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Chapter 2

Neonatal cranial ultrasonography: how to optimize its performance

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Abstract

Cranial ultrasonography (CUS) is an excellent and non-invasive tool for brain imaging during the neonatal period. It is traditionally performed through the anterior fontanel. Although the advantages of CUS are numerous, there are also diagnostic limitations. Alternative imaging techniques including the use of different transducer types and frequencies and of additional acoustic windows can improve image quality and the diagnostic accuracy of CUS. This review will focus on techniques to be applied for optimizing the performance of CUS in the newborn infant.

Introduction

Cranial ultrasonography (CUS) is an essential part of the routine standard of care in high-risk neonates. Its major advantages are that it is safe, relatively inexpensive, and can be performed at the bedside, with little disturbance to the infant. It can be initiated at an early stage and repeated as often as necessary, making it the most suitable tool for serial imaging of the neonatal brain (1).

Since the introduction in the late 1970s, image quality has significantly improved and with optimal settings CUS has become a reliable tool for detecting congenital and acquired brain anomalies and assessing brain maturation in both preterm and full-term neonates.

Although the advantages of CUS are numerous, there are some limitations. CUS is routinely performed through the anterior fontanel (AF). If settings are optimized for neonatal brain imaging, this provides an excellent view of most supratentorial structures, but evaluation of the most peripheral and superficial structures located at the convexity of the cerebral hemispheres may remain difficult. Visualization of structures located far away from the transducer, such as the cerebellum, may also be less optimal (1).

Adapting focus and transducer frequency and using different transducers may overcome some of these limitations. Furthermore, the use of supplemental acoustic windows, including the mastoid fontanel (MF), the posterior fontanel (PF) and the temporal windows (TW) enables a better view of structures located further away from the AF and a better visualization of the posterior fossa, brain stem, and the occipital regions of the brain (1-6).

This review will focus on different techniques that can optimize the performance of CUS in the newborn infant and covers the following issues:

1. General technical considerations
2. Standard CUS views through the anterior fontanel
3. Adapting transducer frequency and focus
4. The use of different transducer types
5. The use of alternative acoustic windows
 - a. mastoid fontanel
 - b. posterior fontanel
 - c. temporal window

General technical considerations

Neonatal CUS should be performed at the bedside, by an experienced sonographer who is aware of the needs of the sick newborn infant and who is familiar with normal ultrasound anatomy, brain maturation, and frequently encountered anomalies of the newborn brain (1).

A high resolution, real-time, 2D ultrasound machine should be equipped with special settings for the newborn infants' brain and with a multifrequency transducer or different frequency transducers (5, 7.5 and 10 MHz). The transducer should be small enough to fit the AF of the (preterm) neonate.

It is essential to record the images for patient archives and teaching purposes. Images can be printed and kept with the patients' files, but facilities for centralized digital image storage are preferred.

Standard CUS views through the anterior fontanel

Images through the AF should be recorded in at least six coronal and five sagittal planes as described by van Wezel-Meijler (1). Anterior coronal views should include the frontal lobes and frontal horns of the lateral ventricles, anterior parts of the parietal and temporal lobes, the basal ganglia, and the body of the lateral ventricles. Posterior coronal views should include posterior parts of the parietal and temporal lobes, the occipital lobes, the occipital horns of the ventricular system and the posterior fossa (7). The transducer can be angled laterally for visualization of superficial structures at the convexity of the cerebral hemispheres. A midline sagittal view should include the corpus callosum, cavum septum pellucidum, third and fourth ventricle, aqueduct, pons, mesencephalon, cerebellar vermis and cisterna magna. Parasagittal views should include the right and left lateral ventricles, choroid plexus, periventricular white matter, thalamus and basal ganglia. The angulation of the probe should be sufficient to include the Sylvian fissure and insula on each side (7).

In addition to the standard planes, the whole brain should be scanned to obtain an overview of its appearance and to allow detection of possible abnormalities. Any suspected lesion should be visualized in both planes (1).

Adapting transducer frequency and focus

In neonatal CUS, most brain structures are located close to the transducer. This allows the use of high frequency transducers with a high resolution. Usually, good quality images can be obtained using a broadband transducer frequency of 7.5 MHz. This enables detailed visualization of the ventricular system and periventricular white matter, while penetration is still sufficient for visualization of the deep grey matter structures. However, in some cases more detailed assessment of superficial structures located at the convexity of the cerebral hemispheres, including the sub-arachnoid spaces, cortex, and subcortical white matter is necessary. In these cases, additional scanning with a higher frequency of 10 MHz provides more detailed information. This is, for example, indicated in (near) term neonates with (suspected) hypoxic-ischemic brain injury. While in preterm infants brain injury is often confined to the (peri)-ventricular areas and/or white matter, in (near) term infants the cortical and subcortical areas may be involved (8,9). Additional scanning with a higher frequency is also indicated in neonates with suspicion of focal infarction or white matter injury in the peripheral regions of the brain (Figure 1). CUS is not the optimal imaging modality for the detection of extracerebral hemorrhage and abnormal cortical development, such as cortical dysplasia. However, when higher transducer frequencies are applied, such abnormalities can sometimes be detected. In very small premature neonates with a very short distance between the brain structures and the transducer, a frequency of 10 MHz can further optimize image quality.

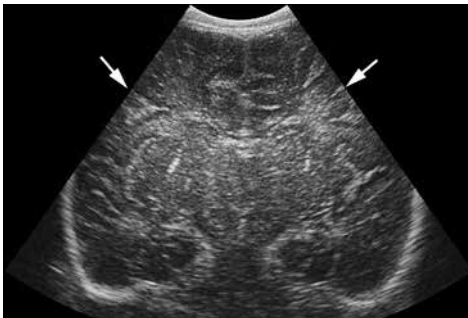


Figure 1. Coronal CUS scan, at the level of the bodies of the lateral ventricles, performed through the AF with a CV probe and transducer frequency of 10 MHz, showing increased echogenicity in the periventricular and subcortical white matter (arrows) in a term born infant with parechovirus meningo-encephalitis.

A limitation of using a high frequency transducer is the loss of penetration. A lower transducer frequency allows better penetration and a better view of deeper structures such as the deep grey matter, the temporal lobes, and the posterior fossa. When abnormalities in these areas are suspected, additional scanning at a lower frequency of 5 MHz is helpful. In the (near) term born asphyxiated infant this can improve visualization of the thalami and basal ganglia, areas that are vulnerable to hypoxic-ischemic injury in this age group (8,9). In preterm infants using a lower transducer frequency can help to detect cerebellar injury while scanning through the AF (Figure 2A) (10). In addition, in large full-term neonates and in infants with thick hair a transducer frequency of 5 MHz is often necessary to obtain enough penetration for sufficient image quality (1).

A disadvantage of using a lower transducer frequency is the loss of resolution. In addition to changing transducer frequency, the focus can be adapted to improve image quality. At the depth of the focus point, the ultrasound beam has the narrowest width. This improves resolution and allows more detailed images of the area of interest. Alternatively, two focus points can be applied, that can be adapted to the location of interest, allowing detailed visualization of the area between these points.

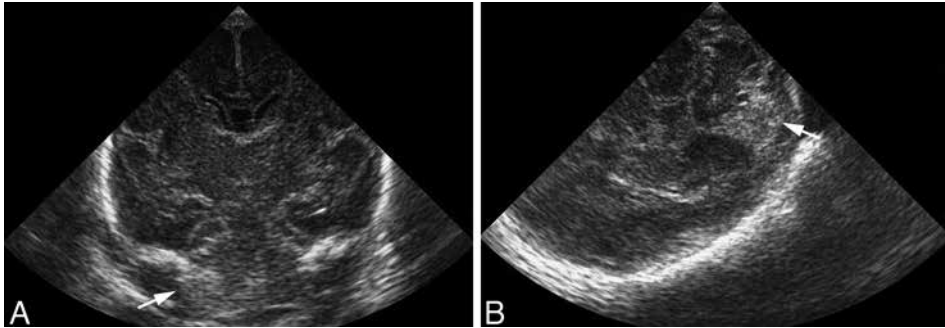


Figure 2A. Coronal CUS scan at the level of the bodies of the lateral ventricles, performed through the AF with a PA probe and transducer frequency of 5 MHz in a preterm infant, showing an echodensity in the right cerebellar hemisphere (arrow) suspect for hemorrhage.

Figure 2B. Coronal CUS scan of the posterior fossa, performed through the left MF with a PA probe and transducer frequency of 7.5 MHz in the same infant, clearly demonstrating hemorrhage in the right cerebellar hemisphere (arrow).

The use of different transducer types

Ultrasound transducers are available in many shapes and sizes. The length of the array of the transducer determines its number of crystal elements, the shape determines its field of view. The neonatal CUS transducer should have a small footprint to match the size of the AF. In small preterm infants only a pediatric phased array (PA) transducer may be small enough to fit the AF, while still providing a sufficiently large acoustic window. The ultrasound beam starts at one point and diverges; therefore the far field resolution of this probe is limited. If the size of the fontanel allows the use of a larger convex (CV) transducer, this improves image quality as the size of the acoustic window becomes larger, enabling visualization of the more peripheral and superficial brain structures (Figure 3). In addition, a CV probe provides sharper images and enables better near field resolution. The ultrasound beam is divergent, leading to some loss of far field resolution. However, the far field resolution of the CV probe remains superior as compared to the PA probe (Figure 4). In infants with ventricular dilatation, the use of a CV probe with a larger scan area is essential. In these neonates, when using the PA probe, visualization of brain structures is limited as the small field of view is often taken up by the dilated ventricles (Figure 5).

In the linear array (LA) transducer, the crystal elements are arranged along a line, resulting in a parallel arrangement of the ultrasound beam. This provides optimal image quality. The very high scanning frequency is useful for Doppler sonography of the superior sagittal sinus and for detailed visualization of superficial structures. However, because of its large size, this transducer is not suitable for routine neonatal CUS procedures.

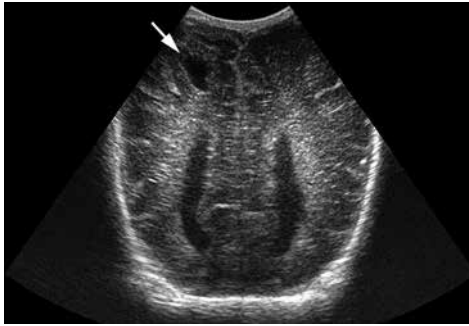


Figure 3. Coronal CUS scan, at the level of the trigone of the lateral ventricles, performed through the AF with a CV probe and transducer frequency of 7.5 MHz in a preterm infant, showing a large cystic lesion in the subcortical white matter on the right side (arrow).



Figure 4. Normal coronal CUS (AF view) in a preterm infant at the level of the bodies of the lateral ventricles, with transducer frequency set at 7.5 MHz. The far field resolution of the CV probe is sufficient to give a clear view of the temporal lobes (short arrows) and posterior fossa (arrow).

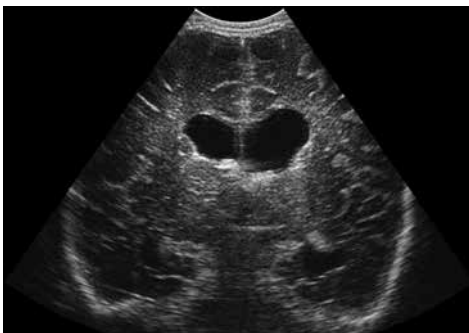


Figure 5. Coronal CUS scan, at the level of the bodies of the lateral ventricles, performed through the AF with a CV probe and transducer frequency of 10 MHz in a preterm infant with severe post hemorrhagic ventricular dilatation, with sufficient size of the acoustic window to enable visualization of the periventricular white matter.

The use of alternative acoustic windows

Mastoid fontanels

The AF is an excellent acoustic window to obtain good views of supratentorial structures, but visualization of infratentorial structures is less optimal because of their location further away from the transducer. Decreasing transducer frequency and directing focus on the posterior fossa can improve penetration but at the expense of resolution. In addition, the echogenic tentorium and vermis impede detailed imaging. When additionally using the MF (also known as posterolateral fontanel), the transducer is closer to the posterior fossa structures, allowing the use of higher transducer frequencies with better resolution. The structures can be approached at different angles, avoiding the echogenic tentorium.

The MF is located at the junction of the posterior parietal, temporal and occipital bones (2,3). The infant is positioned with the head to one side, and the transducer is placed over the MF, behind the helix of the ear, just above the tragus and then moved slightly, using real-time imaging until an appropriate view of the posterior fossa is obtained. Images can be performed in axial and coronal planes. Axial images are obtained with the transducer almost parallel to the orbitomeatal plane. Coronal views are obtained with the transducer placed along the coronal suture (1,4). Superior axial views include the cerebral peduncles, perimesencephalic and quadrigeminal cisterns, aqueduct and superior vermis. Middle axial views include the vermis, fourth ventricle, cerebellar hemispheres and cisterna magna. Inferior axial views include the inferior part of both cerebellar hemispheres and the inferior vermis (Figure 6A,B).

Superior anterior coronal views include the temporal horns, tentorium, fourth ventricle, vermis, cerebellar hemispheres and cisterna magna. Inferior posterior coronal views include the lateral ventricles, tentorium, cerebellar hemispheres and cisterna magna (Figure 6C,D).

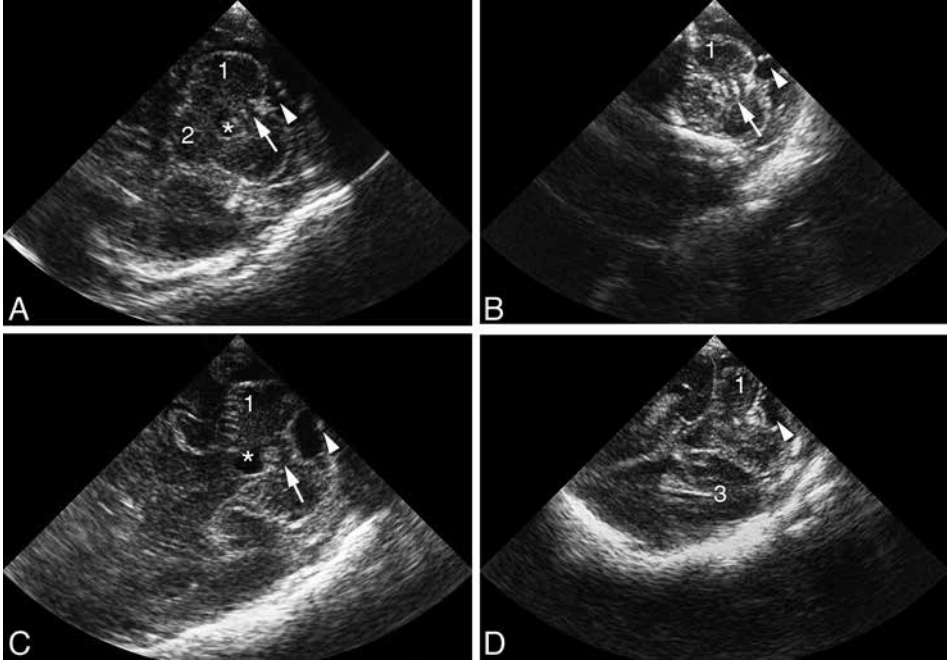


Figure 6. (A) middle and (B) inferior axial CUS scan, and (C) superior anterior and (D) inferior posterior coronal CUS scan of the posterior fossa, performed through the MF with a PA probe and transducer frequency of 7.5 MHz in a preterm infant, showing cerebellar hemispheres (1), pons (2), lateral ventricles (3), fourth ventricle (asterisk), vermis (arrow) and cisterna magna (arrowhead).

Intraventricular hemorrhage (IVH) and ventricular dilatation (PHVD)

Germinal matrix hemorrhage and intraventricular hemorrhage extending into the frontal horn and body of the lateral ventricle is usually well seen while using the AF, but hemorrhage extending into the fourth ventricle, cisterna magna and subdural spaces is more difficult to detect with this approach. The MF approach provides a better visualization of hemorrhage in these structures. This may have clinical consequences, as infants with posterior fossa hemorrhage are at increased risk of developing PHVD and require intensive CUS examinations (11). In addition, scanning through the MF gives a better overview of the entire ventricular system and can help distinguishing between obstructive and communicating forms of hydrocephalus (Figure 7). In infants with unexplained ventricular dilatation, imaging through the MF should be performed to look for posterior fossa abnormalities, including hemorrhage and malformations (4).



Figure 7. Coronal CUS scan of the posterior fossa, performed through the MF with a PA probe and transducer frequency of 7.5 MHz in a preterm infant with post hemorrhagic ventricular dilatation, showing blood residue in third ventricle (arrow), connecting via dilated aqueduct (arrowhead) with a dilated fourth ventricle (asterisk).

Acquired cerebellar lesions

Cerebellar hemorrhage and abscesses are the most commonly described acquired cerebellar lesions in newborns. Cerebellar hemorrhage can occur in association with supratentorial hemorrhage, but can also be an isolated finding with a clinically silent presentation. The exact incidence is unknown, but recent neuroimaging studies have shown that experienced sonographers can detect cerebellar hemorrhage in 19% of very preterm infants (birth weight < 750 g) by using the MF approach (12). Merrill et al. showed that consistent imaging via the MF can demonstrate cerebellar hemorrhage missed by the AF approach (5). In infants in whom cerebellar hemorrhage is detected using the AF, the MF view usually improves visualization of the lesion (Figure 2B) (6). Reliable detection of cerebellar hemorrhage in preterm neonates is of importance, since it can have major impact on neurodevelopmental outcome (13,14).

Cerebellar abscesses can occur in both preterm and full-term neonates, secondary to systemic fungal or bacterial infection. Most cases have been studied by CT or MRI, but abscesses can also be detected by CUS, in particular when scanning is done through the MF (4). Early detection and appropriate treatment are of importance.

Congenital malformations

MF sonography is also a valuable tool for imaging of congenital posterior fossa anomalies such as a mega cisterna magna, arachnoid cyst, cerebellar vermis agenesis or hypoplasia, cerebellar hypoplasia, and Dandy Walker malformation or variants (Figure 8).

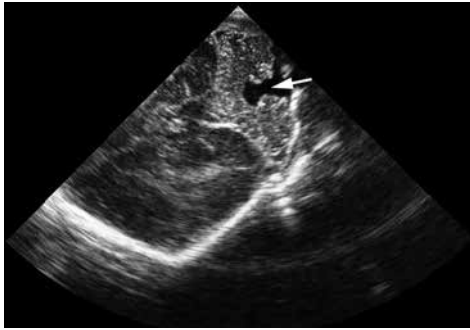


Figure 8. Coronal CUS scan of the posterior fossa, performed through the MF with a PA probe and transducer frequency of 7.5 MHz in a preterm infant with a Dandy Walker variant. The arrow indicates the vermian hypoplasia and abnormal connection between fourth ventricle and cisterna magna.

However, one should be aware of a pitfall of MF ultrasonography: under certain angles the normal communication between the fourth ventricle and the cisterna magna via the foramina of Luschka and Magendie can give a false impression of inferior vermis agenesis. Imaging at different angles in axial and coronal planes through the MF, in combination with a good quality midline sagittal image obtained through the AF, is usually sufficient to distinguish normal structures from a true Dandy Walker variant (6).

Sinovenous thrombosis

Sinovenous thrombosis is a severe condition that can affect the newborn infant. Risk factors are sepsis/meningitis, perinatal hypoxic-ischemic events and polycythemia. Color Doppler sonography can be used to identify the presence of flow in the venous system, but the deeper venous structures are difficult to visualize through the AF. Venous flow in the transverse and sigmoid sinuses can be detected by color Doppler using the MF.

Posterior fontanel

The PF is located at the junction of the lambdoid and sagittal suture (2,3). Compared to the AF, it provides a more detailed view of the occipital regions of the brain and the posterior fossa. The transducer is positioned in the middle of the PF. To facilitate transducer movement, the infant's head can be slightly rotated and lifted by placing it on a folded blanket. Images can be obtained in three coronal and five sagittal planes (1,2). The most superior coronal view includes the lateral ventricles with the choroid plexus and parts of the parietal and occipital lobes. The middle and inferior coronal views show the occipital horns, occipital lobes, tentorium, vermis and cerebellar

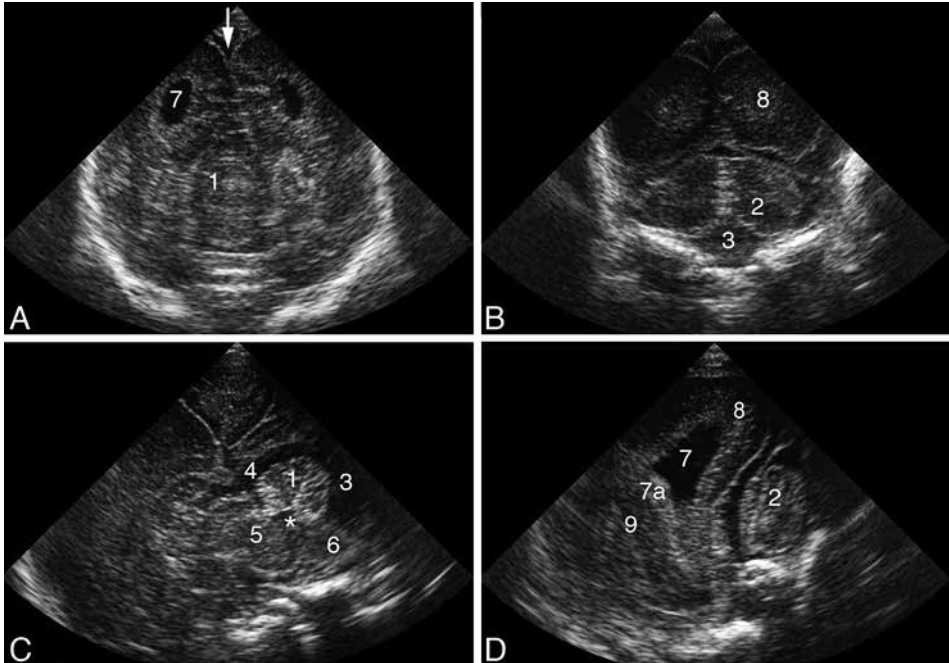


Figure 9. (A) middle and (B) inferior coronal CUS scan, and (C) midline and (D) parasagittal CUS scan performed through the PF with a PA probe and transducer frequency of 7.5 MHz in a preterm infant, showing cerebellar vermis (1) and hemispheres (2), cisterna magna (3), pericerebellar cistern (4), pons (5), medulla oblongata (6), occipital horn of lateral ventricle (7) with choroid plexus (7a), occipital periventricular white matter (8), thalamus (9), fourth ventricle (asterisk) and interhemispheric fissure (arrow).

hemispheres (Figure 9A,B). The midline sagittal view gives a detailed image of the vermis, fourth ventricle, pericerebellar cisterns, pons and medulla. The parasagittal views show the thalamus, the choroid plexus, the entire occipital horns of the lateral ventricles and the occipital periventricular white matter (Figure 9C,D).

Intraventricular hemorrhage

Small amounts of blood in the occipital horns are difficult to detect with the AF approach, especially in the absence of germinal matrix hemorrhage. According to the classification of Volpe, grade II IVH is defined as a hemorrhage with less than 50% filling of the lateral ventricle, without ventricular dilatation (15). As in these cases hemorrhage is often only present in the occipital horns, the most important contribution of PF sonography in addition to AF sonography, is the diagnosis of grade II IVH (Figure 10) (2,3).

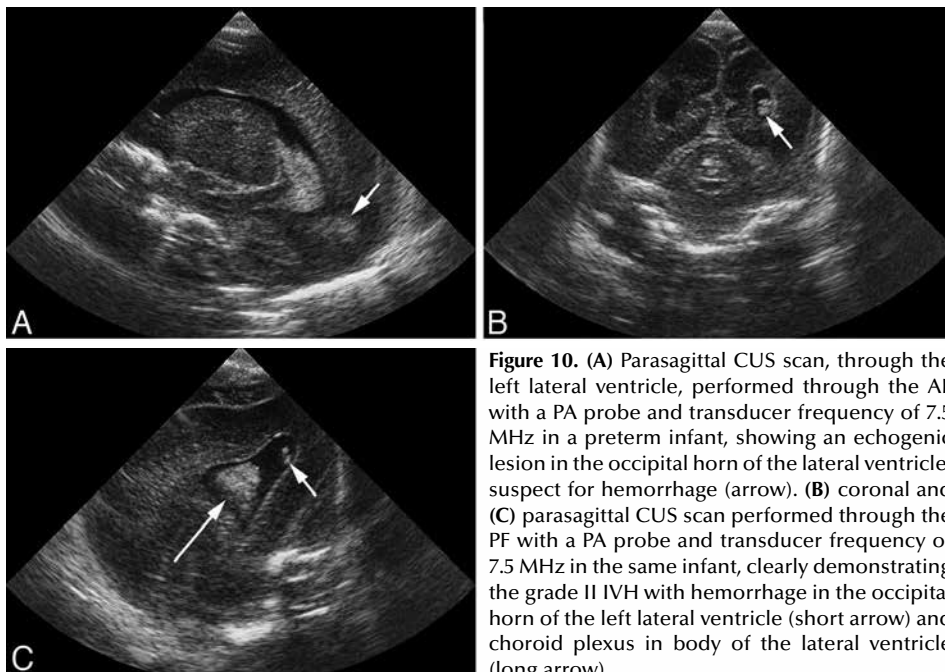


Figure 10. (A) Parasagittal CUS scan, through the left lateral ventricle, performed through the AF with a PA probe and transducer frequency of 7.5 MHz in a preterm infant, showing an echogenic lesion in the occipital horn of the lateral ventricle, suspect for hemorrhage (arrow). (B) coronal and (C) parasagittal CUS scan performed through the PF with a PA probe and transducer frequency of 7.5 MHz in the same infant, clearly demonstrating the grade II IVH with hemorrhage in the occipital horn of the left lateral ventricle (short arrow) and choroid plexus in body of the lateral ventricle (long arrow).

Posterior fossa abnormalities

Compared to the AF, the PF is located closer to the posterior fossa structures. A mid-line sagittal view can give more detailed information on the size and shape of the cerebellar vermis, fourth ventricle and cisterna magna. This can be helpful in diagnosing congenital malformations of the posterior fossa, although in our experience the MF approach is better for this purpose. On the coronal and parasagittal views the cerebellar hemispheres can be visualized and abnormal echodensities including hemorrhages can be detected. However, the MF approach is also more reliable for the detection of cerebellar hemorrhages.

Temporal windows

The TW allows a detailed transverse view of the brainstem area. The transducer is placed in a horizontal position, above the ear, approximately 1 cm above and anterior to the external auditory meatus. The transducer is then moved slightly, using real-time imaging until an appropriate image is obtained (1). The anatomic structures

that can be recognized are the mesencephalon and pons, the perimesencephalic cistern, the third ventricle, aqueduct, and the temporal lobes. This can be helpful for detecting structural abnormalities of the brainstem and brainstem hemorrhage. Furthermore, scanning through the TW window allows Doppler sonography and flow measurement within the circle of Willis (1).

Conclusions

CUS is an excellent and noninvasive tool for brain imaging during the neonatal period. Traditionally, it is performed through the AF. The use of additional acoustic windows including the MF, PF, and TW can significantly improve its diagnostic abilities and help to define abnormalities in regions that are difficult to visualize with routine CUS views. Using different transducer frequencies and several transducer types, and adapting focus points can further optimize image quality and improve the diagnostic performance of CUS.

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