J Korean Radiol Soc 1999;40:519-525

Three-Dimensional Power Doppler Imaging[1]

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Three-dimensional (3-D) ultrasonographic imaging techniques have recently shown rapid development and their clinical application has begun to attract considerable attention. Power Doppler sonography is known to be more sensitive than color Doppler for detecting blood flow, and there is also less noise and clutter. This paper describes the basic principles and initial clinical experience of 3-D power Doppler sonography.

Index words : Ultrasound (US), technology
Ultrasound (US), Doppler studies
Ultrasound (US), three-Dimensional

Ultrasonography, including color and power Doppler varieties, is a study in two dimensions. We scan in slices and obtain two-dimensional images which are interpreted as mental images of three-dimensional(3-D) topography. Techniques which permit 3-D imaging through the use of US have been enthusiastically received; they have involved adding a third plane(z), thus producing a view of anatomic structures which has perspective(1-4). Three dimensional power Doppler is a recently introduced technology in which vascular structures are displayed in three dimensions. The dynamic rotation of images, together with tissue subtraction, provides a vascular map with good depth, transparency, and plasticity (5).

This paper describes the basic principles and operational techniques of 3-D power Doppler imaging(PDI), and illustrates our preliminary clinical experience.

Basic Principle

Three-dimensional imaging involves three basic steps, regardless of imaging modalities: volumetric data acquisition, image rendering, and image display(4,5). Volumetric data acquisition is the process of measuring certain parameters of interest(e.g. echo amplitude) as well as spatial information, and the source of this information under investigation can thus be located. This process effectively breaks up the single(large) volume into a lot of smaller volumes, with one or more attributes associated with each. Volumetric data can be collected by translating, rotating or fanning a 2-D probe along the axis(Fig. 1).

Rendering is the process of creating a visual representation of the parameter(s) of interest, and once volumetric data have been acquired, an image suitable for display must be rendered. In this process, the magnitude of the echo from a given voxel is represented by coloring that voxel with a brightness related to the magnitude. Power Doppler angiographic data is represented by coloring a voxel to represent local Doppler power. The represented data are computed through the projection and rotation process; image display then involves the presentation of the rendered representation for

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Received June 29, 1998 ; Accepted October 30, 1998
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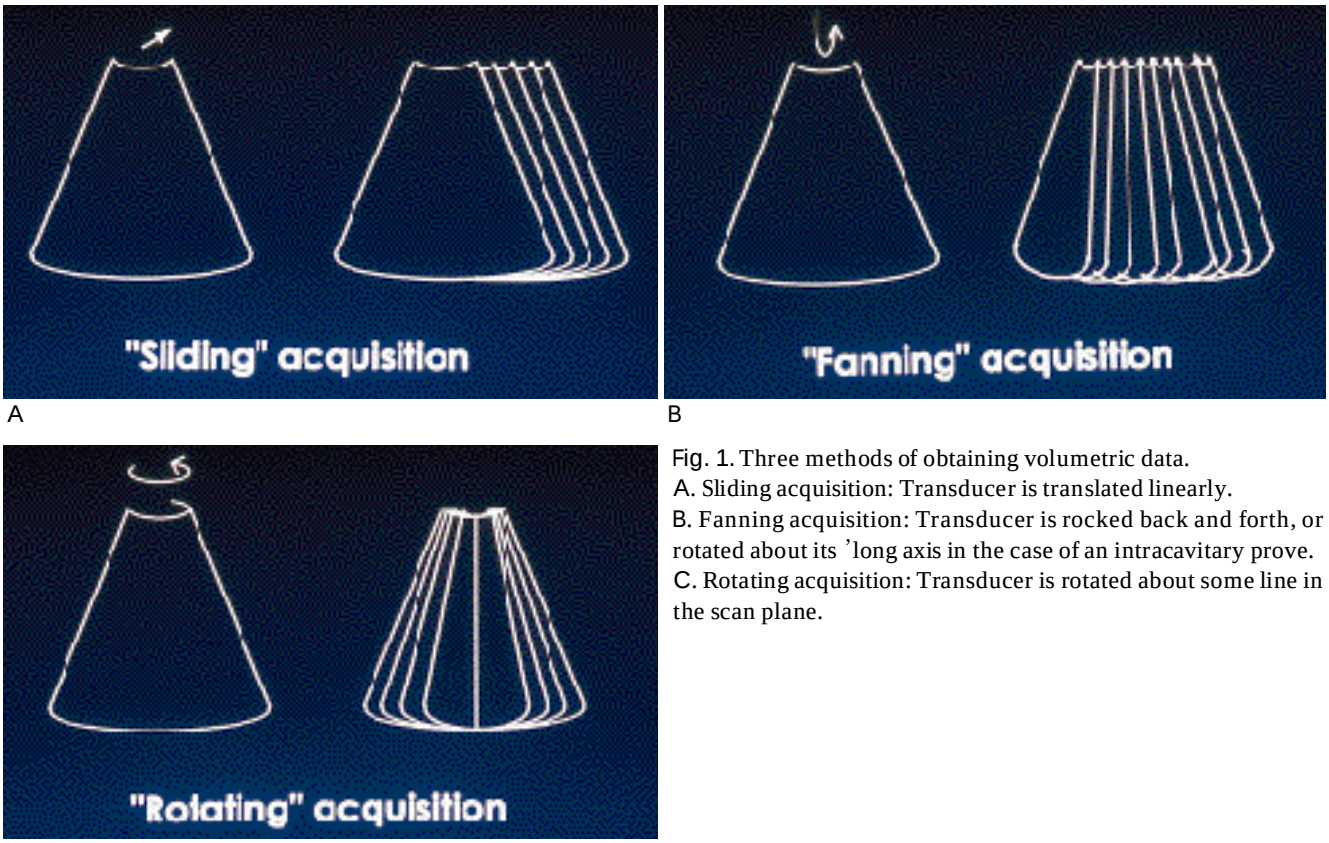
viewing, and for this there are several options for display of 3-D images. There are true 3-D display mechanisms such as holographic projectors using varifocal mirrors or spatial light modulators. There are stereopsis systems, which can be as simple as" red-blue" colored glasses and a conventional 2-D display, or synchronized LCD shutter systems where an independent 2-D display is provided for each eye. The simplest and most widespread display technique is the use of a conventional 2-D display to show a projection image of the 3-D data.

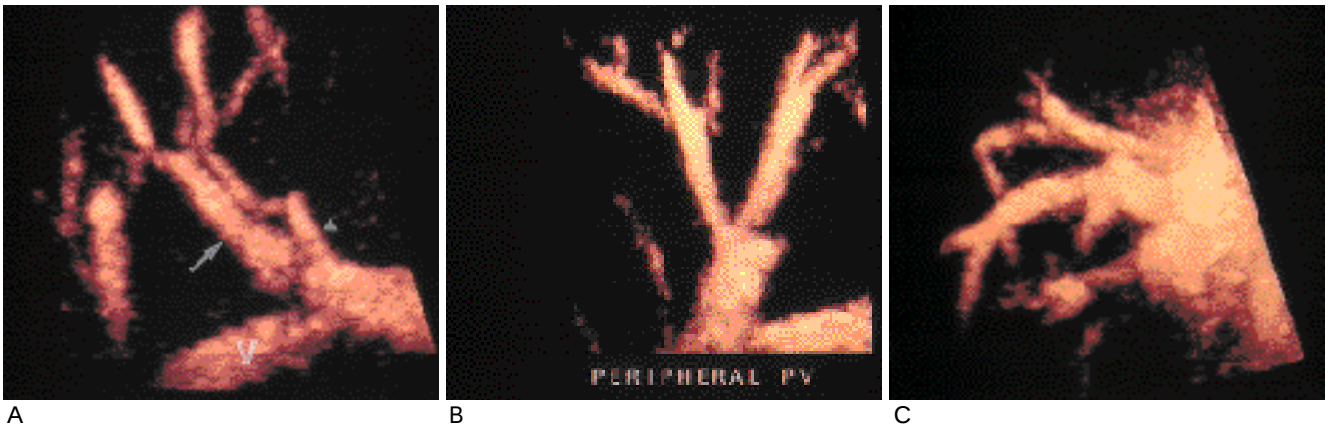
Operational Technique(6)

For making 3-D PDI, we are currently using a 3-D C-



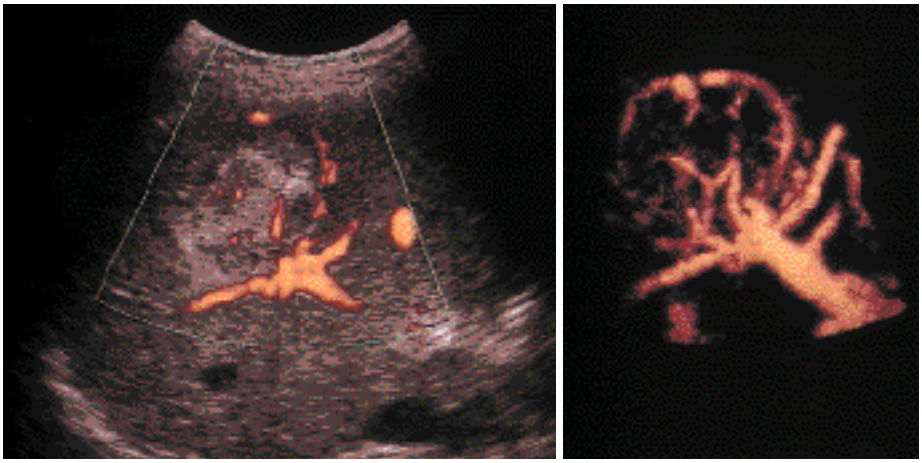
A B C

Fig. 1. Three methods of obtaining volumetric data.
A. Sliding acquisition: Transducer is translated linearly.
B. Fanning acquisition: Transducer is rocked back and forth, or rotated about its 'long axis in the case of an intracavitary prove.
C. Rotating acquisition: Transducer is rotated about some line in the scan plane.



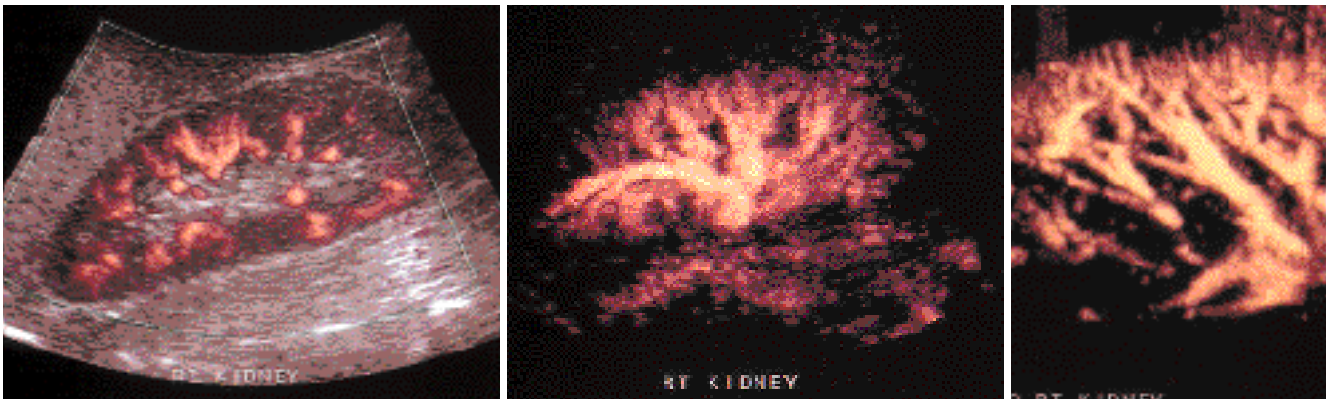
A B C

Fig. 2. Three-dimensional power Doppler images (PDI) of hepatic vessels.
A. Three-dimensional PDI in a patient with liver cirrhosis nicely shows main portal vein (arrow) and its 'branches. Note a hypertrophied hepatic artery (arrowhead). V: inferior vena cava.
B. Peripheral portal branches are clearly seen at the subcapsular parenchyma with a high-frequency (5-10 MHz) linear-array transducer.
C. All hepatic veins are seen in a single 3-D image.



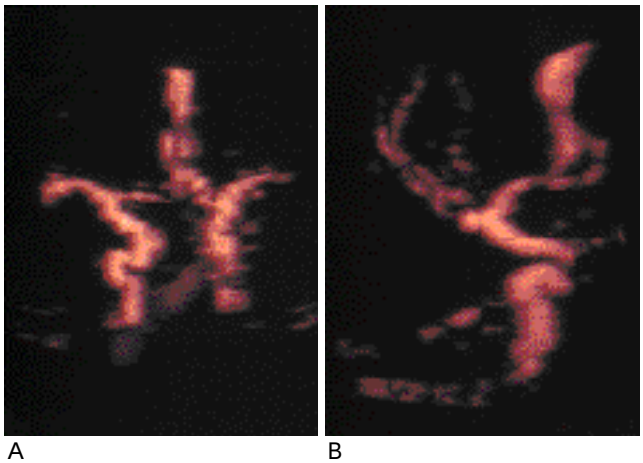
A B

Fig. 3. A 39-year old man with hepatocellular carcinoma.
A. 2-D PDI shows peripheral and central tumor vessels in the echogenic liver mass.
B. 3-D PDI shows" basket-pattern "tumor vascularity which is characteristic of hepatocellular carcinoma.



A B C

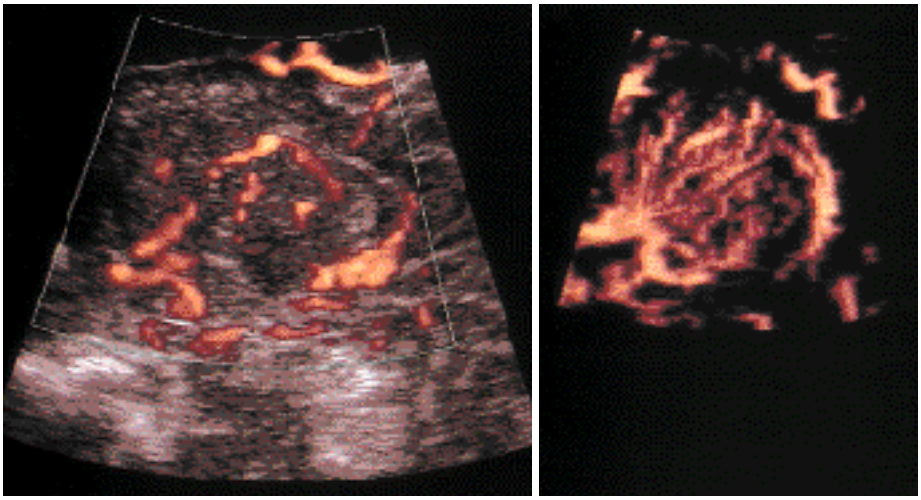
Fig. 4. PDI of normal intrarenal vessels.
A. 2-D PDI of native kidney.
B. 3-D PDI of the same kidney shows renal perfusion more nicely.
C. With the use of higher frequency transducer, cortical brush, arcuate arteries and interlobar arteries are more clearly demonstrated.



A B

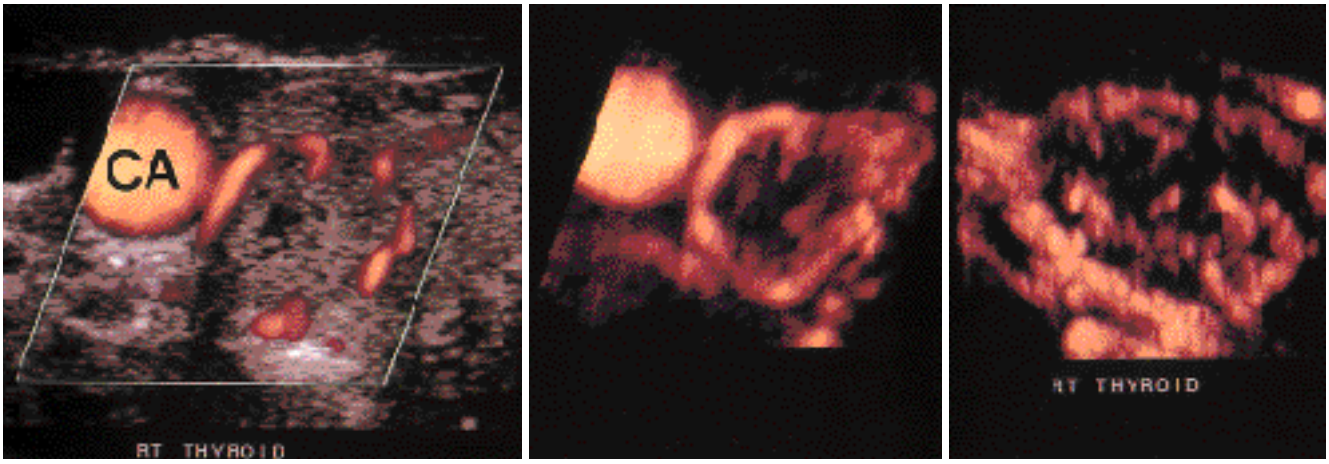
Fig. 5. 3-D PDI of intracranial vessels in a neonate.
A. Circle of Willis is nicely seen.
B. Selective right carotid 3-D PDI shows carotid artery, anterior and middle cerebral arteries.

PA (Color Power Angiography) package on with an HDI 3000 system (Advanced Technology Laboratories, Bothell, WA). In this section, operational tips and 3-D parameters for reconstruction are presented. Before going to 3-D PDI, power Doppler parameters (including color gain, pulse repetition frequency, and wall filters) should be optimized, and various power Doppler patterns (background, dynamic range, and display mode) be controlled. Once power Doppler controls the 3-D mode can be engaged. The use of too much color gain, leading to color oversaturation, causes blurring of the 3-D image at the edges of the vessel. PDI is known to be sensitive to low velocity flow, thus motion artifact is a frequent problem. Motion artifacts can be suppressed or deleted by using wall filters or by trimming the artifacts out of the cineloop before reconstruction. A higher frequency transducer provides better spatial resolution, so



A B

Fig. 6. A Vascular perfusion of basal ganglia in a neonate.
A. 2-D PDI shows numerous vessels in the basal ganglia.
B. The vascular perfusion of basal ganglia is better appreciated on 3-D PDI.



A B C

Fig. 7. A 54-year old man with thyroid cancer.
A. 2-D PDI shows peripheral tumor vessels in a necrotic thyroid mass. CA : Carotid Artery
B & C. Transverse (B) and longitudinal (C) 3-D PDI give us global information about vascular supply to the mass.

the highest possible frequency should be used.

For uniform and clear acquisition of volumetric data, the scan head should be swept over the organ, maintaining a stationary pivot point, rather than moving the scan head across the skin surface, and throughout a constant sweep.

Within the cineloop menu key there are several helpful tools: views, slice and cine mode. Views are the number of slices or view points; their number does not affect the quality of reconstruction, only the smoothness of 3-D rotation. The greater the number of views chosen, and the more images within the cineloop buffer, the longer the reconstruction time. Slice represents the distance between slices (interslice thickness) and affects the flatness of the 3-D image. Cine mode allows for choice between a review of the 2-D cineloop or 3-D rotation.

The 3-D image can be repeatedly reconstructed without rescanning, and views, slice thickness and maps can all be changed without rescanning. In general, a 3-D image can be obtained within one minute of starting reconstruction, and the created 3-D image rotates 100 degrees. We are currently recording 3-D images with a videorecorder and making hard copy films with a color printer.

Clinical Application

The situation of recent development of 3-D PDI would be the same with 2-D PDI. Using the former technique, it may be possible not only to detect the low-velocity flow but also to delineate areas of segmental infarction and the abnormal vessel architecture known to occur in most tumors. In one experimental study by

Downey et al.(4), blood flow was detected in vessels less than 1 mm in diameter. Due to a lack of reports, however, it is too early to predict the fate of 3-D PDI. It is hard to know whether this technique contributes diagnostic information beyond that provided by 2-D imaging techniques such as gray-scale, and color and power Doppler.

We have been using the 3-D technique in various parts of the body and have found it very promising. Unlike most existing 3-D applications, the technique enables us to reconstruct 3-D images very promptly, so can be an interactive part of an examination. Reconstructed images were technically impressive and beautiful to look at.

Liver

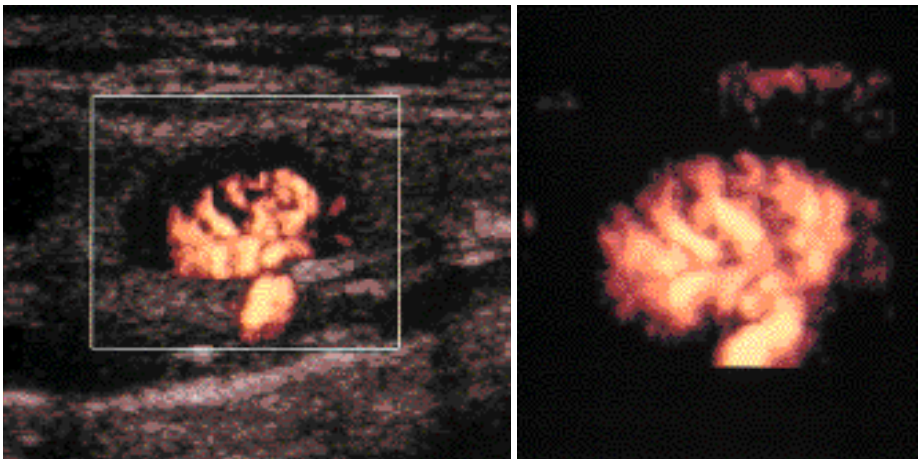
3-D images of intrahepatic vascular structures enable us to understand relationships more quickly and easily than 2-D sectional images are employed (Fig. 2). Possible applications include portal hypertension, Budd-Chiari syndrome, transplants, and the characterization of hepatic masses. We have recently used this technique to evaluate the vascular pattern of hypervascular hepatocellular carcinomas (HCCs); preliminary experience showed that these patterns correlate closely with those seen on conventional angiography, and that 3-D PDI was superior to 2-D PDI or color Doppler US (Fig. 3).

Kidney

Three-dimensional PDI shows great promise for the evaluation of the renal cortical vascular network in both native kidneys and transplants. Using 2-D color and power Doppler techniques, it is difficult to obtain global information regarding the renal vasculature, but with 3-D PDI, this can be obtained (Fig. 4).

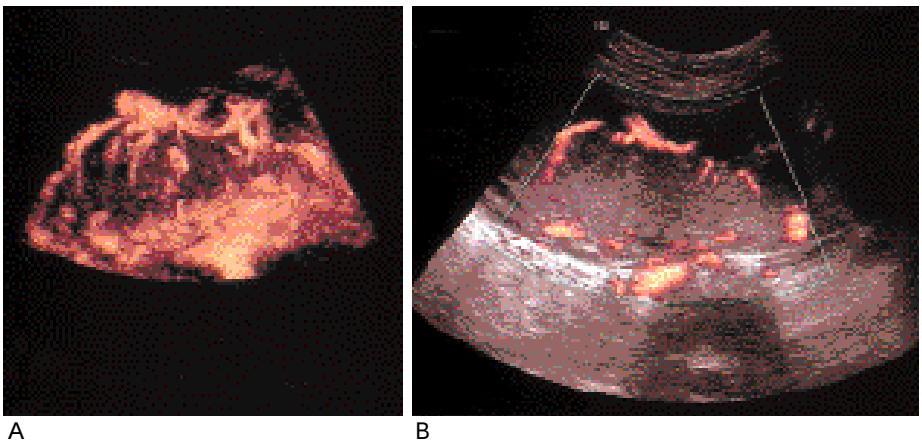
Cerebral perfusion

Using transcranial US, intracranial vessels in neonates and infants were beautifully imaged; circle of Willis and its branches can be clearly demonstrated (Fig. 5). Detailed imaging of even small vessels in the basal ganglia and periventricular brain was successfully achieved



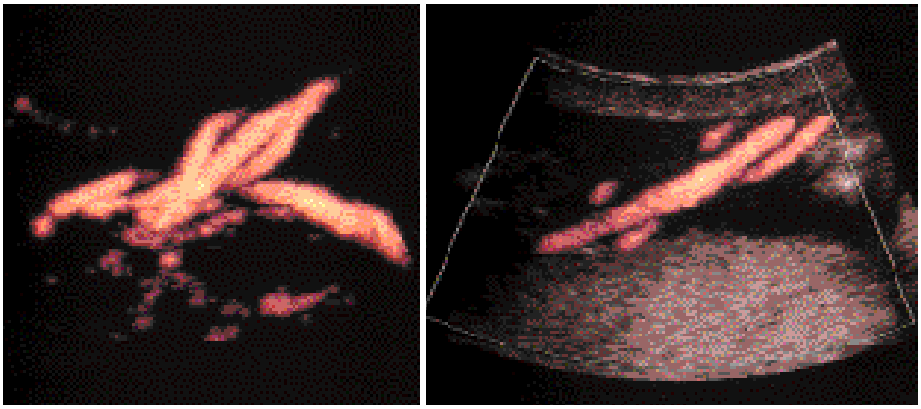
A B

Fig. 8. Benign lymphoid hyperplasia of the neck.
A. 2-D PDI shows hilar vessel and its intranodal branches.
B. 3-D PDI also shows cortical vessels which are not seen on 2-D PDI.



A B

Fig. 9. Placental perfusion.
A & B. 3-D PDI (A) shows placental vascular perfusion more nicely than 2-D PDI (B).



A B

Fig. 10. Umbilical cord vessels.
A & B. The three vessels of the umbilical cord are better visualized without interruption on 3-D PDI (A) than on 2-D PDI (B)

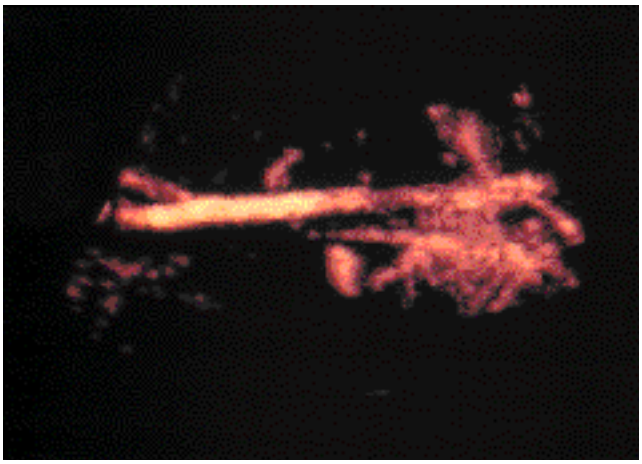


Fig. 11. Fetal abdominal and thoracic aorta.
The aorta and its 'bifurcation are nicely demonstrated on 3-D PDI. HT : heart

(Fig. 6), and this may help detect areas of ischemia in premature infants with periventricular leukomalacia or hypoxic/ischemic injury.

Thyroid and cervical lymph node

Because it moves only slowly, the thyroid is one of the organs to which 3-D PDI is most easily applied, and we successfully imaged vascular supply to malignant thyroid nodule (Fig.7). The technique shows some promise for the differentiation of malignant and benign lymphadenopathy (Fig. 8).

Gestation

3-D PDI shows the greatest possibilities in obstetrics. The vascular perfusion status of the placenta (Fig. 9), umbilical cord (Fig. 10), and fetus (Fig. 11) was easily visualized without interruption. Possible applications include placental insufficiency, fetal distress, miscarriage, ectopic gestation, trophoblastic neoplasia and various malformations.

Other possible application

3-D PDI can be used in various scrotal diseases (e.g. varicocele, inflammation, and tumor), soft tissue inflammation, and vascular abnormalities of the extremities.

Limitations and Future Prospects

There are several possible technical drawbacks of 3-D PDI. The technique is not totally automated, and like other US examination techniques, requires manual skill and thorough training. To avoid undesirable artifacts the tissue or organ under study must be as immobile as possible. 3-D PDI does not permit quantification of the dimensions of vessels in the tissue under study, it is qualitative, providing only a 3-D model of the vascular network. The operator is able to perform qualitative visual analysis and anatomic-clinical correlation.

In spite of these technical drawbacks and limited experience of clinical usage, 3-D PDI, which is being rapidly developed, has a promising future. The technique permits an understanding of relationships which is quicker and easier than if sectional 2-D images are assembled in the brain, particularly in areas in which complex structures are present. With the further development of the technique, it may be possible to achieve true 3-D imaging that combines parenchymal anatomy with the vascular network, and this will be the most valuable mode.

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대한방사선의학회지 1999;40:519-525

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임 효 근·김 승 훈

최근 삼차원 초음파검사는 급속히 발전하고 있으며 이의 임상적 이용에 많은 관심이 모아지고 있다. 출력 도플러 초음파검사는 종래의 색조 도플러 초음파검사에 비해 저속 혈류에 보다 민감하며 인공물이 적다는 장점으로 임상적 이용이 날로 증가하고 있다. 이 임상화보에서는 새로운 기술인 삼차원 출력 도플러 초음파검사의 기본 원리와 임상적 경험을 토의하고자 한다.