Technology and Early Clinical Experience with Real Time 3D Ultrasound

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Introduction

3D Ultrasound has been an academic research topic for many years, but significant barriers have existed historically to slow the introduction and utility of 3D into the ultrasound clinical environment. Some of these barriers have been processing speed, the reliance on and size of position sensing devices and poor resolution of images in the elevation plane. This has slowed the process of identification for the clinical applications of 3D Ultrasound in the routine clinical environment.

Scientific advances in image processing in recent years have taken ultrasound into the next generation and broken this “sound barrier”. Signal processing speeds have increased 50,000 times over since the early days of ultrasound. Until recently, processing speeds were still too slow to offer real time benefit to 3D Ultrasound systems. New advances will now allow real time 3D imaging in ultrasound – real time reconstruction during acquisition and real time interactivity.

New developments with motion estimation and image registration techniques can allow 3D data acquisition to be accomplished without the need for position sensing devices. Where needed, however, the decreased size of and increased reliance on position sensing devices, makes their utility much more feasible and attractive. The development of new transducer technology, such as multi-dimensional arrays, bring us much closer to addressing the critical issue of image quality and fast, reliable data acquisition. All these things will make ultrasound increasingly complex – making it essential that developers design smarter systems that are easier to use.

Ultrasound 3D data acquisition will play an increasing role in the future of medical imaging as ultrasound routinely offers interactive visualization of underlying anatomy in real time.

To be useful in medical imaging, 3D volume visualization techniques must offer

- Understandable data representations
- Quick data manipulation
- Fast rendering

Physicians should be able to change parameters and see the resulting image in real time.

The Sonoline® Elegra from the Siemens Ultrasound Division is soon to introduce their integrated 3D Ultrasound option. The technology and our early clinical experience are presented here.

Technological process of 3D Ultrasound

Acquisition and volume creation

To obtain a freehand ultrasound volume, a user has to scan over the region of interest while the system acquires multiple images and their position in space. The position can be estimated using several methods:

- Image registration and motion estimation, based on the speckle patterns.
- Constant velocity, where it is assumed that the probe is moving at a constant speed,
  or
- Position sensor, where a device is attached to the probe to track its precise position in space.

During acquisition the system processes the 2D images and their position to build a volume in real time. Reconstruction of the data in real time provides the user with immediate visual feedback of the third dimension (Fig. 1), allowing the user to follow the anatomy and allowing for an instant assessment of the motion artifacts and any other distortions. Upon completion of the acquisition a rendered volume and the orthogonal views are instantly displayed.

Acquisition can be done in a combined 2D and Power Mode.

Volume review

To review volumes two types of display techniques are commonly used:

- Arbitrary Slicing (or Multiplanar Reformating), where a 2D image is extracted from the volume at an arbitrary orientation. This method provides the user
with a view which is similar to a regular 2D Ultrasound but at a location not always achievable with a conventional 2D exam. Simultaneous display of the volume and 3 orthogonal views offers a new access to structures, showing relationships and relative position of vessels and other landmarks. (Fig. 2).

- Volume rendering with Maximum Intensity Projection to view bones or vessels (Fig 3), with Gradient and Opacity Modes to display the surface of soft tissue.

Interactive manipulation

Through an intuitive user display, the real time manipulation greatly facilitates the interactivity with the volume. The arbitrary slices and the volume may be rotated in any plane, through any angle. Slices can be zoomed or displayed to a full screen view.

With a single acquisition of 2D and Power Mode, the ability to subtract the B-Mode data and view the Power Mode data only, provides a qualitative technique that demonstrates the spatial orientation of vascular anatomy.
This can be useful in renal and liver vessel mapping (Fig 4.), evaluation of tumors, fetal and placental flow applications (Fig 5) and surgical planning.

Storage and Retrieval

With the enhanced on-board storage capacity, multiple volumes can be stored and retrieved for further interactive manipulation at a later time. The volume data can also be sent via the network to a remote station for further review or archiving. Integrated storage of both volume and 2D image data and seamless DICOM network interface capabilities complete an integrated 3D offering. These requirements are met on the Siemens Sonoline Elegra by a 9 GB hard disk, and the support of evolving DICOM standards for 3D data.

Outlook for future clinical application of real time 3D technology

With recent advances in on-line processing capabilities real time 3D Ultrasound is going to be the next major advancement in obstetric and gynecologic imaging. The soon to be introduced 3D Ultrasound option on the Sonoline Elegra system from the Siemens Ultrasound Division is currently in use in our department. The real time interactivity will greatly enhance our ability to image the pelvis, pregnant uterus and fetus. Enhanced imaging with real time 3D can be broadly categorized into three subgroups: 1) Multiplanar reconstruction of acquired volumes to obtain desired 2D views, particularly from orientations not available with routine 2D imaging; 2) 3D volume calculation of numerous organs within the maternal pelvis, uterus and fetus to assess presence or absence of pathology; and 3) Rendering tools such as surface shading for detection of fetal dysmorphic features and Maximum Intensity Projection (MIP) for evaluation of fetal bony structures.

Multiplanar reconstruction

Detail evaluation of the fetus requires careful imaging of numerous anatomical structures. One of the main difficulties confronting advanced fetal imaging is fetal motion. During the course of the exam, the fetus frequently moves into positions that do not allow for optimal imaging of different anatomic structures (E.g.: the fetal heart, face, cord insertion). Multiplanar reconstruction allows manipulation of the stored volume in infinite orthogonal planes. Such reconstruction capability, coupled with greatly improved processing speed, has taken multiplanar reconstruction from a labor intensive external workstation process to a fully integrated on-line real time phenomena. In our first experience, users who begin working with this application (Fig. 6 and 7), were able to easily obtain usable volumes with a minimal learning curve.

3D volumetric calculation of maternal and fetal structures

Volumetric calculation of maternal and fetal structures should allow a more comprehensive evaluation of the organ of interest. For example, volumetric assessment of ovarian masses, the fetal liver, and the placenta may improve clinical diagnostic accuracy. Assessment of ovarian volume may improve assessment of suspected malignancies. Assessment of fetal liver and spleen volumes should improve the ultrasonographic assessment of patients with isoimmunization, and reduce the need for invasive testing. Volumetric calculation of the placenta in the second trimester may provide prognostic information about future fetal growth. Previous work has shown that placental volume is closely correlated with fetal weight [1]. Preliminary work in our lab has shown that actual and calculated placental volumes agree to within 15 %. Actual error is probably considerably less, as the actual measurement is made after maternal blood has been lost during delivery of the placenta. Additionally, we have noted that placental volumes calculated prior to 26 weeks gestation correlate closely with fetal weight in the third trimester and at birth. This preliminary data has been collected with a Siemens Elegra system connected to an off-line workstation. Unfortunately this method is quite time consuming, averaging 20-25 minutes per calculation. However, recent development of integrated 3D software, and ongoing development of online calculation techniques should greatly reduce the time from this calculation. In the near future,
Figure 6
Volume acquisition using multiplanar reconstruction, of a 10-wk fetus, demonstrating sagittal suture without the need for additional rendering tools.

Figure 7
Fetus at 36 weeks gestation using multiplanar reconstruction of the aortic arch from a transverse acquisition through the fetal heart. Of note: there was minimal image degradation from fetal cardiac motion.

Figure 8
Fetus at 32 weeks gestation showing dilated renal pelvis suggestive of renal pelvic junction obstruction. On 2D imaging the ureters were not seen well. This arbitrary slice clearly shows dilated ureters, suggesting a diagnosis of ureterovesicle junction obstruction.

Figure 9
Fetal facial details are clearly depicted in this B-Mode surface rendered 3D volume.
fast, real time 3D volumetric assessment of the placenta may become part of a routine screening ultrasound exam.

Volume rendering methods

One of the most difficult aspects of prenatal ultrasound of the fetus is that many dysmorphic features cannot be evaluated with traditional 2D imaging. As such, we are limited in our ability to fully evaluate the fetus and we rely on structural anomalies, rather than being able to combine both structural integrity with morphology. The fetal face, head, hands, and torso are examples where surface rendering will improve our diagnostic capabilities. The ability to surface render using Gradient and Opacity Modes, and image enhancement will make many views of the fetus “come to life” and should improve our ability to show the fetus to the parents. (Fig. 8 and 9) This ability to improve the “lifeseness” of the fetus may also revolutionize parental bonding as the parents will be able to “see” the fetus months before it is born [2]. This has been shown in other studies to provide reassurance to parents in cases of critical pregnancy termination decisions. The use of B-Mode and Power Mode Maximum Intensity Projection (MIP) rendering may also improve our ability to view the fetal skeleton and placental blood flow.

Conclusion

In conclusion, our early experience with the 3D application on the Sonoline Elegra from the Siemens Ultrasound Division has shown that the technique does not require a long learning curve and can be integrated into our routine studies without increasing the study time significantly. The benefit of having the ability to store, retrieve and manipulate the volume data should greatly enhance our ability to image the maternal pelvis, the fetus and the placenta. Finally, 3D volume acquisition should improve our ability to communicate our ultrasound findings to the patient and referring physicians.

Literature
