Experimental Analysis of Energy Safety Limits for Photoacoustic-Guided Endonasal Surgery

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Endonasal transsphenoidal surgery, an effective approach for pituitary adenoma resection, poses the serious risk of internal carotid artery injury. We propose to visualize these carotid arteries, which are hidden by bone, with an optical fiber attached to a surgical tool and a transcranial ultrasound probe placed on the temple (i.e. intraoperative photoacoustic imaging). To investigate energy requirements for vessel visualization, experiments were conducted with a phantom (Fig. 1&2) containing ex vivo sheep brain, bovine blood, and 0.5-2.5 mm thick cadaveric skull bone specimens. Photoacoustic images were acquired with 1.2-9.3 mJ laser energy, and the resulting vessel contrast was measured at each energy level (Fig. 3). The distal vessel boundary was difficult to distinguish as energy decreased (Fig. 4), and the contrast threshold for visibility was chosen to be 4.5 dB. The intersection between this threshold and the contrast data was used to measure the minimum energy required for vessel visualization, which could then be plotted as a function of bone thickness (Fig 5). Minimum laser beam diameter requirements (Fig. 6) were derived from energy measurements using the maximum permissible exposure limit defined by the American National Standards Institute (26.4 mJ/cm^2 given a 760 nm laser). The blood vessel was successfully visualized through the 0-2.0 mm thick sphenoid and temporal bones with up to 19.2 dB contrast. The minimum energy required ranged from 1.2-5.0 mJ, 4.2-5.9 mJ, and 4.6-5.2 mJ for the 1.0 temporal and 0-1.5 mm sphenoid bones, 1.5 mm temporal and 0-0.5 mm sphenoid bones, and 2.0 mm temporal and 0-0.5 mm sphenoid bones, respectively. These minimum energies correspond to minimum laser beam diameters of 2.4-5.3 mm, assuming a circular surface area. Results hold promise for vessel visualization within safety limits through the use of a modified fiber bundle design.

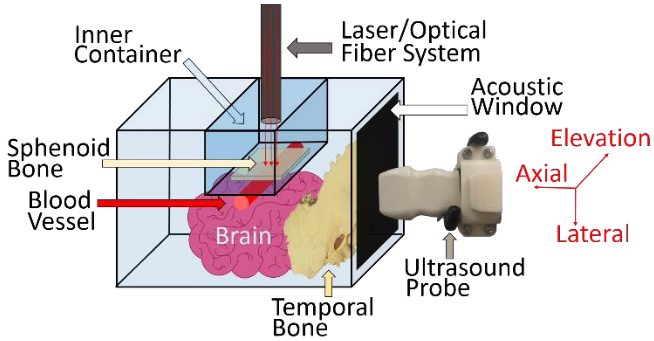

Fig. 1: Schematic of general phantom setup.

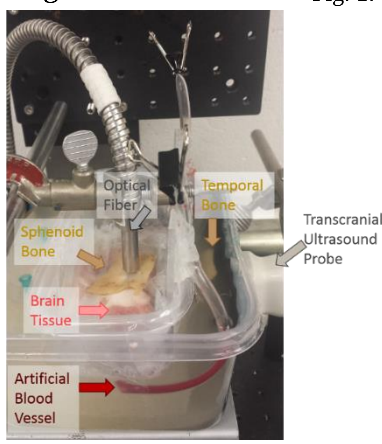

Fig. 2: Picture of general phantom setup.

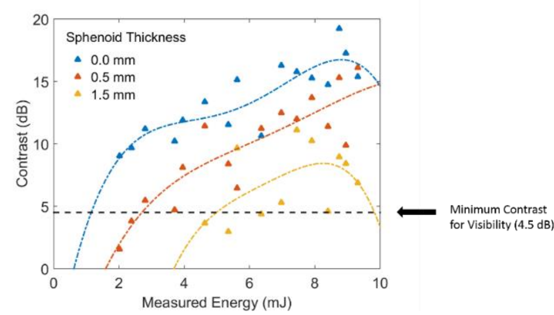

Fig. 4: Distal vessel boundary contrast vs. applied energy for the phantom setup with 1.0 mm thick temporal bone.

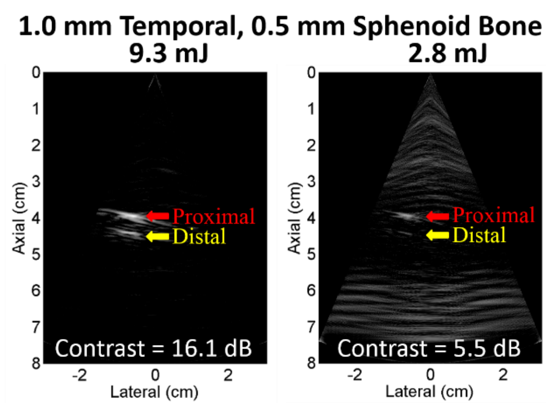

Fig. 3: Photoacoustic images, signal gets weaker as energy is reduced, distal boundary becomes difficult to distinguish.

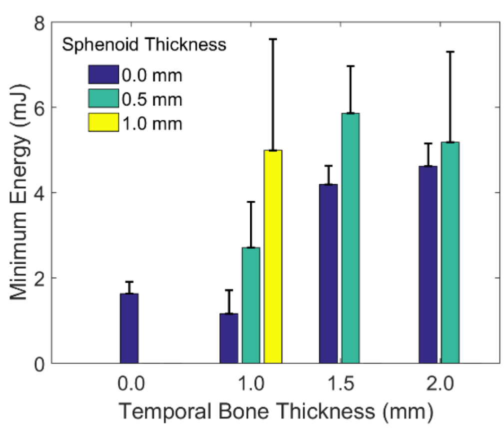

Fig. 5: Minimum Energy for distal vessel boundary visibility plotted as a function of sphenoid and temporal bone thickness.

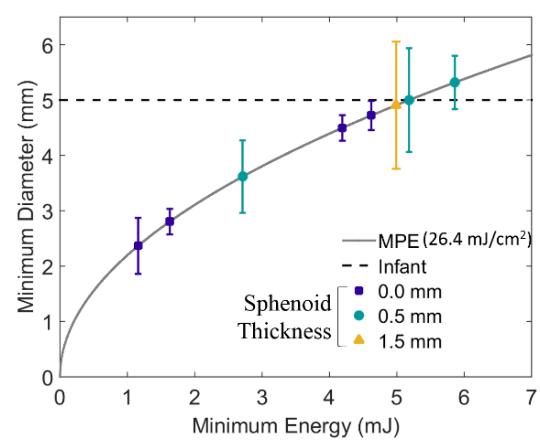

Fig. 6: Minimum laser beam diameter required to maintain safety limits, plotted using MPE conversion of minimum energy. Most required diameters are within size of infant's sphenoid sinus.