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Non-invasive procedures are favored, especially when dealing with an organ as frail as an injured brain.

Ultrasound Diagnosis for Head Injuries

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COMA following head injury poses a serious problem in management. Physicians must quickly determine whether the coma will resolve spontaneously, whether surgical evacuation of a hematoma is indicated, or whether prolonged supportive care is the only recourse.

Cerebral angiography helps to differentiate hemorrhage from edema as the cause for coma. It can be used only once, safely, during the few hours immediately after injury, and not again for several days.

Echoencephalography, one-dimensional ultrasound imaging (A mode) can be applied quickly and frequently throughout the critical hours and days immediately after injury. Although valuable information is obtained by echoencephalography, it can only reliably detect shift in the midline of the brain. A midline shift signifies that serious decompensation of brain protective mechanisms has taken place. It does not reliably differentiate between hemorrhage, which can be surgically removed, and cerebral edema that cannot be as readily benefited by surgery.

Computerized axial tomography (EMI Scanner), a significant advance in x-ray imaging, provides a great deal of information to noninvasively differentiate hemorrhage from edema. It will be used increasingly often in determining the presence and severity of brain injury. This new x-ray modality can be used frequently after head trauma, but is difficult to apply repeatedly over a short time span. Additional diagnostic methods are needed to aid in the rapid, effective treatment of acute head injury.

Ideally, a new method must be quickly and painlessly applied to restless, irrational patients. It must not compromise tissue that is functioning marginally as a result of trauma, and it must be reliable.

Two-dimensional ultrasound imaging is a versatile source of diagnostic information. Multiple attempts to apply it to the brain have been thwarted because the adult skull absorbs two thirds of the ultrasound beam. Recent advances in ultrasound technology[1] suggest that two-dimensional ultrasound tomography may become a useful method for early, rapid visualization of brain pathology frequently during the first few critical hours after head injury.

This paper is a report of progress in two-dimensional brain visualization with the prototype ultrasound instrumentation being investigated at Indiana University Medical Center.

Method

Ultrasound (1.7 MHz) is used in a focused, pulse-echo, linear scanning mode. Patients lie in the lateral position, on a cupped pillow that supports and partially immobilizes the head. A water bath with a soft plastic bottom is applied to the upper surface of the head (Fig. 1). The 3-5 cm of warm water in the bath provides additional immobilization to the head, and has a soporific effect on the restless patient. The immobilization is particularly comforting to newborn infants being studied for birth injury to the brain. A coupling gel is placed between the patient's hair and the bottom of the tank to remove all air bubbles. Air bubbles interfere with transmission of the sound beam, and produce artifacts in the visual image.

The ultrasound transceiver makes

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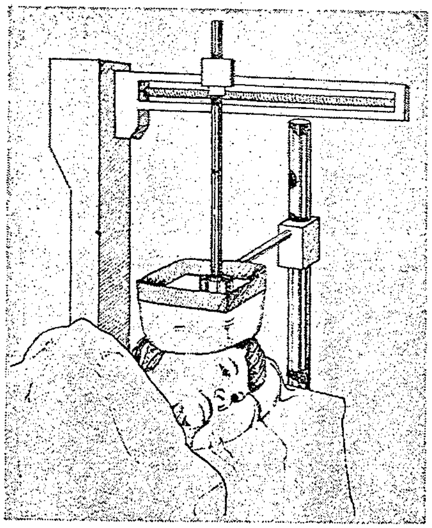

FIGURE 1
PATIENT'S head in scanning position.

a linear sweep through the water bath, either from vertex to base or anterior to posterior, to produce coronal or horizontal scans. Each scan visualizes a cross sectional image of the head 1 mm thick. The head is scanned at 5 mm or 1 cm intervals. An entire brain atlas can be generated in a few minutes.

The horizontal or coronal tomograms are displayed on two monitors. The large 17-inch TV-like monitor is used for rapid assessment of head alignment in relationship to the instrument, as well as for quick identification of the problem areas to be more carefully scanned. A separate 9-inch monitor displays an identical image and is used to make permanent records. The dual monitor system is particularly helpful in handling restless and uncooperative patients rapidly.

As many individual scans as are needed for diagnosis can be made without adding injury to an already damaged brain. Patients should be scanned as soon as possible after injury, and hourly or less frequently thereafter, depending on the rate of decline or improvement in clinical condition. Representative scans are preserved on video tape or Polaroid film for comparison to determine whether hematomas are increasing in size, or brain hemispheres have shifted to cause clinical deterioration.

Results

It is difficult to visualize brain structure with ultrasound through the adult's skull. In spite of this, intracranial hemorrhage is so reflective of ultrasound beams that it can be identified and reliably localized in most individuals. Subdural (Fig. 2) and epidural hematomas (Fig. 3) have been identified, and their distribution over the brain surface accurately demonstrated. In the two cases illustrated, the hematoma echoes decreased in size as the patient's clinical condition improved—the subdural hematoma without surgery, and the epidural hematoma after surgical evacuation. In both cases the presence of the hematoma was verified by cerebral angiography.

Ultrasound can easily penetrate the skulls of infants until the age of three or four years, when the inner and outer tables of the skull are separated by the growth of diploe. The method appears to be particularly valuable in the assessment of brain trauma soon after birth. The high reflectance of extravascular blood makes epidural, subdural, subarachnoid and intracerebral hematomas visible to ultrasound instrumentation. In thin infant skulls it is usually possible to identify the brain stem and observe distortions of this structure by a collection of blood, as well as intracerebral abnormalities indicating contused or hemorrhagic areas (Fig. 4).

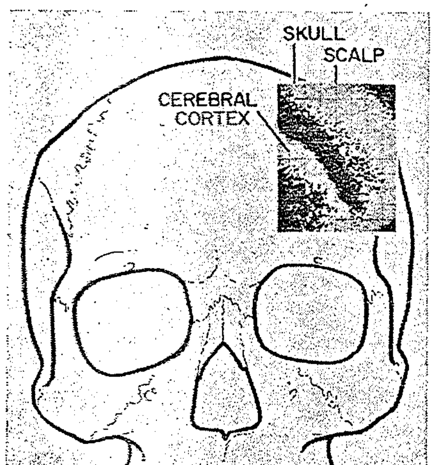

FIGURE 2
A coronal ultrasound scan of a segment of the head is displayed in relationship to the whole skull. Echoes from the cerebral cortex are separated 1 1/2 cm from the inner surface of the skull to suggest fluid between the two. A subdural hematoma was demonstrated angiographically.

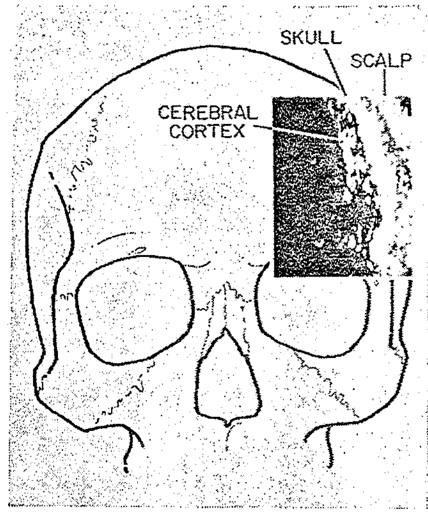

FIGURE 3
THIS coronal ultrasound scan shows the scalp slightly separated from the skull by a dark area of fluid, suggesting a subgaleal hematoma. The cortical surface is separated from the inner table of the skull. The echoes arising from the space between the cortex and skull suggest clotted rather than the liquefied blood shown in Fig. 1. An epidural hematoma was evacuated.

Discussion

Ultrasound visualization in two-dimensional tomography has a promising potential in the diagnosis of brain disease. The severe barrier to passage of sound beams provided by the adult skull has kept the method from reaching its full capability before now. Application to the infant brain and to intracranial hemorrhage in the adult adds new diagnostic information in the management of head injury.

Although ultrasound tomography cannot be expected to replace radiographic diagnostic methods, such as cerebral angiography and computerized axial tomography (EMI Scan), it adds sufficient information to make its contribution to the entire diagnostic picture quite valuable. This is particularly true in children under four years of age and in most adults. Since the prototype ultrasound instrument can be moved to the bedside, it can provide rapid and repeated brain visualizations during the early critical hours after head injury.

Ultrasound diagnostic technics are particularly attractive because they are non-invasive and non-accumulative, so that they are virtually free of deleterious effects on already severely damaged brains. It is not necessary to inject contrast media into a patient to provide visualization of the intracranial contents. The possibility for scanning the head rapidly, repeatedly, and without damaging an already compromised brain, should improve the acquisition of diagnostic information for management of head injuries. This is particularly useful in dealing with patients who are critically ill following head injury, and in infants whose brains should not be subjected to the added irritation produced by radiologic diagnostic studies.

Difficulty in getting diagnostic ultrasound beams through the adult skull has, up until recently, made two-dimensional ultrasound tomography impractical for diagnosis of brain dysfunction. Recent technical advances at the Fortune-Fry Research Laboratory, as well as in German[2] and Australian centers[3] open the field to renewed efforts, particularly in the early diagnosis of head injury. Refraction and scattering of ultrasound beams by the skull has been shown at the Fortune-Fry laboratories not to interfere with focused ultrasound beams.[1] The major problem is in attenuation of ultrasound beam intensity by the calvarium. Artifactual images produced by multiple echoes reverberating off the surface of the skull have led to confusion. These artifactual images can be differentiated from true structural changes by moving the ultrasound focal point in relationship to the skull surfaces.

Gathering ultrasound data is rapid enough that it should not interfere with the progress of the patient from the emergency room to definitive care for his serious head injury.

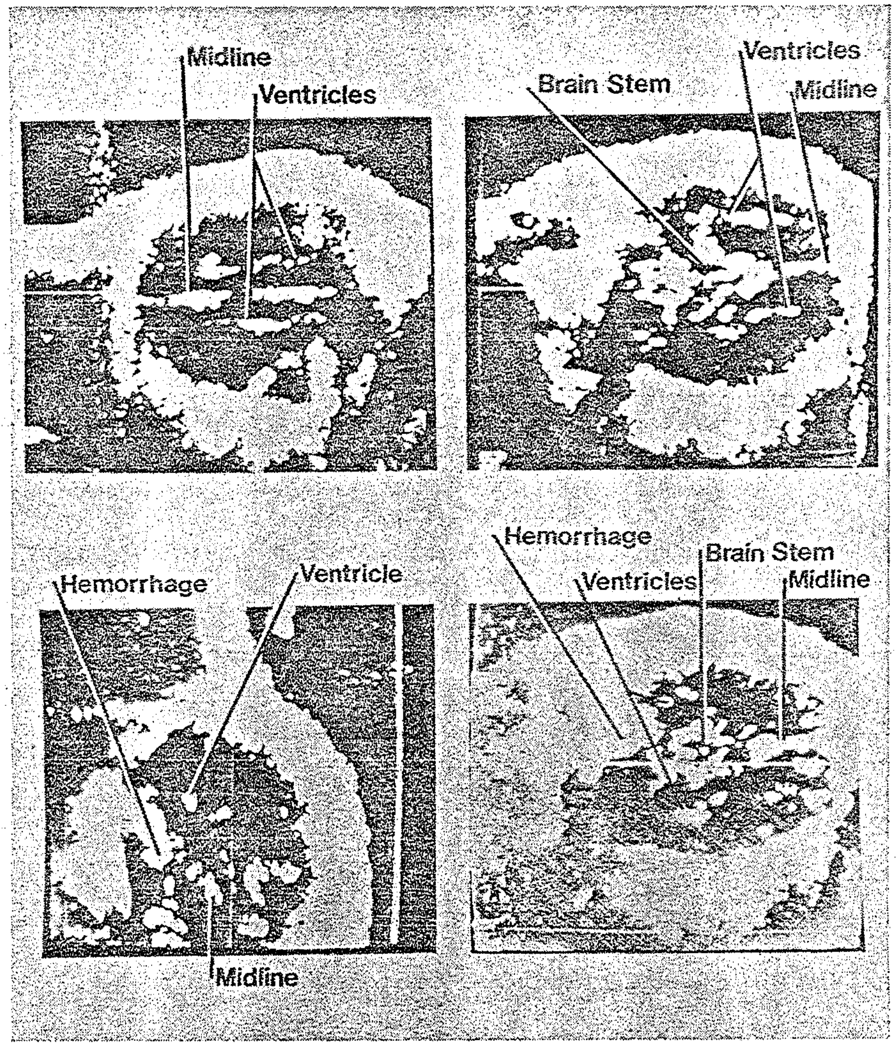

FIGURE 4

FOUR entire sections of a newborn infant's head are shown in coronal scan in the lower left ultrasound scan, and in horizontal section in the other three. The midline of the brain and the two lateral ventricles are shown in the upper left horizontal scan. The midline and lateral ventricle on the left and an abnormal highly reflective area, probably hemorrhage, are seen in coronal section, lower left. The brain stem, in addition to the midline and temporal horns of the lateral ventricles, is shown in the two horizontal sections on the right. The heavy reflection in the frontal region of the right lower scan suggests hemorrhage. The infant recovered from neonatal convulsions.

Summary

Ultrasound instrumentation is undergoing rapid refinement and improvement. The prototype model being tested at Indiana University Medical Center can add to rapid and accurate determination of brain injury in all age groups, but particularly in infants and small children. Since ultrasound at diagnostic levels is non-invasive and non-accumulative, it can be applied frequently and rapidly during the first few critical hours after head injury, without fear of further compromising the already damaged brain tissue. It promises to aid in the detection and localization of surgically removable hematomas.

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