

Advances in Color Doppler in Obstetrics

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ABSTRACT

With the latest advances in color Doppler such as superb microvascular imaging (SMI), radiant flow, HDlive flow, and HDlive flow silhouette, we can obtain more comprehensive blood flow information compared with conventional color Doppler. Radiant flow, HDlive flow, and HDlive flow silhouette are appropriate for assessment of the fetal cardiac anatomy and prenatal diagnosis of a congenital heart anomaly. SMI is superior for the precise evaluation of fetal peripheral blood vessels and placental vasculature. In this review article, we present the latest state-of-the-art SMI, radiant flow, HDlive flow, and HDlive flow silhouette features of normal and abnormal fetal hearts, fetal peripheral vessels, and placentas. We also discuss the present and future applicability of advanced color Doppler to assess fetal and placental circulations.

Keywords: 3D/4D ultrasound, Color Doppler, HDlive flow, HDlive flow silhouette, Obstetrics, Radiant flow, Superb microvascular imaging.

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INTRODUCTION

Radiant flow is a new color Doppler, which shows three-dimensional (3D) color Doppler information on a two-dimensional (2D) grayscale image by shading based on the amplitude of the color Doppler signal.^{1,2}

HDlive flow comprises 3D color Doppler equipped with a light source that can be adjusted to achieve lighting and shadowing effects, facilitating depth perception on fetal 3D blood flow examination.³

HDlive Flow Silhouette is cutting-edge technology that can present blood flow with marked clarity, being able to show blood vessel walls and semitransparent vessel lumens.⁴

Superb microvascular imaging (SMI) is a novel technology that can augment conventional color/power Doppler.

It shows the following:

- Suppression of low flow velocity motion artifacts,
- High-level sensitivity,
- High-level resolution, and
- High-frame-rate.⁵⁻⁸

The technology employs a proprietary algorithm that can filter out clutter without any loss of clinically significant information at low velocities. Its merit is that it can suppress motion artifacts while retaining low vascularity information; in contrast, conventional color Doppler filters out both of them. So, SMI can detect peripheral small vessels with the low-velocity flow.

In this review article, Radiant flow, HDlive flow, and HDlive flow silhouette features of the normal fetal heart and congenital heart anomalies and SMI findings of fetal peripheral vessels and placental vasculature are shown using various images.

Fetal Heart Depicted by Radiant Flow, HDlive Flow, and HDlive Flow Silhouette

There have been several studies on HDlive flow and/or HDlive flow silhouette features of the normal fetal heart and congenital heart anomalies.^{3,4,9-12}

Normal Fetal Heart

Radiant flow shows more detailed intracardiac blood flow information on four-chamber and three-vessel tracheal views in the normal heart (Figs 1 and 2). HDlive flow and HDlive flow silhouette provide various unique views.¹³ The spatial three-vessel view demonstrates the relationships and course of outflow tracts (crisscross arrangements of the pulmonary artery and aorta) and superior vena cava (Figs 3 and 4). With its panoramic view, spatial relationships of cardiac chambers and vessels can be visualized, promoting understanding of the course of out- and inflow tracts (Figs 5 and 6). This view is unique for evaluating the ductal arch. Three branch arteries from the aortic arch can also be identified (Fig. 7). With the posterior view, the parallel position of

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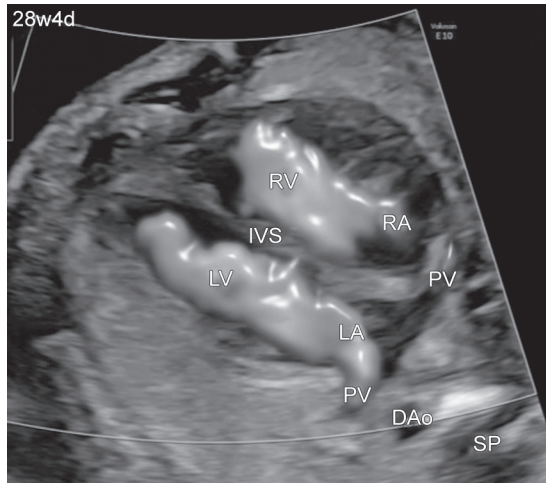


Fig. 1: Four-chamber view depicted by radiant flow at 28 weeks and 4 days of gestation. (DAo, descending aorta; IVS, interventricular septum; LA, left atrium; LV, left ventricle; PV, pulmonary vein; RA, right atrium; RV, right ventricle; SP, spine)

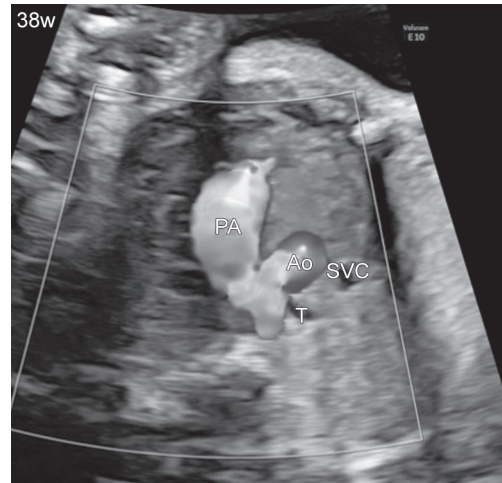


Fig. 2: Three-vessel tracheal view depicted by radiant flow at 38 weeks of gestation. (Ao, aorta; PA, pulmonary artery; SVC, superior vena cava; T, trachea)

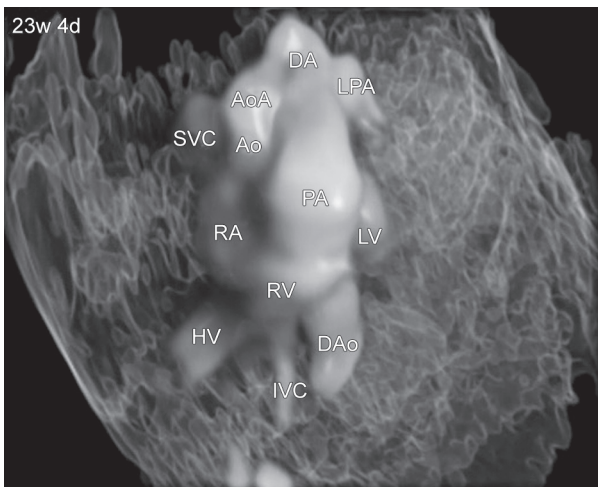


Fig. 3: Spatial three-vessel view depicted by HDlive flow at 23 weeks and 4 days of gestation. (Ao, aorta; AoA, aortic arch; DA, ductus arteriosus; DAo, descending aorta; HV, hepatic vein; IVC, inferior vena cava; LPA, left pulmonary artery; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle; SVC, superior vena cava)

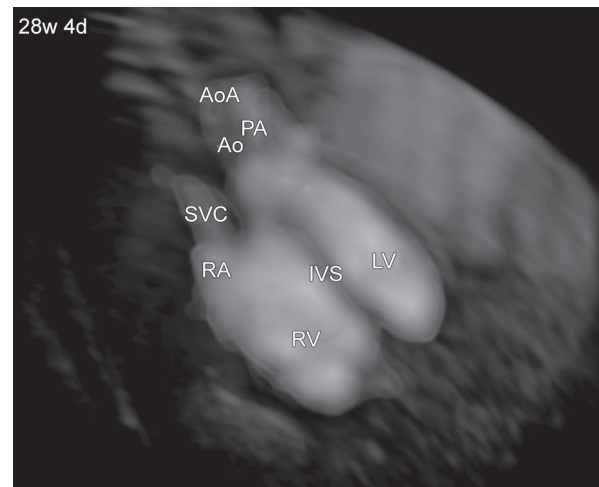


Fig. 4: Spatial three-vessel view silhouette at 28 weeks and 4 days of gestation. (Ao, aorta; AoA, aortic arch; IVC, inferior vena cava; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle; SVC, superior vena cava)

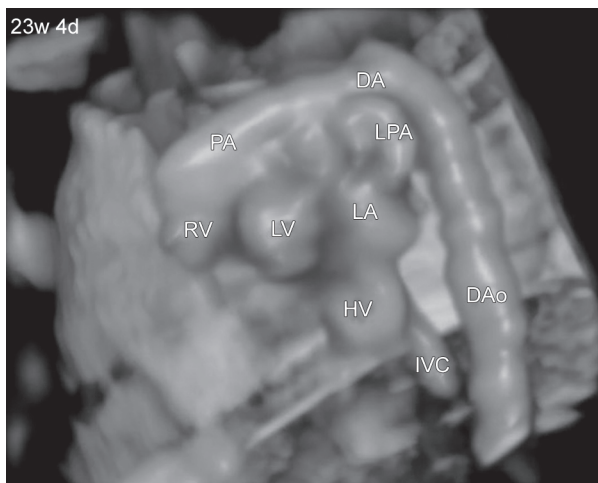


Fig. 5: Panoramic view depicted by HDlive flow at 23 weeks and 4 days of gestation. (DA, ductus arteriosus; DAo, descending aorta; HV, hepatic vein; IVC, inferior vena cava; LA, left atrium; LPA, left pulmonary artery; LV, left ventricle; PA, pulmonary artery; RV, right ventricle)

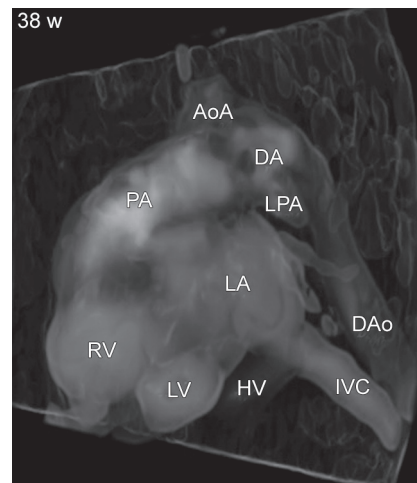


Fig. 6: Panoramic view silhouette at 38 weeks of gestation. (AoA, aortic arch; DA, ductus arteriosus; DAo, descending aorta; HV, hepatic vein; IVC, inferior vena cava; LA, left atrium; LPA, left pulmonary artery; LV, left ventricle; PA, pulmonary artery; RV, right ventricle)

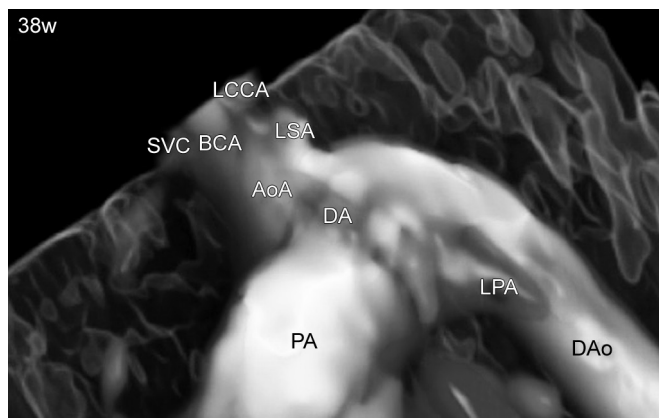


Fig. 7: Enlarged panoramic view depicted by HDlive flow at 38 weeks of gestation. (AoA, aortic arch; BCA, brachiocephalic artery; DA, ductus arteriosus; DAo, descending aorta; LCCA, left common carotid artery; LPA, left pulmonary artery; LSA, left subclavian artery; PA, pulmonary artery; SVC, superior vena cava)

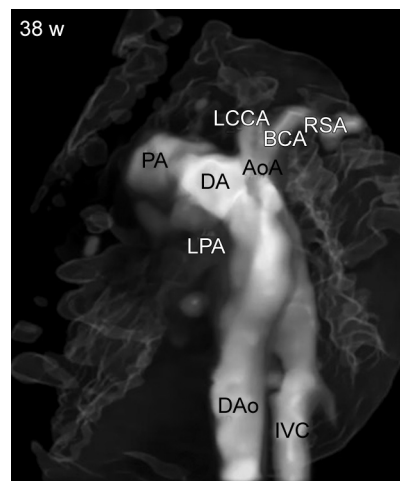


Fig. 8: Posterior view depicted by HDlive flow at 38 weeks of gestation. (AoA, aortic arch; BCA, brachiocephalic artery; DA, ductus arteriosus; DAo, descending aorta; IVC, inferior vena cava; LCCA, left common carotid artery; LPA, left pulmonary artery; PA, pulmonary artery; RSA, right subclavian artery)

the vertical descending aorta and inferior vena cava is evident (Fig. 8).

Congenital Heart Anomaly

According to our literature search, seven reports have described the use of HDlive flow and/or HDlive flow silhouette to examine congenital heart anomalies: a right aortic arch with aberrant left subclavian artery, transposition of great arteries, double-outlet right ventricle, hypoplastic left heart syndrome, hypoplastic right heart syndrome, pulmonary stenosis, ventricular septal defect, idiopathic dilatation of pulmonary artery, truncus arteriosus, and ectopia cordis with a left ventricular diverticulum.^{3,4,9-13} The modalities of HDlive flow and HDlive flow silhouette reveal spatial relationships among fetal cardiac chambers, great arteries, and veins, as well as differences in great vessel sizes, helping us to understand complicated cardiac structures associated with congenital heart anomalies. HDlive flow silhouette generates

holographic images of fetal hearts with hidden vessels, such as descending aorta and veins.⁴

In a fetus with a persistent left superior vena cava (PLSVC), radiant flow clearly shows PLSVC in the left atrium (Fig. 9).

In a fetus with a large ventricular septal defect (VSD) (Fig. 10) with tricuspid regurgitation (TR), radiant flow clearly demonstrates shunt flow through VSD and TR in the right atrium (Fig. 11). HDlive flow silhouette shows spatial relationships among intra-cardiac blood flow, shunt flow through VSD, and TR (Fig. 12).

In a fetus with a double-outlet right ventricle (DORV), a large aorta and small pulmonary artery leaving the right ventricle in parallel can be noted (Figs 13 and 14). Moreover, shunt flow through VSD between the left and right ventricles can be noted using HDlive flow silhouette (Fig. 15).

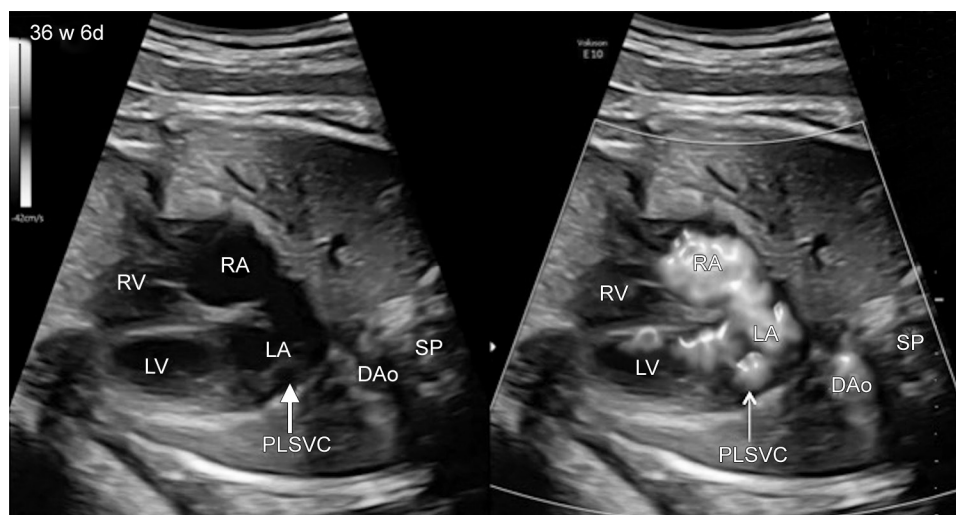


Fig. 9: Persistent left superior vena cava (PLSVC) depicted by radiant flow at 36 weeks and 6 days of gestation. (DAo, descending aorta; LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle; SP, spine)

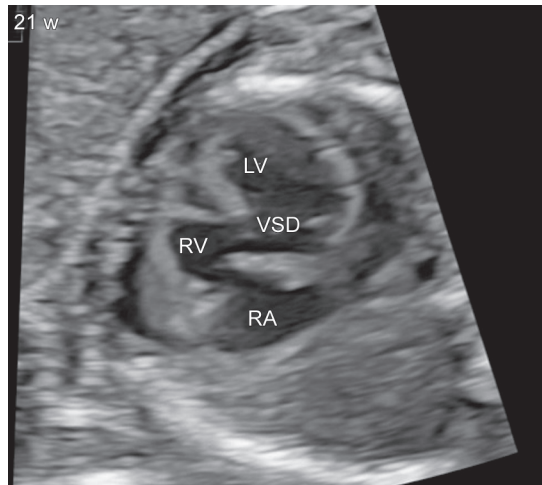


Fig. 10: Large ventricular septal defect (VSD) at 21 weeks of gestation. (LV, left ventricle; RA, right atrium; RV, right ventricle)

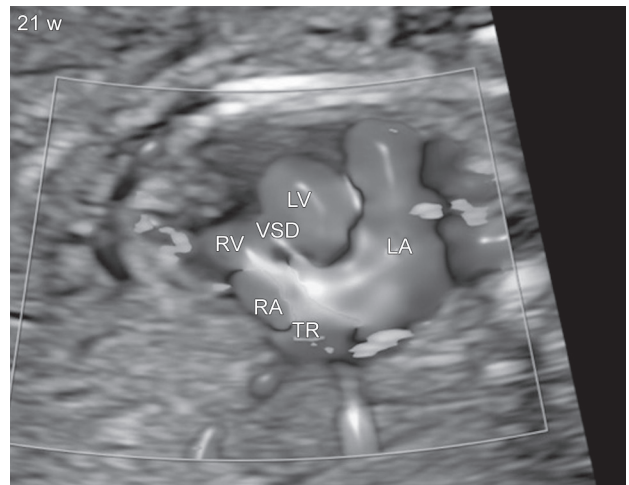


Fig. 11: Large ventricular septal defect (VSD) with tricuspid regurgitation (TR) depicted by radiant flow at 21 weeks of gestation. (LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle)

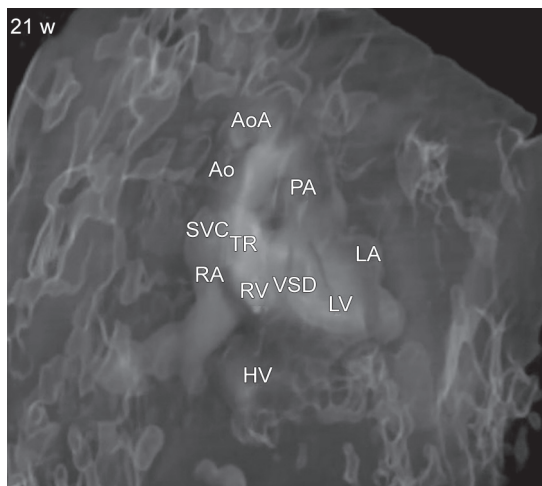


Fig. 12: Large ventricular septal defect (VSD) with tricuspid regurgitation (TR) depicted by HDlive flow silhouette at 21 weeks of gestation. Ao, aorta; AoA, aortic arch; HV, hepatic vein; (LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle; SVC superior vena cava)

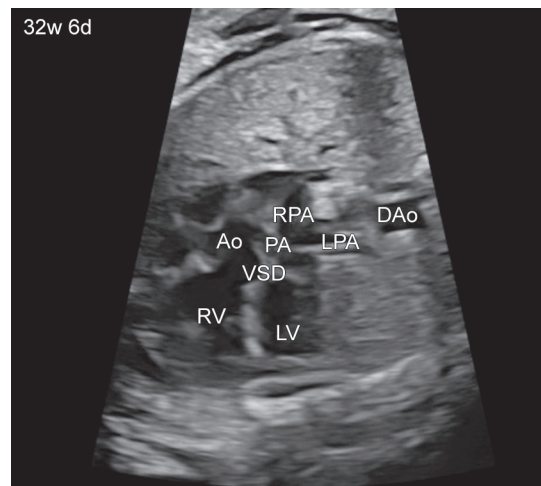


Fig. 13: Double-outlet right ventricle at 32 weeks and 6 days of gestation. (Ao, aorta; DAo, descending aortic; LV, left ventricle; LPA, left pulmonary artery; PA, pulmonary artery; RPA, right pulmonary artery; RV, right ventricle; VSD, ventricular septal defect)

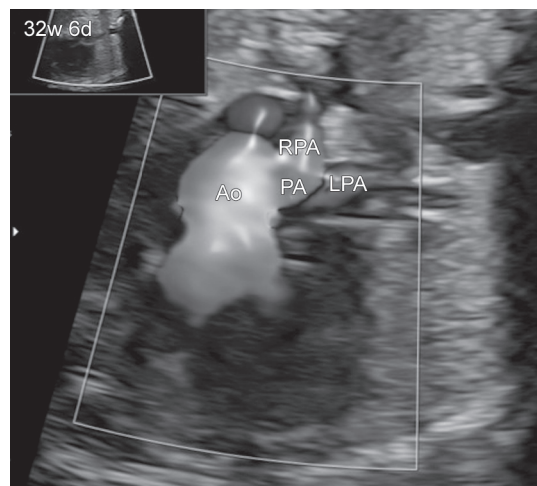


Fig. 14: Double-outlet right ventricle depicted by radiant flow at 32 weeks and 6 days of gestation. (Ao, aorta; LPA, left pulmonary artery; PA, pulmonary artery; RPA, right pulmonary artery)

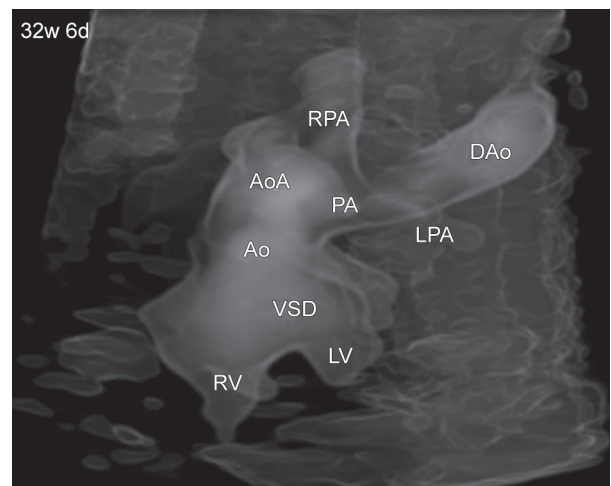


Fig. 15: Double-outlet right ventricle depicted by HDlive flow Silhouette at 32 weeks and 6 days of gestation. (Ao, aorta; AoA, aortic arch; DAo, descending aortic; LV, left ventricle; LPA, left pulmonary artery; PA, pulmonary artery; RPA, right pulmonary artery; RV, right ventricle; VSD, ventricular septal defect)

Fetal Peripheral Vessels Depicted by SMI

There has been only one study on SMI evaluation of fetal peripheral vessels.¹⁴ A significant reduction of motion artifacts, as well as low-velocity blood flow in small vessels of fetal organs, can both be achieved with SMI. Fetal intracranial vessels can be detected as early as 10 weeks of gestation using SMI (Fig. 16). SMI clearly shows intracranial small vessels (Figs 17 to 21). Moreover, the fetal ophthalmic artery can be identified (Figs 22 and 23). Vascular densities of the fetal lung (Figs 24 to 26), liver (Figs 27 and 28), spleen (Figs 29 and 30), and kidney (Figs 31 and 32) increase with advancing gestation.

There has been only one report on antenatal SMI findings of a fetal anomaly: right diaphragmatic eventration at 21 weeks and 4 days of gestation.¹⁵ SMI suggested an abnormal elevation of the right hemidiaphragm in this case. Figure 33 shows 2D sonographic findings of a multicystic dysplastic kidney at 21 weeks of gestation. SMI clearly shows no blood flow in either kidney (Fig. 34). HDlive Flow with the HDlive silhouette mode demonstrates spatial relationships among both kidneys, the descending aorta, and inferior vena cava (Fig. 35).

Placenta Assessed by SMI

SMI more clearly showed intraplacental small vessels than conventional color/power Doppler¹⁴ (Fig. 36).

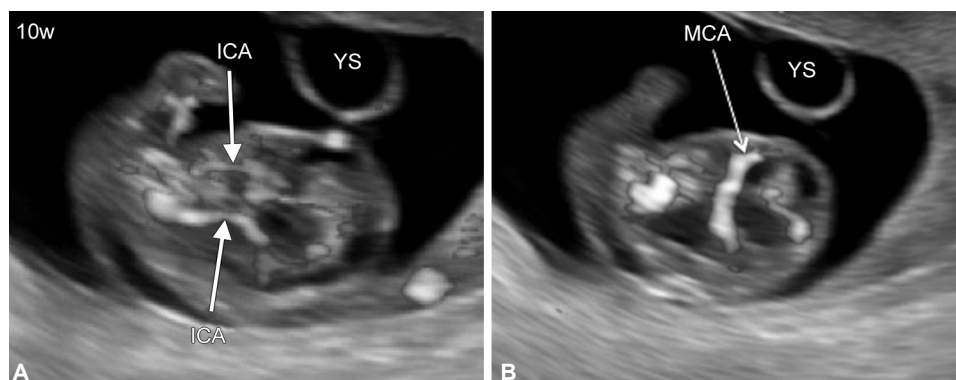
Normal Placenta

In the first trimester of pregnancy, SMI demonstrates intraplacental vessels such as primary and secondary stem villous vessels¹⁶ (Fig. 37). Velamentous insertion of the umbilical cord can also be clearly identified (Fig. 38).

In the second and third trimesters of pregnancy, SMI clearly shows intraplacental vessels such as primary, secondary, and tertiary stem villous vessels, chorionic surface vessels, decidual vessels, and spiral arterial jet flow¹⁶ (Figs 39 to 42). Also, 3D SMI more clearly depicts the spatial reconstructions of dense intraplacental vessels (Fig. 41). Further, 2D and 3D SMI with an 18-MHz linear probe more clearly show small vessels in the placenta compared with conventional 2D and 3D SMI (Fig. 43).

Placenta with Fetal Growth Restriction

In the case of placental infarction with severe fetal growth restriction (FGR), a previous report stated that villous trees in the placenta could not be visualized, and branch-



Figs 16A and B: Fetal intracranial vessels depicted by transvaginal superb microvascular imaging at 10 weeks of gestation. Internal carotid artery (ICA) (A) and middle cerebral artery (MCA); (B) are identified. YS, yolk sac

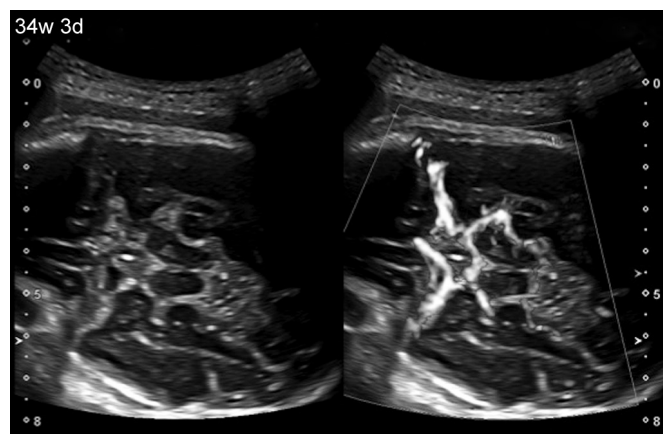


Fig. 17: Circle of Willis depicted by superb microvascular imaging at 34 weeks and 3 days of gestation

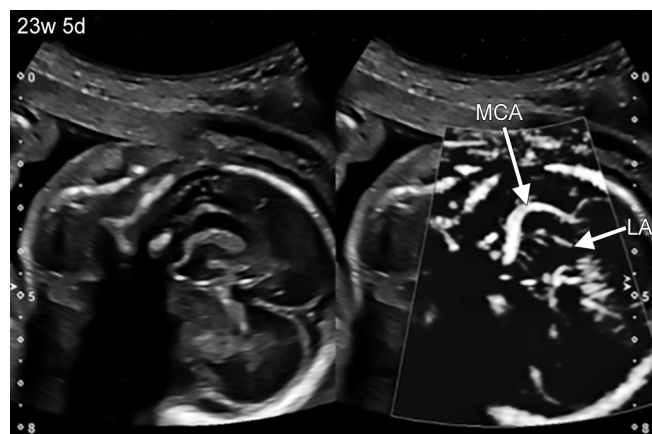


Fig. 18: Intracranial vessels depicted by superb microvascular imaging at 23 weeks and 5 days of pregnancy. LA, lenticulostriate artery; MCA, middle cerebral artery

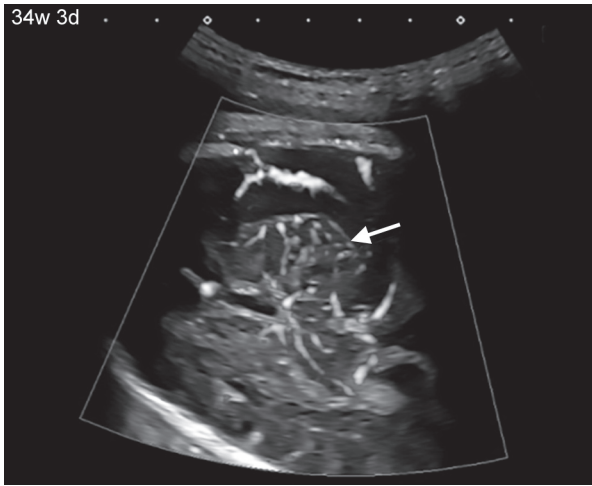


Fig. 19: Small vessels in the thalamus depicted by superb microvascular imaging at 34 weeks and 3 days of gestation

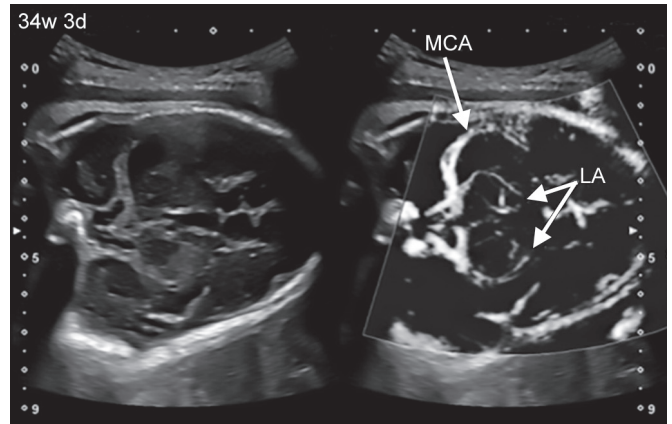


Fig. 20: Intracranial vessels depicted by superb microvascular imaging at 34 weeks and 3 days of pregnancy. (LA, lenticulostriate artery; MCA, middle cerebral artery)

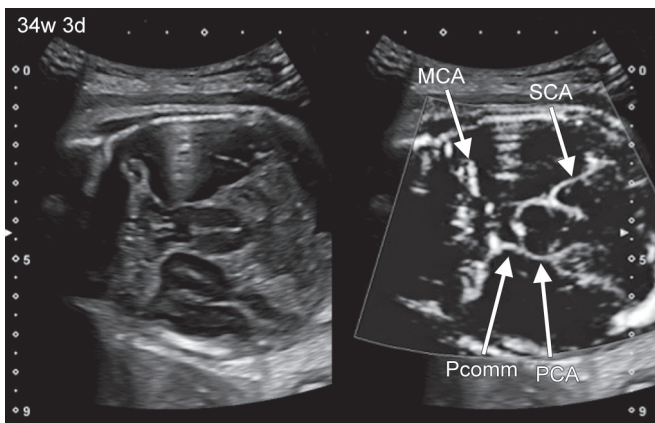


Fig. 21: Intracranial vessels depicted by superb microvascular imaging at 34 weeks and 3 days of pregnancy. (MCA, middle cerebral artery; PCA, posterior cerebellar artery; Pcomm, posterior communicating artery; SCA, superior cerebellar artery)

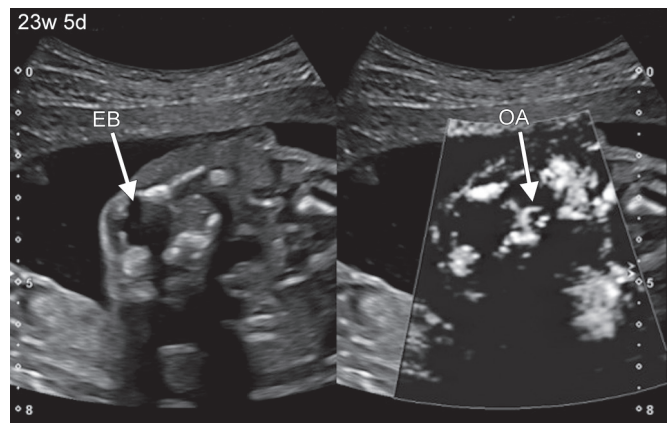


Fig. 22: Fetal ophthalmic artery (OA) depicted by superb microvascular imaging at 23 weeks and 5 days of gestation (EB, eyeball)

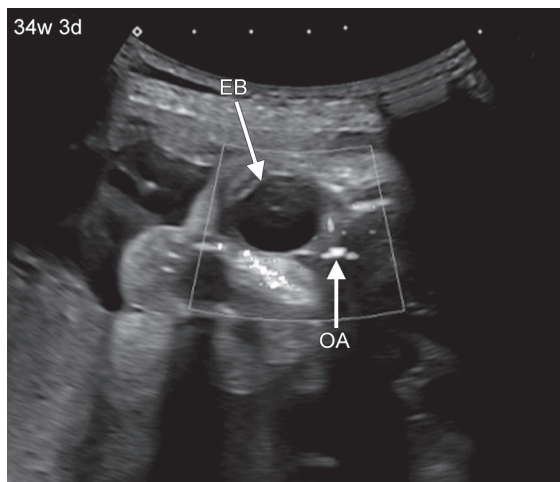


Fig. 23: Fetal ophthalmic artery (OA) depicted by superb microvascular imaging at 34 weeks and 3 days of gestation. (EB, eyeball)

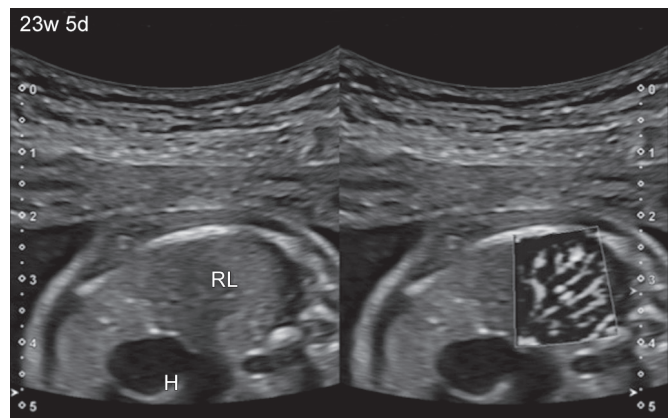


Fig. 24: Fetal pulmonary vessels depicted by superb microvascular imaging at 23 weeks and 5 days of gestation. (RL, right lung)

ing vessels showed congestion.¹⁷ However, SMI demonstrated sparse villous trees in a thick placenta with FGR, and each stem villous vessel became straight.¹⁶ Especially, primary stem villous vessels were thick and long.

Placenta Accreta Spectrum

In a case of placenta accreta spectrum (PAS) examined using a new ultra-high frequency liner probe (18–24 MHz) with SMI, enlarged dull vessels with low echogenicity without SMI Doppler signals were observed, whereas

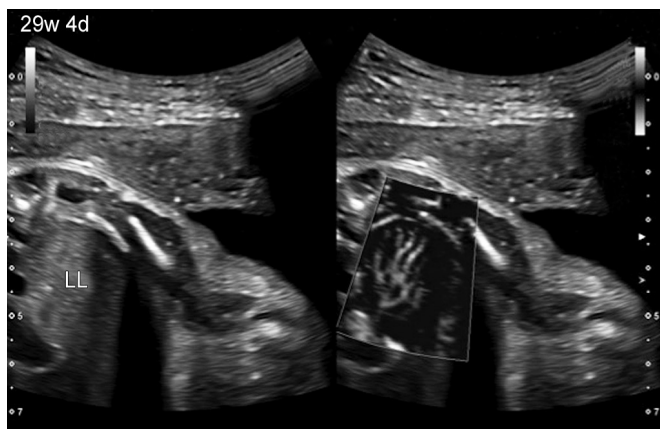


Fig. 25: Fetal pulmonary vessels depicted by superb microvascular imaging at 29 weeks and 4 days of gestation. (LL, left lung)

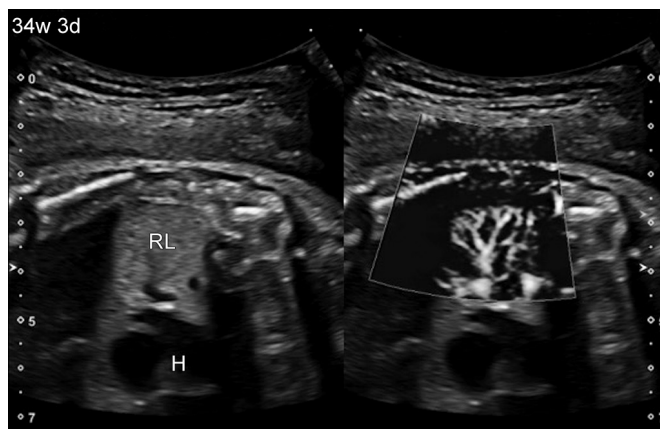


Fig. 26: Fetal pulmonary vessels depicted by superb microvascular imaging at 34 weeks and 3 days of gestation. (H, heart; RL, right lung)

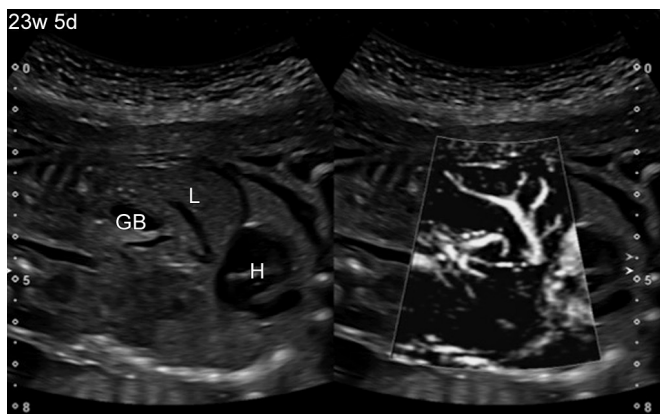


Fig. 27: Fetal hepatic vessels depicted by superb microvascular imaging at 23 weeks and 5 days of gestation. (GB, gallbladder; H, heart; L, liver)

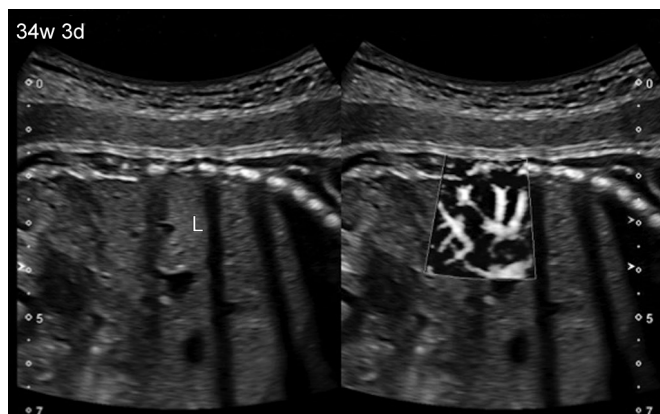


Fig. 28: Fetal hepatic vessels depicted by superb microvascular imaging at 34 weeks and 3 days of gestation. (L, liver)

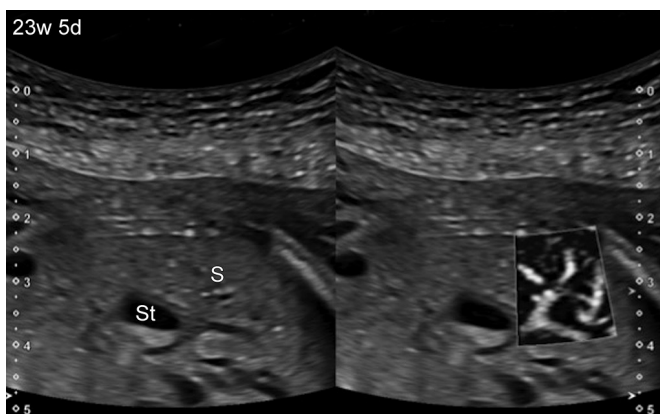


Fig. 29: Fetal splenic vessels depicted by superb microvascular imaging at 23 weeks and 5 days of gestation. (S, spleen; St, stomach)

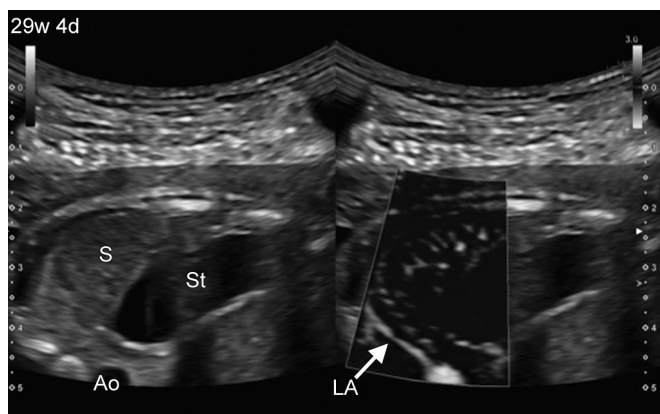


Fig. 30: Fetal splenic vessels depicted by superb microvascular imaging at 29 weeks and 4 days of gestation. (Ao, aorta; LA, lenticulostriate artery; S, spleen; St, stomach)

SMI revealed small vessels in the villous tree at a site not showing adhesion of the placenta.¹⁸

In a normal placenta at 30 weeks of gestation, high-resolution SMI clearly shows a sharp placental basal line with/without decidual vessels between the placenta and myometrium. The uterine wall is thick, and arcuate arteries in the wall are also noted (Fig. 44).

In the case of pregnancy after previous uterine fundal incision of placenta previa with suspected PAS at 30

weeks and 6 days of gestation, conventional 2D sonography cannot clearly identify a uterine wall (Fig. 45). However, high-resolution SMI with an 18-MHz probe can clearly identify the very thin uterine wall (Fig. 46). In this case, the placental baseline is evident, which is different from PAS. Moreover, no abnormal blood flow cannot be recognized. During the operation, the placenta can be removed without any adhesion. However, the membranous uterine wall at the fundal lesion is evident (Fig. 47).

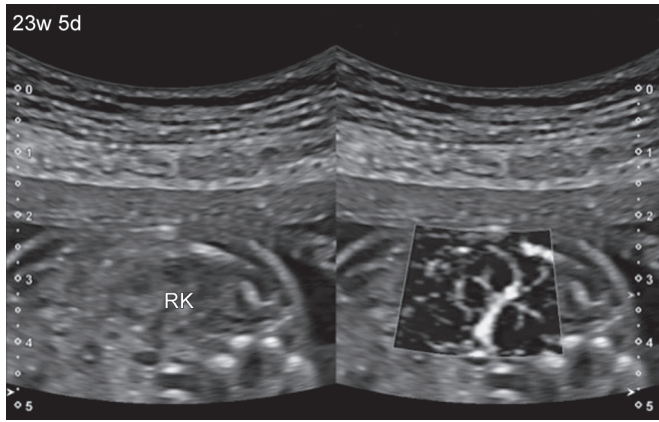


Fig. 31: Fetal renal vessels depicted by superb microvascular imaging at 23 weeks and 5 days of gestation. (RK, right kidney)

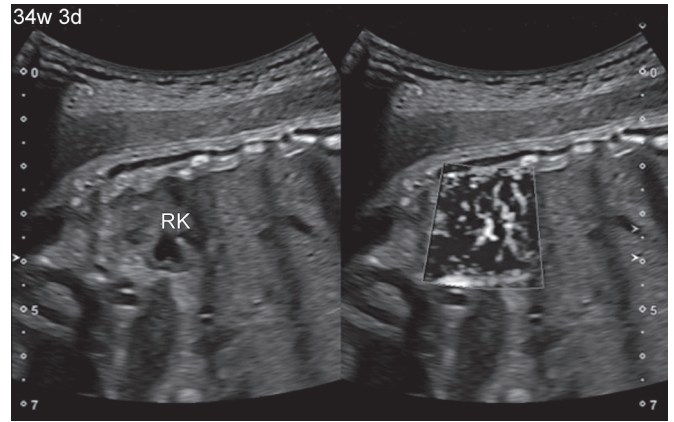


Fig. 32: Fetal renal vessels depicted by superb microvascular imaging at 34 weeks and 3 days of gestation. (RK, right kidney)

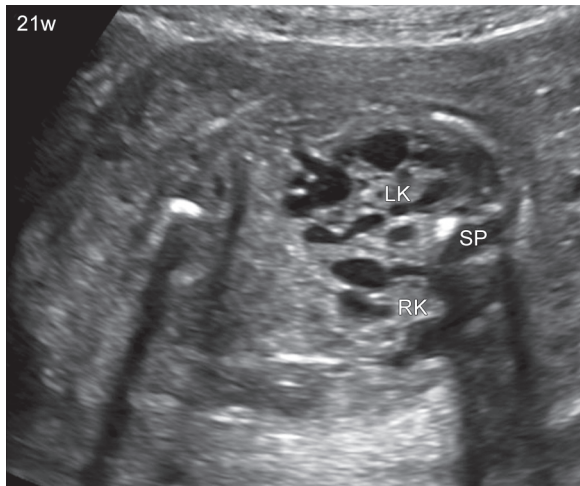


Fig. 33: Multicystic dysplastic kidney at 21 weeks of gestation. (LK, left kidney; RK, right kidney; Sp, spine)

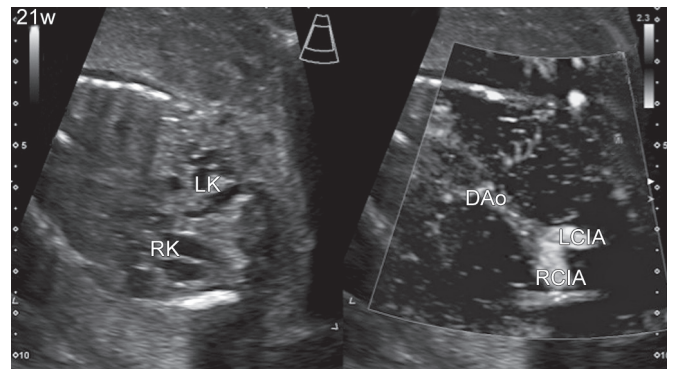


Fig. 34: Superb microvascular imaging findings of the multicystic dysplastic kidney at 21 weeks of gestation. (DAo, descending aorta; LCIA, left common iliac artery; LK, left kidney; RCIA, right common iliac artery; RK, right kidney)

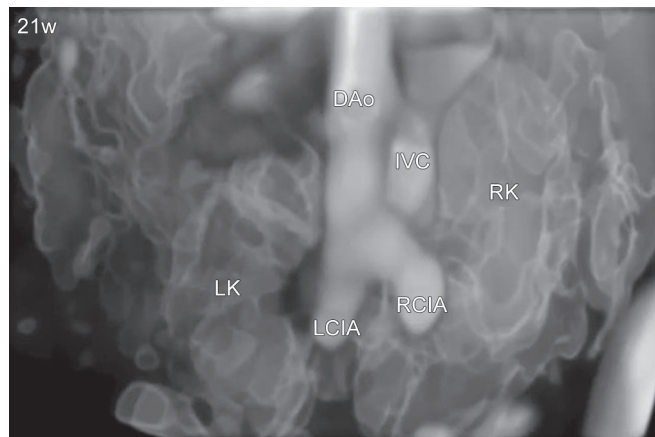
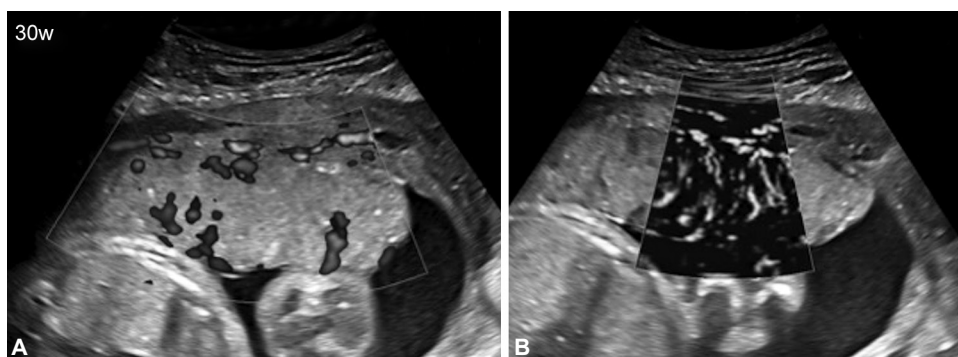


Fig. 35: HDlive flow with HDlive silhouette mode findings of the multicystic dysplastic kidney at 21 weeks of gestation. (DAo, descending aorta; IVC, inferior vena cava; LCIA, left common iliac artery; LK, left kidney; RCIA, right common iliac artery; RK, right kidney)

CONCLUSION

For examiners lacking experiences, 2D/3D fetal echocardiography with new color Doppler might be more straightforward to use, and it may facilitate more accurate diagnoses of congenital heart anomalies. By the clear anatomical visualization, these techniques provide novel visual experiences for obstetricians and pediatric

cardiologists of the fetal heart. They may also provide an easier way to show spatial relationships among fetal cardiac chambers, great arteries, and veins, and differences in great vessel sizes. Thus, in the future, 2D/3D fetal echocardiography may develop into an important diagnostic tool for examining congenital heart anomalies.



Figs 36A and B: Comparison of placental vascularity between color Doppler (A) and superb microvascular imaging; (B) for detecting small vessels in the placenta at 30 weeks of gestation

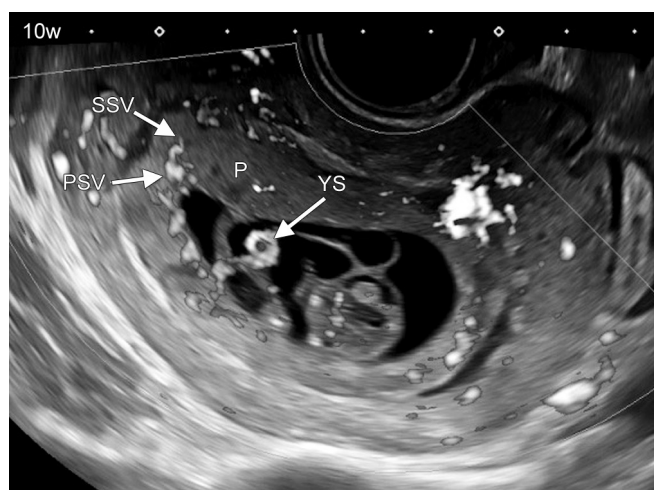
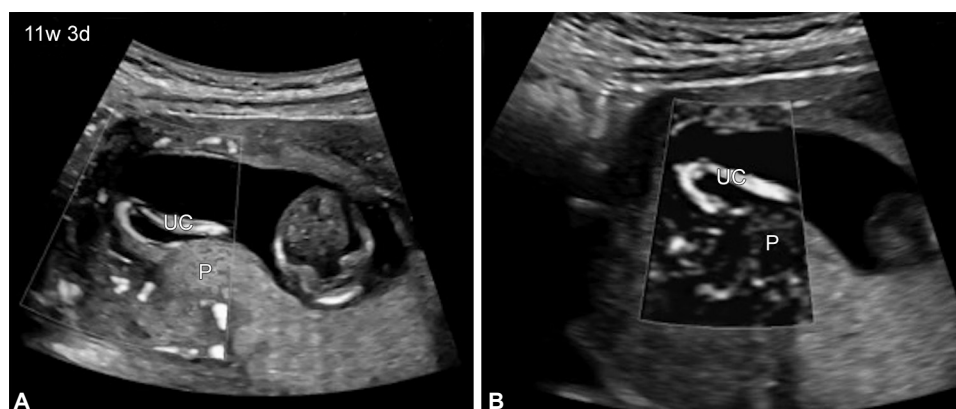


Fig. 37: Normal placenta at 10 weeks of gestation on superb microvascular imaging. (P, P.gunta; PSV, primary stem villous vessels; SSV, secondary stem villous vessels; YS, yolk sac)



Figs 38A and B: Velamentous insertion of the umbilical cord (UC) at 11 weeks and 3 days of gestation. (P, placenta); (A) color-coded superb microvascular imaging (SMI); (B) monochrome SMI

Small peripheral vessels in fetal organs can be identified using SMI in normal and abnormal fetuses. Studies on fetal lung maturation, the mechanism of FGR, fetal infection, etc., may be advanced using SMI in future research programs.

Regarding umbilical cord vessels, chorionic surface vessels, stem villous vessels, spiral arteries, and decidual

vessels, spatial relationships could be observed with SMI in both normal and abnormal placentas. SMI characteristics of a thickened placenta with FGR are sparse villous trees, and each stem villous vessel becomes straight. With the application of an 18–24 MHz linear probe, high-resolution ultrasound, and SMI may become novel diagnostic tools to identify PAS and other placental abnormalities.

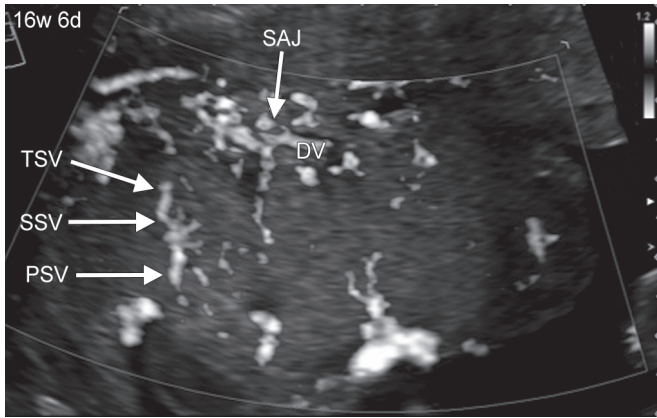


Fig. 39: Normal placenta at 16 weeks and 6 days of gestation on superb microvascular imaging. (DV, decidual vessel; PSV, primary stem villous vessels; SAJ, spiral artery jet flow; SSV, secondary stem villous vessels; TSV, tertiary stem villous vessel)

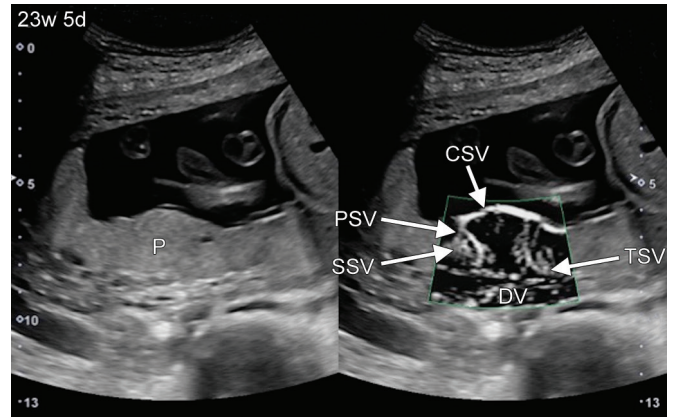


Fig. 40: Normal placenta at 23 weeks and 5 days of gestation on superb microvascular imaging. (CSV, chorionic surface vessel; DV, decidual vessel; P, placenta; PSV, primary stem villous vessels; SSV, secondary stem villous vessels; TSV, tertiary stem villous vessel)

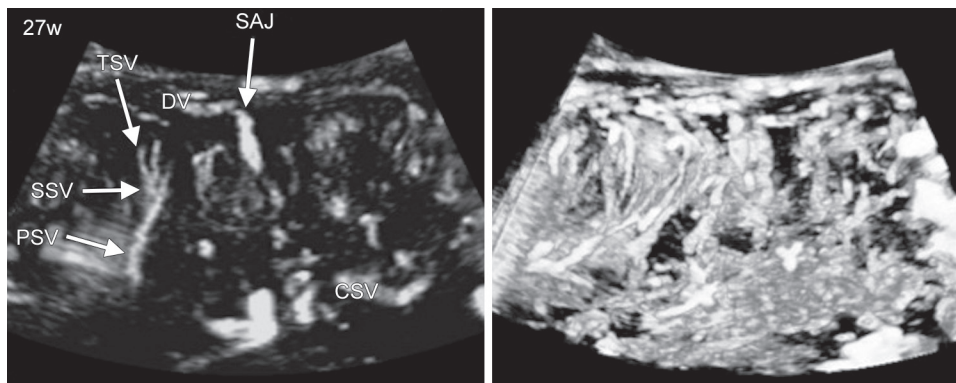


Fig. 41: Normal placenta at 27 weeks of gestation on superb microvascular imaging (SMI). (CSV, chorionic surface vessel; DV, decidual vessel; PSV, primary stem villous vessels; SAJ, spiral artery jet flow; SSV, secondary stem villous vessels; TSV, tertiary stem villous vessel. a, two-dimensional SMI; b, three-dimensional SMI)

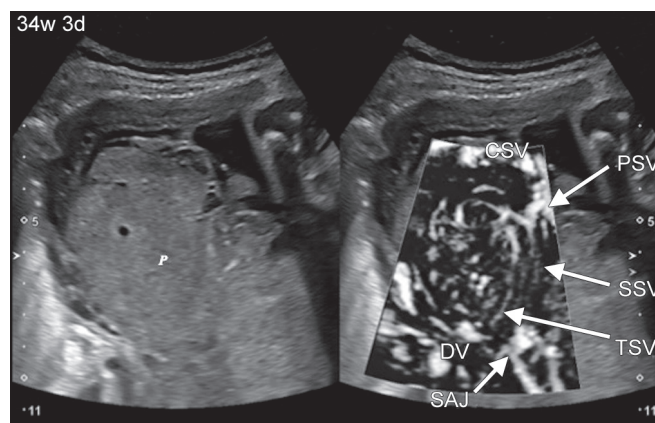
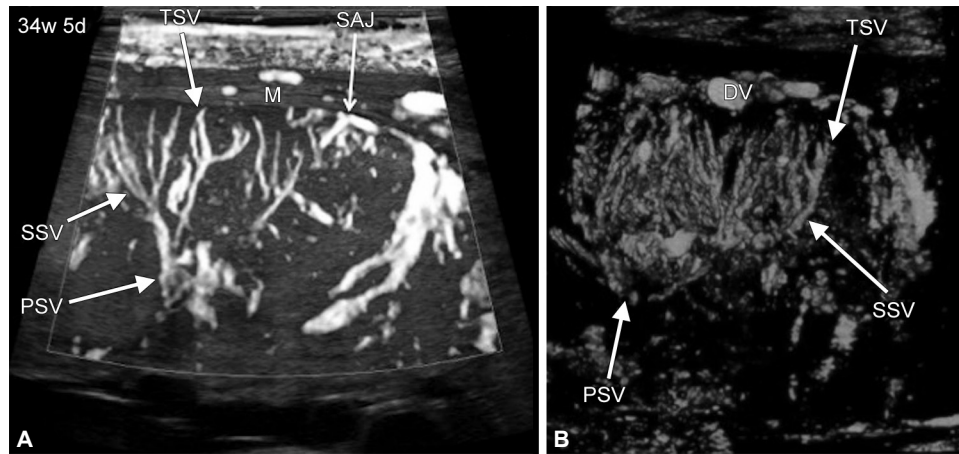
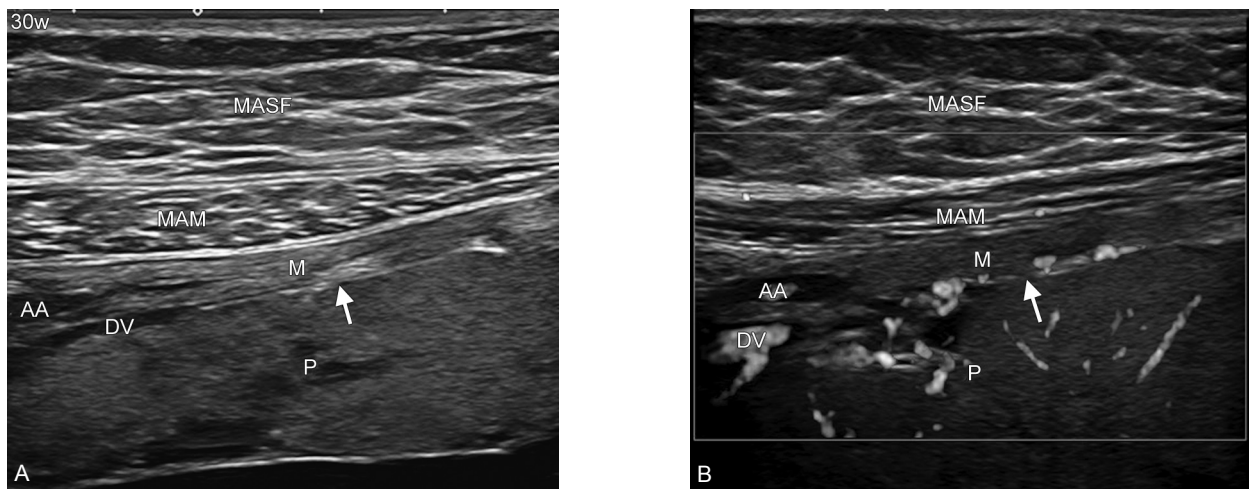


Fig. 42: Normal placenta at 34 weeks and 3 days of gestation on superb microvascular imaging. (CSV, chorionic surface vessel; DV, decidual vessel; P, placenta; PSV, primary stem villous vessels; SAJ, spiral artery jet flow; SSV, secondary stem villous vessels; TSV, tertiary stem villous vessel)



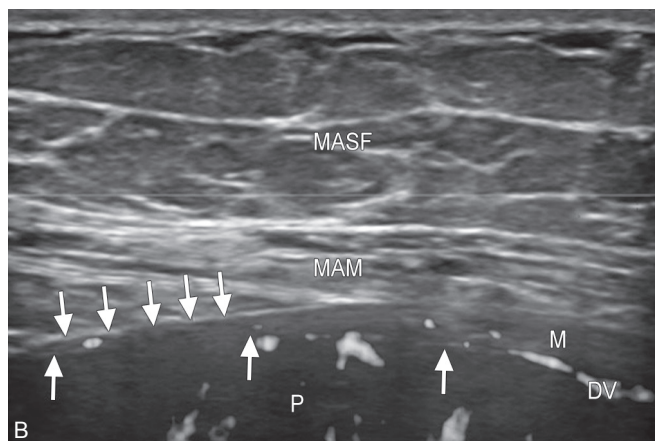
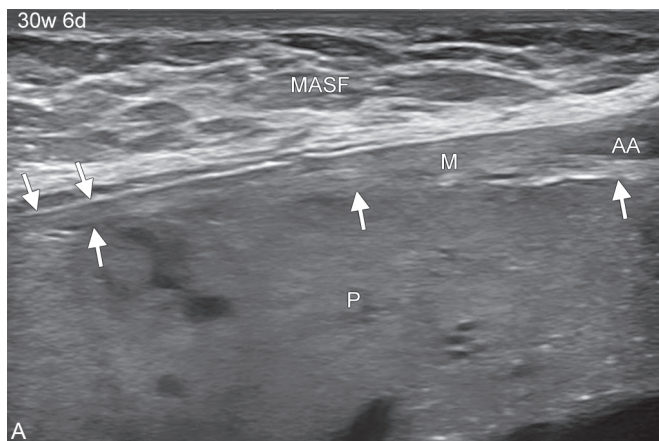
Figs 43A and B: Normal placenta at 34 weeks and 5 days of gestation on superb microvascular imaging (SMI) with an 18-MHz linear probe. (DV, decidual vessel; M, myometrium; PSV, primary stem villous vessels; SAJ, spiral artery jet flow; SSV, secondary stem villous vessels; TSV, tertiary stem villous vessel. (A) Two-dimensional SMI; (B) three-dimensional SMI)



Figs 44A and B: Normal placenta at 30 weeks of gestation on superb microvascular imaging (SMI) with an 18-MHz linear probe. SMI clearly shows a sharp placental basal line (arrow) with/without decidual vessels (DV) between the placenta and myometrium. The uterine wall (M) is thick, and arcuate arteries (AA) in the uterine wall are also noted. (MAM, maternal abdominal muscle; MASF, maternal abdominal subcutaneous fat, P, placenta); (A) High-resolution two-dimensional sonographic image; (B) Image on SMI



Fig. 45: Conventional two-dimensional sonographic image of a pregnancy after previous uterine fundal incision of placenta previa with suspected placenta accreta spectrum at 30 weeks and 6 days of gestation. (P. placenta)



Figs 46A and B: High-resolution (A) and superb microvascular imaging; (B) features with an 18-MHz probe at 30 weeks and 6 days of gestation. A very thin uterine wall (small arrows) is evident. The placental baseline (large arrows) is clearly identified. (AA, arcuate artery; DV, decidual vessel; M, myometrium; MAM, maternal abdominal muscle; MASF, maternal abdominal subcutaneous fat, P, placenta)



Fig. 47: Macroscopic findings of the uterus during the operation. A membranous uterine wall at the fundal lesion (arrows) is evident

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