INTUITIVE INTRAOPERATIVE ULTRASOUND GUIDANCE USING THE SONIC FLASHLIGHT: A NOVEL ULTRASOUND DISPLAY SYSTEM

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OBJECTIVE: The Sonic Flashlight (SF) is a new handheld ultrasound (US) display device being developed at our institution. It replaces the standard monitor on a conventional ultrasound (CUS) system with a miniature monitor and half-silvered mirror to reflect real-time US images into the body. With the SF, the imaged body part appears translucent, with the US image appearing to float below the surface of the anatomy, exactly where it is being scanned. The SF merges the patient, US image, instrument, and operator's hands into the same field of view, allowing the user to operate directly on the US image using normal hand-eye coordination. In contrast, CUS procedures result in displaced hand-eye coordination when the operator looks away from the patient to view the CUS monitor. Intraoperatively, the SF may make localizing and accessing tumors, foreign bodies, hematomas, vascular malformations, and ventricles easier and more accurate, especially for those without extensive CUS training.

METHODS: In this cadaver study, the SF was used to visualize the brain and guide a needle into an implanted simulated tumor. The needle was inserted both in the US plane and outside of the US plane.

INSTRUMENTATION: Sonic Flashlight fifth generation research prototype.

CONCLUSION: The needle was easily and intuitively visualized and guided into the lesion, both within and outside of the US plane. By having the US image appear directly beneath the brain surface, the surgeon can easily and quickly guide the needle or surgical instrument to the lesion. The operator's eyes never have to leave the surgical field, as they do with CUS technology. The impact of this device on neurosurgical procedures could be significant. The ease of use, intuitive function, and small instrument size allow the surgeon to quickly localize lesions, confirm surgical positioning, and assess postoperative results.

KEY WORDS: Augmented reality, Biopsy, Interventional ultrasonography, Intraoperative ultrasound, Sonic Flashlight, Ultrasound

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In most ultrasound (US)-guided interventional procedures, the US transducer is held in one hand to scan a target below the visible anatomy, while the other hand guides a needle into the target. Much of the difficulty in learning US-guided procedures stems from the displaced sense of hand-eye coordination that occurs when the operator has to look away from the operating field to see the display. This difficulty is one of the chief reasons why US guidance has not reached widespread adoption outside of radiology.

To address this difficulty, some researchers have explored methods for viewing the US image, patient, instrument, and operator's hands in a single environment. Head-mounted display (HMD) systems have been developed to display a US image within the patient (3, 10–12). These systems track the location of the US transducer relative to the HMD so the US image can be computed and displayed in the HMD with the correct stereoscopic perspective and location. To the person wearing the HMD, the US image appears within the patient at its actual physical location. Despite their promise, HMD systems have yet to overcome significant obstacles, including lag time, low resolution, limited field of view, weight, and expense. Furthermore, if multiple observers are cooperating in a

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procedure, each observer requires a separate HMD to observe the same in situ US image.

Based on real-time tomographic reflection, the Sonic Flashlight (SF) is a novel way to display real-time US images inside the patient, without using positional tracking or an HMD system (2, 13). The SF fixes the relative geometry of the transducer, display, and a half-silvered mirror that the operator looks through to produce a virtual US image inside the patient (*Figs. 1* and *2*). The US image appears to float within the patient, with each pixel of the US image appearing to emanate from its correct anatomic location within the patient, exactly where the US is being scanned (*Fig. 2*). Using the SF, the US image, patient, instrument, and operator's hands are all merged into a single environment. This makes US-guided interventional procedures as simple as aiming for the US image that appears to float below the surface of the visible anatomy. The SF is viewpoint-independent, meaning that users looking through the mirror from any vantage point will see the US image properly registered with the internal anatomy. It should be noted that photographs cannot convey the strength with which the US image appears within the patient, as if emanating from the front of the US probe.

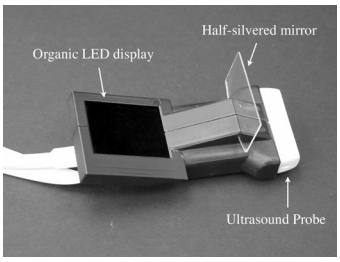

FIGURE 1. *The Sonic Flashlight incorporates a Terason 10-MHz linear probe, a 54.8-mm organic light-emitting display, and a 20 × 50-mm 40% reflective mirror.*

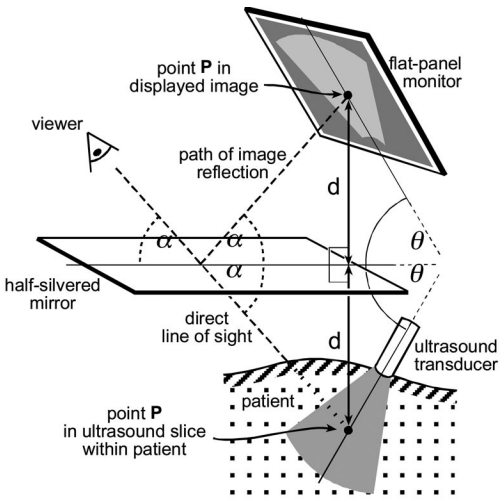

FIGURE 2. *The half-silvered mirror bisects the angle between the US slice within the patient and the flat-panel monitor. Point* P *in the US slice and its corresponding location on the monitor are equidistant from the mirror along a line perpendicular to the mirror* (d, *distance). Because the angle of incidence equals the angle of reflectance* (α, *angle), the viewer sees each point in the reflection precisely at its corresponding physical three-dimensional location.*

Current technologies used by neurosurgeons to localize lesions intraoperatively include stereotactic frames with computed tomography or magnetic resonance guidance, traditional US systems, intraoperative computed tomographic or magnetic resonance scanners, and frameless neuronavigation systems (4–9, 14). Each of these requires expensive and bulky equipment, specialized training, and, in the case of framed and frameless stereotaxy, prospective awareness that the system will need to be used so appropriate presurgical imaging can be performed. In addition, framed and frameless stereotaxy does not provide real-time lesion localization. Because preoperative imaging is used for the localization techniques, any alterations in lesion location during the surgical procedure (secondary to brain shift or partial lesion resection) will not be recognized by the localization system. To recalibrate the system, repeat imaging needs to be performed using either intraoperative computed tomography or magnetic resonance imaging. This procedure is both expensive and time consuming.

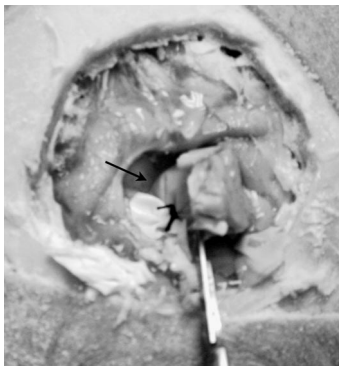

FIGURE 3. *In a cadaver brain, a 10-mm water-filled latex balloon simulating a tumor (*arrow*) was inserted beneath a flap made from the surface of the brain.*

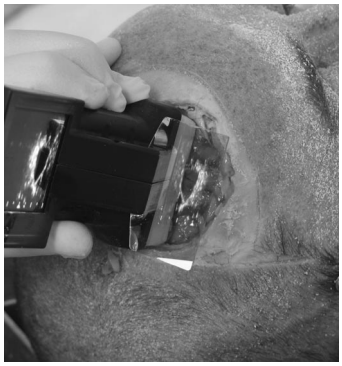

FIGURE 4. *As one looks through the SF, the simulated tumor is visualized at its expected physical location relative to the surface anatomy.*

MATERIALS AND METHODS

The fifth generation handheld SF research prototype consists of a Food and Drug Administration-approved, commercially available 10-MHz US probe (Terason, Burlington, MA), a small (44 × 33 mm) flat-panel organic light-emitting display (AM550L; Kodak, Rochester, NY), and a 25 × 50-mm, 2-mm-thick half-silvered mirror (40% reflectance; Edmund Optics, Barrington, NJ) (*Fig. 1*). This version of the SF can image and display US images up to 44 mm deep and 33 mm wide. The US probe and the flat-panel display are fixed at 80 degrees on opposite sides of the mirror by a rigid mount. The US probe upon which this version of the SF prototype is built measures approximately 16 × 54 × 92 mm with a 14 × 54-mm scanning footprint. The SF retains the same scanning footprint of 14 ×

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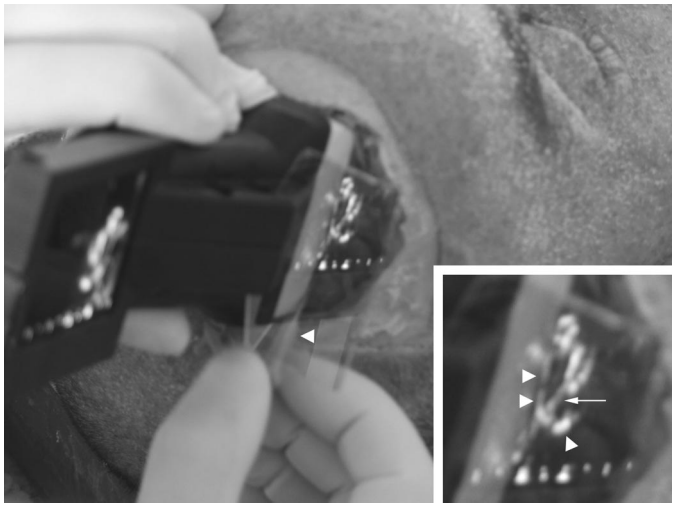

FIGURE 5. *In-plane insertion of the needle in the ultrasound scan. The needle was guided into and through the simulated tumor. The* arrowhead *in the large image points to the needle hub. In the* inset, *the* arrow *indicates the needle shaft passing through the simulated tumor and the* arrowheads *denote the edge of the simulated tumor.*

54 mm, with the entire device measuring approximately 44 × 57 × 133 mm.

The US data from the transducer is transmitted to a laptop computer (Latitude C840; Dell Computer Corp., Round Rock, TX), which performs the rotation, scale, and translation necessary to display the US image at its correct size and position on the flat-panel display. The US system displays 22 US frames per second, with the SF components adding no appreciable latency (<11 ms). The digital US data contain 512 × 128 pixels, which is displayed on the flat-panel display with 521 × 218-pixel resolution, resulting in no loss of display resolution or US data.

The cadaver was a male of unrevealed age and cause of death. A 50-mm circular hole was cut through the skull in the right frontal and parietal region to expose the brain. A ~10-mm-thick flap of the brain surface was reflected, and a cavity ~10 mm in diameter was created. In this cavity, a 10-mm-diameter water-filled latex balloon was inserted to simulate a tumor, and the flap was replaced (*Fig. 3*). The SF was placed against the surface of the brain above the region of the simulated tumor. A 40-mm 18-gauge needle was aimed at the tumor in the US image appearing below the surface of the brain, with the needle beginning in the US plane. The needle was then advanced into the simulated tumor, causing the water to drain from it. This procedure was repeated with the needle beginning outside of the US plane.

RESULTS

Using the SF, the sulci and the simulated tumor were visualized at their expected physical locations relative to the surface anatomy (*Fig. 4*). On the first attempt, the needle was inserted in the US plane and was clearly seen advancing into the brain tissue and the tumor (*Fig. 5*). On the second attempt, when the needle's insertion point was outside of the US plane, the needle was seen intersecting the US plane at its expected location as it was advanced into and through the tumor (*Fig. 6*).

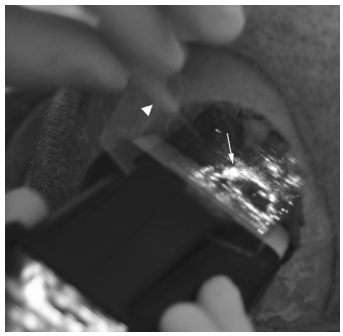

FIGURE 6. *Starting the needle insertion out of the US plane and guiding the needle into the edge of the simulated tumor. The needle tip is visible in the US slice at its expected location (*arrow *denotes tip in the US image;* arrowhead *indicates needle hub).*

DISCUSSION

Tumor biopsy and intraoperative localization are applications to which the SF may be particularly well suited. Unlike radiologists, many physicians performing these procedures have not had extensive US training. They often find US guidance nonintuitive and difficult and, therefore, do not use it, even when it has the potential to greatly improve accuracy and patient safety.

Since the current SF prototype requires approximately a 50-mm hole to access the brain, it is likely that this version would find limited neurosurgical use. However, the SF tech-

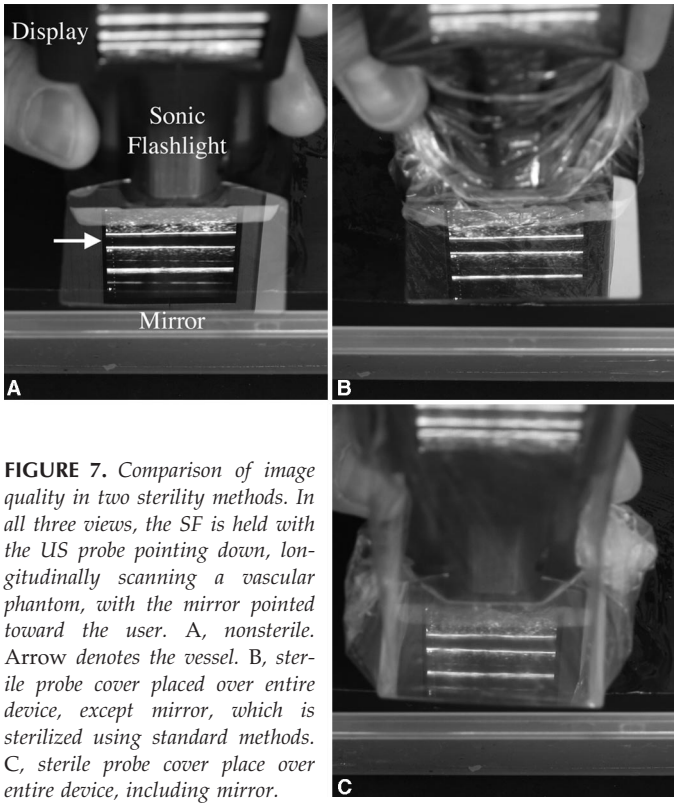

FIGURE 7. *Comparison of image quality in two sterility methods. In all three views, the SF is held with the US probe pointing down, longitudinally scanning a vascular phantom, with the mirror pointed toward the user.* A, *nonsterile.* Arrow *denotes the vessel.* B, *sterile probe cover placed over entire device, except mirror, which is sterilized using standard methods.* C, *sterile probe cover place over entire device, including mirror.*

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nology can be easily adapted to nearly any US probe, including those with a smaller head that could be used through burr holes made in the cranium. One can imagine such a version of the SF accessing the brain through a burr hole, while another nearby burr hole is used for the operating instrument (e.g., biopsy needle).

Sterility of the device can currently be obtained in one of two ways: fitting a standard sterile US probe cover over the entire SF, including the mirror, or fitting such a probe cover over the entire SF, except for the mirror, with the mirror sterilized by standard methods. While both methods do not severely interfere with the image quality, the latter produces slightly better results. *Figure 7* illustrates the difference in image quality when a vascular phantom is scanned longitudinally. Other methods of sterilizing the device are currently being explored.

In a previously conducted study, we showed that novice users perform vascular access in phantoms significantly faster using the SF compared to conventional US guidance (1). Further studies approved by the University of Pittsburgh Institutional Review Board are under way to show that the SF improves accuracy and ease in the placement of venous lines. Previous versions of the SF include a large 2 × 1-m floor-mounted version and a 30 × 30-cm pistol grip device. Additional work is under way to continue the trend of decreasing the size and weight of the SF while improving the resolution, ergonomics, and features.

Given the decreasing costs of portable US machines, we believe that production of a low-cost SF is possible in the near future and that such a device may have a significant impact by enabling a broad population of health care professionals who are currently uncomfortable with US guidance to use it. A future version of the SF could be collapsible and small enough to fit in the clinician's pocket, much like a stethoscope, handheld computer, or cell phone.

DISCLOSURE

A patent has been issued to GDS on this technology.

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COMMENT

Chang et al. report on a new technological device that combines the patient, the ultrasound image, the ultrasound device, and the surgeon's hand into the same field of view. If this device becomes commercially available, it may significantly increase the use of ultrasound among neurosurgeons because of its apparent ease of use. This device is much more intuitive than conventional ultrasound machines, which require the surgeon to look away from the surgical field to a monitor, because the surgeon is able to look directly at the treatment field when using the Sonic Flashlight. The device seems to still be in the early stage (prototype), and no live human studies were included in this technical note. Furthermore, the authors do not predict the cost of the commercial product should it become available. An inexpensive final product would increase the adoption of the Sonic Flashlight in the operating room. This is a promising product, and I would look forward to seeing studies in actual patients.

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