new Doppler porto-hepatic shunts.tif

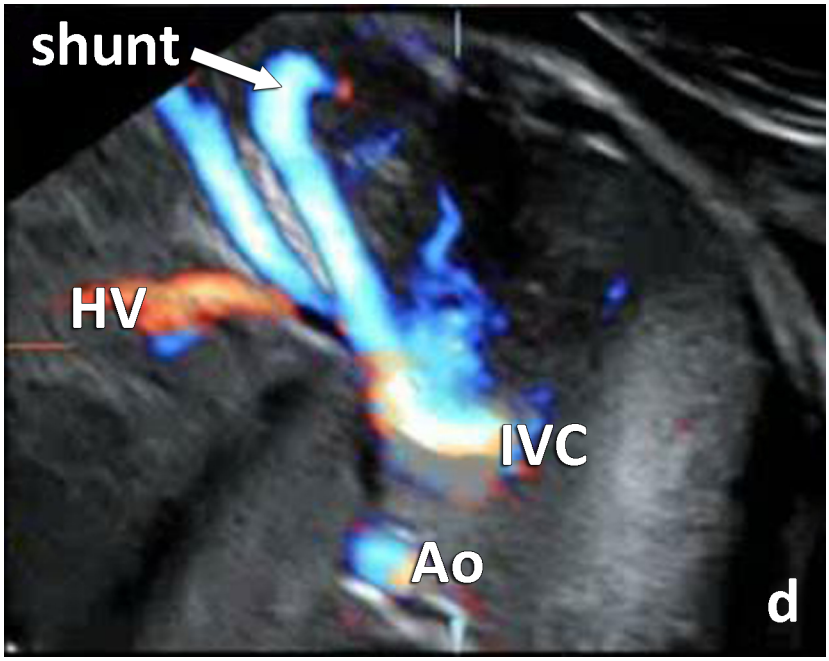

Figure 3d left porto-hepatic shunt B plane.tif

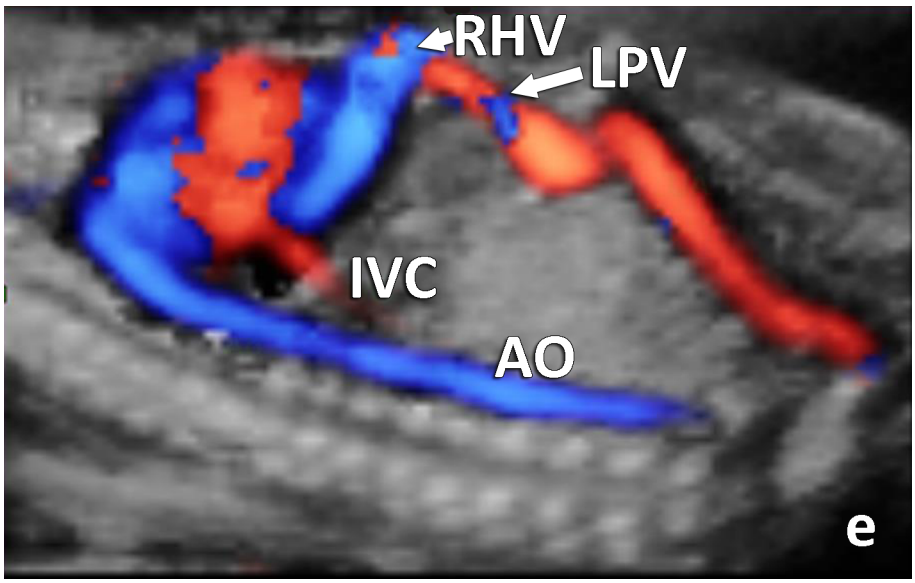

Figure 3e plane C rt porto-hepatic shunt.tif

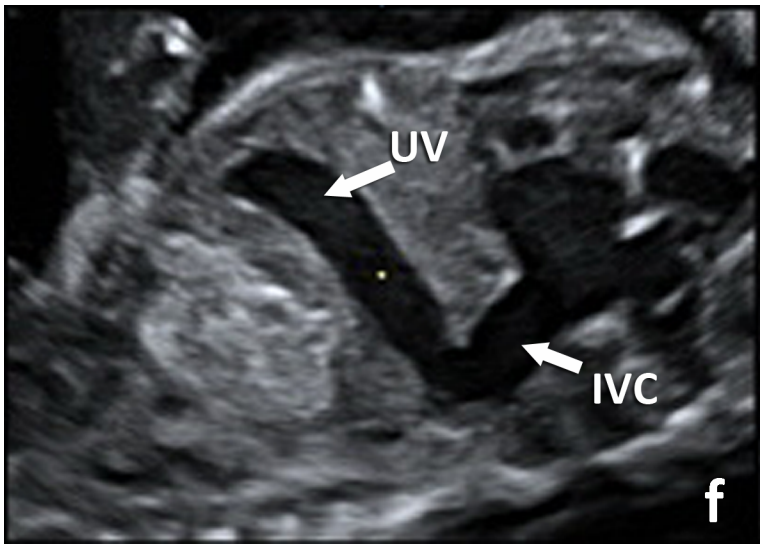

Figure 3f C plane ADV to IVC.tif

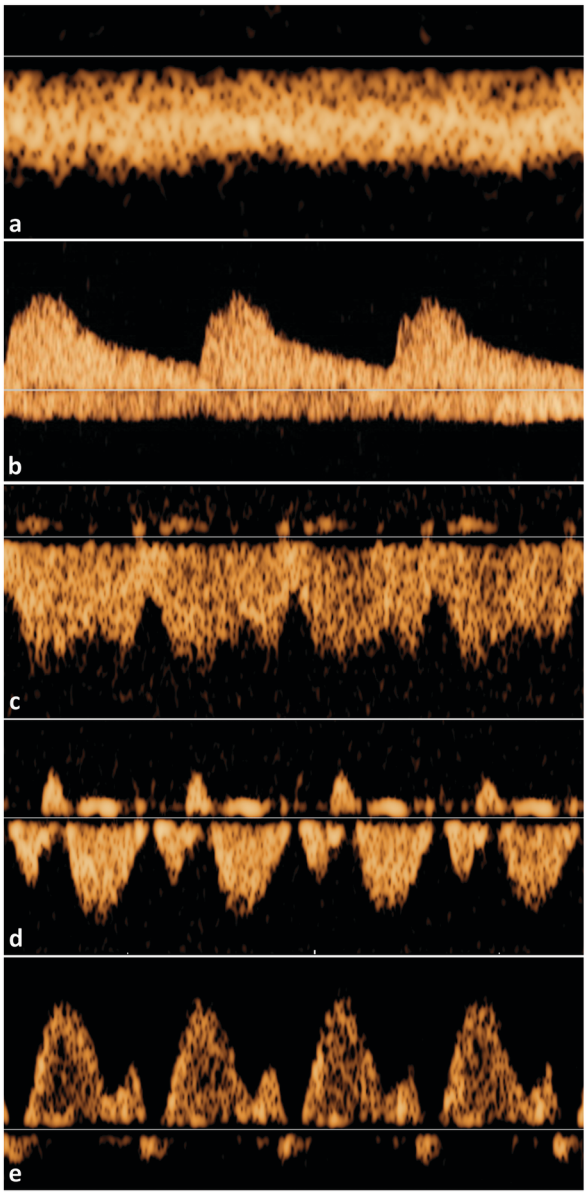

Figure 4 a-e all waveforms together reproduced.tif