Noninvasive Continuous Imaging of Reduced Cerebral Perfusion with a Novel Diffuse Optical Tomography System: A Preliminary Carotid Artery Occlusion Study in Pig

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Outline

Diffuse optical tomography (DOT) systems have demonstrated the ability to noninvasively measure changes in oxy- and deoxy-hemoglobin concentrations in brain tissue. Cephalogics has introduced a novel, compact DOT system that may help clinicians monitor changes in brain perfusion and oxygenation following injuries such as ischemic stroke, vasospasm, or traumatic brain injury [1]. In this study, we tested the ability of the DOT device to track changes following irreversible occlusion of the internal carotid arteries (ICAs) of a pig.

Methods

Portable Diffuse Optical Tomography (DOT) System

- A picture of the portable DOT sensor is provided in (Fig.1 a).
- High-density arrangement: 10x18 (sources x detectors) on rigid-flex circuit boards.
- Five time-encoded, amplitude-modulated VCSELs operating at five wavelengths ranging 690-850nm within each source optode.
- Photodiodes, synchronous detection, overlapping CW measurements.
- Source-detector distances: 13-87mm over 9 nearest-neighbors.
- 180 channels per wavelength at 5Hz frame-rate. Acquired data is digitized, processed, and transmitted to a laptop via Ethernet connection for post-processing (Fig. 1 a).

Experimental Protocol

- A 41kg Yorkshire pig was anesthetized (isoflurane) and prepared for surgery.
- The pig was placed in a supine position; a Cephalogics DOT sensor was positioned under the pig's cranium; the sensor was secured using an elastic bandage wrap (Fig. 1 b). A second sensor was placed on the hind leg of the pig for monitoring systemic perfusion during the protocol.
- Catheters were inserted into the femoral artery and advanced into both left and right ICAs just proximal to the retia mirabilia.
- Following few minutes of baseline DOT recording, surgical glue was injected into both ICAs occluding the primary blood supply to the brain. DOT recordings from the head and the leg continued for ~20 minutes following the occlusion, which was confirmed angiographically.
- DOT optical data were recorded to a laptop and images of the change in cerebral tissue oxygen saturation ($SctO_2$) and systemic tissue oxygen saturation ($SstO_2$) were reconstructed every 1 minute.
- We compared mean (±SD) $SctO_2$ across the entire imaged field ($SctO_2$–A) with the mean (±SD) $SctO_2$ in a regional area ($SctO_2$–R) associated with the pig's brain.
- All animal procedures were approved by the Institutional Animal Care and Use Committee of Tufts Medical Center and the Human Nutrition Research Center on Aging.

Discussion and Conclusion

Angiography images confirmed the blocked blood flow in the ICAs and cerebral tissue following glue occlusion. It was also demonstrated that flow in the external carotid arteries remained intact (Fig. 2). Estimates of O_2 saturation in the leg muscle was considered a correlate for systemic tissue oxygen saturation ($SstO_2$) including non-cerebral tissue (skin, scalp, fat, etc.).

$SstO_2$ showed a modest increase (4%±2%) following occlusion, which is consistent with elevated venous O_2 return and increased flow to the limbs as a result of blocked cerebral blood flow. The difference between $SstO_2$ and $SctO_2$ (as reported in Fig. 3) is a demonstration of our ability to resolve cerebral tissue estimates from measurements through intact pig skull.

Pre- and post-occlusion $SctO_2$–A showed a modest decrease (–3%±7%) while $SctO_2$–R decreased more significantly (–15% ± 2%) (Fig. 4), highlighting the heterogeneity of the sampled tissue.

Despite the thickness of the pig's skull, we captured a significant drop in $SctO_2$ following complete, irreversible occlusion of both ICAs. Due to the small size of the pig brain, the imaging field of the DOT sensor includes both cerebral and non-cerebral tissue. The DOT images show a larger drop in $SctO_2$ in regions likely to reflect cerebral tissue.

Protocol

Fig.1. Experimental setup: ⓐ DOT sensor with a high-density imaging arrangement of 10 sources (yellow circles) and 18 detectors (blue circles). Green lines indicate all measurement pairs, ranging from 1–9 nearest neighbors; ⓑ picture of the animal operating room showing setup for glue occlusion of ICAs in pig. Angiography images visible in the background; ⓒ DOT sensor placement on the pig's head for monitoring cerebral perfusion pre- and post- glue occlusion of ICAs. Sensor placement on leg is not shown.

Results

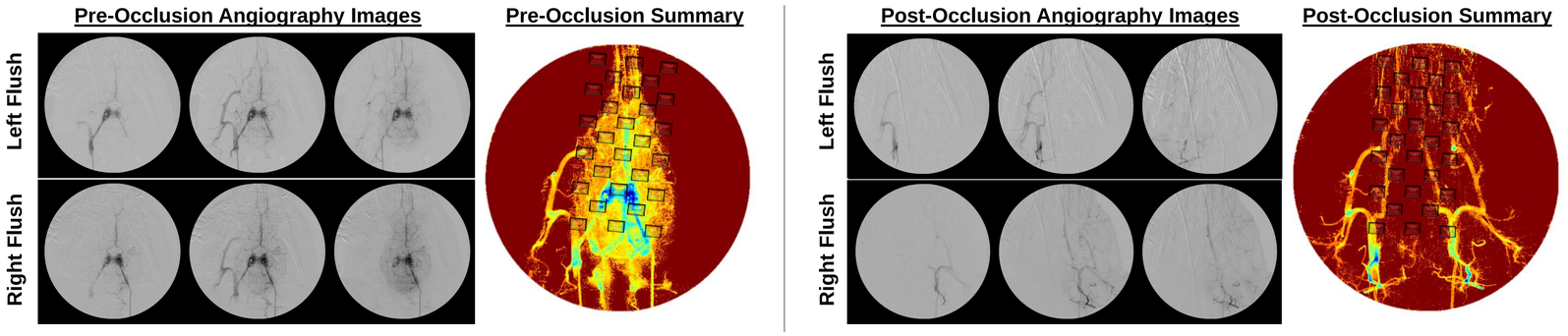

Fig.2. Angiographic confirmation of the occlusion of the ICAs (and retia mirabilia). Pre-occlusion images and summary are shown on the left. Post-occlusion images and summary are shown on the right. Black squares in the summary images represent co-registered sensor position with respect to vasculature through angiography images.

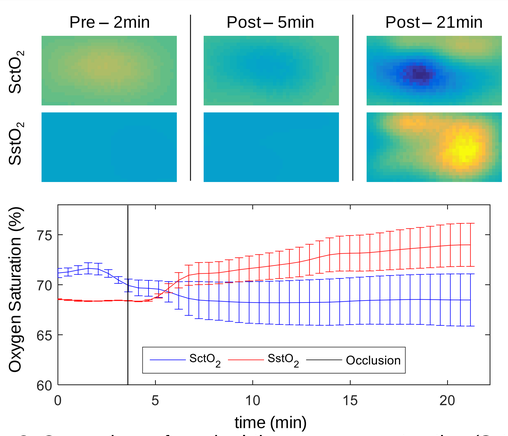

Fig. 3. Comparison of cerebral tissue oxygen saturation ($SctO_2$) and systemic tissue oxygen saturation ($SstO_2$).

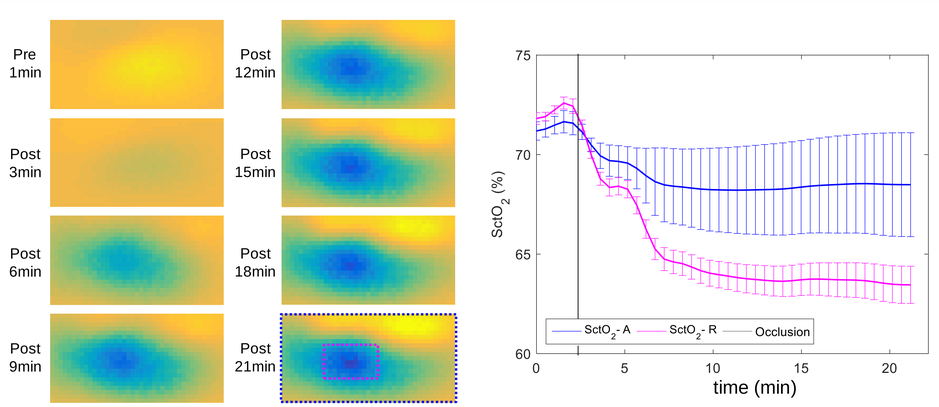

Fig. 4. Comparison of cerebral oxygen saturation of the entire imaged field ($SctO_2$–A) shown in blue and the regional field ($SctO_2$–R) shown in magenta.

References

[1] Hallacoglu, Bertan, Jason W. Trobaugh, Kate L. Bechtel, and Chandran V. Seshagiri. "Blood phantom verification of a new compact DOT system." In Cancer Imaging and Therapy, pp. JM3A-3. Optical Society of America, 2016.