Photoacoustic Guided Spinal Surgery

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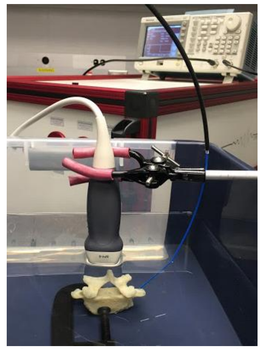
Introduction

I investigated using a photoacoustic system to track three different drill tip models as they passed through a pre-drilled human vertebra, as well as the visualization of blood through bone. The photoacoustic tracking coordinates were registered to both ultrasound and CT images of the vertebra. This system has clinical significance in spinal surgeries, particularly when inserting pedicle screws during spinal fusion surgery.



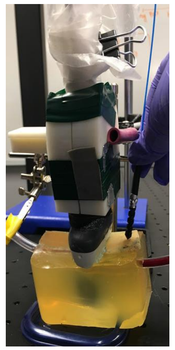


Figure 1. Data collection. A) phased array set-up for drill tracking experiments B) linear array set-up for blood visualization

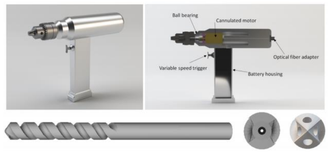


Figure 2. Example of drill that could be incorporated into this system and the 3D models of the drill tips used. *Left:* solid tip; *Middle:* single-holed tip; *Right:* multiple-holed tip

Problem

The current standard of care in spinal fusion surgeries is intraoperative fluoroscopy. Intraoperative imaging introduces harmful radiation to the surgeon and the patient. Ultrasound (US) imaging is a cheaper and less harmful alternative, but it is more difficult to visualize anatomy other than the cortical bone of the spinal column with US because bone distorts the signal. We propose a similarly safe intraoperative imaging modality that is still effective inside the vertebra: photoacoustic (PA) imaging. PA imaging also has the potential to show vasculature and nerves depending on the wavelength of light used in the system.

Solution

To determine how well blood can be visualized with this system, I imaged blood in 4 mm inner diameter tubing through thin bone at multiple depths. All data across all experiments was taken using a 760 nm wavelength to ensure blood visualization and tracking could be done with the same system.

In order to ensure the cortical bone is not breached during pedicle screw insertion we propose inserting an optical fiber into a drill tip and tracking the resulting PA signal.

I wrote processing and tracking scripts that generated plots of the US B-mode image, the PA intensity image, and registered these to the CT image of the vertebra used. PA images with matched video and US images were taken with the different drill tips as they entered a dry lumber vertebra. The PA coordinate was found based on signal amplitude.

Acknowledgements

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Tracking Results

Tracking data was collected using a phased array. For each trial, a US image was taken in the same position as the PA tracking data for that trial. The highest amplitude was plotted as the drill tip was inserted into the vertebra.

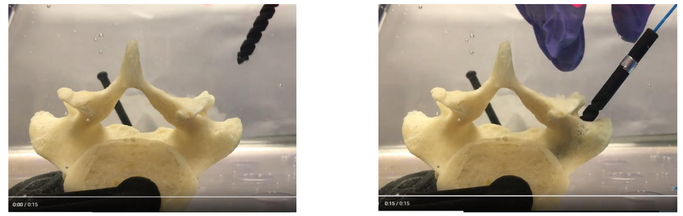

Figure 2. Data collection. *Left:* before data collection; *Right*: fully inserted drill tip

Tracking the drill tip was fairly successful, though registration was imperfect. Noisy data caused significant outliers along the bounds of the phased array capture. Based on these trials, the single-holed drill tip produced the smoothest tracking.

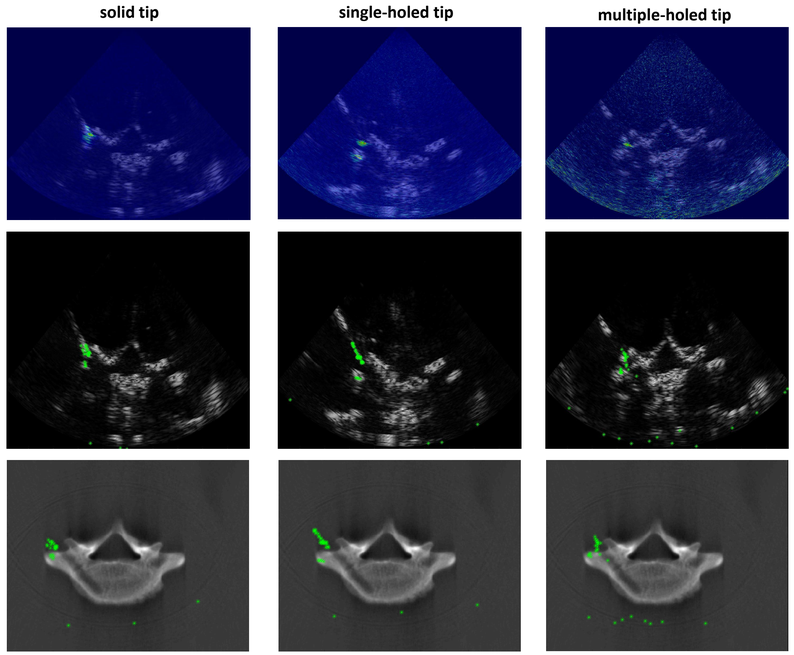

Figure 3. *Top row:* representative PA image overlaid on US image; *Middle row:* tracking results on US image; *Bottom row:* coordinates overlaid on CT registered image.

Blood Visualization Results

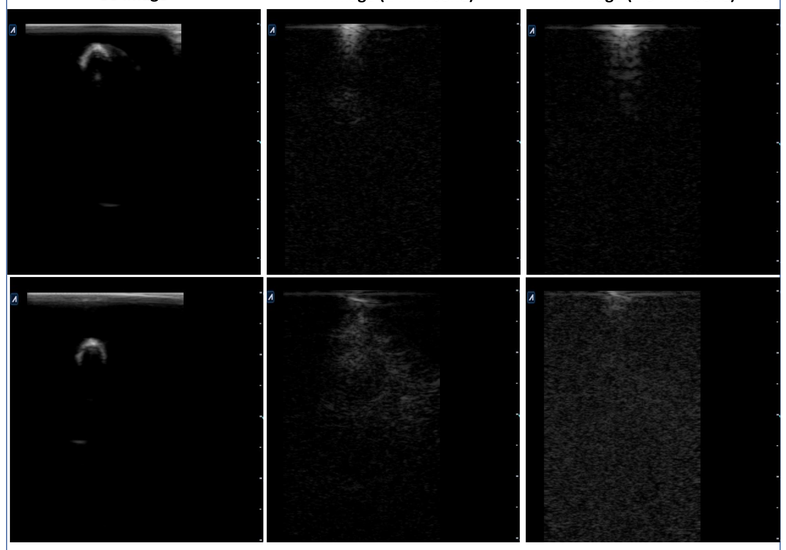

Figure 3. Results from blood visualization experiments. *Top:* blood vessel 5 mm deep; *Bottom*: blood vessel 10 mm deep

Tubing was filled with fresh human blood and imaged at multiple depths inside a phantom. All images were taken using a 760 nm wavelength, which is optimal for deoxygenated blood. Blood was not easily visualized through bone for this photoacoustic system. However, the change in signal for different bone thicknesses is evident. There was more diffraction present in the thicker bone.

Future Work

Future work includes filtering out the noisy images from the tracking data for smooth tracking, optimizing the drill prototype and the qualities of the inset optical fiber, and optimizing the system for visualizing blood. We plan to publish this work in a future Pulse Lab paper in conjunction with other related work done.

Lessons Learned

- Acquiring fresh blood samples from JHMI was tedious and in some cases prolonged data collection.
- A smaller blood visualization experiment with the fiber should have been done prior to other experiments with the same fiber. There might have been time to optimize the system for blood visualization before acquiring tracking data.

References

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