Ultrasound in Med. & Biol., Vol. 33, No. 8, pp. 1277–1284, 2007
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0301-5629/07/$–see front matter

doi:10.1016/j.ultrasmedbio.2007.02.004

● *Original Contribution*

REAL-TIME 3-D INTRACRANIAL ULTRASOUND WITH AN ENDOSCOPIC MATRIX ARRAY TRANSDUCER

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(*Received* 26 *July* 2006, *revised* 4 *December* 2006, *in final form* 8 *February* 2007)

Abstract—A transducer originally designed for transesophageal echocardiography (TEE) was adapted for real-time volumetric endoscopic imaging of the brain. The transducer consists of a 36 × 36 array with an interelement spacing of 0.18 mm. There are 504 transmitting and 252 receive channels placed in a regular pattern in the array. The operating frequency is 4.5 MHz with a −6 dB bandwidth of 30%. The transducer is fabricated on a 10-layer flexible circuit from Microconnex (Snoqualmie, WA, USA). The purpose of this study is to evaluate the clinical feasibility of real-time 3-D intracranial ultrasound with this device. The Volumetrics Medical Imaging (Durham, NC, USA) 3-D scanner was used to obtain images in a canine model. A transcalvarial acoustic window was created under general anesthesia in the animal laboratory by placing a 10-mm burr hole in the high parietal calvarium of a 50-kg canine subject. The burr-hole was placed in a left parasagittal location to avoid the sagittal sinus, and the transducer was placed against the intact dura mater for ultrasound imaging. Images of the lateral ventricles were produced, including real-time 3-D guidance of a needle puncture of one ventricle. In a second canine subject, contrast-enhanced 3-D Doppler color flow images were made of the cerebral vessels including the complete Circle of Willis. Clinical applications may include real-time 3-D guidance of cerebrospinal fluid extraction from the lateral ventricles and bedside evaluation of critically ill patients where computed tomography and magnetic resonance imaging techniques are unavailable. (E-mail: edl@duke.edu) **© 2007 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Real-time 3-D imaging, 2-D array transducer, Intraoperative guidance.**

INTRODUCTION

In a recent study, we showed real-time 3-D transcranial ultrasound scans with simultaneous transcranial axial, coronal and sagittal image planes and real-time volume-rendered images of the gross anatomy of the brain in a human subject. In a transcranial sheep model we obtained real-time 3-D color flow Doppler scans and perfusion images using bolus injection of contrast agents into the internal carotid artery (Smith et al. 2004).

There has been growing interest in the use of ultrasound for intraoperative surgical guidance of tumor resections in the brain (Commeau et al. 2000; Unsgaard et al. 2002a). By placing a burr hole in the calvarium, the transducer can rest directly on the dura, thereby eliminating the image-degrading artifacts seen on transcranial sonographic images. Without the intervening bone, image quality can be quite good (Unsgaard et al. 2002a). Additional improvement in image quality can be obtained through the use of intravascular contrast agents. It has been shown that cerebral tumors can be better identified and the borders more exactly located (Hansen et al. 2005). Better imaging would be expected to result in more complete tumor resection and less damage to adjacent healthy tissue. Although magnetic resonance imaging (MRI) can also be adapted for surgical guidance (Black et al. 1997), it encumbers the costly MRI scanner, entails a restricted working space and requires special surgical tools that can be used within the MRI magnet.

Although both of these approaches are promising, they require the alignment of a 2-D slice with the target tissue and fail to provide real-time 3-D intraoperative guidance. MRI requires minutes to update the near real-time 2-D slices into a 3-D volume. Previous volumetric intracranial ultrasound approaches have also not been

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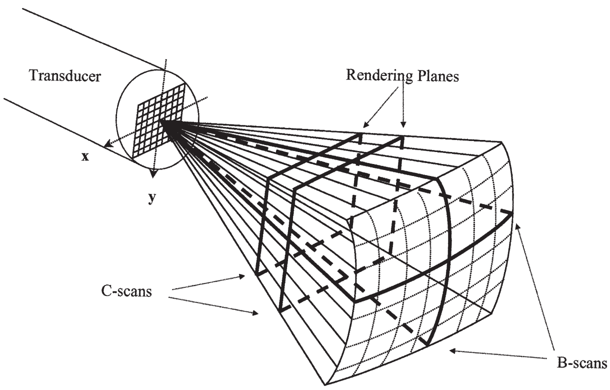

Fig. 1. Schematic of the pyramidal scan from a 2-D array transducer. Bold lines indicate possible display planes. By integrating and spatially filtering between two user-selected planes, real-time 3-D rendered images are displayed.

real-time (Unsgaard et al. 2002b). In addition, the conventional ultrasound procedures required a relatively large burr hole (3-cm diameter) to accommodate the transducer (Unsgaard et al. 2002a). The goal of this study was to develop an endoscopic transducer to facilitate real-time 3-D ultrasound imaging of the brain *via* a 10-mm transcalvarial burr-hole and to demonstrate the ability to conduct imaging in an animal model.

METHODS

Volumetric scanner

We have previously described our work in real-time 3-D ultrasound imaging (Smith et al. 1991; von Ramm et al. 1991). We have modified the Duke/Volumetrics 3-D scanner (Model 1, Volumetrics Medical Inc., Durham, NC, USA) as the system platform for imaging with our transducers. The commercial Volumetrics Medical Imaging ultrasound scanner generates a real-time 3-D pyramidal scan using as many as 512 transmitters and up to 256 receive channels. The scanner uses 16:1 receive mode parallel receive processing to generate 4100 B-mode image lines at up to 30 volumes per second. Figure 1 shows a schematic of B-mode display planes (perpendicular to the face of the transducer array) and two C-scan planes (parallel to the face of the transducer). Each image plane can also be inclined at any

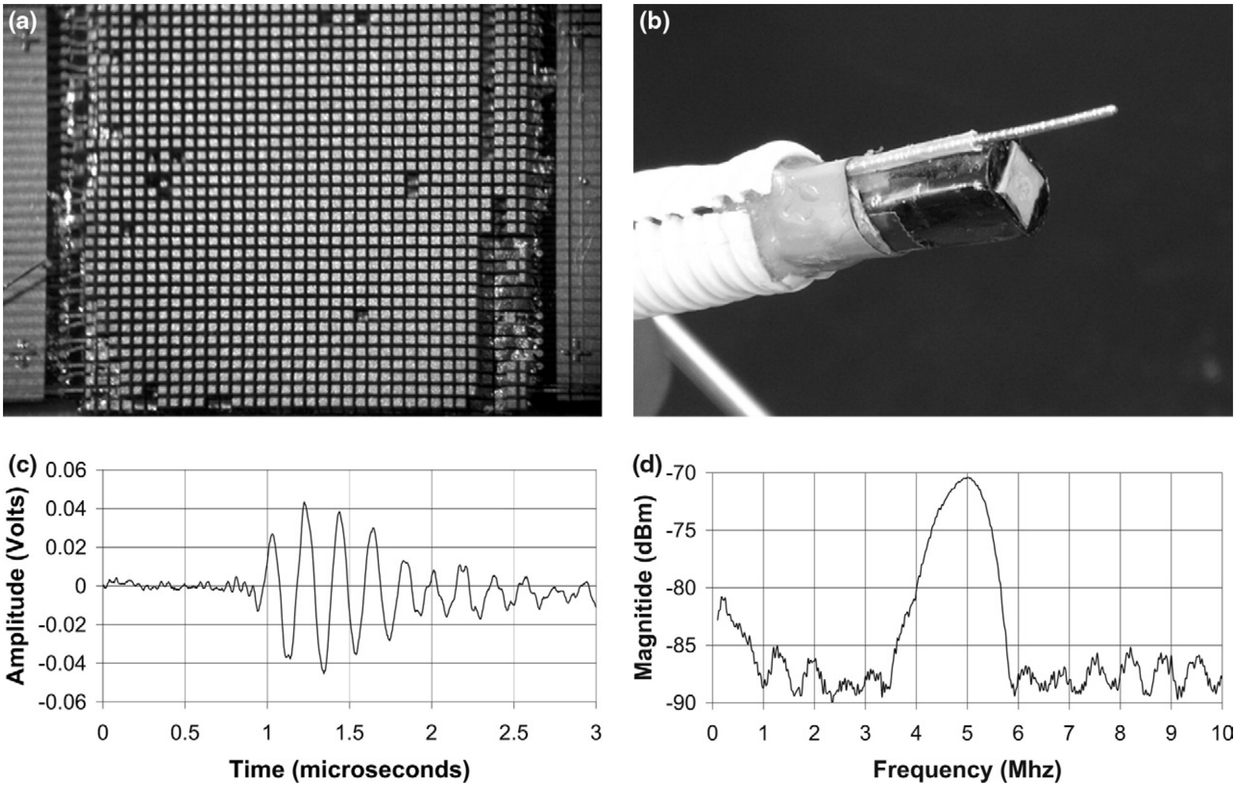

Fig. 2. Transducer photographs and typical pulse and spectrum from the transducer are shown. (a) A close up of a diced 5-MHz matrix array transducer for intracranial brain imaging. The total aperture size is 6.48 × 6.48 mm. (b) A photograph of a completed matrix array transducer showing working port and a Brockenbrough needle exiting the port. (c, d) Typical pulse and spectrum from the transducer pictured in (a) and (b). The center frequency is 4.5 MHz and the −6 dB fractional bandwidth is 30%.

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