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REVIEW ARTICLE

Contribution of Transvaginal High-Resolution Ultrasound in Fetal Neurology

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ABSTRACT

Transvaginal high-resolution ultrasound and three-dimensional (3D) ultrasound have been establishing sonoembryology as well as neurosonography in the first trimester. Fetal brain is rapidly developing and changing its appearance week by week during pregnancy. The most important organ, but it is quite hard to observe detailed structure of this organ by conventional transabdominal sonography. It is possible to observe the whole brain structure by magnetic resonance imaging in the post half of pregnancy, but it is difficult in the first half gestation, and transvaginal high-resolution 3D ultrasound is the most powerful modality. As for brain vascularization, main arteries and veins have been demonstrated and evaluated in various CNS conditions. Transvaginal high-resolution 3D ultrasound can demonstrate cerebral fine vascular anatomy, such as medullary vessels and it is greatly expected to estimate neurological prognosis relating with vascular development during fetal period.

Keywords: Transvaginal sonography, Fetus, Neurology, High-resolution, 3D ultrasound.

INTRODUCTION

Imaging technologies have been remarkably improved and contributed to prenatal evaluation of fetal central nervous system (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 central nervous system 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 central nervous system 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.

Introduction of high-frequency transvaginal transducer has contributed to establishing "sonoembryology"[1] and recent general use of transvaginal sonography in early pregnancy enabled early diagnoses of major fetal anomalies.[2] In the middle and late pregnancy, fetal CNS is generally evaluated through maternal abdominal wall. The brain, however, is three-dimensional structure, and should be assessed in basic three planes of 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 1990s. It was the first practical application of three-dimensional central nervous system assessment by two-dimensional (2D) 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. This method has contributed to the prenatal assessment of congenital CNS anomalies and acquired brain damage *in utero*.

TRANSVAGINAL HIGH-RESOLUTION 3D NEUROIMAGING

Three-dimensional (3D) 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 fan scan. With this method, a shift and/or angle-change of the transducer is not required during scanning and scan duration needs only several seconds. After acquisition of the target organ, multiplanar imaging analysis and tomographic imaging analysis are possible. Combination of both transvaginal high-resolution sonography and 3D ultrasound[9-16] may be a great diagnostic tool for evaluation of three-dimensional structure of fetal CNS. Recent advanced 3D ultrasound equipments have several useful functions as bellows:

- Surface anatomy imaging of spinal development, cranial surface and brain surface

- Bony structural imaging of the calvaria and vertebrae
- Multiplanar imaging of the intracranial structure
- Tomographic ultrasound imaging of fetal brain in any cutting section
- Thick slice imaging of the intracranial structure (volume contrast imaging, VCI)
- 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
- Inversion mode demonstrating hypoechoic parts, such as ventricles and cystic lesions.

It is well known that 3D ultrasound demonstrates the surface anatomy. In cases of CNS abnormalities, facial abnormalities and extremities anomalies are often complicated. Therefore, surface reconstructed images are helpful. In the first trimester, surface reconstructed imaging show the changing appearance from early neural tube to spinal cord between 6 and 9 weeks of gestation, shown in Figure 1 (upper picture). In early pregnancy, small cephalocele can be demonstrated (Fig. 2). Bony structural imaging of the calvaria and vertebrae are useful in cases of craniosynostosis and spina bifida. Figure 3 shows the craniovertebral imaging in an acranial case. Surface anatomy imaging can demonstrate the brain surface shown in Figures 4 and 5. Migration occurs during 3 to 5 gestational month but the gyration and sulcation can be visualized in the late pregnancy. Figure 4 shows obviously different appearance of the brain surface at 19 and 30 weeks of gestation. Figure 5 shows the brain surface with less gyration at 33 weeks of gestation seen in a case of pachygyria. Thus, brain development can be objectively understandable by surface reconstructed imaging.

In Multiplanar imaging of the brain structure and tomographic ultrasound imaging (TUI, Fig. 2 left and Fig. 6) are quite helpful to understand intracranial detailed brain structure. It is possible to compare the anatomy in exactly same cutting sections. Figure 1 (lower picture) shows changing appearance of early premature brain development in the mid-sagittal cutting section between 8 and 10 weeks of gestation. Figure 7 shows the changing appearance of sylvian fissure during the second and early third trimesters. Figure 8 shows

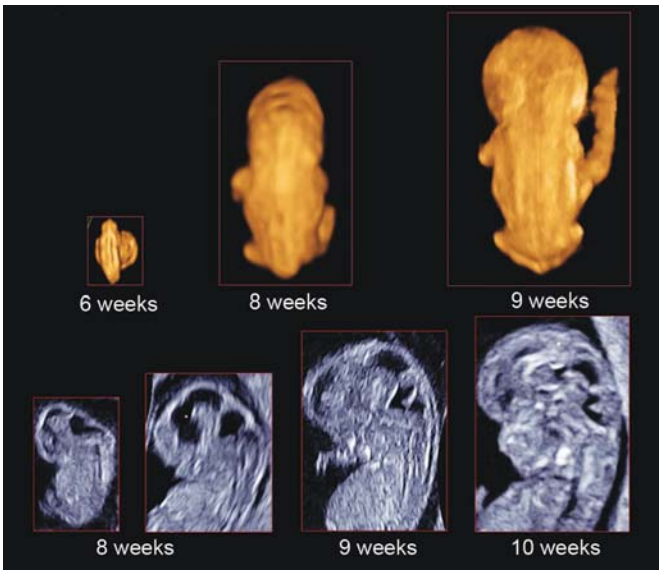

Fig. 1: Transvaginal 3D images of early fetal CNS development. Changing appearance from early neural tube to spinal cord between 6 and 9 weeks of gestation (upper picture). Changing appearance of early premature brain development in the mid-sagittal cutting section between 8 and 10 weeks of gestation (lower picture)

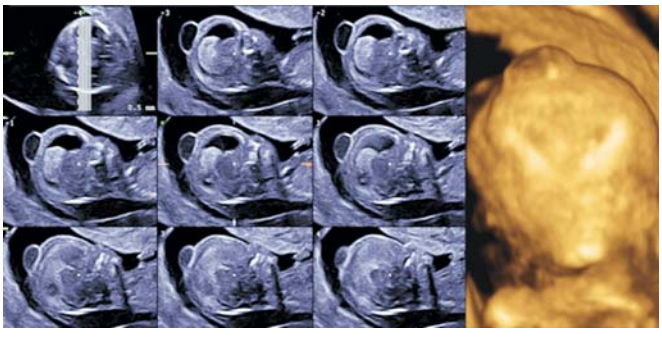

Fig. 2: Cephalocele at 12 weeks of gestation. Left figure; tomographic ultrasound imaging (TUI). Right figure; 3D reconstructed image

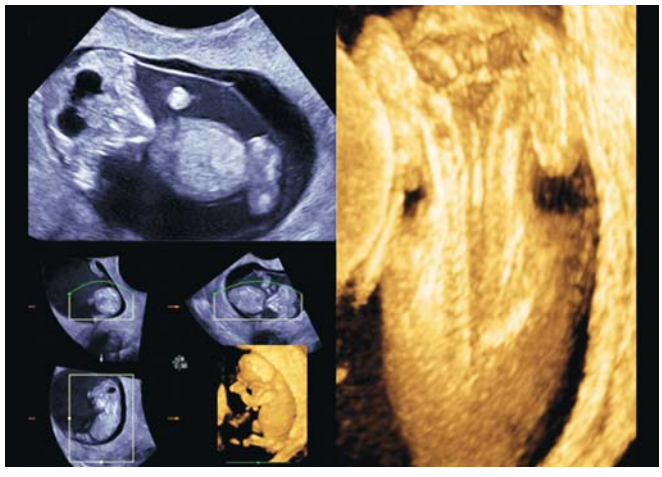

Fig. 3: Craniovertebral imaging in an acranial case. Left upper image is 2D ultrasound imaging and left lower image is multiplanar imaging. Right picture shows 3D bony structure of craniovertebral part. Acrania and opening of cervical vertebrae are demonstrated

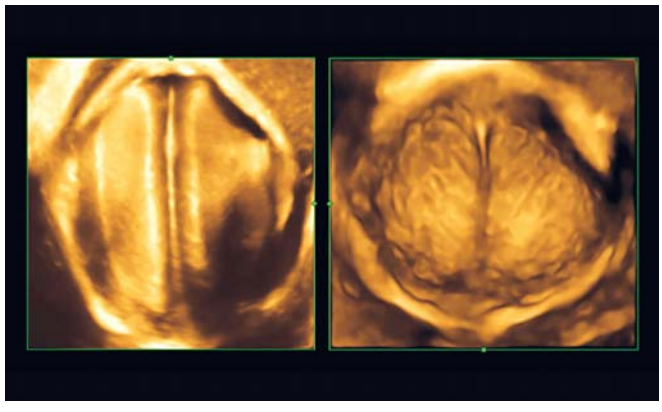

Fig. 4: Normal brain 3D surface anatomy in 19 and 30 weeks of gestation. Notice obviously different appearance of the smooth brain surface at 19 weeks and matured brain surface with gyration at 30 weeks

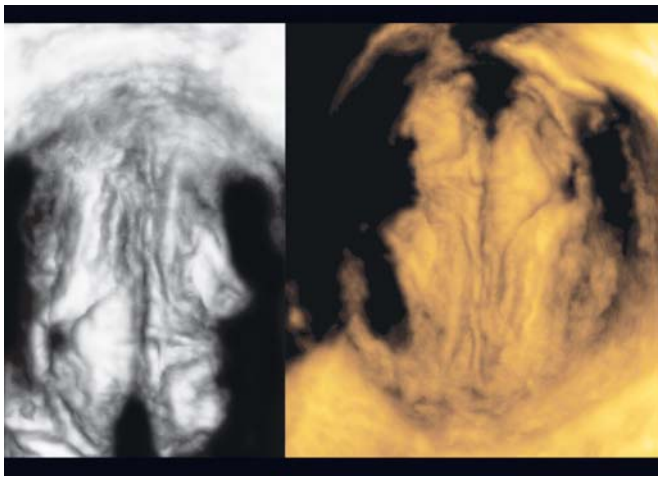

Fig. 5: Abnormal brain 3D surface anatomy in pachygyria. The brain surface with less gyration at 33 weeks of gestation is well-demonstrated in a case of pachygyria

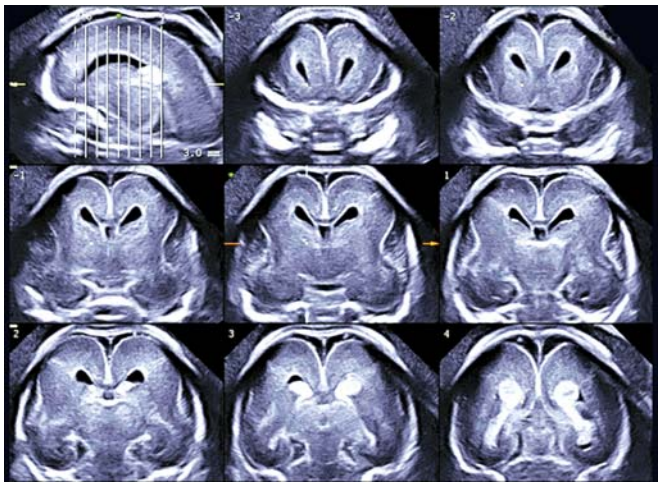

Fig. 6: Tomographic ultrasound imaging of normal brain in coronal cutting section at 20 weeks

early intracranial hemorrhage case and dedicated transvaginal high-frequent sonography detected the subtle change of ventricular wall between 16 and 17 weeks of gestation. TUI demonstrates multi-parallel cutting sections and is quite similar imaging technology to magnetic resonance imaging. The superior point of TUI to MRI is that it is easily possible to change slice width, to rotate the images, to magnify images, and to rotate images to any directions. This function is extremely useful for detailed CNS assessment and also for consultation to neurosurgeons and neurologists. Figure 9 shows abnormal migration disorder in the second trimester. The intracranial brain structure is quite abnormal and it is difficult to obtain the orientation but TUI is quite helpful to show the intracranial structure very clearly. Thick slice imaging of the intracranial structure and simultaneous volume contrast imaging (VCI) of the same plane or vertical plane of conventional 2D image are often convenient to observe the gyral formation inside lateral ventricles.[14] The premature brain image obtained by use of VCI clearly demonstrates anatomical CNS structure.

Volume extracted image and volume calculation of the fetal brain in early pregnancy was reported from 1990s.[17-21] On three orthogonal images, the target organ can be traced automatically or manually with rotation of volume imaging data. After tracing, volume extracted image is demonstrated and volume calculation data is shown. 3D fetal brain volume measurements have a good intraobserver and interobserver reliability[22,23] and could be used to determine estimated gestational age. Volume analysis by 3D ultrasound provides exceedingly informative imaging data. Volume analysis of the structure of interest provides an intelligible evaluation of the brain structure in total, and longitudinal and objective assessment of enlarged ventricles and intracranial occupying lesions (Fig. 10). Any intracranial organ can be chosen as a target for volumetry, no matter how distorted its shape and appearance may be. In new method of inversion mode, the cystic portions within the volume are displayed entirely as an echogenic area, while the grayscale portions of the image are rendered as transparent[24] and recently it has been applied in fetal diagnosis.[25,26]

Inversion mode is inverted imaging technology which shows volume of only hypoechoic parts. Figure 11 shows TUI and inversion-mode images of enlarged ventricles seen at 19 weeks of gestation.

Thus, owing to transvaginal high-resolusion 3D neuro-imaging, details of CNS normal development and maldevelopment have been elucidated.

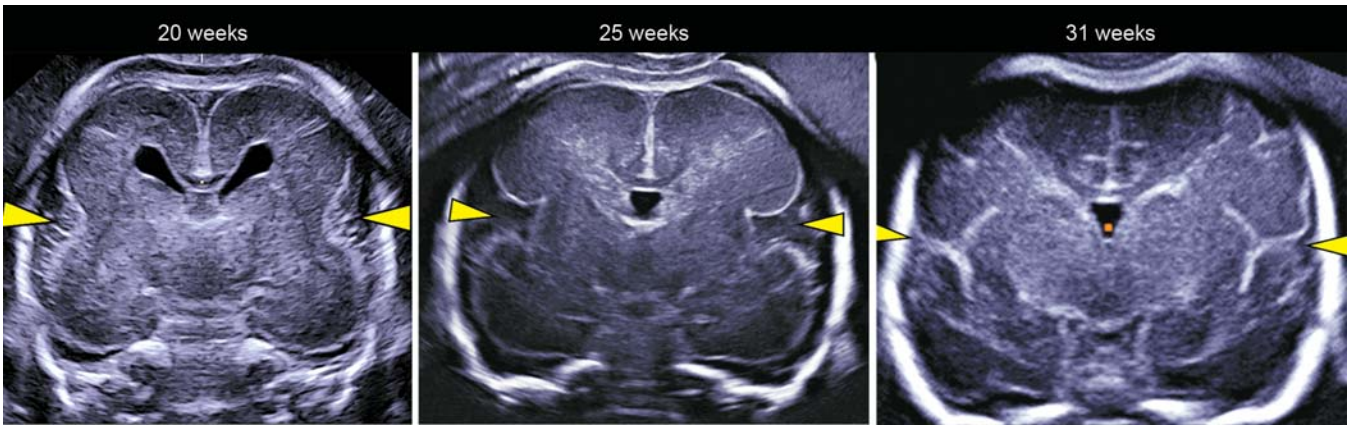

Fig. 7: Changing appearance of sylvian fissure during the second and early third trimesters

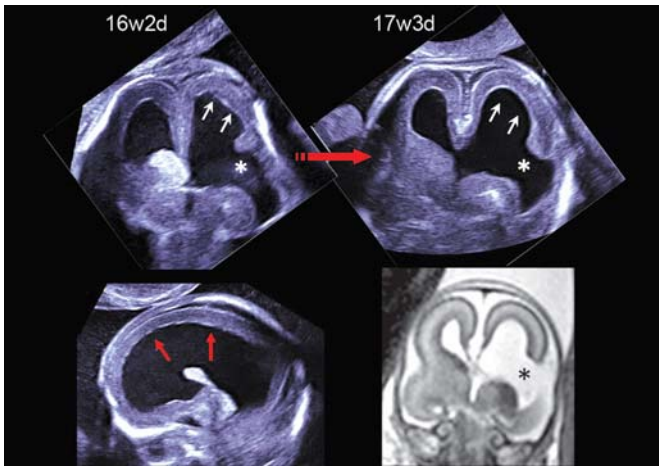

Fig. 8: Early intracranial hemorrhage/porencephaly case (upper figures) dedicated transvaginal high-frequent sonography detected the subtle change of ventricular wall between 16 and 17 weeks of gestation (arrows). (Left lower) ventricular wall is irregular and hyperechogenic (red arrows), indicating intraventricular hemorrhage. (Right lower) MR image of the same fetus at 20 weeks. Asterisks indicate the missing brain (porencephaly) because of early brain hemorrhage

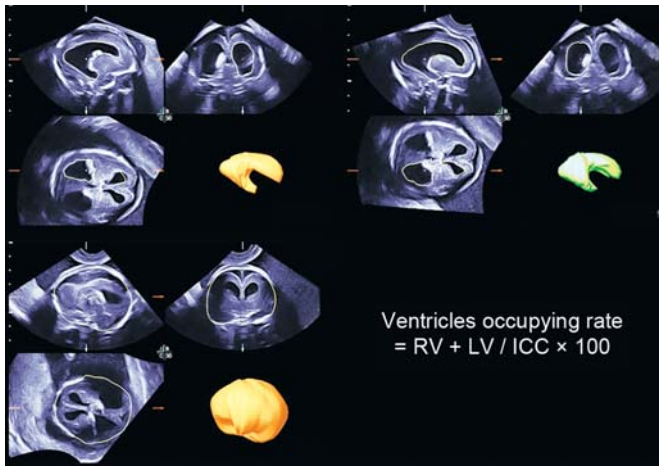

Fig. 10: 3D volume extraction and volumetric analysis of lateral ventricle and intracranial cavity. Each volume of right (RV) and left ventricles (LV) and intracranial cavity volume can be calculated by 3D volumetry. Total ventricular volume/intracranial cavity (ICC) volume shows ventricles occupying rate and it is useful for longitudinal assessment of ventriculomegaly cases

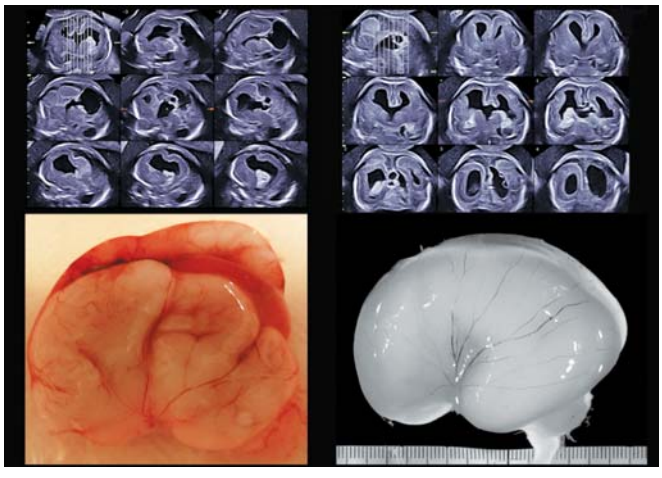

Fig. 9: Abnormal migration disorder in the second trimester. (Upper figures) TUI in the sagittal (left) and coronal (right). The intracranial brain structure is quite abnormal and it is difficult to obtain the orientation but TUI is quite helpful to show the intracranial structure very clearly. Lower left picture shows the brain surface at autopsy in the same case. Abnormal gyration which cannot exist at 21 weeks is seen. Lower right figure is normal smooth brain surface at the same gestation for comparison

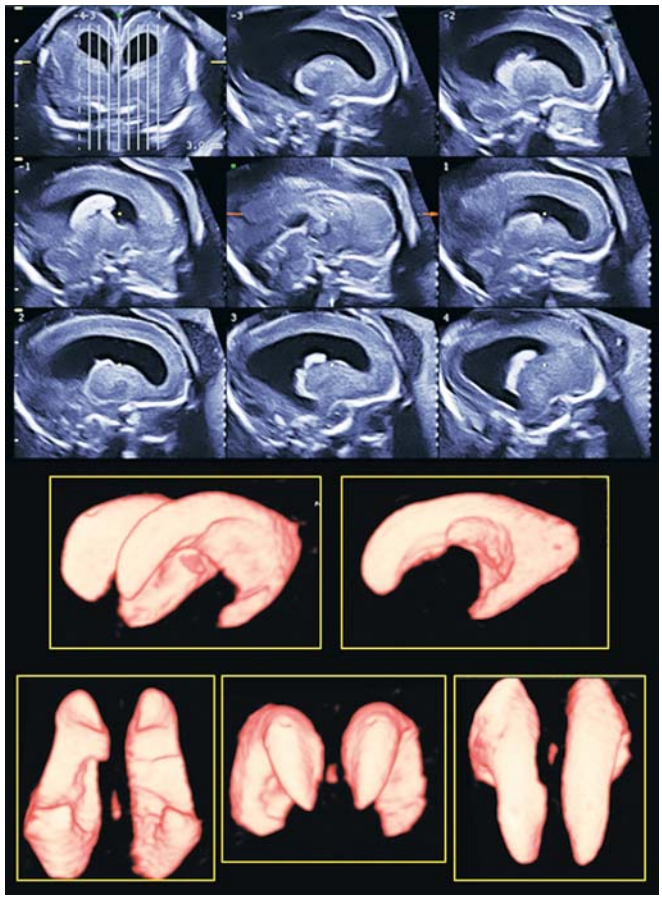

Fig. 11: TUI and inversion mode of enlarged ventricle at 19 weeks of gestation. Ventricular appearance is objectively demonstratable by inversion mode

TRANSVAGINAL HIGH-RESOLUTION 3D NEUROANGIOGRAPHY

The author first reported brain circulation demonstrated by transvaginal 2D power Doppler in 1996.[27] Thereafter, transvaginal 3D power Doppler assessment of fetal brain vascularity was successful.[20,28] Recently, owing to the advanced technology of directional power Doppler, furthermore sophisticated 3D angiostructural images have been able to be demonstrated with vascular direction.[29] In the first trimester, it is possible to demonstrate the fetal cranial circulation clearly as early as 7 weeks of gestation (Fig. 12). Brain circulation can be well-documented during the first trimester. Figure 13 shows the fetal brain circulation at 14 weeks by 3D bidirectional power Doppler. Furthermore, recent high-frequent transvaginal neuroscan has been able to demonstrate the medullary vessels from the cortex towards subependymal area. Medullary veins

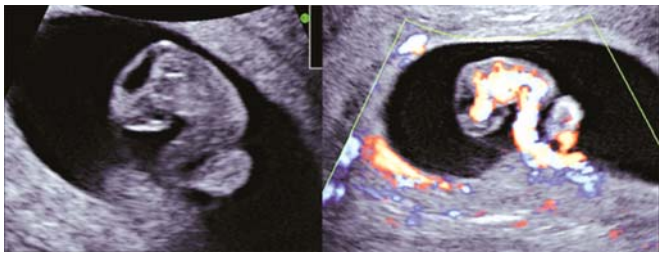

Fig. 12: Early cranial circulation at 7 weeks of gestation. Left upper shows B-mode image of sagittal section and right figure shows fetal circulation by bidirectional power Doppler technology

are demonstrated between pia mater and longitudinal vein of Schlesinger in the anterior coronal cutting section and between brain surface and periventricular subependymal area in the parasagittal section[29] (Fig. 14). Medullary vessels are detectable from early second trimester and they rapidly develop during second trimester as shown in Figure 15. Medullary vessels are developing according to advancing gestational age in normal cases and maldevelopment of those vessels may relate with the postnatal neurological prognosis.[29] Figure 16 shows two cases; one case had morphologically normal brain structure but abnormally maldeveloped medullary vessels and the other case had morphologically abnormal brain structure (ventriculomegarly) but normally developed medullary vessels. The former case had unfavorable neurological prognosis and the latter case have had favorable neurological prognosis. Of course, we have to be prudent to jump to conclusion because each case has different basic diseases or syndromes, therefore we have to analyze case by case.

FUTURE ASPECT

As described in this article, transvaginal high-resolution ultrasound technology has greatly contributed to fetal neuroscience. Neurological prognosis should be longitudinally and carefully evaluated according to precise diagnoses.

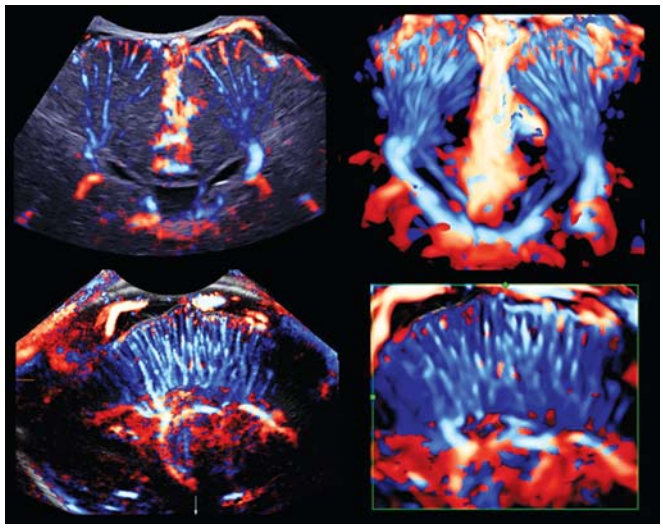

Fig. 14: Medullary vessels in normal 29-week fetus by 3D bidirectional power Doppler. (Upper) Coronal cutting section of 2D (left) and 3D reconstructed images (right). (Lower) parasagittal cutting section of 2D (left) and 3D reconstructed images (right). Medullary veins are demonstrated between pia mater and longitudinal vein of Schlesinger in the anterior coronal cutting section and between brain surface and periventricular subependymal area in the parasagittal section

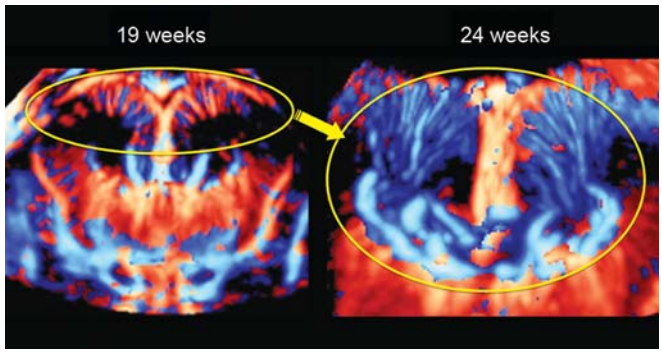

Fig. 15: Development of medullary vessels in the second trimester. Medullary vessels (yellow circles) at 19 and 24 weeks of gestation. These images were taken from the same fetus. Thus, medullary vessels are detectable from early second trimester and they are rapidly developing during second trimester

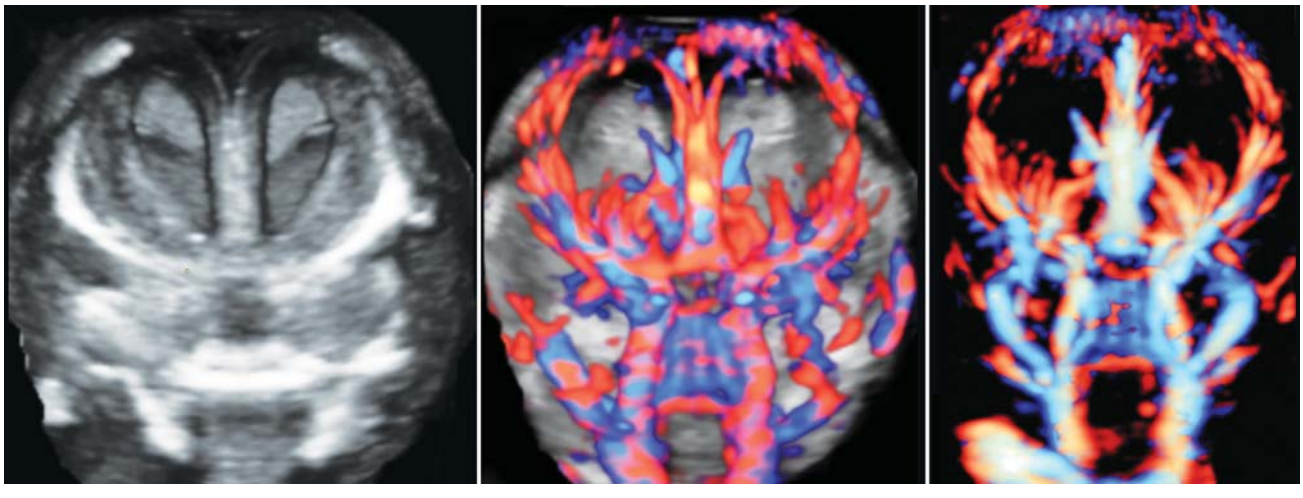

Fig. 13: Brain circulation at 14 weeks by 3D bidirectional power Doppler. (Left) Volume contrast imaging in coronal cutting section. (Middle) 3D bidirectional power Doppler reconstructed image with B-mode. (Right) Brain angiography by 3D bidirectional power Doppler. These three images are obtained by a single acquisition

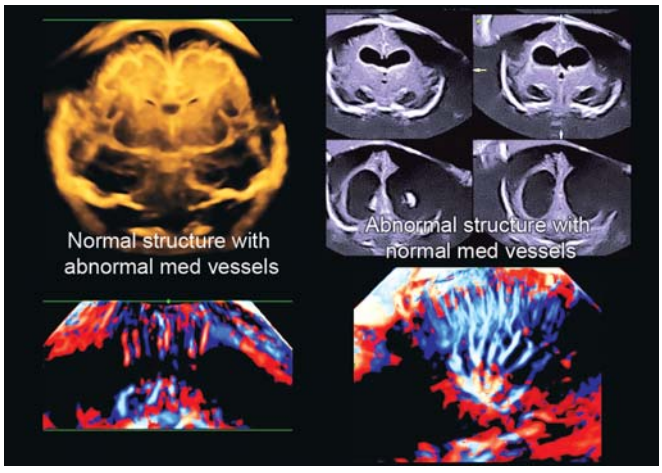

Fig. 16: Brain morphology and medullary vessel development. Left case had morphologically normal brain structure but abnormally maldeveloped medullary vessels, and right case had morphologically abnormal brain structure (ventriculomegaly) but normally developed medullary vessels. The former case had unfavorable neurological prognosis and the latter case have had favorable neurological prognosis

Considering future in fetal neurology, those precise morphological detection by transvaginal high-resolution neuroimaging should be combined with four-dimensional ultrasound research on fetal behavior (KANET scoring system)[30-33] and molecular genetics which has recently been remarkably contributed to prenatal diagnosis as *Sonogenetics*.[34]

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