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Examination of the fetal brain by transabdominal three-dimensional ultrasound: potential for routine neurosonographic studies

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KEYWORDS: fetus; neurosonography; prenatal diagnosis; three-dimensional ultrasound

ABSTRACT

Objective *To evaluate the role of transabdominal three-dimensional (3D) ultrasound in the assessment of the fetal brain and its potential for routine neurosonographic studies.*

Methods *We studied prospectively 202 consecutive fetuses between 16 and 24 weeks' gestation. A 3D ultrasound volume of the fetal head was acquired transabdominally. The entire brain anatomy was later analyzed using the multiplanar images by a sonologist who was expert in neonatal cranial sonography. The quality of the conventional planes obtained (coronal, sagittal and axial, at different levels) and the ability of the 3D multiplanar neuroscan to visualize properly the major anatomical structures of the brain were evaluated.*

Results *Acceptable cerebral multiplanar images were obtained in 92% of the cases. The corpus callosum could be seen in 84% of the patients, the fourth ventricle in 78%, the lateral sulcus (Sylvian fissure) in 86%, the cingulate sulcus in 75%, the cerebellar hemispheres in 98%, the cerebellar vermis in 92%, the medulla oblongata in 97% and the cavum vergae in 9% of them. The thalami and the cerebellopontine cistern (cisterna magna) were identified in all cases. At or beyond 20 weeks, superior visualization (in > 90% of cases) was achieved of the cerebral fissures, the corpus callosum (97%), the supracerebellar cisterns (92%) and the third ventricle (93%). Some cerebral fissures were seen initially at 16–17 weeks.*

Conclusion *Multiplanar images obtained by transabdominal 3D ultrasound provide a simple and effective approach for detailed evaluation of the fetal brain anatomy. This technique has the potential to be used in the routine fetal anomaly scan. Copyright © 2006 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

Since the early 1980s, three-dimensional (3D) ultrasound has become a major field of research in obstetrics and gynecology. At this point in time, the clinical application of 3D is advancing rapidly, as improved 3D rendering technology becomes more widely available[1]. In the case of the fetal brain, the 3D multiplanar orthogonal display modality allows study of the cerebral anatomy by navigation through the three classical planes (coronal, sagittal and axial) simultaneously, which is virtually impossible using two-dimensional (2D) scanning[2]. A 3D neurosonographic technique was described some years ago[3], but it has not been incorporated into routine fetal anomaly scanning in most centers; mostly it has been performed using 3D transvaginal ultrasound probes through the fetal anterior fontanelle[3,4]. Although 2D transvaginal sonography of the fetal brain has proved to be a valuable technique and is now more widely accepted, it is perceived by many as cumbersome and time-consuming[3]. Moreover, transvaginal examination of the fetal brain is dependent on the position of the fetal head and this is an important limitation of the technique.

There are few reports in the literature on the use of transabdominal 3D neurosonography[5,6]. None of these assessed the value of this technique in identifying normal brain anatomical structures. Besides, they were undertaken 4–5 years ago and the conclusion was that technological improvements in the quality of resolution would be required. The aim of our study was to evaluate

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the present role of 3D ultrasound in the assessment of cerebral anatomy when the volume of the fetal brain is obtained abdominally from the transcerebellar axial plane. Traditionally, the axial plane has been the mainstay for fetal cerebral scanning and it is the plane used most widely for such purposes in the majority of centers. We also assessed the potential of this technique for routine neurosonographic studies.

METHODS

A total of 202 consecutive pregnant women attending our maternal–fetal medicine unit for routine anomaly scanning were included in this prospective observational study. The study was approved by the local ethics committee. The gestational age of the women ranged from 16 to 24 weeks and all cases were singleton pregnancies. The maternal body mass index ranged from 18.12 to 41.26 kg/m^2 (mean ± SD, 25.25 ± 3.68 kg/m^2). Only cases without any abnormal findings in the routine fetal anomaly scan were included in the study. All patients were scanned by three of the authors (C.L., J.B. and V.S.) using a Voluson 730 Expert (General Electric, Vienna, Austria) ultrasound machine. Once a clear 2D transabdominal axial plane of the fetal brain had been visualized, a 3D volume of the fetal head was acquired. All volumes were acquired in the axial view; thus, boxes A, B and C of the acquired multiplanar images always corresponded to the axial, coronal and sagittal planes, respectively. Care was taken to meet the following requirements: (1) the initial axial cerebral plane corresponded to the transcerebellar plane (Figure 1b); (2) the 2D image was previously optimized as much as possible, mostly using harmonic imaging; (3) the cerebral midline in the 2D axial plane was as horizontal as possible and the upper reference line of the 3D region of interest was aimed to be completely parallel to the cerebral midline; (4) the 3D volume box was adjusted to include the whole fetal head, placing the upper reference line of the volume box adjacent to the most anterior parietal bone; (5) there was a lack of visible fetal movements during volume acquisition. One or two acquisitions were performed in each case depending on the quality of the original axial plane and the acquired multiplanar images. However, only the acquisition judged to be best was considered for the study. In some cases it was necessary to modify the brightness and contrast settings of the multiplanar images to ameliorate their resolution.

Only cases with an acceptable quality of cerebral multiplanar images were included in the study: those that allowed visualization of both choroid plexuses, both lateral ventricles (from the anterior to the posterior horns, including the body and the atrium) and the entire interhemispheric fissure, using the views provided by any combination of the three acquired boxes (axial, coronal and sagittal planes). When these requirements were met, the entire brain anatomy was analyzed by a sonologist who was expert in neonatal cranial sonography (F.F.C.), using the acquired multiplanar images. The images were manipulated as described by Monteagudo *et al.*[3], 'navigating' within them in the three orthogonal planes. The quality of the planes obtained and the ability to visualize properly the major brain anatomical structures were evaluated. The following cerebral structures were analyzed: choroid plexuses, lateral ventricles, interhemispheric fissure, lateral sulcus (Sylvian fissure), cingulate sulcus, parieto-occipital fissure, calcarine fissure, corpus callosum, subarachnoid space, thalami, pons, medulla oblongata, third and fourth ventricles, cavum septi pellucidi and cavum vergae, tentorium, cerebellar vermis and hemispheres, supracerebellar cisterns and cisterna magna.

All cases included in the study had a normal fetal neurosonographic examination and this was later confirmed after birth. The neonatal cerebral scan evaluated all anatomical structures analyzed in the prenatal study, confirming their presence and normal sonographic aspect.

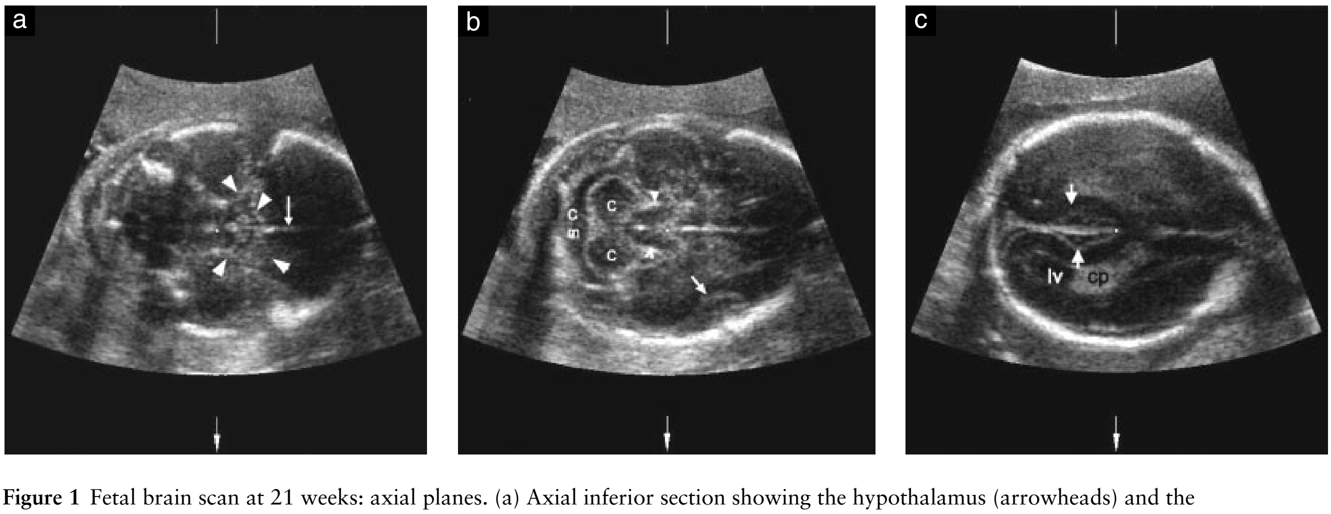

Figure 1 Fetal brain scan at 21 weeks: axial planes. (a) Axial inferior section showing the hypothalamus (arrowheads) and the interhemispheric fissure (arrow). (b) Axial median section depicting the lateral sulcus (arrow), the thalami nuclei (arrowheads), the cerebellar hemispheres (c) and the cerebellopontine cistern (cisterna magna, cm). This image corresponds to the original 2D plane. (c) Axial superior section showing the lateral ventricles (lv), the choroid plexuses (cp) and the parieto-occipital fissures (arrows).

Statistical comparisons were performed using chi-square analysis. A *P*-value < 0.05 was considered statistically significant.

RESULTS

Of the 202 fetuses enrolled in the study, we obtained good-quality cerebral multiplanar images in 186 (92%). In these 186 fetuses, navigation through the acquired multiplanar images enabled us to perform a detailed analysis of the quality of each orthogonal plane, sectioning each one as follows: the axial plane was divided into the superior, median and inferior sections (Figure 1); the coronal plane was subclassified into anterior, median and posterior sections (Figure 2); finally, the sagittal plane was divided into median and two parasagittal sections, one on each side of the midline (Figure 3). The ability to visualize each of the cerebral planes studied is described in Table 1. The easiest planes to acquire by 3D were the 'median' cerebral sections (axial, coronal or sagittal). The axial and coronal sections had higher quality imaging compared with the sagittal sections, due basically to the relatively poor visualization of one of the parasagittal sections; as demonstrated in Table 1, in only 33% of the cases could we obtain both right and left parasagittal sections. The most lateral parasagittal planes (at the level of the lateral sulcus and the most peripheral parieto-occipital parenchyma) could only be visualized properly in a minority of cases.

The ability of 3D neurosonography to identify the major cerebral anatomical structures was also analyzed in relation to gestational age (Table 2). Including the choroid plexuses, the lateral ventricles and the interhemispheric fissure (whose visualization was a prerequisite for considering acceptable the acquired 3D multiplanar images), 17 of 21 major cerebral anatomical structures analyzed had a very high rate of visualization ($> 90\%$) at or beyond 20 weeks. The only structures less visible at this gestational age were the fourth ventricle (88%), the calcarine fissure (67%), the parieto-occipital fissure (67%) and the cavum vergae (13%).

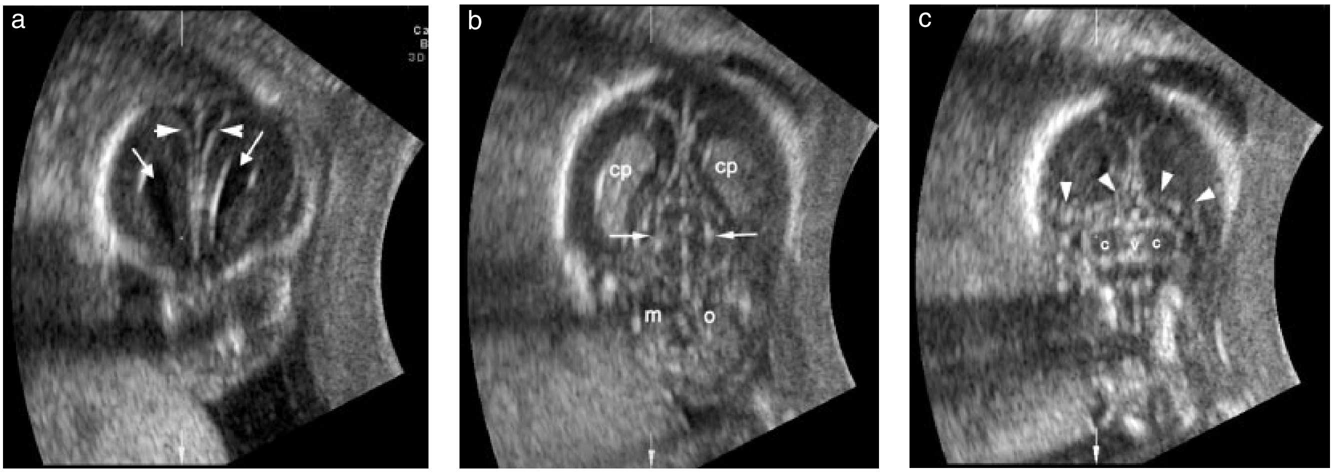

Figure 2 Fetal brain scan at 18 weeks: coronal planes. (a) Coronal anterior section showing the anterior horns of the lateral ventricles (arrows) and the subarachnoid space (arrowheads). (b) Coronal median section depicting the choroid plexuses (cp), the pons (arrows) and the medulla oblongata (mo). (c) Coronal posterior section showing the tentorium (arrowheads), the cerebellar hemispheres (c) and the vermis (v).

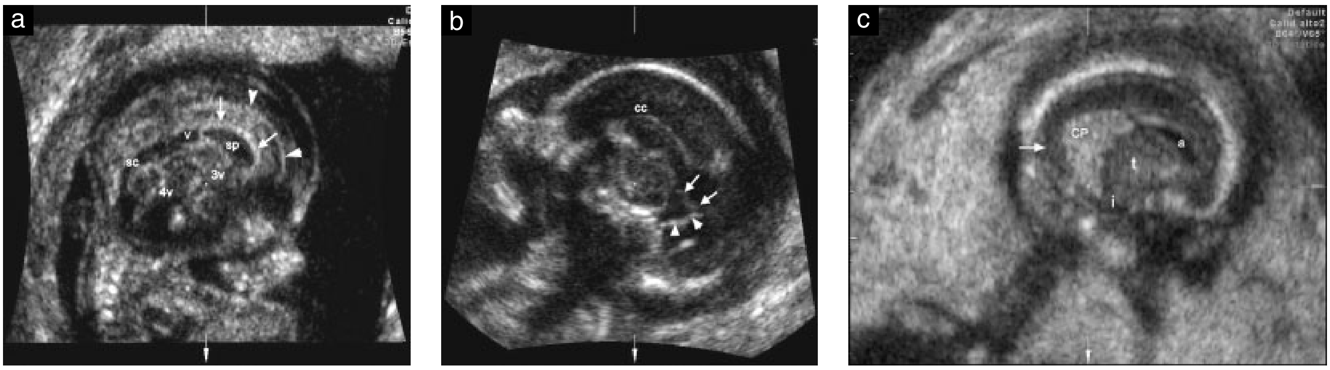

Figure 3 Fetal brain scan at 20 weeks: sagittal planes. (a) Median sagittal section showing the cingulate sulcus (arrowheads), the corpus callosum (arrows), the cavum septi pellucidi (sp) and the cavum vergae (v), the third ventricle (3v), the supracerebellar cisterns (sc) and the fourth ventricle (4v). (b) A plane slightly oblique from the median sagittal section depicting the parieto-occipital fissure (arrows) and the calcarine fissure (arrowheads). cc, corpus callosum. (c) Parasagittal section corresponding to the three-horn view showing the anterior (a), the posterior (arrow) and the inferior (i) horns of the lateral ventricle. Also visible are one of the choroid plexuses (CP) and the thalamus (t).

Table 1 Visualization of the different cerebral planes in the acquired multiplanar sections ($n = 186$)

Section	*Visualization* n	%
Axial		
Inferior	145	78
Median	176	95
Superior	162	87
Coronal		
Anterior	141	76
Median	168	90
Posterior	149	80
Sagittal		
Median	158	85
Parasagittal 1	140	75
Parasagittal 2	61	33

In the study of the cerebral fissures, the lateral sulcus was best depicted by navigating in the axial and coronal planes (Figure 1b), the cingulate sulcus in the sagittal median section (Figure 3a) and the calcarine and parieto-occipital fissures in the axial planes (Figure 1c) and the sagittal median section (Figure 3b). The third ventricle was easily seen in the sagittal median section (Figure 3a), and the fourth ventricle was well imaged using an axial plane or a sagittal median section (Figure 3a). The cavum vergae was always visualized in the sagittal median section (Figure 3a), as was the cavum septi pellucidi. The tentorium, cerebellar hemispheres and vermis were best imaged in the coronal posterior plane (Figure 2c).

In order to evaluate the potential of 3D neurosonography to be used in the routine fetal anomaly scanning, the time spent on the evaluation of the rendered multiplanar images was also estimated. Once the learning curve was over, the median time used in the study was 4 min (approximately 1 min for the axial planes, 1 min for the coronal planes and 2 min for the sagittal planes).

DISCUSSION

Based on our results, 3D multiplanar ultrasound examination of the fetal brain is feasible even when the volume is obtained by the classical transabdominal approach. We were unable to get good-quality cerebral multiplanar images in only 8% of the patients. In these cases the reasons were varied: subtle fetal movements during volume acquisition, low quality of the initial 2D image due to poor sonographic transmission, initial 2D image too tilted with respect to the upper reference line of the 3D volume box, or simply, the learning curve. In our opinion, the low quality of the initial 2D image due to poor sonographic transmission was the main limitation of this novel scanning technique.

With respect to the quality of the planes obtained, the reason for the lower-quality visualization of both right and left parasagittal sections might have been that in these cases the initial 2D image was not perfectly symmetrical. This parasagittal section is comparable to the three-horn view described by Monteagudo *et al.*[7] (Figure 3c). In contrast, the median sagittal section was well identified in 85% of cases. This is important because such a view provides considerable information on the corpus callosum and other structures of the midline (Figure 3a). Moreover, this section is difficult to obtain using the classical 2D transabdominal approach and

Table 2 Visualization of the major cerebral anatomical structures in relation to gestational age

Structure	*Visualization (n (%)) at gestational weeks* 16–17 (n = 26)	18–19 (n = 54)	20–21 (n = 87)	22–24 (n = 19)	Overall: 16–24 (n = 186)	P*
Lateral sulcus (Sylvian fissure)	17 (65)	45 (83)	80 (92)	18 (95)	160 (86)	< 0.01
Cingulate sulcus	2 (8)	40 (74)	79 (91)	19 (100)	140 (75)	< 0.001
Parieto-occipital fissure	3 (12)	21 (39)	57 (66)	14 (74)	95 (51)	< 0.001
Calcarine fissure	3 (12)	23 (43)	56 (64)	15 (79)	97 (52)	< 0.001
Corpus callosum	10† (38)	43† (80)	84 (97)	19 (100)	156 (84)	< 0.001
Subarachnoid space	26 (100)	54 (100)	85 (98)	19 (100)	184 (99)	NS
Thalami	26 (100)	54 (100)	87 (100)	19 (100)	186 (100)	NS
Pons	26 (100)	54 (100)	87 (100)	19 (100)	186 (100)	NS
Medulla oblongata	25 (96)	53 (98)	83 (95)	19 (100)	180 (97)	NS
Third ventricle	20 (77)	32 (59)	81 (93)	18 (95)	151 (81)	< 0.001
Fourth ventricle	19 (73)	33 (61)	78 (90)	15 (79)	145 (78)	< 0.01
Cavum septi pellucidi	25 (96)	53 (98)	87 (100)	19 (100)	184 (99)	NS
Cavum vergae	0 (0)	3 (6)	11 (13)	3 (16)	17 (9)	NS
Tentorium	25 (96)	52 (96)	86 (99)	19 (100)	182 (98)	NS
Cerebellar vermis	22 (85)	48 (89)	83 (95)	18 (95)	171 (92)	NS
Cerebellar hemispheres	25 (96)	51 (94)	87 (100)	19 (100)	182 (98)	NS
Supracerebellar cisterns	23 (88)	39 (72)	83 (95)	15 (79)	160 (86)	< 0.01
Cerebellopontine cistern (cisterna magna)	26 (100)	54 (100)	87 (100)	19 (100)	186 (100)	NS

*Chi-square analysis. †Partial visualization (see text). NS, not significant.

sometimes it is time-consuming when doing a transvaginal 2D neurosonographic study. As the original plane from which the cerebral volume was acquired in our study corresponded to the 'median' axial cerebral plane, it is not surprising that the easiest planes to acquire by 3D were also the 'median' coronal and sagittal sections. On some occasions on the axial images, we encountered the phenomenon of the 'blurred hemisphere' close to the probe (Figure 1c), as described in 2D axial neurosonography. However, this effect was avoided in most cases by studying the structures of this hemisphere in the views provided by the other two rendered planes.

As reported by Monteagudo *et al.*[2,3], one of the most significant attributes of the 3D fetal neuroscan was the possibility of navigating through multiple sections in all three planes, with no need to have a finite number of predetermined sections. It could be used effectively to identify the major brain structures and it could depict structures usually not visualized by the classical 2D transabdominal axial approach (Table 2).

Interestingly, the anatomical structures with relatively low visualization (< 90%) varied with gestational age (Table 2). All four sulci analyzed, particularly the calcarine and the parieto-occipital fissures, were better visualized at a more advanced gestational age. This is logical as the developmental maturation of the fissures, sulci and gyri follows a predictable timetable[8]. Previous reports have found the sonographic display of these anatomical features to lag behind the actual anatomical appearance of such structures[8,9]. However, in a recent study by Toi *et al.*[10], the parieto-occipital and calcarine fissures were the first to be imaged at 18.5 weeks. The lateral sulcus, seen initially with an obtuse angle, was reported to be found in some fetuses as early as 17 weeks and the cingulate sulcus was not imaged before 23.2 weeks. We have demonstrated that the lateral sulcus, cingulate sulcus, parieto-occipital fissure and calcarine fissure can be identified sonographically in some cases as early as 16–17 weeks, which is more compatible with their actual anatomical appearance. We feel that the differences between our study and that of Toi *et al.*[10] can be explained because the latter was a transabdominal 2D study with only three fetuses scanned at 16–17 weeks. Indeed, 3D multiplanar evaluation of the fetal brain allows assessment of a single structure in different planes, with considerable improvement in its visualization. In the specific case of the cingulate sulcus, the good resolution of the acquired sagittal median plane (Figure 3a) was fundamental to its visualization as early as 17 weeks; to our knowledge, this ultrasound study is the first to approximate so closely its anatomical appearance at 16 weeks.

The corpus callosum was better seen at more advanced gestational ages, as expected according to its developmental sequence. According to the literature[11], this structure does not reach a developmental stage that allows its sonographic imaging until 18–19 weeks' gestation. In fact, when the corpus callosum was identified at 16–17 weeks in our study, only part of this structure could be seen. However, we could recognize the entire corpus callosum in all cases at 20–24 weeks using the sagittal median section (Figure 3a). This is important because it is difficult to obtain this section and, consequently, to image this structure using the classical 2D transabdominal approach, in which its agenesis is suspected only by indirect signals[12,13]. It is true that it can be depicted beautifully using transvaginal imaging in the sagittal median plane[2], but this technique has not been incorporated into the routine fetal anomaly scan worldwide. In a previous short report published in 2000, which evaluated only the median sagittal section generated by 3D ultrasound, the corpus callosum was visualized correctly in 25 of 32 cases (78%), at a mean gestational age of 27.4 weeks[12]. In the same study, the corpus callosum was seen on 2D ultrasound in only one of 32 cases (3%)[12]. In 2002, another report on the 3D median sagittal section demonstrated the superior role of 3D technology compared with 2D ultrasound in the assessment of cerebral midline structures[14]; there was a high visualization rate of the corpus callosum (91%) in pregnancies from 18–38 weeks. Although these two studies differ from ours because they analyzed only the 3D sagittal median section and compared 2D and 3D techniques, we are not aware of any other publications assessing the value of transabdominal 3D neurosonography. In our opinion, the fact that we could assess the entire corpus callosum in all cases at or beyond 22 weeks illustrates the recent improvements in 3D ultrasound technology.

The percentage of visualization of the third and fourth ventricles was also quite high (Table 2). Although it has been reported that the third ventricle is better imaged transvaginally in the first and early second trimesters[2], in our transabdominal study this structure had a high rate of visualization at or beyond 20 weeks. Our study also shows that the combination of views provided by the different acquired 3D planes allows better assessment of the cerebellar vermis compared with the conventional 2D approach.

The cavum vergae is the posterior extension of the cavum septi pellucidi. It can be detected in only 1–9% of neonates[15], which coincides with our poor visualization rate.

The cerebral trunk, more specifically the pons and the medulla oblongata, were visualized excellently in our study (Table 2), mainly through the coronal plane (Figure 2b). By knowing the normal anatomy of these structures, early detection of pathology (e.g. Arnold–Chiari malformation) is feasible at earlier gestational ages[2].

Finally, several cisterns in the subarachnoid space can also be visualized sonographically but these structures have not been studied frequently in the fetal brain. Evaluation of these cisterns in a fetus with ventriculomegaly may allow the prenatal diagnosis of a communicating hydrocephalus[16]. We evaluated the anatomy of the supracerebellar cisterns, best imaged in the sagittal median section (Figure 3a), and they could be identified in 86% of the cases, mainly at 20–24 weeks.

In conclusion, we believe that transabdominal 3D multiplanar fetal neurosonography can be used efficiently to study the major anatomical structures of the fetal brain, provided there is good acquisition of the cerebral volume and the examiner has sufficient expertise in neurosonography. The superiority of 3D over 2D studies is based on the possibility of simultaneous navigation in all three cerebral planes (axial, sagittal and coronal), even when the acquired multiplanar images are obtained from the classical transabdominal approach (the transcerebellar view). Our results have shown that not only is this technique effective in the detection of the major brain structures, but it also allows identification of cerebral structures not usually identifiable by 2D ultrasound. The best time for the examination was at 20–24 weeks. The time consumed on the post-imaging analysis of the multiplanar rendered images was reasonable, making this technology even more feasible. We are not proposing that transvaginal 2D or 3D imaging of the fetal brain should not be used; the final goal of fetal neurosonography should be to achieve the best possible visualization of brain structures, taking advantage of different scanning techniques. We suggest that transabdominal 3D multiplanar neurosonography is a valuable technique and has the potential to be used in routine fetal anomaly scanning.

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