Multiplanar 3-Dimensional Neonatal Neurosonography: Initial Experiences and Potential Benefits

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Neonatal neurosonography is commonly used to evaluate infants for the presence of intracranial hemorrhage, hydrocephalus, congenital defects, and other abnormalities. The size and location of the fontanelles that are used as acoustic windows to view brain structure can impose limits on the conventional technique. A relatively recent advance in ultrasound imaging technology is multiplanar 3-dimensional ultrasound imaging (3D US). Ten neonates received 3D neurosonographic examinations in addition to their clinically indicated conventional examinations. Comparisons between the two techniques included assessment of the image acquisition process as well as the diagnostic value of the data obtained. Comparisons were made to computed tomography and/or magnetic resonance imaging examinations when available. Compared to conventional neurosonography, the 3D US technique had several advantages including faster, easier, and more consistent data acquisition. Multiplanar 3D imaging also improved the ability to assess normal anatomy and pathology, and better correlated with other imaging modalities. Additional studies are necessary to determine the ultimate clinical utility of 3D neonatal neurosonography.

Key words: 3-dimensional sonography, neonatal neurosonography, ultrasound imaging

The use of sonography for the evaluation of intracranial anatomy and pathology dates back to the 1950s when A-mode ultrasound was used to define the midline echo and shift of the midline resulting from intracranial hemorrhage and other causes. In the 1980s, small handheld real-time capable transducers became available that were better suited for evaluation of the neonatal brain through the fontanelles that function as acoustic windows to view brain structure. Transfontanelle scanning permitted the use of higher frequency transducers, which improved gray-scale
image quality and the overall diagnostic potential and clinical utility of neonatal neurosonography. The portability of ultrasound systems was an additional benefit because it permitted sonograms to be performed within the intensive care nursery (ICN), thereby eliminating the need for transportation of the neonate out of the critical care setting. Combined with its recognized safety, these beneficial attributes of sonography have contributed to its widespread utilization, particularly for evaluation of the premature infant brain. It is now considered standard of care to perform serial neurosonographic examinations of premature infants to evaluate for the presence of intracranial hemorrhage, ischemic insults, hydrocephalus, congenital defects, and other abnormalities.

A relatively recent advance in ultrasound imaging (US) technology is multiplanar 3-dimensional ultrasound imaging (3D US). Several manufacturers have 3D US–capable systems in their product lines. Some manufacturers’ units employ a “free-hand” technique for data acquisition. This method typically uses conventional 2-dimensional (2D) US probes that are manually swept or pivoted through a region of interest, and the individual image slices are used to create multiplanar images and/or 3D reconstructions. An alternative approach to 3D US data acquisition utilizes “dedicated” 3D US probes (i.e., probes with a mechanized drive contained within the probe case itself). These probes are also referred to as volume probes. They utilize a tilt scanning “automatic volume acquisition” technique where the probe surface is kept stationary and, when activated, the mechanized assembly within the probe tilts (i.e., pivots) the transducer element to sweep through the operator-selected region of interest (ROI). With these instruments, individual voxels (i.e., a 3D grid of picture elements) are automatically acquired at predefined intervals resulting in a volume of data, which can then be used to create images in an infinite number of scan planes. The volume of data can be analyzed at the time of the study or stored digitally for retrospective analysis. The volume of US data permits the display of images in a single or multiplanar format. Once displayed on the system monitor, the multiplanar display includes three images, one in the original plane used during the acquisition and two in orthogonal planes of section (e.g., simultaneous display of coronal, sagittal, and axial images) (Fig. 1). The operator can manipulate each of the three images to obtain any desired plane(s) of section. This effectively eliminates many limitations imposed on conventional US imaging (which can be limited by the location or size of acoustic windows). The volume of digitally stored data can also be used to create true 3D US reconstructions using a variety of rendering algorithms (e.g., maximum intensity projections, transparent, and surface renderings).

There are other methods of obtaining 3D US images, including off-line systems that have mechanized devices in which a conventional 2D transducer is placed. With these instruments, the US data are acquired automatically by sweeping or pivoting the transducer in a similar manner as is done with the dedicated 3D probes. In this case, the US data obtained are downloaded to a 3D work station for retrospective review and analysis.

Each of the 3D data acquisition techniques offers benefits and has drawbacks. The free-hand technique is generally less technically demanding because it uses the same probes used for 2D US and is relatively easily incorporated into existing systems by implementation of 3D software. The automated data acquisition method requires use of specialized hardware including probes that house the transducer motor drive and systems that can accept the dedicated 3D US probes. The external probe-holding mechanisms are typically bulky and awkward to use for routine scanning, and an off-line analysis station is required to review and manipulate the data. Dedicated 3D US probes with the motor drive mechanisms contained within their cases are larger and somewhat more cumbersome to use than a conventional 2D probe, but they are not as awkward to use as the external drive mechanisms. In terms of images produced by the two techniques, multiplanar images and 3D reconstructions created using the free-hand method generally cannot be used for accurate measurement of structures and they are more likely to suffer from acquisition-related artifacts. Images obtained with the automated approach (either dedicated 3D probes or external probe-holding mechanisms) permit relatively accurate measurements and demonstrate more precise spatial relationships of structures.

Since the early 1990s, when 3D US first became available, there have been continual advancements in this technology. Advances in personal computer technology have significantly enhanced the function-
ality and clinical utility of 3D US and can be expected to continue to do so. The latest advances include more useful image-manipulation features, faster rendering times, and real-time acquisition and display of 3D US images or “4-dimensional ultrasound imaging,” with time being the fourth dimension of data.

FIG. 1. A-C. Coronal (A) and sagittal (B) conventional 2-dimensional ultrasound imaging images of an infant with ventriculomegally and cystic periventricular leukomalacia (arrows). Multiplanar imaging display (C) of the same infant performed 1 day after the conventional exam demonstrates the coronal image, sagittal image, and axial image in the top left, top right, and bottom left locations, respectively. The multiplanar image format provides a more accurate depiction of the location and extent of pathology. Also note that the periventricular cystic area is better defined on the multiplanar image than on the corresponding conventional images, which may be related to the operator dependency of the conventional scan technique.
Herein we report our initial experiences in using 3D US for evaluation of the neonatal brain.

**Materials and Methods**

From April 1999 to May 2000, a total of ten multiplanar 3D neonatal head ultrasound (HUS) examinations were performed on neonates in our ICN who had had previous, clinically indicated 2D HUS examinations. The 2D and 3D HUSs were performed with the infant at rest in his or her crib or within an isolette. In some cases, scanning was performed through the isolette’s portholes. Parental informed consent was obtained prior to the 3D US examination as per our Institutional Review Board.

A Voluson 530D system (Medison, Inc., Cypress, CA) was utilized for all 3D HUS imaging. This system has both 2D and 3D imaging capabilities. Initially, a dedicated 3D endovaginal (EV) probe (SVDW 5-8) was used because the pediatric probe for this unit was not available. More recently, a dedicated 3D US pediatric probe (SVNA 5-8) has been made available and utilized for these studies. This probe has a smaller case that is generally easier to use and better suited for neonatal neurosonography. Both of these transducers use broadband technology and operate at 5.0 to 8.0 MHz. They both have gray-scale and color Doppler imaging capabilities and small transducer “foot-prints,” which are well suited for transfontanellar scanning. The 3D US scans were performed within 2 days of the conventional studies used for comparison.

During the 3D volume acquisition process, the size of ROI (based on the size of the neonate’s brain) was determined with conventional 2D imaging using the same system and transducer. The 3D ROI was sized so that it contained as much of the neonate’s brain as possible. An attempt was made to acquire a volume set that would contain anatomical data consistent with that obtained by use of our established clinical neonatal neurosonography protocol (described below).

The 3D HUS examinations included acquisition of a minimum of two volume sets acquired in the coronal plane and two volume sets acquired in the sagittal plane. In some cases, additional volumes were acquired (e.g., to obtain 3D color flow data, use different acquisition techniques, etc.). On this unit, the operator can choose a slow, medium, or fast speed for acquisition of the 3D volume. Use of a slow speed will result in a higher number of voxels and increased spatial resolution, whereas a fast speed will result in fewer voxels and reduced spatial resolution. A “medium” volume acquisition setting was used for these examinations.

A Logiq 500 (General Electric Medical Systems, Milwaukee, WI) system equipped with a 7.0 MHz curved linear transducer having a small (21 mm) radius of curvature was used for all clinically indicated 2D HUS imaging. These examinations were performed using the established clinical scanning protocol that consists of coronal (and para-coronal) imaging from a plane anterior to the frontal horns of the lateral ventricles and extends to the region posterior to the atria of the lateral ventricles. Sagittal (and para-sagittal) imaging planes extend from midline laterally to the region of the Sylvian fissures bilaterally. The 2D HUS scans were performed by one of several clinical sonographers, whereas all 3D HUS scans were performed by one individual (D.A.M.).

The 3D HUS scans were video recorded, and the volume data sets were digitally stored allowing for retrospective review of the multiplanar images, 3D reconstruction, and overall analysis of the imaging results. Documentation of the 2D HUS scans included still images on hard copy film and video recording of real-time imaging. The length of time required for the 3D data acquisition was determined prospectively and by review of the videotape. The duration of the examination for the 2D HUS examinations was determined by review of the video and/or hard copy films.

Comparisons of the data obtained with 3D US were made to the conventional 2D HUS scans and computed tomography (CT) and/or magnetic resonance imaging (MRI) examinations when available.

**Results**

The conventional 2D HUS examinations provided the diagnostic information typically provided by neonatal neurosonography (e.g., presence or absence of intracranial hemorrhage, ventriculomegaly, increased periventricular echogenicity, congenital abnormalities, etc.).

Clinically acceptable 3D HUS volume sets were obtained in all ten cases. The multiplanar display of data proved to be of more diagnostic and interpretive value than an actual 3D reconstruction of the data.
FIG. 2.  A–D. Multiplanar 3-dimensional ultrasound imaging display (A) of an infant with holoprosencephaly permits rapid assessment of the congenital defect in three orthogonal planes, coronal, sagittal midline, and axial (top left, top right, and bottom left, respectively). The 3D US reconstruction using a surface-rendering technique (B) has limited additional diagnostic value. A magnified view of the axial US section (C) correlates well with the magnetic resonance image (D).
There was no significant difference between the image quality of scans performed with the vaginal probe compared to that of the smaller neonatal probe. There also was no significant difference between the 3D US volume data obtained in the coronal plane compared with data obtained in the sagittal plane. In most cases, the coronal plane data set was used for review. The 3D HUS data acquisition was performed equally well on infants in an isolette (working through the portholes) or in an open crib. In some cases, when the examination was performed with the infant in an isolette, the scanning process was facilitated by passage of the shaft of the EV probe through the isolette’s porthole to reach the neonate’s fontanelle. This reduced to some degree the amount of reaching and stretching required by the sonographer to perform the examination, as well as obviating the need to remove the neonate from the isolette.

Of the ten neonates who had 3D HUS studies, there were two normal examinations, six cases of intracranial hemorrhage (five with posthemorrhagic ventriculomegaly), and two cases of congenital anomalies (one Vein of Galen aneurysm, one holoprosencephaly). Two infants with intracranial hemorrhage also had periventricular leukomalacia with porencephalic cyst formation.

Two neonates had cranial CT examinations, one had a cranial MRI examination, and two others received both cranial CT and MRI examinations. Retrospective review of the volumetric data contained in the 3D volumes enhanced the depiction of the location and extent of pathology (Figs. 1, 2, and 3). The additional axial image provided by 3D US also correlated well with the MRI and/or CT examinations, thus enhancing the ability to compare data obtained with these complementary imaging modalities (Fig. 2). This was made possible by the ability to obtain and display 2D images in an axial scan plane that more closely approximates that of MRI and CT examinations. In this series, no axial scans were performed during the clinical 2D HUS studies.

The 3D HUS volume data acquisition required from 4 to 7 seconds in gray-scale mode and as much as 52 seconds in the color flow imaging mode. The duration of the acquisition was dependent on the overall size of the volume and the number of individual voxels obtained through the volume (both of which are operator selectable). In comparison, the length of time required for a typical 2D HUS examination (e.g., acquisition of a minimum of 18 still images and video recording of real-time imaging) ranged from 4 minutes to as much as 10 minutes.

**Discussion**

Neonatal neurosonography is an important diagnostic imaging modality during the early neonatal period. It is particularly useful for evaluation of the premature infant’s brain because of the increased likelihood of intracranial hemorrhage and ischemic insults in these patients and for evaluation of pathology and/or congenital defects that may initially be identified on prenatal sonograms. The ability to evaluate the cranial anatomy at the neonate’s bedside allows early identification of intracranial pathology that may influence clinical management, as well as allowing for early identification of infants who may be at a higher risk for developmental abnormalities such as cerebral palsy, blindness, and early learning disabilities. When pathology is identified by neurosonography, additional imaging modalities such as CT and/or MRI may be indicated to better evaluate and identify the extent of pathology. This is particularly true for the infant with complicated congenital intracranial defects and after closure of the fontanelles.

The pathology most likely encountered with neurosonography tends to be confined to specific entities and occurs in common anatomical locations. There are important advantages of having serial HUS studies. Serial studies allow comparison of images during the interpretation process, which is crucial for identification of progression or regression of pathology and to enhance diagnostic accuracy. As in other aspects of sonography, there is a high level of operator dependency of performing HUS examinations. The scan quality and images obtained could influence the ability to compare the serial studies and the accuracy of the diagnosis.

Performing conventional 2D HUS studies requires acquisition of individual images in both coronal and sagittal planes, as well as real-time sweeps through the scan planes. Neurosonography, not unlike other applications of sonography, is highly operator dependent and can be time-consuming. Often the sonographer is required to scan through the isolette’s portholes, which further complicates the examination process. Scanning through the portholes requires a high degree of manual dexterity to obtain the appropriate image sections. Scanning in this fashion...
FIG. 3. A–C. Multiplanar gray-scale (A) and color flow (B) displays of an infant with a Vein of Galen aneurysm (VGA) shown in three orthogonal planes, sagittal midline, coronal, and axial (top left, top right, and bottom left, respectively). Demonstration of the VGA in three orthogonal planes enhances depiction of the location and extent of the vascular abnormality. A 3-dimensional ultrasound imaging reconstruction (C) using a surface-rendering projection of the color flow data (gray-scale data are not shown in this display technique) is a dramatic means of demonstrating the spatial relationships of the vascular abnormality and could prove useful for preoperative planning and postoperative follow-up.
also potentially places the operator in compromising postural positions that could increase the likelihood of placing undue stress on the sonographer’s neck, upper extremity, and torso, which could lead to increased incidence of musculoskeletal injuries (MSI) or aggravate an existing MSI. Alternatively, to have an HUS, the neonate may need to be taken out of the isolette and be exposed to the ICN environment, which potentially could have adverse consequences. At our institution, we perform on average six to eight neonatal HUSs per day. Typically, one sonographer spends the majority of a morning or an afternoon performing the examinations in the ICN. Each scan requires approximately 4 to 8 minutes (excluding the time it takes to move the unit, turn on the system, cleanse the transducer, etc.). During the scanning procedure, the neonate is stimulated by manipulation of the probe, changing the position of its head, exposure to the environment (if taken out of an isolette), and so on, all of which potentially could have an adverse effect on the fragile infant’s health.

In comparison to performing a conventional 2D neurosonogram, the acquisition of a volume of data via 3D US potentially has several advantages. Obtaining the data during a 3D HUS only requires a few seconds, and the actual acquisition process is automated. The sonographer simply places the probe surface against the infant’s fontanelle, establishes the appropriate plane of section, and, after adjusting the system parameters and activating the control, the system automatically acquires the 3D volume. Minimal transducer manipulation is required on the part of the sonographer. Because the data-acquisition process is automated and a volume of data is acquired, 3D US has the potential to reduce interoperator variability, which would have a beneficial effect on the ability to compare serial HUS examinations. Although in this series several 3D US data acquisitions were performed, for clinical applications, a single coronal acquisition (requiring only seconds) would likely be diagnostically adequate. The rapid acquisition of data would also reduce the duration of stimulation to the infant and speed the examination process, thereby improving sonographer efficiency.

In this study, the 3D US data acquisition was performed equally well on infants in an isolette (working through the portholes) or in an open crib. Initially, it was felt that the EV probe would not be suitable for neonatal HUS studies. However, when scanning through the isolette portholes, the examination process was often actually easier using the vaginal probe. The extended shaft of the EV probe made for easy access to the infant’s fontanelle and reduced the amount of stretching required on the part of the sonographer. The long shaft of the EV probe is often not a problem because the probe itself is not moved during data acquisition. This is accomplished by the pivoting mechanism housed within the probe. Three-dimensional US made the examination process significantly easier and less strenuous using either of the two probes. The use of automated 3D US for neonatal neurosonography as well as in other applications may be an important advancement in terms of the ergonomics of performing sonography. Three-dimensional US may have the potential to reduce some of the existing MSI-related occupational hazards in the sonographer population.

The image quality of conventional 2D US imaging is generally better than that provided by 3D US imaging. This is to be expected because of the significantly different methods in which the echo data are obtained and processed using the two techniques. However, US used for neonatal neurosonography is not as diagnostically challenging as in other applications. Diagnostic US has established itself as a sensitive means of detecting a wide variety of intracranial pathologies. The identification of intracranial hemorrhage, parenchymal insults, and other pathologies is relatively straightforward even with the most basic of 2D US–capable systems. However, there remains room for improvement in the performance and diagnostic accuracy of conventional neonatal neurosonography. The size and location of the fontanelles limits visualization of some areas of the cranial vault and effectively limits the most clinically useful imaging planes to coronal and sagittal sections. In some cases, when using 2D US, areas of suspected increased periventricular echogenicity may be difficult to differentiate from normal parenchymal echogenicity. Also, the use of the lateral ventricle frontal horn dimension may not always be a sensitive means of detecting ventriculomegaly because the lateral ventricle may enlarge in the atrial region while the frontal horn size remains normal.

Three-dimensional US may be able to reduce some of the limitations of conventional 2D imaging because it provides a means of evaluation of images...
displayed in an infinite number of planes (i.e., it is not limited by the location of the fontanelles) and has the potential to permit measurement of ventricular volumes. In our series, the multiplanar presentation of images provided by 3D US proved useful for review and analysis of normal intracranial anatomy and pathology. Multiplanar 3D US provided unique imaging planes of section (i.e., axial and para-axial slices) as well as the conventional coronal and sagittal images. The simultaneous display of the three orthogonal images contributed to a better appreciation of the location and extent of intracranial pathology, including the ability to define the extent of cystic periventricular leukomalacia and assessment of the Vein of Galen aneurysm. The ability to demonstrate intracranial vasculature and vascular abnormalities with multiplanar color flow 3D US may prove valuable to surgeons for preoperative planning of surgical procedures and to enhance postsurgical follow-up evaluations in infants (Figs. 3 and 4).

In this small series, the 3D renderings were not as diagnostically useful as the multiplanar display. The challenge of creating clinically useful 3D renderings is related to the acoustic properties (and differences in acoustic properties) of tissue interfaces and to other factors. Three-dimensional US renderings have been proven to be useful in obstetric applications where there are adequate fluid-tissue interfaces allowing for good delineation of the surfaces of structures such as the fetal face and limbs. Color flow 3D US renderings can also be diagnostically useful for the identification and display of spatial relationships of both normal and abnormal vessels (Fig. 3). For many applications, the ability to produce clinically useful 3D US renderings remains an obstacle and is an area of intense research.
Future advances promise to improve this important aspect of the technology. The lack of the ability to utilize 3D US renderings does not diminish the practical and diagnostic value of obtaining 3D US volumes for use in multiplanar displays, as evidenced by the results of this and other studies.

The rapid acquisition of 3D US data is clearly a beneficial aspect of using this new technology. However, after acquiring the data, additional time and expertise is required to evaluate the 3D US volume and manipulate the images to derive a diagnosis and/or document the study results. While these tasks can be performed at a later time out of the critical care setting, this remains an area that needs improvement to make 3D US a more viable routine clinical tool. In a relatively standard scanning protocol (such as neonatal neurosonography), perhaps the display of specific multiplanar sections could be automated (in a manner similar to that used in CT and MRI), which would reduce some of the tediousness of manually reviewing the 3D US volume. Technological advances in the future will likely improve this and other aspects of multiplanar 3D US imaging. Another important potential advantage of having a volume of data is that the digitally stored volume can be transmitted via the Internet to clinical experts to obtain additional diagnostic consultation, thus enhancing the use of teleradiology. The consulting physician can use the 3D US volume to display any images necessary to derive the diagnosis, as opposed to being limited by the images obtained using the conventional (2D US) technique.

The potential benefits of 3D US compared to conventional neonatal neurosonography are summarized in Table 1. An important aspect of this trial was that there were no instances where a cranial abnormality identified with conventional 2D US imaging was not identified with multiplanar 3D US (Fig. 5). However, this admittedly was a small series, and larger studies are necessary to better identify the potential benefits and limitations and to determine the ultimate clinical utility of using 3D US for neonatal neurosonography.

### TABLE 1

**Potential Benefits of Multiplanar Three-Dimensional Ultrasound Imaging Compared to 2D Neonatal Neurosonography**

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<thead>
<tr>
<th>Image acquisition</th>
<th>Reduced data acquisition</th>
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<tr>
<td>Faster data acquisition</td>
<td>Reduced operator dependence</td>
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<tr>
<td>Reduced sonographer fatigue and/or stress</td>
<td>Reduced sonographer fatigue and/or stress (impact on musculo-skeletal injuries)</td>
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<td>Reduced interoperator variability</td>
<td>Reduced interoperator variability</td>
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<tr>
<td>More time efficient</td>
<td>More time efficient</td>
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<td>Less stimulation/stress on the neonate</td>
<td>Less stimulation/stress on the neonate</td>
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<tr>
<td>Image analysis and interpretation</td>
<td>Enhanced detection and delineation of anatomy and pathology</td>
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<td>Less limitations to imaging planes</td>
<td>Better correlation to other imaging modalities</td>
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<td>Enhanced use in teleradiology applications</td>
<td>Enhanced use in teleradiology applications</td>
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<td>Additional biometric assessments</td>
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**FIG. 5.** A, B. A resolving germinal matrix hemorrhage (arrows) as demonstrated using the sagittal projection from the multiplanar 3-dimensional ultrasound imaging data (A) and conventional 2D US (B). There is no diagnostically significant difference in the information provided by the 2 imaging techniques.
Conclusions

These initial experiences suggest that multiplanar 3D US imaging may be a clinically acceptable method of performing routine neonatal neurosonography examinations. Used for this application, multiplanar 3D US imaging has several potential advantages over conventional 2D imaging, including reducing the length of time required to perform the examination and reducing sonographer fatigue, which may reduce the likelihood of sonographer MSIs. Also, the ability to retrospectively review images in an infinite number of scan planes with 3D US can reduce the interoperator variation between serial studies and enhance the diagnostic interpretation process. Multiplanar 3D US imaging has the added potential of providing images obtained in planes not obtainable by conventional means, which may enhance the detection or exclusion of pathology and permit better correlation of the US imaging data to other imaging modalities. Some of these beneficial attributes of 3D US are also likely to be useful in other applications of sonography.

References