Clinical Application of Three-dimensional Ultrasound in Fetal Brain Assessment

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Aim. To clarify the usefulness of three-dimensional (3D) ultrasound in the assessment of the fetal head and brain, according to 3D ultrasound surface reconstruction, multiplanar image analysis, three-dimensional angiography, and volume calculation.

Methods. We examined 326 normal fetuses between 10 and 40 weeks of gestation using 3D ultrasound (Voluson, 530D, Medison, Seoul, Korea), mainly with transvaginal 3D transducer. Fetal head structures, such as skull, brain structure, and brain circulation, were presented by surface mode, multiplanar imaging mode, and three-dimensional Doppler mode. After automatic volume acquisition of the fetal head, image analyses were performed off-line, and 3D View soft ware was used for volume imaging of the lateral ventricle and choroid plexus in randomly selected 30 normal fetuses. Seven fetuses with intracranial abnormalities were evaluated by 3D ultrasound functions.

Results. Surface mode of 3D ultrasound objectively depicted in vivo development of the cranial bones and formation of the cranial sutures and fontanelles in normal fetuses. Multiplanar imaging of the brain presented a fetal brain in more cutting sections than conventional 2D ultrasound. Transvaginal 3D angiography was successful in 13% of normal fetuses and rotation of 3D circulatory images allowed the analysis of the intracranial vessels. Volume imaging showed the individual intracranial structures, such as the lateral ventricle and choroid plexus. Intracranial abnormalities were longitudinally evaluated by 3D ultrasound and objective images helped in reaching prenatal diagnoses.

Conclusion. Advanced 3D ultrasoundography and software for volume analysis can provide additional objective information about the fetal skull formation, brain structure, and brain circulation.

Key words: blood vessels; brain, ultrasonography; Doppler ultrasonography, color; embryonic structures; fetal ultrasonography; sonography, transvaginal Doppler; ultrasonography, Doppler, transvaginal

The intrauterine development of the central nervous system is one of the most interesting fields in perinatology. Transvaginal sonographic approach to the fetal brain provides detailed information about the fetal intracranial morphology and circulation. It depicts the fetal brain in the sagittal and coronal sections from the parietal direction, using fontanelles and cranial sutures as ultrasound windows. Transvaginal sonography of the fetal brain opened a new field in medicine, “neurosonography” (1), and its use has allowed detection of many intracranial normal and abnormal conditions.

Clinical significance of 3D ultrasound sound for prenatal diagnosis has been discussed since three-dimensional (3D) ultrasound was introduced in obstetrics (2-4). 3D ultrasound has several functions: surface reconstruction, multiplanar image analysis, three-dimensional angiography, and volume calculation. The aim of this study was to clarify the usefulness of all these functions of transvaginal 3D ultrasound in the assessment of the fetal head and brain.

Methods

From January 1999 to March 2000, we examined 326 normal fetuses between 10 and 40 weeks of gestation by transvaginal 3D ultrasound. The ultrasound device used in our study was Voluson 530D (Medison, Seoul, Korea). In 64 cases, as transvaginal sonography failed to depict the cranial sutures, transabdominal volume scan was added for surface reconstruction of the calvaria. Intracranial structures were assessed by transvaginal approach in all cases. After transvaginal two-dimensional (2D) approach to the fetal head, automatic volume acquisition was performed and all the data were saved on the magnetic optical disks. The image analysis was done off-line. Surface mode was used for assessment of the superficial structure of the fetal cranial bone, whereas multiplanar image analysis was used for the assessment of the intracranial morphology of the fetal head. 3D color/angiography mode was used for the demonstration of the brain circulation. Thirty normal cases were selected for volume imaging study. Brain volume data were re-formatted for volume analysis on a personal computer (Sony, Tokyo, Japan). Volume imaging and volume estimation of the intracerebral...
structures, i.e., the lateral ventricle and choroid plexus, were done with 3D View version 3.2 soft ware (Kretztechnik AG, Zipf, Austria).

Seven cases with ab nor mal brain struc ture were ex am ined dur ing the study pe riod. Cen tral ner vous sys tem in each case was eval u - ated by use of all 3D ultrasound func tions men tioned ear lier.

**Results**

Ex am ining the fe tal cra nial bone struc tures by sur - face mode, we were able to de tect more than one of the su tures (sagittal, cor o no lal, fron tal, and lam boid) and fon ta nelles (an te rior, pos ter ior, and ante rior lateral) in 265 fe tu ses (81%). Some times, the cra nal suture could be rec og nized at 13 weeks as a wide and short space be tween par i etal bones. At 12 weeks, met opic su ture was rec og nizable as a very short space be tween the bi lat eral ear lifes, whereas wide an terior fon tal nes occupied most of the cranium from the top of the head to fore head. With de vel op - ment of the bi lat eral ear lifes, the met opic suture was rap id ly formed as a lin ear su ture be tween 13 and 17 weeks of ges ta tion. The an terior fon tal nes were rec og - nized by its dia mond shape af ter 15 weeks of ges ta tion. The co ro nal su tures could be clearly de tected from 12 weeks of ges ta tion on. The lam boid suture was de tect - able af ter 12 weeks, and the pos ter ior fon tal nes grad u - ally took a tri an gu lar shape. By 23 weeks of ges ta tion, the skull shape re sem bled a neo na tal cra nial for ma tion.

In fe tal brain scan ning, the mean ac ci - si o n time was 1.84, 3.30, 4.76, and 6.07 sec onds at 15, 20, 30, and 40 weeks of ges ta tion, re spectively. The brain struc ture was si - multane ously de tect able in the sagittal, cor o nal, and ax ial sec tions (Fig. 2) by ro tat ing the brain im ages un der var i ous angles, and par a llel dis place ment of each sec tion showed that the cranial su tures be tween the top of the head and fore head could be re vealed. By 23 weeks of ges ta tion, the co ro nal su tures could be clearly de tected from 12 weeks of ges ta tion on. The lam boid suture was de tect - able af ter 12 weeks, and the pos ter ior fon tal nes grad u - ally took a tri an gu lar shape. By 23 weeks of ges ta tion, the skull shape re sem bled a neo na tal cra nial for ma tion.

Table 1. Detection rate of intracranial structure by transvaginal 2D and 3D approach in 326 normal fetuses

<table>
<thead>
<tr>
<th>Sections</th>
<th>Detectable structures</th>
<th>No. (%) of cases detected by transvaginal Doppler approach</th>
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<tbody>
<tr>
<td>Median (mid-sagittal)</td>
<td>CC, SP, C, IV</td>
<td>287 (88), 287 (88)</td>
</tr>
<tr>
<td>Serial oblique-sagittal</td>
<td>LV, SAS, Hemisphere</td>
<td>287 (88), 285 (87)</td>
</tr>
<tr>
<td>Serial oblique-sagittal (opposite)</td>
<td>LV, SAS, Hemisphere</td>
<td>213 (65), 264 (81)</td>
</tr>
<tr>
<td>Oblique-coronal</td>
<td>bilateral AH, PH, hemisphere</td>
<td>232 (71), 261 (80)</td>
</tr>
<tr>
<td>Parallel sagittal</td>
<td>LV, SAS, hemisphere</td>
<td>– (0), 285 (87)</td>
</tr>
<tr>
<td>Parallel coronal</td>
<td>bilateral AH, PH, hemisphere</td>
<td>– (0), 264 (81)</td>
</tr>
<tr>
<td>Parallel axial</td>
<td>Falx, bilateral LV</td>
<td>– (0), 192 (59)</td>
</tr>
</tbody>
</table>

Notes: CC – cor pus cal lo sum; SP – sep tum pellucidum; C – cere bel lum; IV – fourth ven tri cle; LV – lateral ven tri cle; SAS – subarachnoid space; AH – an terior horn; PH – pos ter ior horn.

20 and 30 weeks of ges ta tion. The suc cess ful ori en ta tion of the brain cir cu la tion with me dian ves sels and bi lat eral sym met ri cal mid dle cerebral ar ter ies and their branches (Fig. 4) was ob tained in 42 cases (13%). By ro tat ing 3D cir cu la tory age, the in tracranial ves sels could be con - firmed from var i ous di re c tions.

Volume imag ing and volume cal cu la tion with 3D View soft ware (Fig. 5) were suc cess fully per formed in all 30 cases. Vol ume imag ing showed changes in ap pear - ance of the lateral ven tri cle and choroid plexus dur ing preg nancy (Fig. 6). Eti o path o logical ev a lu a tion of all struc tures in creased dur ing preg nancy.

In all 7 cases with in tracranial ab nor mal i ties – a hy dro cephalus with my elo me ningoe ge; per vi nter cu lar leu ko ma lacia; intra ven tricular hem or rhage; Dandy-Walker vari ant; asym met ri cal mid dle cerebral hypo plasia with my elo me ningoe ge; ag ene sis of the cor pus cal lo sum with in terhe mi spheric cy st; and par tial fusion of he mi - sphere with cerebel lar fusion – longi du mal multiplan im age age y ses were suc cess ful and the objec tive age im ages and vol ume data ob tained by ro ta tion of the brain helped in reach ing pre na tal diag no sis and con sid er ing post na tal treat ment (Fig. 7). Sur face re con struc tion was used for ob jective dem on stra tion of the craniofacial ab nor mal i ty and spinal ab nor mal i ty with my elome ningoe ge (Fig. 8). Three-di men sio nal angiogra phy showed dis place ment of intra cranial ves sels due to the brain ab nor mal i ties. 3D vol - u me anal y sis was used for the eval u a tion of the lateral ven triculo me ngeal y (Fig. 9) and intra cranial le sion.

**Discussion**

In this study, we showed the nor mal cranial bone for ma tion in vivo using 3D-ultrasound sur face mode. The calvar ia and its ma jor su tures de vel op be tween 12 and 18 weeks of fe tal life, with dura as guid ing tis sue in the mor pho gene sis of the skull (5). The cra nal su tures serve as ul tra sound win dows for ob ser va tion of the in tracranial struc tures. So far, the sutural fu sion has not been de mon strated in vivo and pre na tal diag no sis of craniosynostosis was al ways made on in di rect ev i dence of craniofacial ab nor mal shape and in tracranial ab nor mal mor ph ology (6). Al though a fe tus with fron tal boss ing and low na sal bridge in our study (Fig. 8) had in tact cranial su tures, the cra nal ab nor mal i ty could be de tected in utero by 3D sur face mode.
The introduction of high frequency 2D transvaginal transducer opened a new field in medical imaging – sonoembryology (7). The new technique made a detailed visualization of the brain structure of early fetuses possible (8-10). A case of intracranial abnormality diagnosed in the second trimester transvaginally was first reported in 1989 (11). Transvaginal approach to the normal fetal brain during the second and third trimester was introduced in the early 1990s. It was the first practical application of 2D ultrasound in three-dimensional central nervous system assessment (12). Transvaginal observation of the fetal brain offered sagittal and coronal views of the brain from parietal direction (1,13-17), whereas sonographic images through the fontanelles and/or the sagittal and coronal sutures depicted brain structures in detail. This method contributed to the prenatal sono graphic assessment of congenital central nervous system anomalies and acquired brain damage in utero, especially when compared with conventional transabdominal method.

Transvaginal 2D as well as multiplanar two-dimensional imaging of the fetal brain has its limitations. With 2D transvaginal imaging of the fetal brain, we can produce series of oblique sections from the same ultrasound window by shifting and changing the angle of the transducer within the narrow space of the vagina. Some images, however, it is impossible to obtain in the frontal plane of the brain. This method contributed to the prenatal sono graphic assessment of congenital central nervous system anomalies and acquired brain damage in utero, especially when compared with conventional transabdominal method.

According to the anatomical location of the brain vessels, the Wilis’ ring, the source of the cerebral arteries and transverse sinus is located at the axial plane of the head. But, there are many other brain vessels which rise and fall within the sagittal and coronal planes. Therefore, transvaginal approach to the fetal brain from the frontal parietal direction plays an important role in brain assessment as well. Transvaginal 2D color/power Doppler angiography of the brain at this level shows the cerebral vessels and their location (18,19). How ever, it is difficult to present the complex three-dimensional structure of the brain vessels in a single two-dimensional plane. Three-dimensional reconstruction of the brain circulation in neonates has been reported (20). Com bi na tion of...
**Figure 2.** Multiplanar image analysis of the fetal brain at 20 weeks of gestation. Coronal (upper left), sagittal (upper right) and axial (lower left) planes of the brain are shown.

**Figure 3.** Parallel slicing of each section of the brain. Intracranial morphology can be shown in the same way with magnetic resonance imaging.
sound may contribute to the fetal brain circulatory assessment, since the 3D vascular image can be rotated in any direction, and the vessels can be observed from the frontal, occipital, lateral, oblique, parietal, or basilar part of the brain (21).

There are several problems with 3D color/power Doppler, such as ambiguity of color/power signals and long scanning time. Because of these problems, the success rate of 3D angiography in our study was much lower than that of 3D B-mode scan. Further device development and more clinical studies will be required to find a clinical significance in the application of 3D angiography.

3D volume imaging of fetus brain cavities at 7, 9, and 10 weeks of gestation was first reported in 1995 by Blaas et al (22). They extracted the detailed structure of premature hemisphere, diencephalon, mesencephalon, and rhombencephalon in vivo by 3D ultrasound. Thereafter, they reported volume estimation of the fetal brain cavities in early fetuses (23). In low-birth-weight neonates, a volume difference between upper and lower ventricles due to the head position was reported by free-hand 3D ultrasound volume calculation (24). In this study, we

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**Figure 4.** Brain circulation revealed by 3D Doppler angiography. 3D power Doppler reconstructed image of brain circulation can be seen from any direction. These 4 figures show the y-axis rotation of same 3D image.

**Figure 5.** The volume imaging and volume calculation of the lateral ventricle (left) and choroid plexus (right) by 3D View (17 weeks of gestation).

**Figure 6.** Changing appearance of the lateral ventricle and choroid plexus during pregnancy.
chose to produce the volume images and estimated volume of the lateral ventricle and choroid plexus in fetuses from 12 to 34 weeks of gestation. Volume analysis of the structure of interest provides an intelligible evaluation of the brain structure in total and objective assessment of abnormal brain morphology, such as ventriculomegaly and intracranial occupying lesion.

In conclusion, transvaginal 3D sonography is an easy, non-invasive, and reproducible method with little technical requirements and a short scanning time which produces comprehensible and objective information. Surface reconstruction, multiplanar analysis, angiography, and volume imaging are useful for the assessment of the fetal skull formation, intracranial morphology, circulation, and volume estimation. Storage/execution of raw volume data sets and off-line analysis of the fetal head structure are quick and easy. Therefore, in sono-evaluation of central nervous system abnormalities, neurospecialists can find the data acquired by 3D volume much more objective than the data obtained by conventional 2D images.

**Figure 7.** Parallel slicing in sagittal, coronal, and axial planes and multiplanar image analysis in a fetus with asymmetrical ventriculomegaly and agenesis of the corpus callosum and interhemispheric cyst.

**Figure 8.** Fetal abnormality revealed by 3D surface mode. Left: a case with frontal bossing and low nasal bridge at 24 weeks of gestation; transabdominal scan. The coronal and lambdoid sutures are detectable. Right: myelomeningocele at 18 weeks of gestation.

**Figure 9.** Volume image and volume estimation of the ventricle in a fetus with ventriculomegaly (the same case as in Fig. 7).
References


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