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REVIEW ARTICLE

Three-dimensional Evaluation of the Fetal Brain

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ABSTRACT

Three-dimensional (3D) ultrasound is one of the most attractive modalities in the field of fetal ultrasound imaging. Combination of both transvaginal sonography and 3D ultrasound may be a great diagnostic tool for evaluation of 3D structure of fetal central nervous system (CNS). Recent advanced 3D ultrasound equipments have several useful functions, such as surface anatomy imaging; multiplanar imaging of the intracranial structure; tomographic ultrasound imaging of fetal brain in the any cutting section; bony structural imaging of the calvaria and vertebrae; thick slice imaging of the intracranial structure; simultaneous volume contrast imaging of the same section or vertical section of fetal brain structure; volume calculation of target organs, such as intracranial cavity, ventricle, choroid plexus, and intracranial lesions; and 3D sonoangiography of the brain circulation (3D power or color Doppler). Furthermore, recent advanced technologies, such as HDlive silhouette and HDlive flow are quite attractive modalities and they can be applied for neuroimaging.

Up-to-date 3D technologies described in this study allow extending the detection of congenital brain maldevelopment, and it is beyond description that noninvasive direct viewing of the embryo/fetus by all-inclusive ultrasound technology is definitely the first modality in a field of fetal neurology and helps our goal of proper perinatal care and management, even in the era of molecular genetics and advanced sequencing of fetal deoxyribonucleic acid (DNA) in the maternal blood. As a future aspect, collaboration of both molecular genetics and 3D neuroimaging will reveal responsible gene mutation of neuronal migration disorder, and this fetal neuro-sono-genetics will be able to contribute to accurate diagnoses, proper management, possible genetic therapy, and prophylaxis.

Keywords: Brain, Fetus, HDlive, Silhouette, Three-dimensional ultrasound.

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INTRODUCTION

The brain is a 3D structure and should be assessed in three basic planes: Sagittal, coronal, and axial sections. Transvaginal observation of the fetal brain offers sagittal and coronal views of the brain from fetal parietal direction through the fontanelles and/or the sagittal suture as ultrasound windows. This method has contributed to the prenatal assessment of congenital CNS anomalies and acquired brain damage *in utero*.

Three-dimensional ultrasound is one of the most attractive modality in the field of fetal ultrasound imaging. By recent advances of 3D HDlive, HDlive silhouette, and HDlive flow, the brain morphology and vascular structure can be demonstrated more objectively and accurately.

Combination of transvaginal approach and 3D ultrasound technologies provides us more and more information of fetal brain development, congenital anomalies as well as intrauterine acquired injuries.

TRANSVAGINAL APPROACH TO FETAL BRAIN

Imaging technologies have been remarkably improved and contributed to prenatal evaluation of fetal CNS development and assessment of CNS abnormalities *in utero*.

Conventional transabdominal ultrasonography, by which it is possible to observe fetuses through maternal abdominal wall, uterine wall, and sometimes placenta, has been most widely utilized for antenatal imaging diagnosis. By transabdominal approach, whole CNS of fetuses can be well demonstrated; for instance, the brain in the axial section and the spine in the sagittal section. However, transabdominal approach to the fetal CNS has several obstacles, such as maternal abdominal wall, placenta, and fetal cranial bones, and it is difficult to obtain clear and detailed images of fetal CNS structure.

High-frequency transvaginal transducer has contributed to establishing "sonoembryology,"[1] and recent general use of transvaginal sonography in early pregnancy enabled early diagnoses of various fetal anomalies.[2] In the second and third trimesters, fetal brain scan is generally evaluated through maternal abdominal wall and mostly fetal brain is demonstrated in the axial section. The brain, however, is a 3D structure and should be assessed in three basic planes: Sagittal, coronal, and axial sections. Sonographic assessment of the fetal brain in the sagittal and coronal sections requires an approach from fetal parietal direction. Transvaginal sonography of the fetal brain opened a new field in medicine, "neurosonography."[3] Transvaginal approach to the normal fetal brain during the second and third trimester was introduced in the beginning of the 1990s. It was the first practical

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application of 3D CNS assessment by two-dimensional ultrasound.[4] Transvaginal observation of the fetal brain offers sagittal and coronal views of the brain from fetal parietal direction[5-8] through the fontanelles and/or the sagittal suture as ultrasound windows. Serial oblique sections[3] via the same ultrasound window reveal the intracranial morphology in detail. Transvaginal approach to the fetal brain has contributed to the prenatal assessment of brain morphology.

TRANSVAGINAL 3D NEUROSCAN

Three-dimensional ultrasound is one of the most attractive modality in the field of fetal ultrasound imaging. Automatic scan by dedicated 3D transducer produces motor-driven automatic sweeping and is called as a fan scan. With this method, a shift and/or angle change of the transducer is not required during scanning, and the scan duration needs only several seconds. Immediately after acquisition of the targeted organ, multiplanar imaging analysis and tomographic imaging analysis are possible. Combination of both transvaginal sonography and 3D ultrasound[9-14] (Fig. 1) may be a great diagnostic tool for evaluation of 3D structure of fetal CNS. Recent advanced 3D ultrasound equipments have several useful functions, such as surface anatomy imaging; multiplanar imaging of the intracranial structure (Fig. 2); tomographic ultrasound imaging of fetal brain in the any cutting section (Fig. 3); bony structural imaging of the calvaria (Fig. 4) and vertebrae; thick slice imaging of the intracranial structure; simultaneous volume contrast imaging of the same section or vertical section of fetal brain structure; volume calculation of target organs, such as intracranial cavity, ventricle, choroid plexus, and intracranial lesions; and 3D sonoangiography of the brain circulation (3D power or color Doppler).

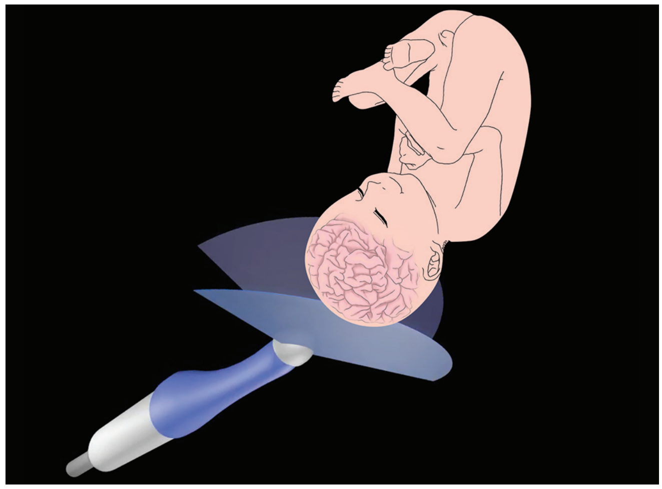


Fig. 1: Transvaginal 3D neuroscan

Figure 5 demonstrates tomographic ultrasound imaging of the fetal ventriculomegaly at 18 weeks in the sagittal and axial sections. Parallel sectional imaging similar to magnetic resonance imaging is quite helpful for evaluation of the brain structure. From a single volume dataset, any cutting section can be extracted. For example, bilateral enlarged ventricles, foramen of Monro, and the third ventricle can be exactly demonstrated in a single cutting section, as shown in Figure 6. By inversion mode (Fig. 7), those structures are depicted with more 3D appearance.

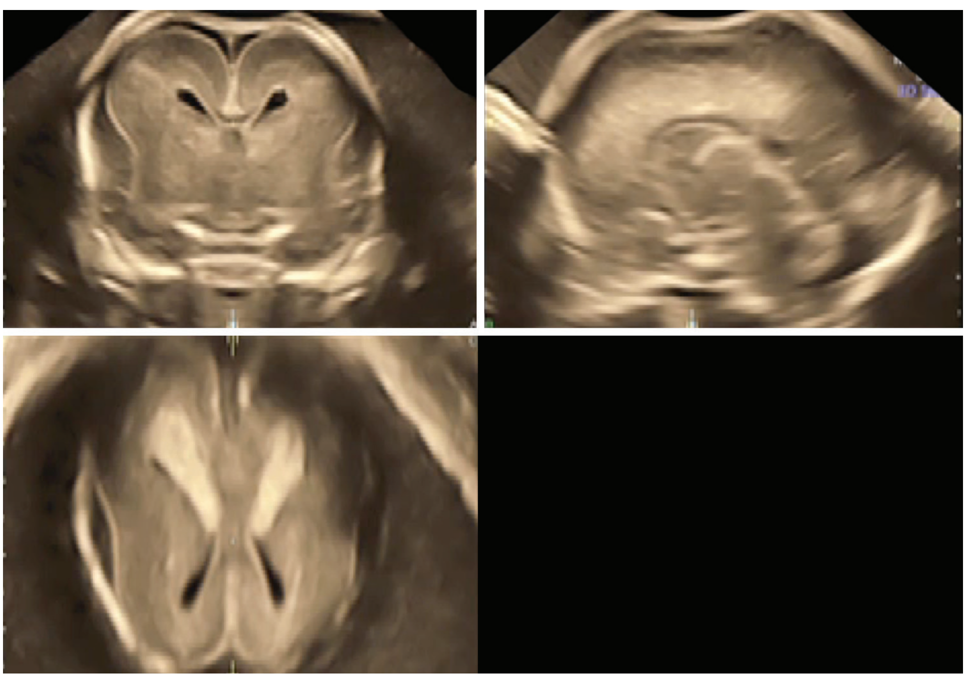


Fig. 2: Three-dimensional multiplanar imaging of the intracranial structure

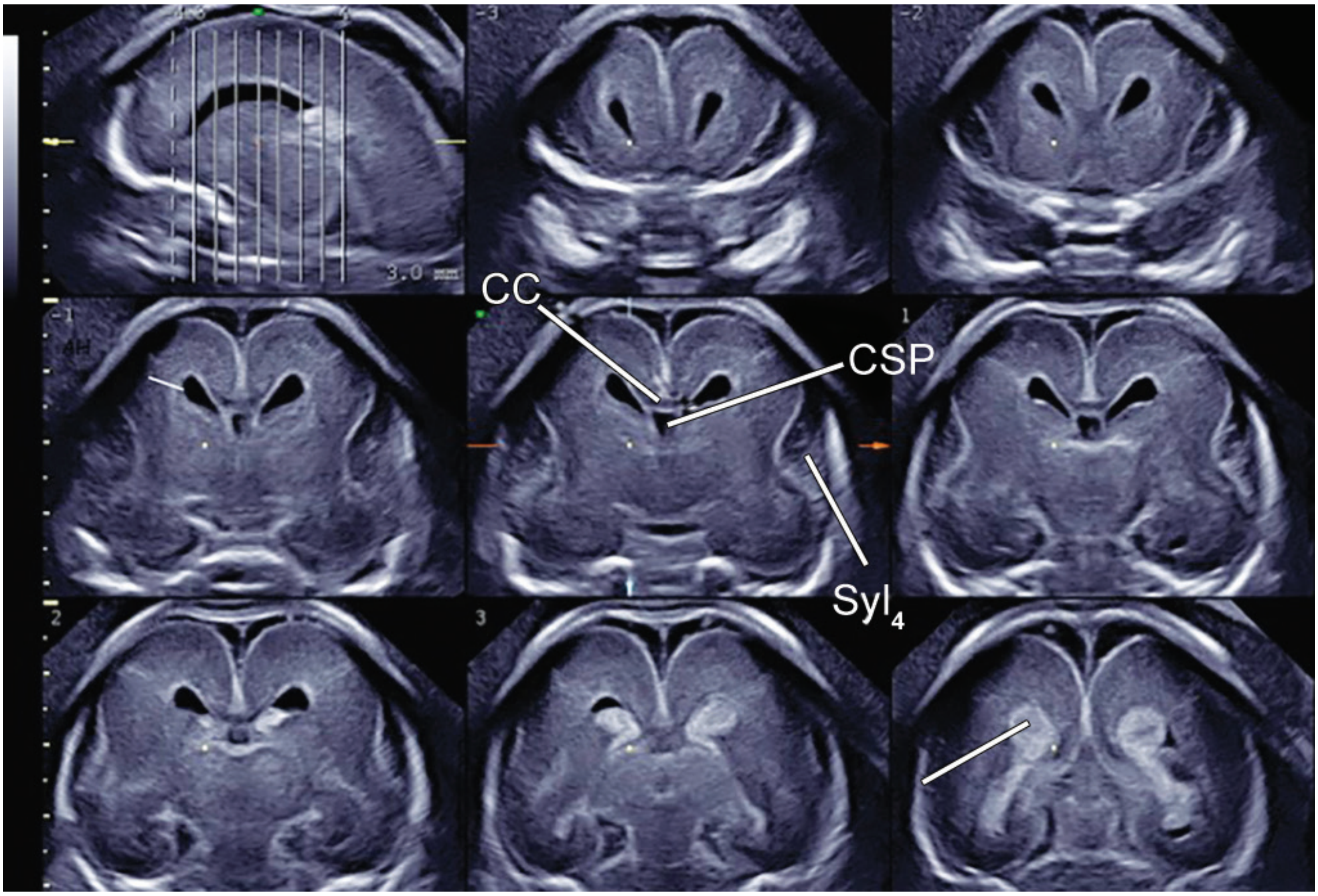
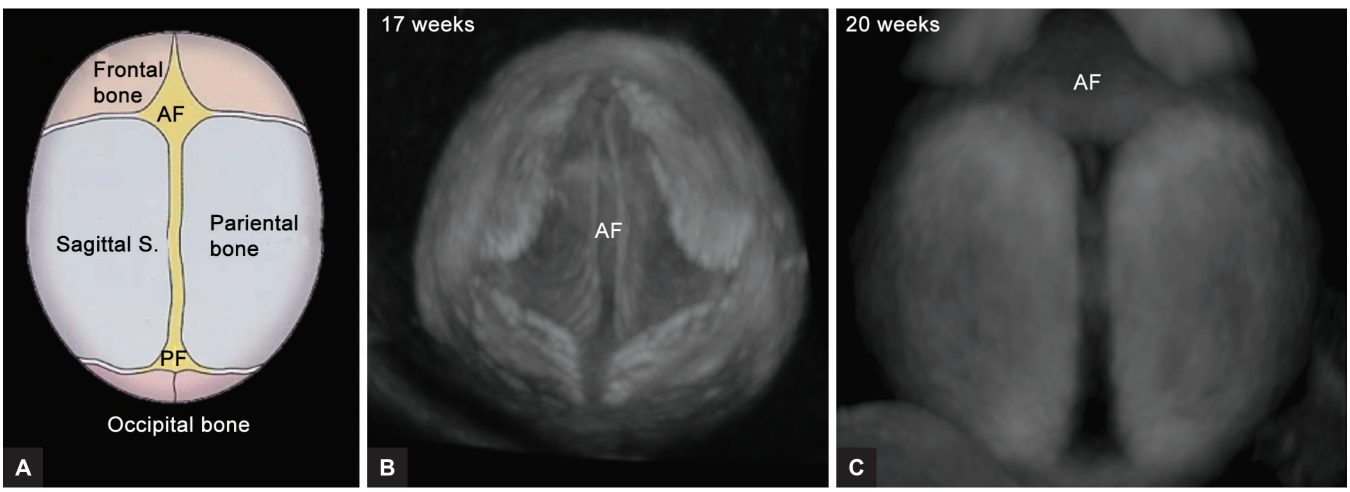


Fig. 3: Tomographic ultrasound imaging of fetal brain (coronal cutting section)



Figs 4A to C: (A) Bony structural imaging of the calvaria; and (B and C) parietal view demonstrating anterior fontanelle (AF) at 17 (middle) and 20 weeks (right) of gestation

HDlive AND SILHOUETTE ULTRASOUND IN FETAL NEUROLOGY

The great achievement in the field of 3D/four-dimensional (4D) ultrasound is HDlive technology.[15] This technology is a novel ultrasound technique that improves the 3D/4D images. HDlive uses an adjustable light source and software that calculates the propagation of light through surface structures in relation to the light direction.[16] The virtual light source produces selective illumination, and the respective shadows are created by the structures where the light is reflected. There have been several reports on HDlive demonstration of fetal surface.[17-20] By use of HDlive of fetal brain, intraventricular morphology, such as choroid plexus is clearly demonstrated as shown

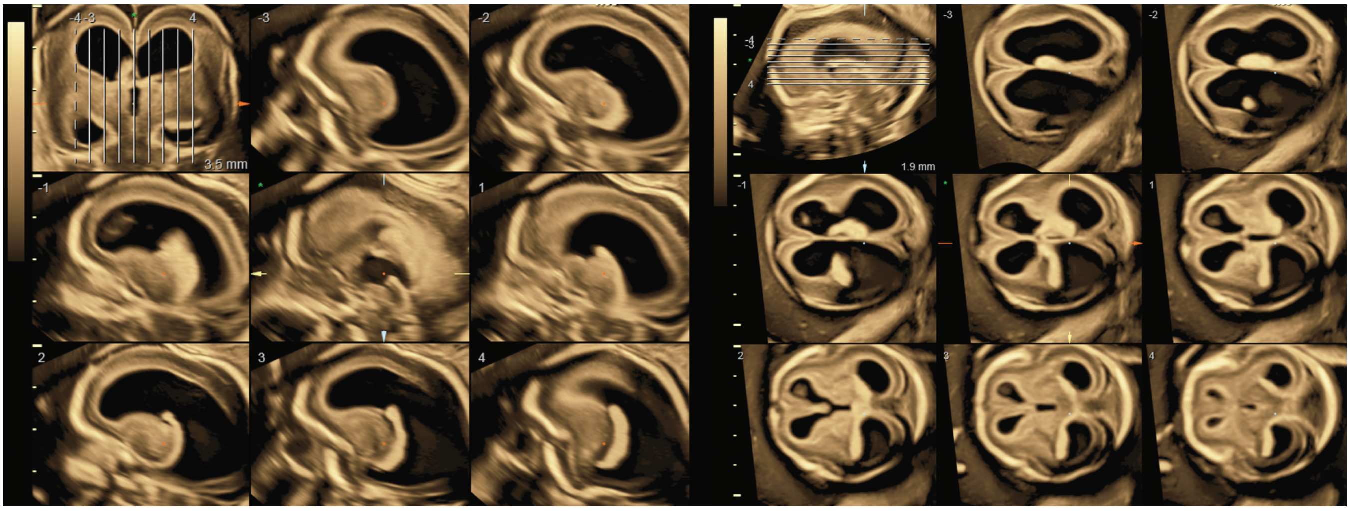


Fig. 5: Tomographic ultrasound imaging of the fetal ventriculomegaly at 18 weeks in the sagittal and axial sections

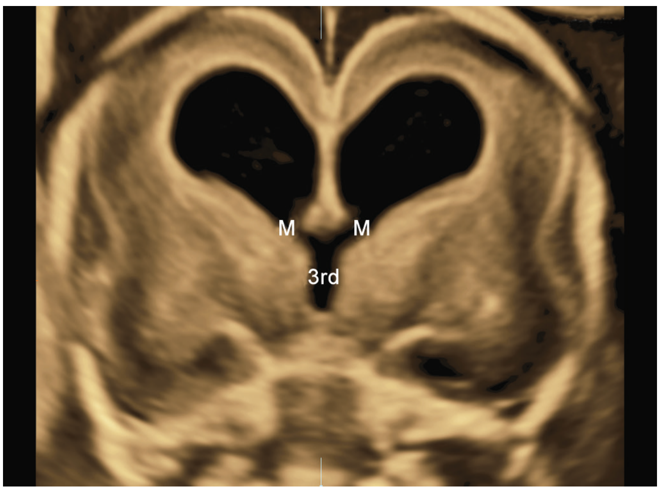


Fig. 6: An anterior coronal cutting section extracted from brain volume dataset (same case as Fig. 5). Bilateral enlarged ventricles, foramen of Monro (M), and the third ventricle (3rd) can be exactly demonstrated

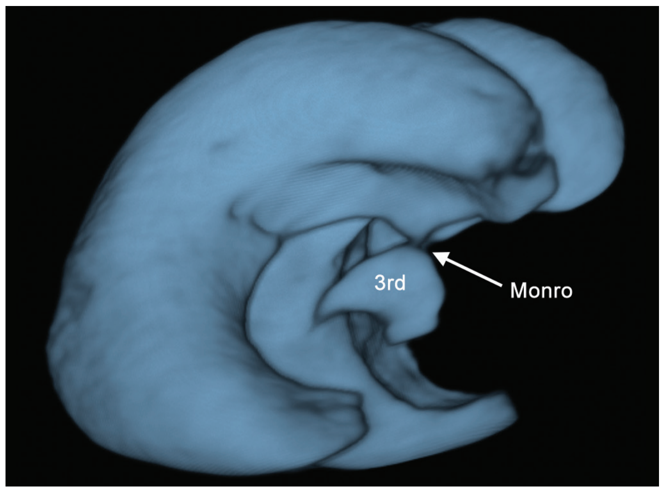


Fig. 7: Ventricular system by inversion mode in a case of ventriculomegaly at 18 weeks. Bilateral enlarged ventricles, foramen of Monro (M), and the third ventricle (3rd) can be exactly demonstrated

in Figure 8. In a case of intraventricular hemorrhage, coagula can be observed (Fig. 9).

Applications of HDlive silhouette and HDlive flow[21] were introduced at the end of 2014. Algorithm of HDlive silhouette creates a gradient at organ boundaries, fluid-filled cavity, and vessels walls, where an abrupt change of the acoustic impedance exists within tissues.[21-24] The examiner can adjust HDlive silhouette percentage with controlling threshold and gain simultaneously for visualizing target organs of interest. HDlive silhouette emphasizes the borderlines between organs with different echogenicity; therefore, both the target of interest floating within fluid correction and cystic area in echogenic organs are simultaneously demonstrated. By HDlive silhouette mode, an inner cystic structure with fluid collection can be depicted through the outer surface structure of the body and it can be appropriately named as "*see-through*

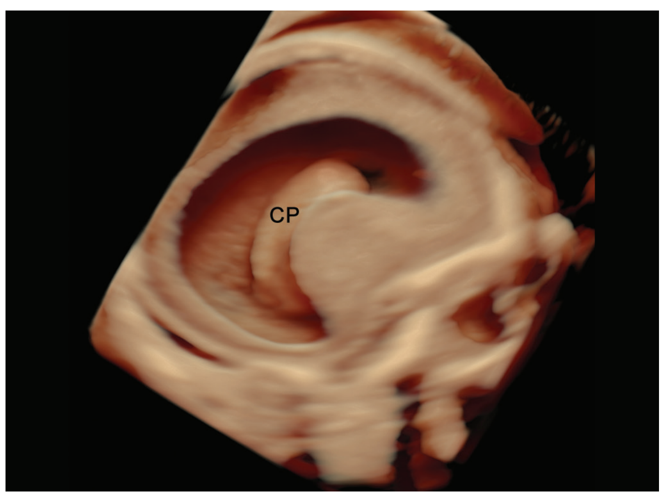
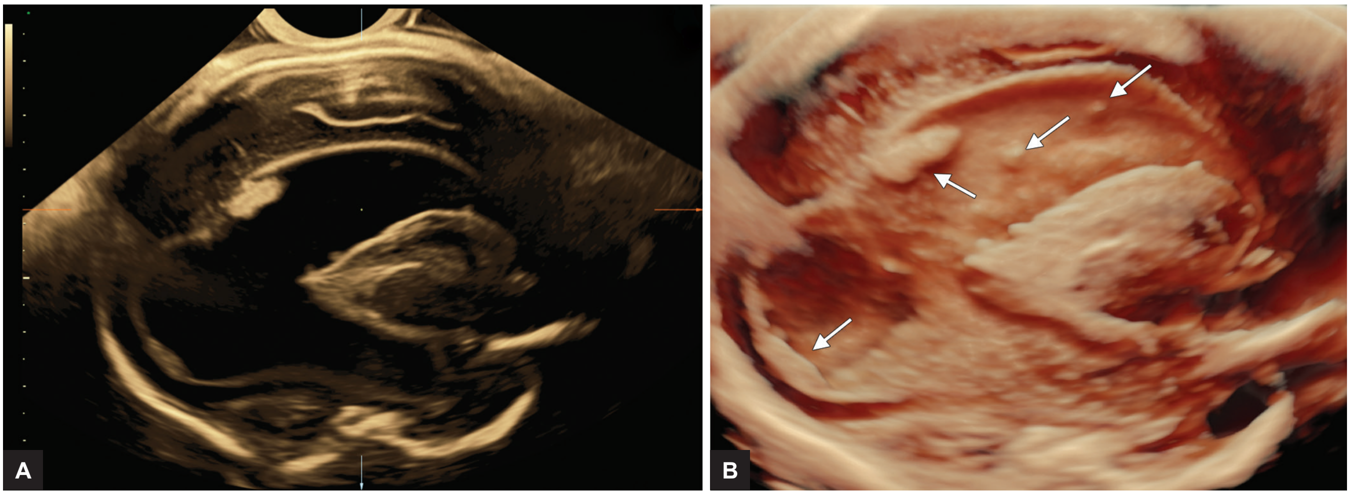


Fig. 8: Inside view of enlarged ventricle by HDlive imaging (same case as Fig. 7). Appearance of choroid plexus (CP) and smooth ventricular wall is well demonstrated



Figs 9A and B: Inside view of enlarged ventricle by HDlive imaging in a case of intraventricular hemorrhage: (A) Single parasagittal cutting section; and (B) inside view of enlarged ventricle with coagula (arrows)

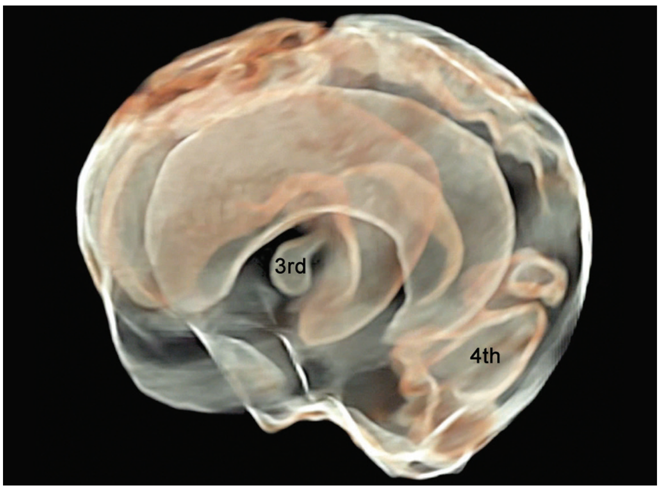


Fig. 10: HDlive silhouette imaging of ventriculomegaly in a case of Dandy–Walker malformation at 16 weeks. Bilateral enlarged ventricles as well as third ventricle (3rd) and enlarged fourth ventricle (4th) are clearly demonstrated inside intracranial volume

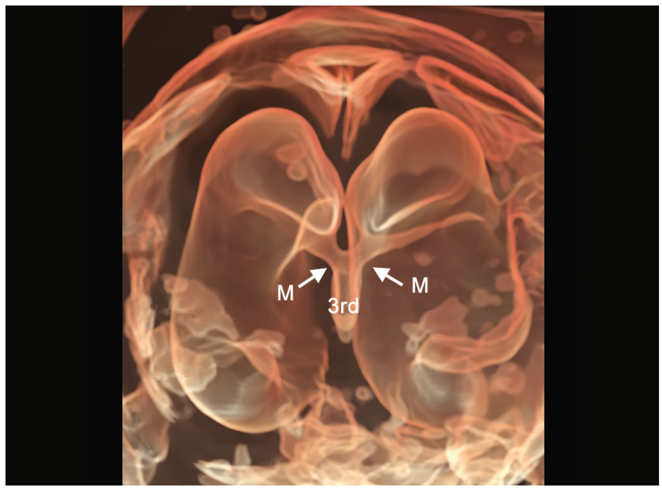


Fig. 11: HDlive silhouette imaging of ventriculomegaly, frontal view. Bilateral enlarged ventricles, foramen of Monro (M), and the third ventricle (3rd) can be exactly demonstrated

fashion."[21-26] Silhouette ultrasound shows comprehensive structure demonstrating inner and outer morphology simultaneously. Figure 10 shows enlarged ventricular system by silhouette ultrasound in a case of Dandy–Walker malformation at 16 weeks. Bilateral enlarged ventricles as well as third ventricle and enlarged fourth ventricle are clearly demonstrated inside intracranial volume. Three-dimensional orientation of ventricular system is easily understandable. Figure 11 is the frontal view of ventricular system in a case of ventriculomegaly at 18 weeks. Three-dimensional location of enlarged bilateral ventricles, third ventricle, and foramen of Monro is demonstrated comprehensively. Lateral view (Fig. 12) of the same case demonstrates the location of choroid plexus and foramen of Monro.

Although silhouette ultrasound neuroimaging is quite helpful, it occasionally seems to demonstrate too many

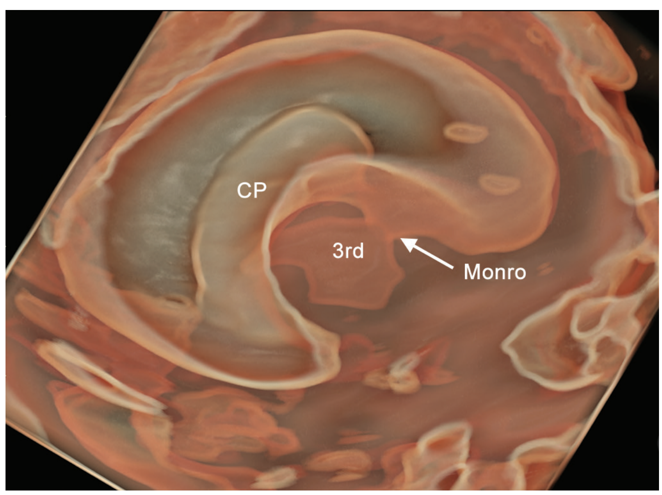
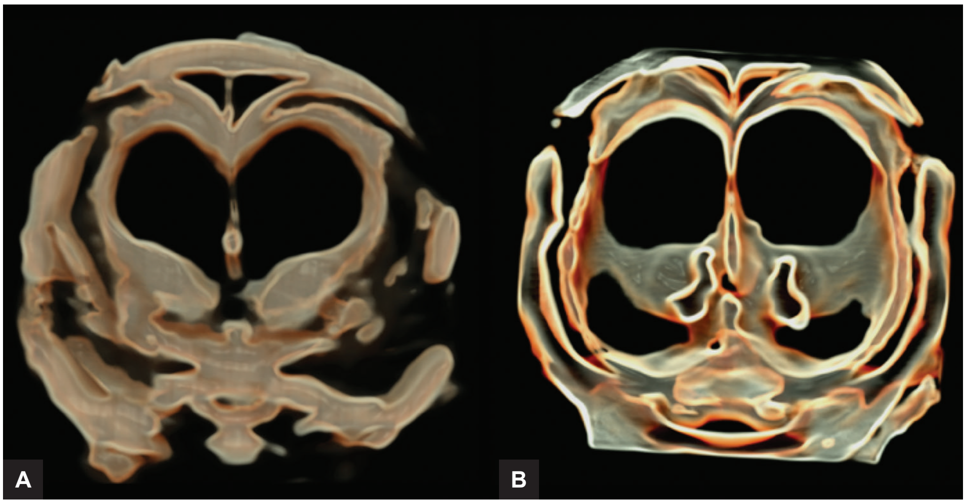
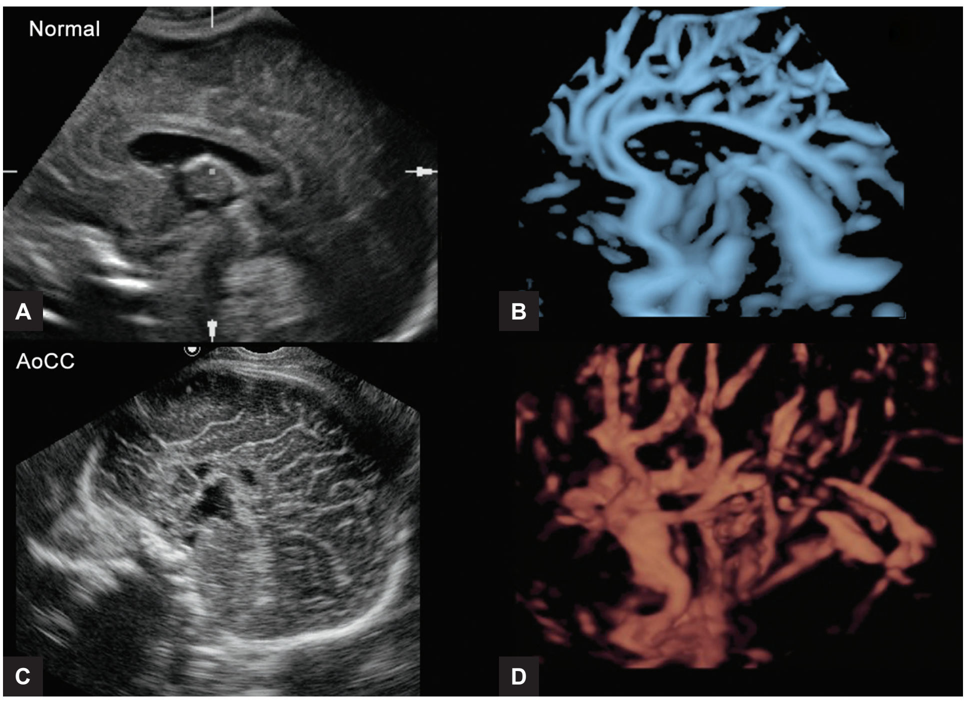


Fig. 12: HDlive silhouette imaging of ventriculomegaly, lateral view. The volume demonstrates the location of choroid plexus (CP) and foramen of Monro, and the third ventricle (3rd)



Figs 13A and B: Ventriculomegaly at 19 weeks imaged by the thick-slice silhouette images: (A) Anterior coronal cutting section; and (B) posterior coronal cutting section



Figs 14A to D: Difference of angiostructure by 3D sonoangiogram in normal and abnormal cases. (A) Normal sagittal cutting section. The corpus callosum is demonstrated. (B) The same cutting section in a case of agenesis of the corpus callosum (AOCC). (C) Typical radial sulcus formation is seen instead of normal cingulate sulcus and gyrus formed with normal development of the corpus callosum. Angiostructure by 3D power Doppler. Normal callosomarginal artery (CMA) is clearly demonstrated. (D) Angiostructure of AOCC. The CMA does not exist and radial formation of the branches of anterior cerebral arteries (ACA) is seen

inner structures overlapping one another to understand their relations inside cranial volume. The author has cut the volume dataset with a rectangle cube and rendered the cut slice with silhouette ultrasound and called this silhouette ultrasound demonstration of thick slice of 3D volume dataset as "thick-slice silhouette."[27] Frontal/occipital ventriculomegaly at 19 weeks by the thick-slice silhouette images from the same 3D volume dataset are shown in Figure 13.

BRAIN VASCULAR IMAGING

Cerebral vascularity has been demonstrated three-dimensionally, as shown in Figures 14 and 15, for more than a decade. Recent technology has added HDlive flow,[24,25] which provides 3D view of the blood flow with a realistic rendering of fine vascular structure. Combination of HDlive silhouette and HDlive flow can be described as a "see-through fashion"[24,26,28] because of its comprehensive orientation and persuasive localization of inner

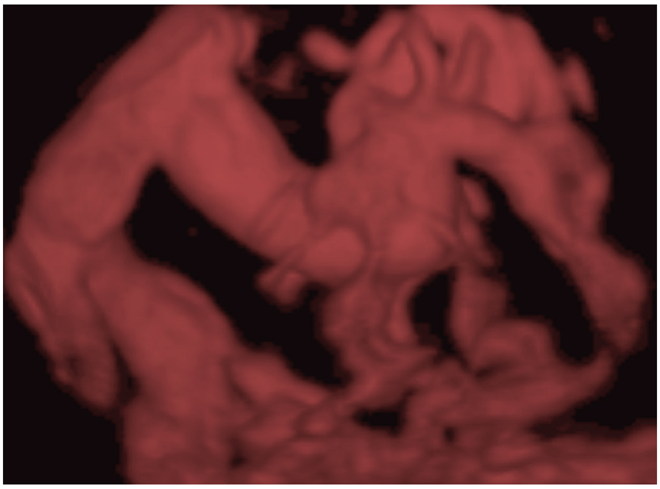


Fig. 15: Three-dimensional B-flow view of vein of Galen aneurysmal malformation (VGAM). Dilated vein of Galen and straight sinus, and arteriovenous shunts are clearly seen

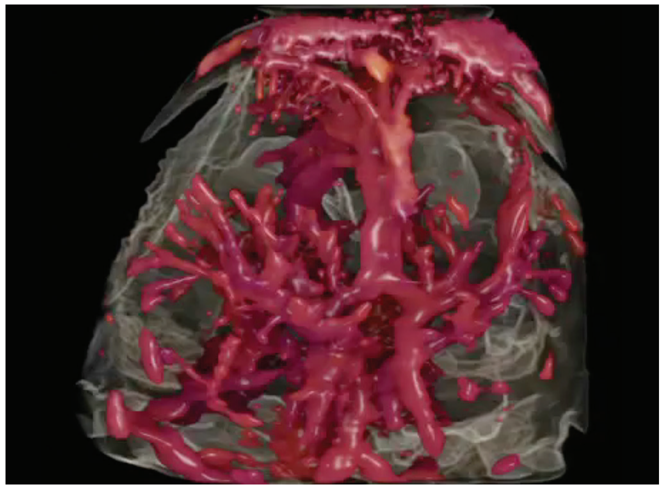
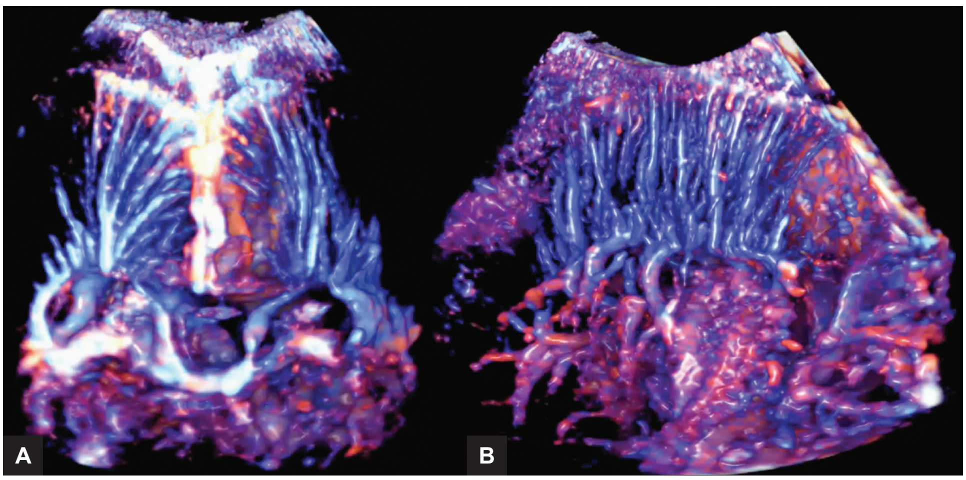


Fig. 16: Normal intracranial angiostructure by 3D HDlive silhouette/flow imaging with power Doppler at 18 weeks of gestation



Figs 17A and B: Medullary veins between pia mater and subependymal zone demonstrated by HDlive flow imaging: (A) Frontal view; and (B) lateral view

structure as well as of fetal angiostructure inside the morphological structure. Figure 16 demonstrates normal intracranial angiostructure by 3D HDlive silhouette/flow imaging with power Doppler at 18 weeks of gestation. Fine venous vascular structure, such as medullary veins can also be well demonstrated by HDlive flow imaging between pia mater and subependymal zone (Fig. 17).

FUTURE ASPECT

Neuro-sonoembryology and neurosonology have been established by transvaginal 3D neuroimaging. By utilizing 3D ultrasound, HDlive, and HDlive silhouette imaging, further detailed information of fetal brain can be obtained.

Up-to-date 3D technologies described in this study allow extending the detection of congenital brain maldevelopment, and it is beyond description that noninvasive direct viewing of the embryo/fetus by all-inclusive ultrasound technology is definitely the first modality in a field of fetal neurology and help our goal of proper perinatal care and management, even in the era of molecular genetics and advanced sequencing of fetal DNA in the maternal blood.[26,28]

As a future aspect, collaboration of both molecular genetics and 3D neuroimaging will reveal responsible gene mutation of neuronal migration disorder, and this fetal neuro-sono-genetics will be able to contribute to accurate diagnoses, proper management, possible genetic therapy, and prophylaxis.

REFERENCES

1. Timor-Tritsch IE, Peisner, DB, Raju S. Sonoembryology: an organ-oriented approach using a high-frequency vaginal probe. J Clin Ultrasound 1990 May;18(4):286-298.
2. Pooh, RK. B-mode and Doppler studies of the abnormal fetus in the first trimester. In: Chervenak FA, Kurjak A, editors. Fetal medicine. Carnforth: Parthenon Publishing; 1999. p. 46-51.

3. Timor-Tritsch IE, Monteagudo A. Transvaginal fetal neurosonography: standardization of the planes and sections by anatomic landmarks. Ultrasound Obstet Gynecol 1996 Jul;8(1):42-47.
4. Monteagudo A, Reuss ML, Timor-Tritsch IE. Imaging the fetal brain in the second and third trimesters using transvaginal sonography. Obstet Gynecol 1991 Jan;77(1):27-32.
5. Monteagudo A, Timor-Tritsch IE, Moomjy M. *In utero* detection of ventriculomegaly during the second and third trimesters by transvaginal sonography. Ultrasound Obstet Gynecol 1994 May;4(3):193-198.
6. Monteagudo A, Timor-Tritsch IE. Development of fetal gyri, sulci and fissures: a transvaginal sonographic study. Ultrasound Obstet Gynecol 1997 Apr;9(4):222-228.
7. Pooh RK, Nakagawa Y, Nagamachi N, Pooh KH, Nakagawa Y, Maeda K, Fukui R, Aono T. Transvaginal sonography of the fetal brain: detection of abnormal morphology and circulation. Croat Med J 1998 Jun;39(2):147-157.
8. Pooh RK, Maeda K, Pooh KH, Kurjak A. Sonographic assessment of the fetal brain morphology. Prenat Neonat Med 1999 Feb;4:18-38.
9. Pooh, RK. Three-dimensional ultrasound of the fetal brain. In: Kurjak A, editor. Clinical application of 3D ultrasonography. Carnforth: Parthenon Publishing; 2000. p. 176-180.
10. Pooh RK, Pooh KH, Nakagawa Y, Nishida S, Ohno Y. Clinical application of three-dimensional ultrasound in fetal brain assessment. Croat Med J 2000 Sep;41(3):245-251.
11. Timor-Tritsch IE, Monteagudo A, Mayberry P. Three-dimensional ultrasound evaluation of the fetal brain: the three horn view. Ultrasound Obstet Gynecol 2000 Sep;16(4): 302-306.
12. Monteagudo A, Timor-Tritsch IE, Mayberry P. Three-dimensional transvaginal neurosonography of the fetal brain: 'navigating' in the volume scan. Ultrasound Obstet Gynecol 2000 Sep;16(4):307-313.
13. Pooh RK, Nagao Y, Pooh KH. Fetal neuroimaging by transvaginal 3D ultrasound and MRI. Ultrasound Rev Obstet Gynecol 2006 Apr;6(3-4):123-134.
14. Pooh RK, Pooh KH. Fetal neuroimaging with new technology. Ultrasound Review Obstet Gynecol 2002;2:178-181.
15. Pooh RK, Kurjak A. Novel application of three-dimensional HDlive imaging in prenatal diagnosis from the first trimester. J Perinat Med 2015 Mar;43(2):147-158.
16. Nebeker J, Nelson R. Imaging of sound speed reflection ultrasound tomography. J Ultrasound Med 2012 Sep;31(9): 1389-1404.
17. Bonilla-Musoles F, Raga F, Castillo JC, Bonilla F Jr, Climent MT, Caballero O. High definition real-time ultrasound (HDlive) of embryonic and fetal malformations before week 16. Donald School J Ultrasound Obstet Gynecol 2013 Jan-Mar;7(1):1-8.
18. Kagan KO, Pintoffl K, Hoopmann M. First-trimester ultrasound images using HDlive. Ultrasound Obstet Gynecol 2011 Nov;38(5):607.
19. Hata T, Hanaoka U, Tenkumo C, Sato M, Tanaka H, Ishimura M. Three- and four-dimensional HDlive rendering images of normal and abnormal fetuses: pictorial essay. Arch Gynecol Obstet 2012 Dec;286(6):1431-1435.
20. AboEllail MA, Kanenishi K, Mori N, Kurobe A, Hata T. HDlive imaging of circumvallate placenta. Ultrasound Obstet Gynecol 2015 Oct;46(4):513-514.
21. Pooh RK. First trimester scan by 3D, 3D HDlive and HDlive silhouette/flow ultrasound imaging. Donald School J Ultrasound Obstet Gynecol 2015 Oct-Dec;9(4):361-371.
22. Pooh, RK. Brand new technology of HDlive silhouette and HDlive flow images. In: Pooh RK, Kurjak A, editors. Donald school atlas of advanced ultrasound in obstetrics and gynecology. New Delhi: Jaypee Brothers Medical Publishers Private Limited; 2015. p. 1-39.
23. Pooh RK. A new field of 'Fetal sono-ophthalmology' by 3D HDlive silhouette and flow. Donald School J Ultrasound Obstet Gynecol 2015 Jul-Sep;9(3):221-222.
24. Pooh RK. 'See-through Fashion' in prenatal diagnostic imaging. Donald School J Ultrasound Obstet Gynecol 2015 Jan;9(2):111.
25. Pooh RK. 13-week pulmonary sonoangiogram by 3D HDlive flow. Donald School J Ultrasound Obstet Gynecol 2015 Oct-Dec;9(4):355-356.
26. Pooh RK. Sonoembryology by 3D HDlive silhouette ultrasound – what is added by the 'see-through fashion'? J Perinat Med 2016 Mar;44(2):139-148.
27. Pooh RK. Three-dimensional HDlive thick-slice silhouette of fetal brain. Donald School J Ultrasound Obstet Gynecol 2016 Jan-Mar;10(1):1-2.
28. Pooh RK. Recent advances in 3D ultrasound, silhouette ultrasound and sonoangiogram in fetal neurology. Donald School J Ultrasound Obstet Gynecol 2016 Jan;10(2):193-200.