Simulation and experimental assessment of optimal receiver locations for photoacoustic image guidance during minimally invasive neurosurgeries

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Background, Motivation, and Objective

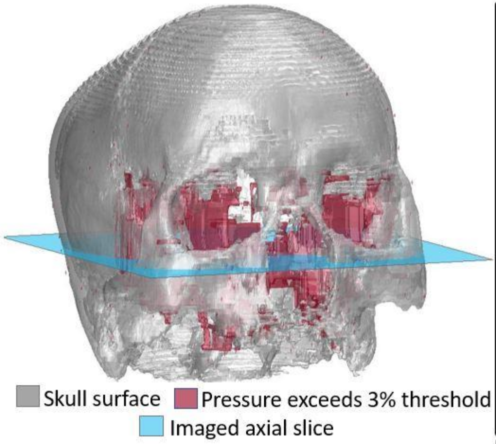
Real-time intraoperative guidance during the endonasal transsphenoidal approach to minimally invasive neurosurgery is often limited to endoscopy, which is suboptimal at locating underlying blood vessels and nerves. We are developing a photoacoustic approach that attaches light sources to the endonasal surgical tools to provide images that will prevent accidental injury to these critical underlying structures. This work investigates the optimal receiver locations for photoacoustic visualization of the internal carotid arteries.

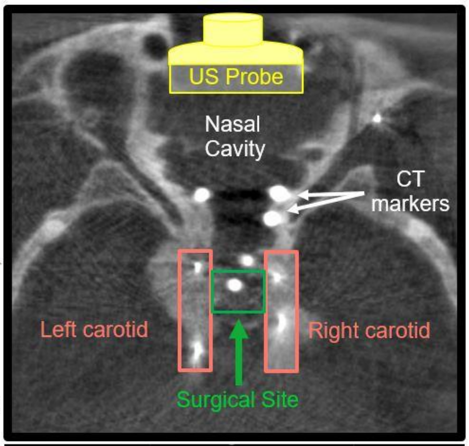
Statement of Contribution/Methods

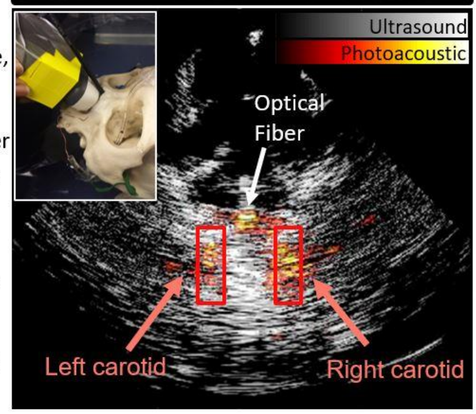
Photoacoustic k-Wave simulations were performed based on a CT volume of an emptied human cadaver skull. Acoustic receivers, distributed across the external skull surface, measured pressure from photoacoustic sources placed within the internal carotid arteries. Sensor locations receiving >3% of the initial source pressure amplitude were tested with the same skull in an *ex vivo* experiment, which involved placing blood-filled tubing in the location of the internal carotid arteries and a sheep eye in the eye socket. Optical fibers emitting 750 nm light were inserted into the nasal cavity for carotid artery illumination with our photoacoustic system. The ultrasound probe was placed on the three optimal regions indicated by simulations: (1) nasal cavity, (2) eye, and (3) temporal bone regions. The contrast of the blood target was calculated from delay-and-sum photoacoustic images. Ultrasound images were acquired for additional anatomical reference.

Results/Discussion

The nasal cavity, eye socket, and temple regions received 9.2%, 4.7%, 3.8% of the initial photoacoustic pressure, respectively, as measured with k-Wave simulations. Attenuation of the acoustic signal was minimized along the acoustic pathway from the photoacoustic source to these three receiver locations due to either the presence of thin bone (less than 3 mm on average) or the absence of bone. The measured contrast when receiving through the nasal cavity, eye socket, and temple regions in the *ex vivo* experiments were 17 dB, 10 dB, and 0 dB, respectively. This investigation of optimal receiver locations supports the introduction of new intraoperative probe designs, such as miniature nasal and ocular probes. In addition, our simulations methods are promising for patient-specific preoperative planning of optimal receiver locations.







(Top left) The locations of maximum pressure measured with k-Wave simulations were the temple, eye socket, and nasal cavity regions. These regions are displayed on a CT reconstruction of a human cadaver skull. **(Top right)** Axial CT scan of the cadaver skull showing the phantom internal carotid arteries, proximity of arteries to the surgical site, and the ultrasound probe located within the nasal cavity (one of the optimal receiver positions indicated by the simulations). **(Bottom right)** Experimental setup and corresponding photoacoustic image obtained through the nasal cavity of the cadaver, overlaid on co-registered ultrasound image. The internal carotid arteries are visualized with 17 dB contrast.