Design of a Multi-Fiber Light Delivery System for Photoacoustic-Guided Surgery

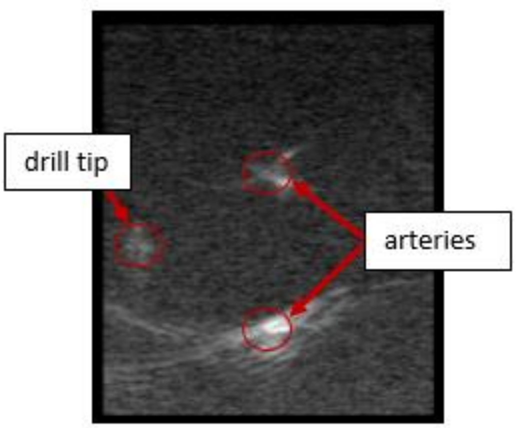
We successfully designed and built a prototype based on the integration of Monte Carlo simulations, Zemax simulations, beam profiler results, and theoretical calculations. This is the first multi-fiber design for an interventional photoacoustic system in order to visualize targets (e.g. blood) for guiding surgeries. This design was successful in creating a photoacoustic image of both of the blood vessel boundaries and the drill tip in a single frame. Previous prototypes were not able to capture both vessel boundaries simultaneously, and image processing was required in order to determine the relative location of the blood vessels and the drill tip after multiple frames were captured. Because only one frame is needed to capture all three targets, this design reduces the frame rate required to operate this system.

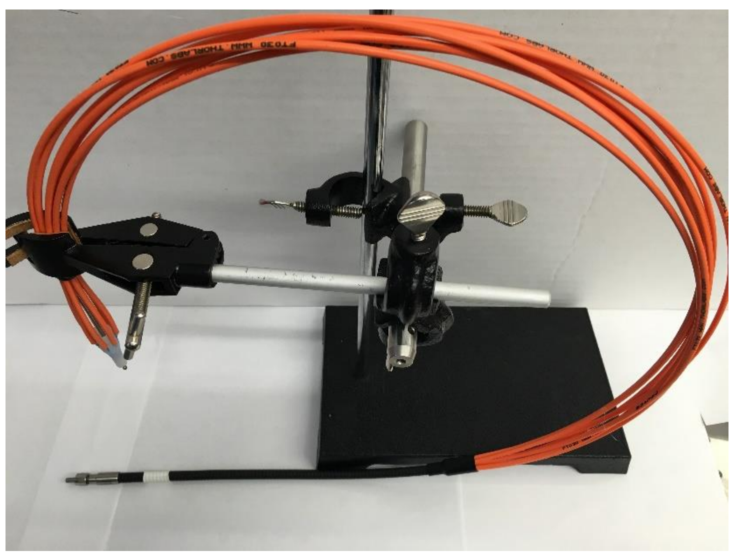
The allowable output energy range with our design was calculated in order to determine how it compares to the previous one-fiber design. Because the spot size is increased through the implementation of multiple fibers, we can now use a higher energy input to make photoacoustic images. Based on a conservative 1/e estimation of spot size, the beam profile ranges from 42 – 76 mm. For blood visualization, this gives an input energy range of 10 mJ – 19 mJ. At least 6 mJ is required to visualize blood through bone, giving our system more reach than the requirements. This means a better photoacoustic image can be created without increasing the patient risk.

The beam profile through bone is larger and more scattered than the profile with no bone. This increase in spot size could be due to a number of factors including an increased distance from the sensor, the use of the Nd:Yag laser instead of the flashlamp, and light being scattered through the bone.

Although the fibers used in this design are much smaller than the fibers used in previous experiments, the design still may be too bulky for a clinical setting. Future designs could be more compact in order to meet the requirements of a minimally invasive endoscopic surgery. A preliminary solution would be stripping more of the outer jacket. The custom 3D printed plastic part used to hold the fibers in place could potentially act as a bushing during the drill's rotation.

This methodology is useful for future designs of interventional photoacoustic systems. Similar methodologies can be used to design custom multi-fiber light delivery for a suite of surgical tools.





Left: Photoacoustic image taken with prototype. Both vessel boundaries and the drill tip are visible. Right: Light delivery Prototype