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Cranial Ultrasonography

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Objectives  After completing this article, readers should be able to:
1. Describe the difference in relative reflectance of various structures in the brain.
2. Describe common imaging approaches for cranial ultrasonography.
3. Explain uses of the resistive index and pulsatility index in Doppler flow studies.
4. Describe the findings on cranial ultrasonography of intracranial hemorrhage, periventricular leukomalacia, and hydrocephalus.

Introduction
A relatively unique modality of neuroimaging is available to newborns in the form of cranial ultrasonography (CUS). Technologic advances and ever-increasing experience with obtaining and interpreting CUS images have led to its widespread acceptance, yielding valuable insight into the anatomy of the preterm and term newborn brain.

Physics and Methods of CUS
The fontanelles in the newborn provide unique windows for ultrasonographic examination of the neonatal brain. These gaps between the calvarial bones serve as acoustic windows through which sound waves of the ultrasound probe can be transmitted and received. The presence of air or bony structures in the path of the sound beam will degrade any echo signal emanating from these regions. CUS employs frequencies between 8 and 15 MHz to yield echoreflective images.

Following application of acoustic gel over the fontanelle of interest, a small (1 to 2 cm) solid-state transceiver probe is placed to obtain an adequate impedance match with the scalp. The resultant signal is processed by a computer to yield a real-time wedge or fan-shaped image that has a working focusing depth of 2 and 12 cm for a standard 8 MHz sector probe with a maximal resolution of approximately 1 to 2 mm. For higher resolution, increased sensitivity to flow, and better near-field focusing (several millimeters to 8 cm), linear phased-array probes designed with higher frequency ranges (8 to 15 MHz) and a larger number of detectors per unit area can be used. In contrast to sector probes, phase-array probes generate rectangular-shaped images of the underlying brain. However, because of their length (5 to 6 cm), which is longer than the largest fontanelle, views are obtained of only the midline or slightly off-midline structures. Further, there is a relative lack of tissue penetration at higher frequencies (ie, the higher the frequency, the less penetration of the sound beam).

Tissue Reflectance
The relative reflectance of tissue in the region of interest provides the imaging contrast to distinguish various intracerebral structures (eg, the cerebral and cerebellar sulci), midline structures (eg, the cavum septum pellucidum), third and fourth ventricles, and the posterior fossa. In addition, the reflectance allows detection of pathology such as hemor-
rhage, ischemia, or hydrocephalus. Cerebrospinal fluid (CSF) without any hemorrhage is normally anechoic, comprising the “darkest” component of a CUS. The most echogenic normal structures in the brain are the choroid plexus and the germinal matrix, a structure normally found in preterm infants. The choroid plexus, located posteriorly in the lateral ventricles and in the roof of the third ventricle, and the germinal matrix, located in the caudothalamic groove of preterm neonates, are both highly reflective because of the millions of tiny interfaces within these dense tangles of capillaries. These interfaces are approximately the same size as the wavelength of the sound beam, which causes the beam to scatter in multiple directions, including back toward the transducer. Normal gray and white matter are of medium echogenicity, with brightness somewhere between that of CSF and the choroid plexus and germinal matrix.

Blood within CSF or the brain contains millions of “miniature mirrors” in the form of clotted red blood cells, which strongly reflect sound waves and, therefore, appear sonographically brighter than either CSF or normal gray or white matter. Curiously, regions of ischemia in either the gray or white matter are also strongly reflective, generating bright echoes. The reason for this apparent anomaly is that regions of ischemia also contain microscopic regions of red blood cells that have extravasated into the interstitium.

**Imaging Approaches**

The most commonly described method for CUS is the so-called “anterior fontanelle approach” in which the probe is placed on the anterior fontanelle. The sonographer slowly angles the probe from side to side and front to back to obtain a sweep of the entire brain in at least two different planes (ie, coronal and sagittal). It is important to angle the fan of the sector probe serially as far lateral, anterior, and posterior as possible to ensure that the lateral convexities of the cerebrum and the frontal and occipital-parietal regions are visualized adequately. Typically, images are viewed real-time during CUS and prints are made of sagittal and coronal views (Fig. 1). CUS images sometimes are displayed or printed with reverse black-white contrast (ie, nonechogenic CSF in the ventricles is the whitest part of the image).

Other approaches are employed routinely to supplement the anterior fontanelle view, including the typically small posterior fontanelle view and the so-called “mastoid view” that is obtained through the smaller posterior-lateral fontanelles located immediately posterior to the ear. The posterior fontanelle view provides excellent detail of the occipital horns for assessing intraventricular hemorrhage that may be layering posteriorly and difficult to distinguish from the echogenic choroid plexus in the anterior fontanelle view. The posterior fontanelle view also is helpful in assessing the echogenicity of the periventricular white matter, which can be increased artifactually in the anterior fontanelle view because of multiple crossings of the normal tiny medullary veins and arteries within the deep white matter exactly perpendicular to the sound beam. The mastoid view yields excellent images of the cerebellum, fourth ventricle, and the remainder of the posterior fossa, structures that may be difficult to see from the more distant anterior fontanelle.
Doppler Flow Studies

Doppler measurements during CUS provide information about relative cerebral blood flow (CBF) of newborns. The Doppler signal is obtained by calculating the frequency shift of the returning sound beam reflected by the red blood cells flowing in a vessel of interest compared with that of the original pulse. Blood flowing away from the transducer has a negative shift less than the original frequency; blood flowing toward the transducer has a positive shift that is greater than the original sound beam. Doppler signals can be displayed as a continuous wave of blood velocities on a scale obtained from a graphically determined volume of interest that is electronically superimposed on the CUS images (ie, pulsed-wave Doppler). The signals also can be displayed on a color scale (typically blue for blood flowing away from the transducer and red for blood flowing toward the transducer) and electronically superimposed on the CUS images. Another display of Doppler signal is the power Doppler mode in which all flow, regardless of direction, is summed to provide a single color image of the magnitude of blood flow. Although precise quantitation of CBF currently is not possible, other calculated Doppler flow indices have been correlated to neonatal brain pathology and neurodevelopmental outcome. Relative changes in the measurements of flow velocities within the anterior or middle cerebral arteries correlate proportionately to changes in global and regional CBF.

One measure of cerebral vascular dynamics is the resistive index (RI or Pourcelot index), which is:

\[
\text{RI} = \frac{\text{peak systolic velocity} - \text{end diastolic velocity}}{\text{peak systolic velocity}}
\]

RI measurements from the anterior cerebral artery are normally slightly higher in preterm infants than term infants, averaging 0.80 (range, 0.5 to 1.0) and 0.71 (range, 0.6 to 0.8), respectively. Increases in intracranial pressure caused by hypoxic-ischemic encephalopathy, brain edema, or hydrocephalus are accompanied by elevations in RI. When intracranial pressure exceeds that of the arterial perfusion pressure, causing brain death, the diastolic flow is reversed, and eventually peak systolic flow is dampened. These Doppler flow findings have been used to support the difficult diagnosis of brain death in infants.

To improve specificity for the diagnosis of hydrocephalus, some institutions recommend serial measurements of RI with the ultrasound probe compressing the anterior fontanelle (<5 sec pressure). The percent change in the RI with compression over time correlates with direct CSF pressure measurements within the ventricles. Other markers of CBF include measurements of area under the velocity curve and velocity amplitudes (systolic, diastolic, mean velocity). The variation of blood flow velocities during the cardiac cycle can be summarized by the calculation of the pulsatility index (PI):

\[
\text{PI} = \frac{\text{peak systolic velocity} - \text{end diastolic velocity}}{\text{mean velocity}}
\]

Increased PI has been associated with the presence of a patent ductus arteriosis and may increase the risk for development of intraventricular hemorrhage (IVH).

Another pathophysiologic phenomenon that can be detected by serial Doppler measurements in the first few days of life is impaired cerebrovascular autoregulation following hypoxic-ischemic injury. Preterm infants who otherwise have the transient ability to autoregulate regional vasomotor tone and vascular cross-sectional areas lose these autonomic functions, particularly in watershed regions such as the periventricular white matter. The loss of autoregulation allows for pressure-passive flow in which the vascular bed is unable to constrict appropriately in response to increases in mean systemic arterial pressure or dilate in response to falls in mean arterial pressure. Pressure-passive flow in preterm infants who have normal mean arterial pressures causes a significant rise in peak velocity within the thalamostriate vessels (the surrogate markers of the perfusion of the periventricular white matter in preterm infants) and the vascular bed cross-sectional area. Both of these findings are associated with an increased risk for the development of intracranial hemorrhage (ICH) and periventricular leukomalacia (PVL).

Doppler CUS studies also have been used to examine the effects of therapies on neonatal CBF. One study suggested that sampling from high-lying umbilical arterial catheters had a more adverse effect on CBF velocity than sampling from low-lying catheters. However, no significant differences in the rate of IVH were found in a large prospective, randomized trial examining umbilical arterial catheter positioning.

Observable Pathology

Intracranial Hemorrhage

The most common use of CUS in the neonatal intensive care unit is to detect the presence and evolution of ICH, especially in the preterm newborn. The incidence of ICH varies most significantly with gestational age and birthweight. Extremely low-birthweight newborns (gestational age <27 wk, birthweight <750 g) are estimated to have ICH at a rate of 10 to 30 per 100 surviving newborns. The incidence of ICH decreases with increasing gestational age and is quite rare in newborns of
greater than 32 weeks’ gestational age or 1,500 g birthweight.

Although the precise mechanisms leading to the evolution of ICH remain obscure, it is generally felt that the preterm brain is at highest risk for ICH for a variety of reasons. These include: relatively late development of the end-arterial circulation during the last trimester; relatively decreased mesenchymal support for this vascular bed, particularly in the region of the germinal matrix (which normally does not involute completely until after the 33rd week of gestation); and decreased autoregulation of CBF, with the extremely preterm infant having virtual pressure-passive CBF. The rare term newborn who has ICH usually has some predisposing factor, such as a history of asphyxia or coagulation abnormalities that may be intrinsic or due to anticoagulation therapy such as that used during extracorporeal membrane oxygenation.

The most widely used classification system for ICH is that originally described by Papile and associates, which grades from 1 to 4 with increasing severity.

Grade 1 occasionally is referred to as a germinal matrix or subependymal hemorrhage. This subset of ICH is seen on CUS as an abnormally increased number of echoes in the caudothalamic groove (ie, notch) in the expected location of the germinal matrix. Normally the germinal matrix echoes taper smoothly as they course anteriorly in the caudothalamic groove. Because the germinal matrix never is located anterior to the foramen of Monro, echoes seen anterior to the foramen of Monro without tapering as they course anteriorly in the caudothalamic groove indicate hemorrhage.

Grade 2 (Fig. 2) describes extension of a germinal matrix/subependymal hemorrhage into the ventricles without any ventricular enlargement. Detection of an IVH that is echogenic in the first several days after a hemorrhage can be confused easily with normal choroid plexus (which normally can be amorphous and has multiple echogenic lumps). The observation of echogenic material within the occipital horn (posterior to the calcar avis) is diagnostic of IVH because the choroid plexus does not extend into the occipital lobe. The observation of an echogenic blood-CSF fluid level with the ventricular system is also diagnostic of IVH. The rare primary choroid plexus hemorrhage, 95% of which occur in term neonates, is considered as Grade 2 for purposes of prognostication.

Grade 3 (Fig. 3) has blood extending into the ventricles and causing ventriculomegaly at the time of the initial observation of IVH. IVH without accompanying hydrocephalus within the first 24 hours after detection is

Figure 2. Grade 2 germinal matrix hemorrhage in a preterm infant on the third day of life. Views obtained with an 8 MHz solid-state sector probe through the anterior fontanelle. A. The sagittal view demonstrates the echogenic bulbous collection of blood that bears no resemblance to the normal germinal matrix that tapers as it courses anteriorly in the caudothalamic groove and also never is seen anterior to the foramen of Monro. B. Coronal view, showing a bulbous echogenic collection of blood in the left caudothalamic groove. C. A sagittal view through the anterior fontanelle that is angled slightly more posteriorly shows an echogenic clot filling the occipital horn posterior to the calcar avis. The choroid plexus never is seen in the occipital horn.
considered as a Grade 2 hemorrhage even if the infant develops posthemorrhagic hydrocephalus (PHH) at a later date.

Grade 4 (Fig. 4) describes a germinal matrix hemorrhage that dissects and extends into the adjacent brain parenchyma, irrespective of the presence or absence of IVH. It is also referred to as an intraparenchymal hemorrhage (IPH) when found elsewhere in the parenchyma. Bleeding extending into the periventricular white matter in association with an ipsilateral IPH has been classified as periventricular hemorrhagic venous infarction (PHVI).

It is useful to note that 70% of all germinal matrix hemorrhages in preterm infants occur by days 3 and 4 of life; 90% occur within the first week of life. Once diagnosed, 90% of germinal matrix hemorrhages do not progress in severity after 24 hours. Hemorrhages occurring 1 week or more after birth almost invariably are Grades 1 or 2 and have minor to no clinical significance.

The final reading of a CUS study for ICH should include a narrative commentary beyond a specific grading that includes a description of both hemispheres and a comparison to previous studies. For Grade 2 IVH, it may be helpful to know the volume of the ventricles that is occupied by blood. Similarly, Grade 3 ICH may have minimal to massive ventriculomegaly, which is important to know when deciding about possible surgical intervention.

The severity of ICH, as reflected by the Papile or other grading systems, generally correlates with increasing risk of long-term neurodevelopmental abnormalities. Premature infants who suffer Grade 1 and 2 germinal matrix

Figure 3. Grade 3 germinal matrix hemorrhage 3 and 10 days after birth. Views are obtained with an 8 MHz solid-state sector probe through the anterior fontanelle. A. On day 3 of life, the coronal view demonstrates massive bilateral intraventricular and germinal matrix hemorrhage with ventricular dilation. B. The sagittal view confirms the presence of massive intraventricular and germinal matrix hemorrhage. On day 10 of life, progressive posthemorrhagic hydrocephalus is evident on the coronal (C) and sagittal (D) views. The development of ependymitis is represented as increased echogenicity of the wall of the lateral ventricles. This transient phenomenon is seen several days after a hemorrhage and is an ependymal reaction to intraventricular heme that persists for at least 2 to 3 weeks.
hemorrhages are at a minimally increased risk of neuro-developmental abnormalities compared with preterm neonates of the same size and gestation (a risk that still is higher than that of term newborns). Grade 3 ICH has a greater risk for central nervous system (CNS) sequelae when hydrocephalus progresses to the point of requiring surgical drainage or shunting. Grade 4 ICH that is severe and bilateral has the most guarded prognosis for normal neurodevelopmental outcome.

Recommendations for timing of CUS in high-risk very low-birthweight newborns vary and depend greatly upon the potential use of the information. ICH usually begins within the first 24 to 72 hours of life. Some authors suggest that the initial examination be made at 3 to 5 days of life; others recommend deferring it until 7 to 10 days. If results of the examination are negative for ICH, it is unlikely to find a hemorrhage thereafter. Although there are no definitive data about the extension of ICH that theoretically could be caused by the effects of indomethacin on platelets, some use early CUS to aid in the decision between medical and surgical intervention for patent ductus arteriosus. Obtaining a final CUS closer to discharge (e.g., 34 to 36 weeks’ gestation) also has been recommended to look for both ICH and PVL. However, recent studies suggest that magnetic resonance imaging (MRI) may be a more sensitive and specific measure of PVL and white matter injury in preterm infants.

Clinical circumstances may play an important role in the timing of CUS. In the very unstable preterm infant, especially one who is experiencing an unexplained hematocrit drop, acidosis, or a change in neurologic status, an earlier CUS may be indicated. The presence of severe ICH then may be incorporated in decisions about the prolongation or escalation of intensive care support. If an initial CUS detects ICH, serial examinations may be performed every 1 to 2 weeks until the ICH is believed to be stable.

**Periventricular Leukomalacia (PVL)**
PVL describes a characteristic pattern of white matter injury found predominantly in preterm newborns, apparently as a response to hypoxic-ischemic insults. PVL is associated with ICH, an association that increases with worsening ICH severity. However, PVL can arise without ICH and vice versa. On CUS, PVL initially presents as numerous foci of increased periventricular echogenic-

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**Figure 4.** Grade 4 germinal matrix hemorrhage on day 2 of life. The view was obtained with an 8 MHz solid-state sector probe through the anterior fontanelle. Coronal view demonstrates a large germinal matrix hemorrhage extending directly into the brain parenchyma. Grade 4 hemorrhages gradually involute over several months, resulting in porencephalic cyst that communicates with the ventricular system.

**Figure 5.** PVL in weeks 1 and 4 of life. Views were obtained with an 8 MHz solid-state sector probe through the anterior fontanelle. A. Coronal view of the frontal lobe region demonstrates abnormally increased periventricular echogenicity bilaterally at week 1. B. Follow-up coronal view at week 4 demonstrates cystic degeneration, involution of the periventricular white matter, and mild ventricular dilation.
ity adjacent to the lateral ventricles that become evident within the first several days after the instigating insult (Fig. 5). Classically these periventricular regions undergo cystic degeneration over the next 2 to 3 weeks, resulting in a “swiss cheese” pattern of white matter loss that can be detected readily with CUS. The evolution of PVL also can be noncystic, manifested primarily by the irregular loss of the periventricular white matter and irregular ventricular dilation. This form of PVL is more difficult to detect with CUS. After 2 to 3 months, both cystic and noncystic PVL are characterized by variable degrees of ventricular dilation and irregular scalloping of the ventricular walls. At 2 to 4 months, MRI is the modality of choice for detection of PVL because it can discern not only the morphologic changes due to PVL but abnormal tissue signals within the periventricular white matter, information that is not available from CUS.

PVL must be distinguished from PHVL, which may have a similar geographic distribution but subtle differences in the evolution of echogenic changes. PVL usually has echodensities that evolve into multiple smaller cysts that do not communicate with the lateral ventricle. Bass and associates used these characteristics to classify 77% of white matter lesions into either PVL or PVHI, with only 11% having overlapping features and an equally small subgroup having echodensities without evolving cystic changes. Neurodevelopmental deficits were observed in all groups, but patients who had PVHI had a normal mean developmental quotient. One large series found PVL in 3.2% of infants whose birthweights were less than 1,500 g, with most affected patients having benign clinical courses without identified risk factors for CNS insult.

**Hypoxic-ischemic Encephalopathy (HIE)**

HIE in both preterm and term neonates may cause a wide range of CNS injuries that may not be visible by CUS. In the term newborn, severe HIE can lead initially to generalized cerebral edema, including small, slit-like ventricles and poor gray-white signal differentiation on CUS. However, HIE may lead to severe neurologic injury without any neuroimaging findings of edema. HIE also has been associated with focal, intraparenchymal hemorrhage, which also may be seen by CUS. At least one recent study of more than 100 asphyxiated newborns was unable to correlate neonatal CUS findings with the infants’ outcomes at 1 year of age.

A recent prospective study found that both computed tomography (CT) and MRI were vastly superior to CUS for the detection of hypoxic-ischemic injury, particularly in the cortical and subcortical gray matter of the lateral cerebral convexities, the most difficult regions to examine adequately by ultrasonography, especially via the anterior fontanelle approach.

**Infection**

Congenital or perinatal infections can lead to anatomic changes that are detectable by CUS. CUS can detect significant infarction from meningitis and more subtle findings, such as ventriculitis, which is seen as diffusely abnormally echogenic ependyma within the walls of the lateral ventricles. CT and MRI with and without intravenous contrast are both vastly superior to CUS for the diagnosis of CNS infections and their complications.

Mineralizing lenticulostriate vasculopathy and parenchymal and periventricular calcifications that may accompany congenital viral or toxoplasmosis infections often are sufficiently echogenic to be seen by CUS. However, in the asymptomatic newborn, isolated mineralizing lenticulostriate vasculopathy (seen as highly echogenic vessels in the basal ganglia) without associated brain tissue calcifications is much more likely to be an incidental finding not associated with congenital infection.

**Hydrocephalus and Abnormal Brain Development**

Congenital and posthemorrhage hydrocephalus are seen easily by CUS. Furthermore, CUS can be used to quantify the progression of hydrocephalus, which can aid in the decision about neurosurgical intervention. One such volumetric analysis for following PHH has been described by Brann and coworkers. PHH tends to be maximal at 6 to 8 weeks after birth. One third of these cases resolve spontaneously over the next several weeks, one third stabilize, and one third progress and require serial ventricular punctures or shunting.

Congenital hydrocephalus often is detected by fetal ultrasonography, which may influence maternal delivery management (eg, whether to transport to a tertiary center or whether a cesarean section is indicated). The most common cause of congenital hydrocephalus is Arnold-Chiari malformation, which almost invariably is associated with myelomeningocele and may have CUS findings of distortion of the lateral ventricles, inferior displacement of the fourth ventricle, and obliteration of the cisterna magna due to a small posterior fossa.

CUS can detect other malformations of the developing brain such as holoprosencephaly, lissencephaly, and schizencephaly. Narrowing or agenesis of the corpus callosum can be suggested by CUS findings, but usually is confirmed by CT or MRI. CUS will demonstrate the larger arteriovenous malformations, which exhibit remarkably abnormal flow studies by Doppler evaluation.
Cerebellar malformations, including vermian and cerebellar hypoplasia, also can be seen by CUS. Arteriovenous malformations are detected most easily by CUS when accompanied by vascular abnormalities that can be detected by Doppler flow studies. CUS also may find the rare neonatal brain tumor or tuberous sclerosis, the latter having periventricular calcifications or echogenic hamartomas. However, the modality of choice for definitive imaging evaluation of these and other central nervous system abnormalities is MRI.

Limitations
Despite being noninvasive and portable, certain technical considerations limit clinical correlations with CUS findings and may require alternative neuroimaging modalities. More superficial structures beneath the skull, particularly adjacent to the lateral cerebral convexities, have limited resolution. For example, subarachnoid hemorrhage routinely is missed on CUS, although massive subarachnoid hemorrhage may appear as prominent, thickened echogenicity within the normally anechoic subarachnoid space. Deeper structures of the brain, such as the basal ganglia and brainstem, are not visualized well by CUS, although supplemental views through the posterior and posterior-lateral fontanelles may alleviate this difficulty partially. More subtle developmental problems (eg, abnormal opercular development), especially of more lateral structures; neuronal migrational abnormalities; and gyral malformations are unlikely to be diagnosed by CUS. These problems require cross-sectional imaging with MRI or CT.

CUS generally has poorer tissue characterization capabilities than CT or MRI. For example, CUS will show an echogenic lesion with mass effect for both IPH and severe focal infarction. In contrast, CT or MRI easily can distinguish blood from the focal cerebral edema associated with ischemia or infarction. CUS is also surprisingly insensitive to global and brainstem ischemia and focal cerebral infarction in the first 24 to 48 hours after an hypoxic-ischemic insult. CT and MRI are vastly superior to CUS for visualizing ischemia/infarction in this time period. These modalities also are superior in the follow-up of complications of severe ischemia, such as transtentorial herniation (and other types of shifts due to massive edema) and white and gray matter loss.

Several authors have tried to determine the relative accuracy of CUS findings in terms of neurodevelopmental outcome or neuropathology. CUS shows a baseline range of anatomic variants in 10% to 20% of healthy term newborns. The more common variants associated with normal neurologic outcome include choroid plexus, subependymal cysts, cavum septum pellucidum, and mild ventricular enlargement. CUS findings that include significant bilateral periventricular changes have the greatest correlation with adverse neurologic outcome (ie, cerebral palsy). In one study comparing CUS results with postmortem neuropathology, CUS correctly identified the primary CNS insult in only 59% of patients, sometimes due to imaging timing. However, in nearly 25% of the patients, CUS did not find the primary injury. Not every CUS abnormality represents significant neurologic injury, and technical limitations may lead to a significant false-negative predictive value for certain pathologies (eg, subarachnoid or subdural hemorrhage).

Summary and Future Advances
Although CUS is used widely in the neonatal intensive care unit, further advances may expand its utility to the clinician. Its portability and relative ease of use have made it the standard of care for initial screening for ICH in preterm infants. Clinicians in intensive care nurseries need to establish protocols for the appropriate and judicious use of CUS, recognizing that other neuroimaging techniques may be needed to complement CUS findings. Besides preterm infants, neonates most likely to have abnormal CUS findings include those who have known coagulopathy, seizures, macrocephaly, or other major dysmorphic findings. Improved CUS technology, with higher frequencies and improved postacquisition processing, may provide increased resolution, especially when combined with Doppler flow studies of the smaller cerebral vasculature. Three-dimensional ultrasonography is being developed to evaluate both the fetus and newborn, again improving the resolution with which we may view the developing or injured brain. Further studies need to determine the correlation of CUS findings with clinical outcomes and interventions.

Suggested Reading
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**NEOREVIEWS QUIZ**

1. Cranial ultrasonography is performed through the anterior fontanelle using either a solid-state transceiver probe or a linear phased-array probe. Of the following, the linear-phased array probe in comparison to the solid-state transceiver probe is most likely to provide:

   A. Decreased sensitivity to flow.
   B. Lower resolution.
   C. Poorer near-field focusing.
   D. Views of only midline structures.
   E. Wedge-shaped images.

2. A very low-birthweight neonate has an unexplained drop in hematocrit within 72 hours after birth. Cranial ultrasonography reveals a germinal matrix hemorrhage. Of the following, the echogenicity associated with a germinal matrix hemorrhage is most likely to be located:

   A. In the caudothalamic groove.
   B. In the roof of the third ventricle.
   C. Posterior to the foramen of Monroe.
   D. Posteriorly in the lateral ventricle.
   E. Within the frontal horn.

3. Cranial ultrasonography, computed tomography, and magnetic resonance imaging are modalities used in the diagnosis of intracranial pathology in newborns. Of the following, the diagnosis most likely to be confirmed by cranial ultrasonography is:

   A. Brainstem abnormality.
   B. Central nervous system infection.
   C. Intracranial arteriovenous malformation.
   D. Hypoxic-ischemic encephalopathy.
   E. Subarachnoid hemorrhage.
## Cranial Ultrasonography

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