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GUIDELINES

Sonographic examination of the fetal central nervous system: guidelines for performing the 'basic examination' and the 'fetal neurosonogram'

INTRODUCTION

Central nervous system (CNS) malformations are some of the most common of all congenital abnormalities. Neural tube defects are the most frequent CNS malformations and amount to about 1–2 cases per 1000 births. The incidence of intracranial abnormalities with an intact neural tube is uncertain as probably most of these escape detection at birth and only become manifest in later life. Long-term follow-up studies suggest however that the incidence may be as high as one in 100 births[1].

Ultrasound has been used for nearly 30 years as the main modality to help diagnose fetal CNS anomalies. The scope of these guidelines is to review the technical aspects of an optimized approach to the evaluation of the fetal brain in surveys of fetal anatomy, that will be referred to in this document as a *basic examination*. Detailed evaluation of the fetal CNS (*fetal neurosonogram*) is also possible but requires specific expertise and sophisticated ultrasound machines. This type of examination, at times complemented by three-dimensional ultrasound, is indicated in pregnancies at increased risk of CNS anomalies.

In recent years fetal magnetic resonance imaging (MRI) has emerged as a promising new technique that may add important information in selected cases and mainly after 20–22 weeks[2,3], although its advantage over ultrasound remains debated[4,5].

GENERAL CONSIDERATIONS

Gestational age

The appearance of the brain and spine changes throughout gestation. To avoid diagnostic errors, it is important to be familiar with normal CNS appearances at different gestational ages. Most efforts to diagnose neural anomalies are focused around midgestation. Basic examinations are usually performed around 20 weeks' gestation.

Some abnormalities may be visible in the first and early second trimesters[6–11]. Even though these may represent a minority they usually are severe and deserve therefore special consideration. It is true that early examination requires special skills, however, it is always worthwhile to pay attention to the fetal head and the brain at earlier ages. The advantage of an early fetal neuroscan at 14–16 weeks is that the bones are thin and the brain may be evaluated from almost all angles.

Usually, a satisfying evaluation of the fetal CNS can always be obtained in the second and third trimesters of pregnancy. In late gestation, visualization of the intracranial structures is frequently hampered by the ossification of the calvarium

Technical factors

Ultrasound transducers

High frequency ultrasound trandsucers increase spatial resolution but decrease the penetration of the sound beam. The choice of the optimal transducer and operating frequency is influenced by a number of factors including maternal habitus, fetal position and the approach used. Most basic examinations are satisfactorily performed with 3–5-MHz transabdominal transducers. Fetal neurosonography frequently requires transvaginal examinations that are usually conveniently performed with transducers between 5 and 10 MHz[12,13] Three-dimensional ultrasound may facilitate the examination of the fetal brain and spine[14,15].

Imaging parameters

The examination is mostly performed with gray-scale bidimensional ultrasound. Harmonic imaging may enhance visualization of subtle anatomic details, particularly in patients who scan poorly. In neurosonographic studies, Color and power Doppler may be used, mainly to identify cerebral vessels. Proper adjustment of pulse repetition frequency (main cerebral arteries have velocities in the range of 20–40 cm/s during intrauterine life)[16] and signal persistence enhances visualization of small vessels.

BASIC EXAMINATION

Qualitative evaluation

Transabdominal sonography is the technique of choice to investigate the fetal CNS during late first, second and third trimesters of gestation in low risk pregnancies. The examination should include the evaluation of the fetal head and spine.

Two axial planes allow visualization of the cerebral structures relevant to assess the anatomic integrity of the brain[17]. These planes are commonly referred to as the *transventricular plane* and the *transcerebellar plane*. A third plane, the so-called *transthalamic plane*, is frequently added, mostly for the purpose of biometry (Figure 1). Structures that should be noted in the routine examination include the lateral ventricles, the cerebellum and cisterna magna, and *cavum septi pellucidi*. Head shape and brain texture should also be noted on these views (Table 1).

The transventricular plane

This plane demonstrates the anterior and posterior portion of the lateral ventricles. The anterior portion of the lateral ventricles (frontal or anterior horns) appears as two comma-shaped fluid filled structures. They have a well defined lateral wall and medially are separated by the *cavum septi pellucidi* (CSP). The CSP is a fluid filled cavity between two thin membranes. In late gestation or the early neonatal period these membranes usually fuse to become the *septum pellucidum*. The CSP becomes visible around 16 weeks and undergoes obliteration near term gestation. With transabdominal ultrasound, it should always be visualized between 18 and 37 weeks, or with a biparietal diameter of 44–88 mm[18]. Conversely, failure to demonstrate the CSP prior to 16 weeks or later than 37 weeks is a normal finding. The value of visualizing the CSP for identifying cerebral anomalies has been debated[17]. However, this structure is easy to identify and is obviously altered with many cerebral lesions such as holoprosencephaly, agenesis of the corpus callosum, severe hydrocephaly and septo-optic dysplasia[19].

Table 1 Structures that are usually noted in a basic ultrasound examination of the fetal central nervous system

Head shape
Lateral ventricles
Cavum septi pellucidi
Thalami
Cerebellum
Cisterna magna
Spine

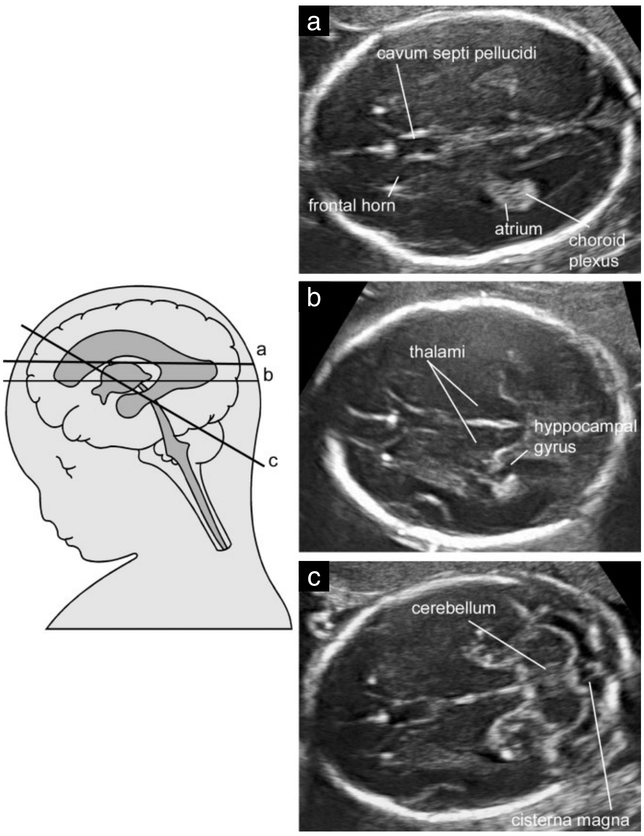

Figure 1 Axial views of the fetal head. (a) Transventricular plane; (b) transthalamic plane; (c) transcerebellar plane.

From about 16 weeks the posterior portion of the lateral ventricles (also referred to as posterior horns) is in reality a complex formed by the atrium that continues posteriorly into the occipital horn. The atrium is characterized by the presence of the glomus of the choroid plexus, which is brightly echogenic, while the occipital horn is fluid filled. Particularly in the second trimester of gestation both the medial and lateral walls of the ventricle are parallel to the midline and are therefore well depicted sonographically as bright lines. Under normal conditions the glomus of the choroid plexus almost completely fills the cavity of the ventricle at the level of the atrium being closely apposed to both the medial or lateral walls, but in some normal cases a small amount of fluid may be present between the medial wall and the choroid plexus[20–23].

In the standard transventricular plane only the hemisphere on the far side of the transducer is usually clearly visualized, as the hemisphere close to the transducer is frequently obscured by artifacts. However, most severe cerebral lesions are bilateral or associated with a significant deviation or distortion of the midline echo, and it has been suggested that in basic examinations symmetry of the brain is assumed[17].

The transcerebellar plane

This plane is obtained at a slightly lower level than that of the transventricular plane and with a slight posterior tilting and includes visualization of the frontal horns of the lateral ventricles, CSP, thalami, cerebellum and cisterna magna. The cerebellum appears as a butterfly shaped structure formed by the round cerebellar hemispheres joined in the middle by the slightly more echogenic cerebellar vermis. The cisterna magna or cisterna cerebello-medullaris is a fluid filled space posterior to the cerebellum. It contains thin septations, that are normal structures and should not be confused with vascular structures or cystic abnormalities. In the second half of gestation the depth of the cisterna magna is stable and should be 2–10 mm[17]. Early in gestation the cerebellar vermis has not completely covered the fourth ventricle, and this may give the false impression of a defect of the vermis. In later pregnancy such a finding may raise the suspicion of a cerebellar abnormality but prior to 20 weeks' gestation this is usually a normal finding[24].

Transthalamic plane

A third scanning plane, obtained at an intermediate level, is also frequently used in the sonographic assessment of the fetal head, and is commonly referred to as the *transthalamic plane* or *biparietal diameter plane*. The anatomic landmarks include, from anterior to posterior, the frontal horns of the lateral ventricles, the *cavum septi pellucidi,* the thalami and the hippocampal gyruses[25]. Although this plane does not add significant anatomic information to that obtained from the transventricular and transcerebellar planes, it is used for biometry of the fetal head. It has been proposed that, particularly in late gestation, this section plane is easier to identify and allows more reproducible measurements than does the transventricular plane[25].

The fetal spine

The detailed examination of the fetal spine requires expertise and meticulous scanning, and the results are heavily dependent upon the fetal position. Therefore, a full detailed evaluation of the fetal spine from every projection is not a part of the basic examination. The most frequent of the severe spinal abnormalities, open spina bifida, is usually associated with abnormal intracranial anatomy. However, a longitudinal section of the fetal spine should always be obtained because it may reveal, at least in some cases, other spinal malformations including vertebral abnormalities and sacral agenesis. Under normal conditions, a longitudinal section of the spine from about 14 weeks' gestation demonstrates the three ossification centers of the vertebrae (one inside the body, and one at the junction between the lamina and pedicle on each side) that surround the neural canal, and that appear as either two or three parallel lines depending upon the orientation of the sound beam. In addition, attempt should be made to demonstrate the intactness of the skin overlying the spine either on transverse or longitudinal views.

Quantitative evaluation

Biometry is an essential part of the sonographic examination of the fetal head. In the second trimester and third trimester, a standard examination usually includes the measurement of the biparietal diameter, head circumference and internal diameter of the atrium. Some also advocate measurement of the transverse cerebellar diameter and cisterna magna depth.

Biparietal diameter and head circumference are commonly used for assessing fetal age and growth and may also be useful to identify some cerebral anomalies. They may be measured either in the transventricular plane or in the transthalamic plane. Different techniques can be used for measuring the biparietal diameter. Most frequently the calipers are positioned outside the fetal calvarium (so called outside to outside measurement)[26]. However, some of the available charts have been produced using an outer to inner technique to avoid artifacts generated by the distal echo of the calvarium[25]. The two approaches result in a difference of a few millimeters that may be clinically relevant in early gestation. It is important therefore to know the technique that was used while constructing the reference charts that one uses. If the ultrasound equipment has ellipse measurement capacity, then head circumference can be measured directly by placing the ellipse around the outside of the skull bone echoes. Alternatively, the head circumference (HC) can be calculated from biparietal diameter (BPD) and occipitiofrontal diameter (OFD) by using the equation $HC = 1.62 \times (BPD + OFD)$. The ratio of the biparietal diameter over the occipitofrontal diameter is usually 75–85%. Moulding of the fetal head particularly in early gestation is however frequent, and most fetuses in breech presentation have some degree of dolicocephaly.

Measurement of the atrium is recommended because several studies suggest that this is the most effective approach for assessing the integrity of the ventricular system[22], and ventriculomegaly is a frequent marker of abnormal cerebral development. Measurement is obtained at the level of the glomus of the choroid plexus, perpendicular to the ventricular cavity, positioning the calipers inside the echoes generated by the lateral walls (Figure 2). The measurement is stable in the second and early third trimesters, with a mean diameter of 6–8 mm[20,22,27] and is considered normal when less than 10 mm[27–32]. Most of the biometric studies on the size of the lateral ventricles have used ultrasound equipment that provided measurements in millimeters[33].

As, with modern equipment, measurements are given in tenths of millimeters, it is uncertain which is the most reasonable cut-off value. We believe that particularly at midgestation a value of 10.0 mm or greater should be considered suspicious.

The transverse cerebellar diameter increases by about one millimeter per week of pregnancy between 14 and 21 menstrual weeks. This measurement, along with the head circumference and the biparietal diameter is helpful to assess fetal growth. The depth of the cisterna magna measured between the cerebellar vermis and the internal side of the occipital bone is usually 2–10 mm[34]. With dolicocephaly, measurements slightly larger than 10 mm may be encountered.

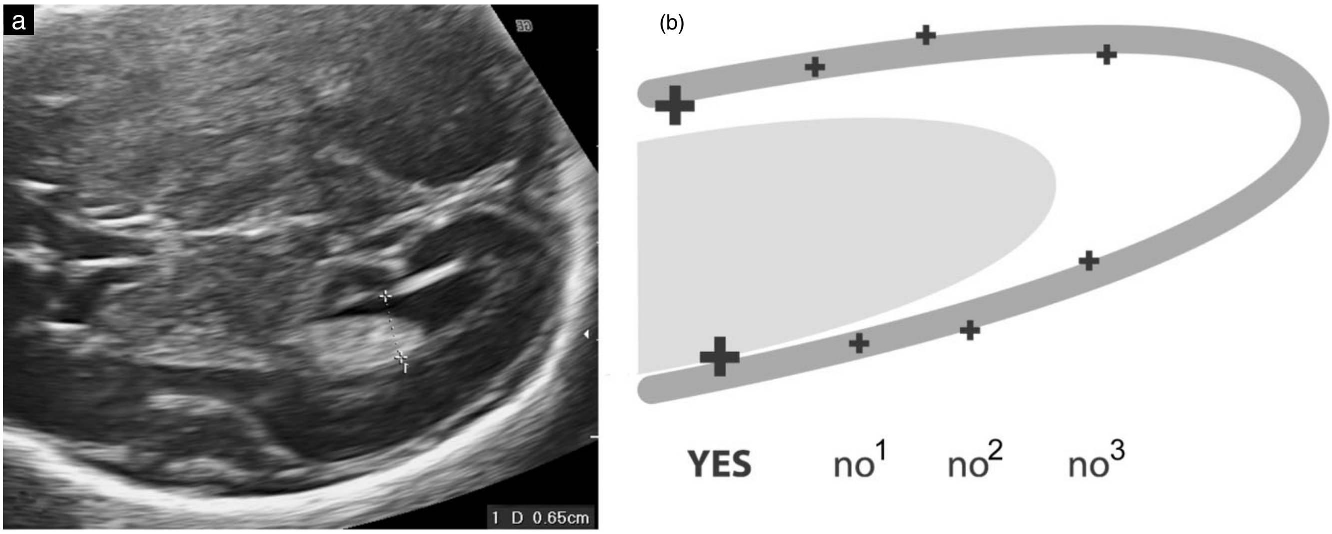

Figure 2 (a) Measurement of the atrium of the lateral ventricles. The calipers are positioned at the level of the glomus of the choroid plexus, inside the echoes generated by the ventricular walls; (b) diagram to illustrate correct caliper placement for ventricular measurement. Calipers are correctly placed touching the inner edge of the ventricle wall at its widest part and aligned perpendicular to the long axis of the ventricle (YES). Incorrect placements include middle–middle (no[1]), outer–outer (no[2]), and placement that is too posterior in the narrower part of the ventricle or not perpendicular to the ventricle axis (no[3]).

FETAL NEUROSONOGRAM

It is commonly accepted that dedicated fetal neurosonography has a much greater diagnostic potential than that of the standard transabdominal examination, and is particularly helpful in the evaluation of complex malformations. However, this examination requires a grade of expertise that is not available in many settings and the method is not yet universally used. Dedicated fetal neurosonography is useful in patients with an increased risk of CNS anomalies, including cases in which the basic examination identifies suspicious findings.

The basis of the neurosonographic examination of the fetal brain is the multiplanar approach, that is obtained by aligning the transducer with the sutures and fontanelles of the fetal head[12,13]. When the fetus is in vertex presentation, a transabdominal/transvaginal approach can be used. In fetuses in breech presentation, a transfundal approach is used, positioning the probe parallel instead of perpendicular to the abdomen. Vaginal probes have the advantage of operating at a higher frequency than do abdominal probes and therefore allow a greater definition of anatomical details. For this reason, in some breech presenting fetuses an external cephalic version may be considered in order to use the transvaginal approach.

Evaluation of the spine is a part of the neurosonographic examination and is performed using a combination of axial, coronal and sagittal planes.

The neurosonographic examination should include the same measurements that are commonly obtained in a basic examination: the biparietal diameter, head circumference and the atrium of the lateral ventricles. The specific measurements obtained may vary also depending upon the gestational age and the clinical setting.

Fetal brain

Whether the exam is performed transvaginally or transabdominally, proper alignment of the probe along the correct section planes usually requires gentle manipulation of the fetus. A variety of scanning planes can be used, also depending upon the position of the fetus[12]. A systematic evaluation of the brain usually includes the visualization of four coronal and three sagittal planes. In the following, a description of the different structures that can be imaged in the late second and third trimesters is reported. Apart from the anatomic structures, fetal neurosonography should also include evaluation of the convolutions of the fetal brain that change throughout gestation[35–38].

Coronal planes (Figure 3)

The transfrontal plane or Frontal-2 plane. The visualization of this plane is obtained through the anterior fontanelle and depicts the midline interhemispheric fissure and the anterior horns of the lateral ventricles on each side. The plane is rostral to the genu of the corpus callosum and this explains the presence of an uninterrupted interhemispheric fissure. Other structures observed are the sphenoidal bone and the ocular orbits.

The transcaudate plane or Mid-coronal-1 plane[12]. At the level of the caudate nuclei, the genu or anterior portion of the corpus callosum interrupts the continuity of the interhemispheric fissure. Due to the thickness of the genu in coronal planes it is observed as a more echogenic structure than the body of the corpus callosum. The *cavum septi pellucidi* is depicted as an anechogenic triangular structure under the corpus callosum. The lateral ventricles are found at each side surrounded by the brain cortex. In a more lateral position the Sylvian fissures are clearly identified.

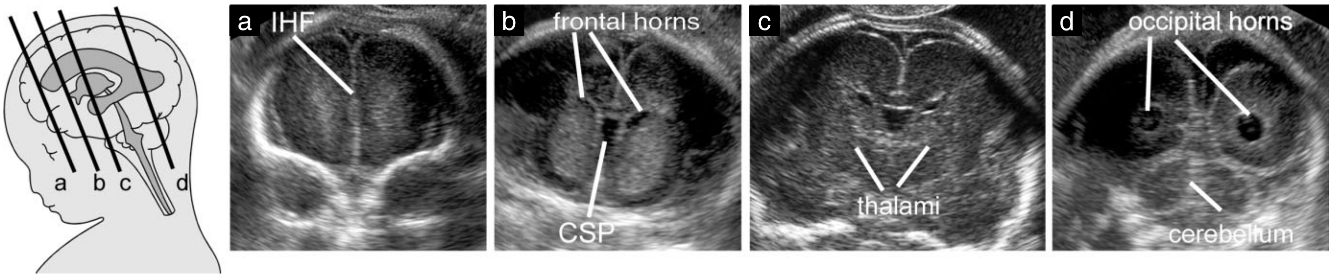

Figure 3 Coronal views of the fetal head. (a) Transfrontal plane; (b) transcaudate plane; (c) transthalamic plane; (d) transcerebellar plane. CSP, *cavum septi pellucidi*; IHF, interhemispheric fissure.

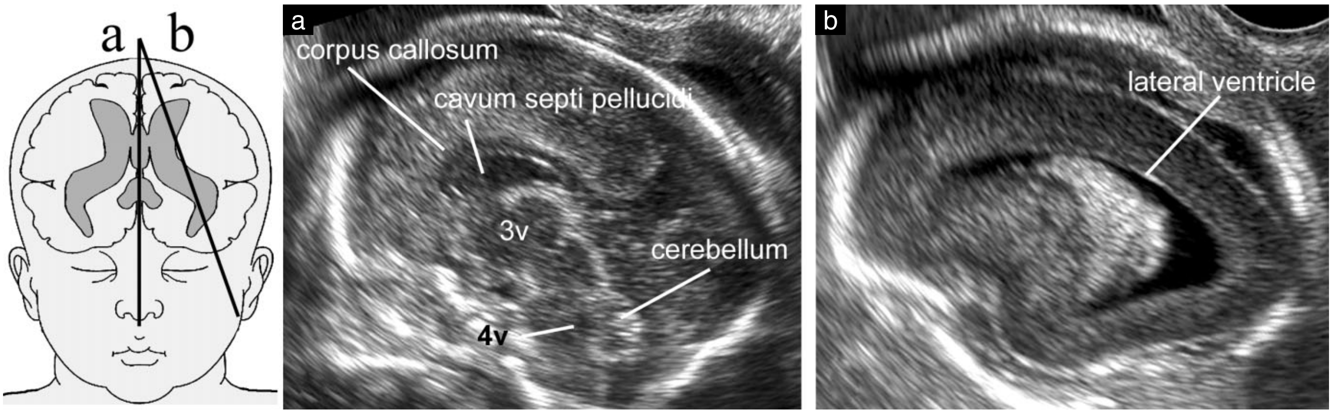

Figure 4 Sagittal planes of the fetal head. (a) Midsagittal plane; (b) parasagittal plane. 3v, third ventricle; 4v, fourth ventricle.

The transthalamic plane or Mid-coronal-2 plane[12]. Both thalami are found in close apposition but in some cases the third ventricle may be observed in the midline with the interventricular foramina and the atrium of the lateral ventricles with the choroid plexus slightly cranial on each side (*Mid-coronal-3 plane*). Close to the cranial base and in the midline the basal cistern contains the vessels of the circle of Willis and the optic chiasma.

The transcerebellar plane or Occipital-1 and 2 plane. This plane is obtained through the posterior fontanels and enables visualization of the occipital horns of the lateral ventricles and the interhemispheric fissure. Both cerebellar hemispheres and the vermis are also seen in this plane.

Sagittal planes (Figure 4)

Three sagittal planes are usually studied: the midsagittal; and the parasagittal of each side of the brain.

The *midsagittal or median plane*[12] shows the corpus callosum with all its components; the *cavum septi pellucidi*, and in some cases also the *cavum vergae* and *cavum veli interpositi*, the brain stem, pons, vermis and posterior fossa. Using color Doppler the anterior cerebral artery, pericallosal artery with their branches and the vein of Galen may be seen.

The *parasagittal or Oblique plane-1*[12] depicts the entire lateral ventricle, the choroid plexus, the periventricular tissue and the cortex.

Fetal spine

Three types of scanning planes can be used to evaluate the integrity of the spine. The choice depends upon the fetal position. Usually, only two of these scanning planes are possible in a given case.

In *transverse planes or axial planes,* the examination of the spine is a dynamic process performed by sweeping the transducer along the entire length of the spine and at the same time keeping in the axial plane of the level being examined (Figure 5). The vertebrae have different anatomic configurations at different levels. Fetal thoracic and lumbar vertebrae have a triangular shape, with the ossification centers surrounding the neural canal. The first cervical vertebrae are quadrangular in shape, and sacral vertebrae are flat.

In *sagittal planes* the ossification centers of the vertebral body and posterior arches form two parallel lines that converge in the sacrum. When the fetus is prone, a true sagittal section can also be obtained, directing the ultrasound beam across the unossified spinous process. This allows imaging of the spinal canal, and of the spinal cord within it (Figure 6). In the second and third trimesters of gestation the conus medullaris is usually found at the level of L2-L3[39].

In *coronal planes*, one, two or three parallel lines are seen, depending upon the orientation of the sound beam (Figure 7).

Integrity of the neural canal is inferred by the regular disposition of the ossification centers of the spine and the presence of soft tissue covering the spine. If a true sagittal

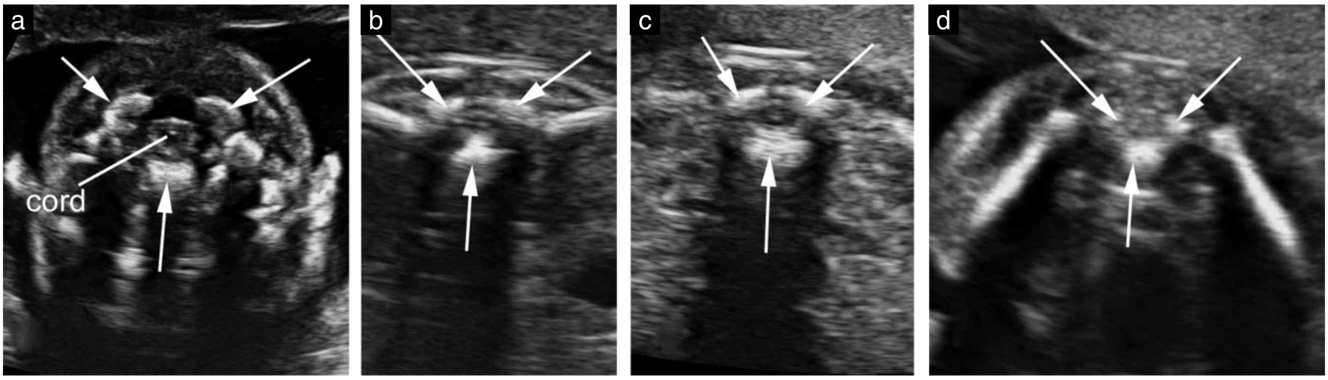

Figure 5 Axial views of the fetal spine at different levels. (a) Cervical; (b) thoracic; (c) lumbar; (d) sacral. The arrows point to the three ossification centers of the vertebrae. Note the intact skin overlying the spine. On images a–c the spinal cord is visible as a hypoechoic ovoid with central white dot.

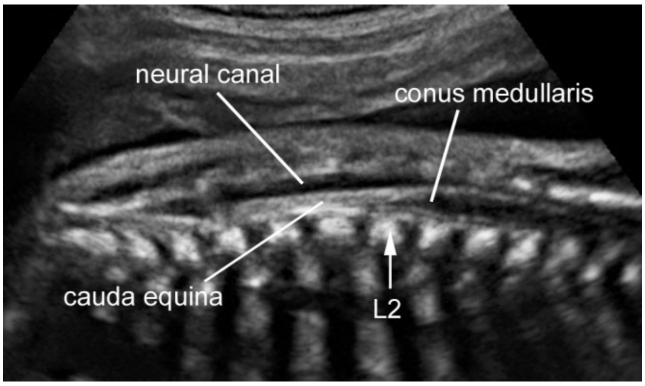

Figure 6 Sagittal view of the fetal spine at midgestation. Using the unossified spinous process of the vertebrae as an acoustic window, the contents of the neural canal are demonstrated. The conus medullaris is normally positioned at the level of the second lumbar vertebra (L2).

section can be obtained, visualizing the conus medullaris in its normal location further strengthens the diagnosis of normalcy.

EFFECTIVENESS OF ULTRASOUND EXAMINATION OF THE FETAL NEURAL AXIS

In a low risk pregnancy around midgestation, if the transventricular plane and the transcerebellar plane are satisfactorily obtained, the head measurements (head circumference in particular) are within normal limits for gestational age, the atrial width is less than 10.0 mm and the cisterna magna width is between 2–10 mm, many cerebral malformations are excluded, the risk of a CNS anomaly is exceedingly low and further examinations are not indicated[17].

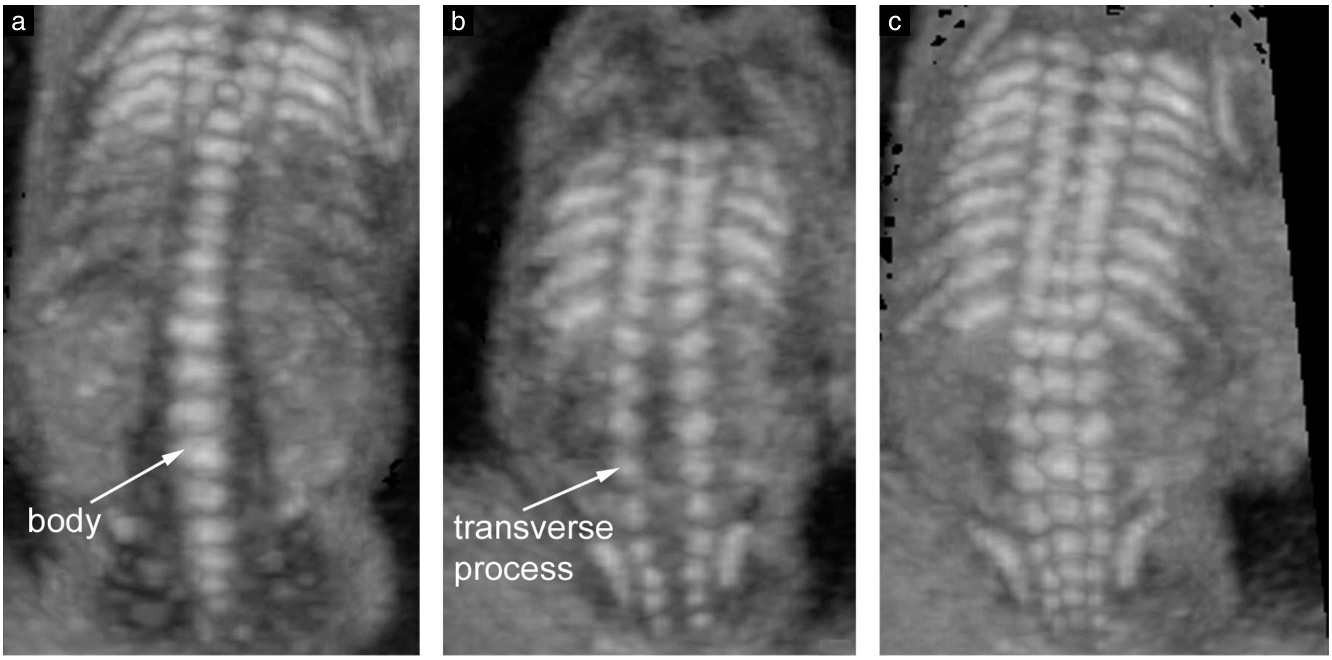

Figure 7 Coronal views of the fetal spine. These images were obtained with three-dimensional ultrasound from the same sonographic volume using different angulations and beam-thicknesses. (a) A thin ultrasound beam is oriented through the bodies of the vertebrae; (b) the same ultrasound beam is oriented more posteriorly to demonstrate the posterior arches of the vertebrae; (c) a thick ultrasound beam is used to demonstrate simultaneously the three ossification centers.

It is beyond the scope of these guidelines to review the available literature on the sensitivity of antenatal ultrasound in the prediction of neural anomalies. Some studies of low risk patients undergoing basic examinations have reported sensitivities in excess of 80%[40,41]. However, these results probably greatly overestimate the diagnostic potential of the technique. These surveys had invariably very short follow-up and almost only included open neural tube defects, whose recognition was probably facilitated by systematic screening with maternal serum alphafetoprotein. Diagnostic limitations of prenatal ultrasound are well documented and occur for a number of reasons[42]. Some even severe anomalies may be associated with only subtle findings in early gestation[43]. The brain continues to develop in the second half of gestation and into the neonatal period thus limiting the detection of anomalies of neuronal proliferation (such as microcephaly[44], tumors[45] and cortical malformations[42]). Also, some cerebral lesions are not due to faulty embryological development but represent the consequence of acquired prenatal or perinatal insults[46–48]. Even in expert hands some types of anomalies may be difficult or impossible to diagnose *in utero*, in a proportion that is yet impossible to determine with precision.

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Gustavo Malinger, MD
Fetal Neurology Clinic, Department of Obstetrics and Gynecology, Wolfson Medical Center, Tel-Aviv University, Israel

Ana Monteagudo, MD
Department of Obstetrics and Gynecology, New York University School of Medicine, New York, USA

Gianluigi Pilu, MD
Department of Obstetrics and Gynecology, University of Bologna, Italy

Ilan Timor-Tritsch, MD
Department of Obstetrics and Gynecology, New York University School of Medicine, New York, USA

Ants Toi, MD
Department of Medical Imaging, Mount Sinai Hospital, University of Toronto, Canada

Copies of this document will be available at: http://www.isuog.org

ISUOG Secretariat
Unit 4, Blythe Mews
Blythe Road
London W14 0HW, UK
e-mail: info@isuog.org

