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# Comparison of Computed Sonographic Tomography and Pulse-Echo Imaging in the Head

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Computed sonographic transmission tomograms of infant and adult human cadaver heads are presented and compared with sonographic pulse-echo and x-ray tomograms of the same horizontal planes. The sonographic attenuation tomograms were reconstructed from broadband transmission data obtained using the rotate/translate axial scan mode in much the same way as x-ray tomography is performed. The formalin-fixed infant cadaver head was scanned through the anterior fontanelle using pulse-echo and in a horizontal plane (3.3 cm superior to the Frankfort plane) using both pulse-echo (3.5 MHz and 5 MHz) and transmission sonography (5 MHz). The computed sonographic transmission tomogram revealed superior anatomic detail as compared with the pulse-echo images obtained in the horizontal plane and compared favorably with x-ray scans. The quantitative, noninvasive nature of sonographic tomography shows promise for clinical applicability in the infant. In the adult human cadaver, sonographic tomograms at 750 kHz are presented in both the transskull and excised brain conditions. These scans also offer promise for the possible clinical exploration of the method.

Pulse-echo sonographic imaging through the open anterior fontanelle has become an important diagnostic tool in the evaluation of pathology of the infant brain. Among its versatile features are excellent resolution, portability, and ease of use in the infant isolette [1-3]. Although the fontanelle as an acoustic window has been shown to be extremely useful, there are some limitations inherent in the method. Not all regions of the brain can be visualized, and pulse-echo scanning is mainly qualitative in regard to tissue classification.

Sonographic computed tomography (CT), on the other hand, provides a quantitative basis for image formation. Until now, there has been little investigation of sonographic tomographic imaging secondary to the assumption that refraction and attenuation of sound by the skull would preclude the obtaining of meaningful images. Thus, the previous work in sonographic CT has focused on imaging soft tissue regions of the body, such as breast, in which refraction of the sound waves can be ignored [4-7]. We present new experimental results that provide insight into the potential applicability of sonographic CT for imaging through the intact skull.

## Materials and Methods

The scanning technique in sonographic CT is similar in principle to that used in x-ray CT. Figure 1 shows the scan configuration

used in our imaging experiments. The heads were mounted in a turntable fixture and immersed in water for acoustic coupling. A pulsed sonographic beam was transmitted through the head at a number of orientations in the plane to be imaged in order to form a set of one-dimensional parallel ray projections similar to the early rotate/translate x-ray CT scanners. The attenuation projections were calculated by computer using an exponential attenuation model applied to the incident and received sonographic pulse energies. The tomograms were then reconstructed from the projections by application of the convolution-back-projection reconstruction method [8].

A formalin-fixed infant head was scanned using the geometry in figure 1 to obtain projections for reconstructing an attenuation tomogram. A plane 3.3 cm superior to the Frankfort plane was scanned using 5 MHz center frequency, broadband, 0.64 cm diameter, and unfocused transducer for both send and receive. Projections were measured for 60 views spaced at 3° intervals over 180°. The projection sampling interval was 1.5 mm, resulting in 92 rays per projection.

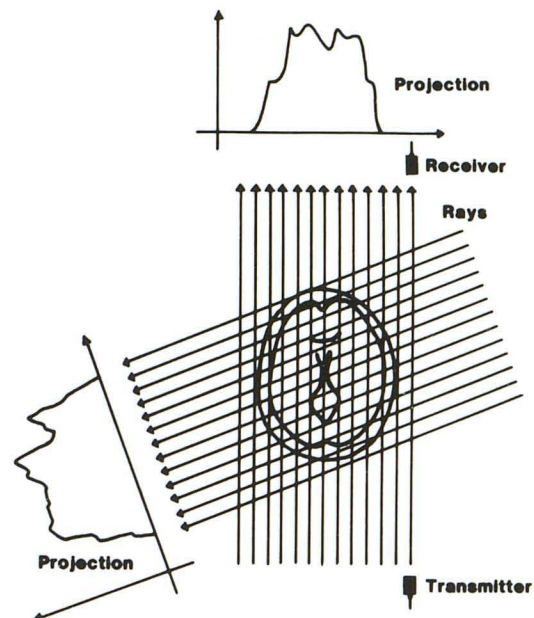


Fig. 1.—Scan configuration used in imaging experiments.

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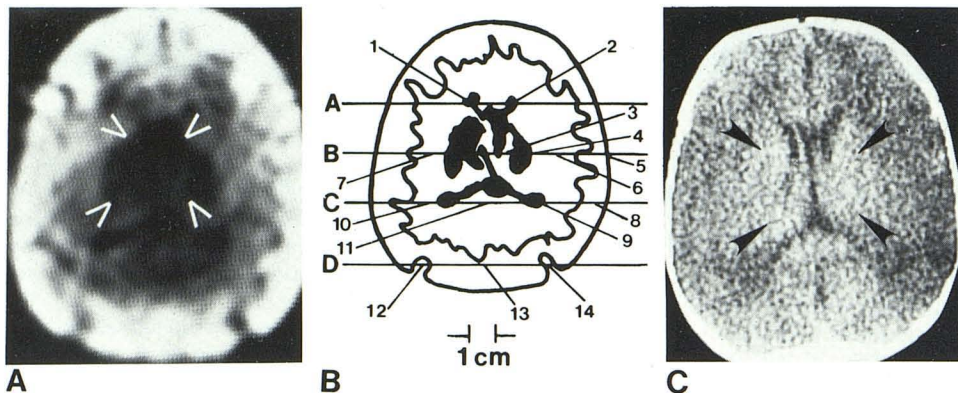


Fig. 2.—Attenuation tomograms of infant cadaver head. A, Computed sonographic tomogram. B, Corresponding line diagram identifies anatomic structures. Key to structures is in table 1. C, X-ray CT scan of same plane. Basal ganglia and thalamus (arrowheads).

TABLE 1: Key to Structures Identified in Figure 2B and Corresponding Attenuation Coefficients

No., Structure	Attenuation (dB/cm)
1, Lateral ventricle, anterior aspect	1.70
2, Lateral ventricle, anterior aspect	1.09
3, Internal capsule	1.15
4, Putamen	0.54
5, Skull	8.79
6, Subcortical white matter	3.65
7, Subcortical white matter	3.04
8, Skull	8.85
9, Lateral ventricle, posterior aspect	0.05
10, Lateral ventricle, posterior aspect	-0.13
11, Splenium of the corpus callosum	1.64
12, Lambdoidal suture	4.02
13, Skull	11.96
14, Lambdoidal suture	2.68

Some preliminary work was performed to determine the feasibility of developing sonographic CT for imaging the adult head. Previous pulse-echo work has shown that lower frequencies (500 kHz to 1.2 MHz) can penetrate the adult skull, detect brain structures, and return through the skull without severe distortion [9]. This fact has led us to consider the use of low frequency sonography to measure projections for tomographic reconstruction of the adult head.

An experiment was performed using an excised, formalin-fixed adult human brain. We measured projections using pulsed sonography with a center frequency of 750 kHz, which would be an appropriate frequency range for imaging through the skull. In this case we chose to image the acoustic speed instead of attenuation. On the basis of the excised brain results, another experiment was performed using a formalin-fixed, intact adult head.

**Results**

The sonographic attenuation tomogram reconstructed of the infant head using the convolution-back-projection algorithm is shown in figure 2, along with an x-ray CT scan of the same plane. General features displayed by the sonographic CT image are consistent with the expected anatomy of the skull and brain. Table 1 provides a key to the anatomic areas diagrammed in figure 2B. Some streaking is evident in the sonogram, as would be expected from refraction of the sound beam at the water-skull and skull-brain interfaces.

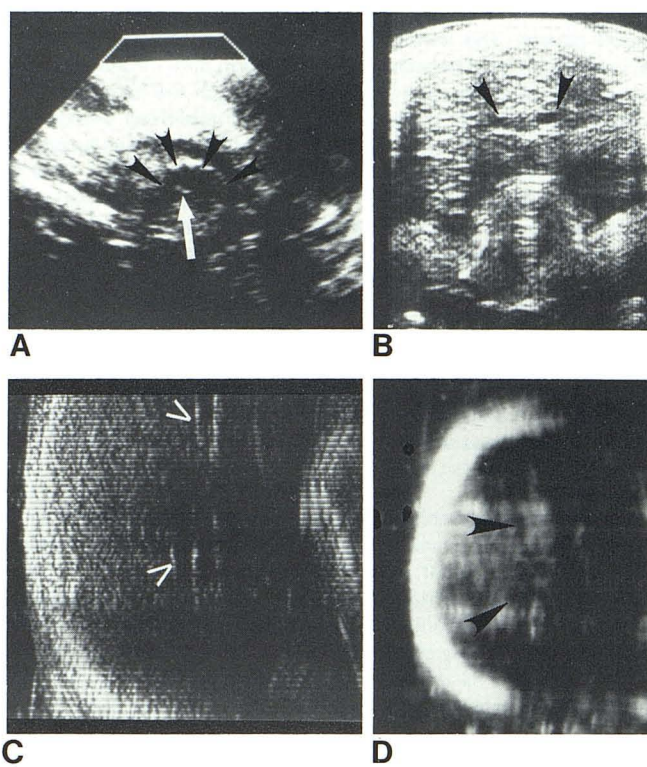
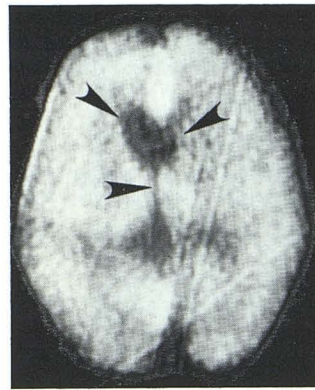


Fig. 3.—Pulse-echo sonograms. A, Parasagittal image through anterior fontanelle (anterior to left). Massa intermedia (arrow) and outline of third ventricle (arrowheads). B, Coronal view through anterior fontanelle (vertex at top). C and D, Horizontal images through temporoparietal bone (anterior at top). Lateral ventricle (arrowheads, B and D).

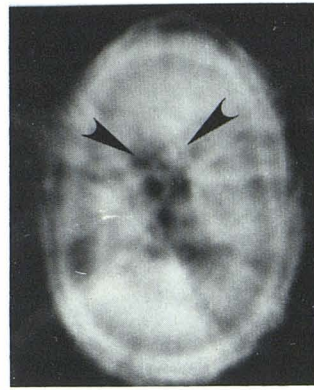
A comparison between the x-ray and sonographic tomogram reveals some similarities and some differences. The increased x-ray density of the thalamus and basal ganglia is displayed in the sonogram as a decreased acoustic attenuation relative to other brain structures. The normal low density of the centrum semiovale is identified in the x-ray scan with corresponding findings in the sonographic image. On a quantitative basis, the reconstructed sonographic attenuation values shown in figure 2 are consistent with values reported in the literature for the associated tissues indicated in the line diagram [10].

In order to test the performance of pulse-echo scanning as

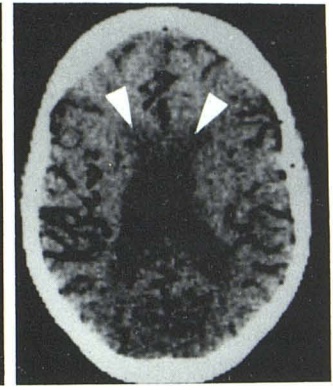
Fig. 4.—Sonographic speed tomogram of excised, formalin-fixed adult brain. Midline and lateral ventricles (arrowheads).



4



5A



5B

Fig. 5.—Attenuation tomograms of formalin-fixed adult head. A, Sonogram 750 kHz. B, X-ray CT. Lateral ventricles (arrowheads).

compared with our transmission tomographic method, we scanned the infant cadaver head using several standard pulse-echo visualization systems. Using an ATL sector scanner (5 MHz), the head was imaged in the sagittal plane (fig. 3A). The structures that can be identified include the third ventricle and massa intermedia. With a Hitachi linear phased array scanner (3.5 MHz), the head was imaged in the coronal (fig. 3B) and horizontal (fig. 3C) planes. In these images, the midline and lateral ventricles can be identified. An experimental mechanical B-mode scanner (5 MHz) was also used to image the head in the horizontal plane (fig. 3D), with the falx being echogenic.

The adult excised brain scanned at a frequency of 750 kHz is shown in figure 4. The spatial resolution achieved at this lower frequency appears sufficient to provide useful differentiation of brain structures. Thus, if this resolution could be maintained with the skull in place, sonographic CT in the intact adult head could be a useful diagnostic technique.

The intact formalin-fixed adult head sonographic attenuation tomogram obtained at 750 kHz is shown in figure 5, along with an x-ray CT image at the same plane. The x-ray image demonstrates intracranial gas. The sonographic reconstruction displays the basic skull shape with good symmetry. In addition, the scalp-skull and skull-brain boundaries are discernible. The highly attenuating intracranial gas is displayed as the bright regions in the brain. It appears that the ventricles can be observed in the sonogram and are reasonably symmetrical with respect to the midline.

## Discussion

Sonographic CT can be done in both the intact infant and adult heads. Our experience with the infant cadaver head demonstrates, in our opinion, superior images can be obtained with transmission sonographic tomography over pulse-echo scans in the same horizontal plane. In addition, the tomographic method allows visualization of areas of the brain not accessible via the fontanelle (fig. 3). In addition, the quantitative tissue values obtained with sonographic CT offers promise for future study. The application of low frequency

sonography (750 kHz) to the intact adult head provides some initial indications that sonographic CT through the intact skull may be feasible.

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