

# Optical imaging of the response of vascular dynamics to a cold shock

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**Abstract:** We have explored the real-time response of the forearm vasculature to a contralateral cold shock. Dual-wavelength measurements were collected at 2 Hz, and the resulting image series (300 images per wavelength) was analyzed using appropriate time-series analysis methods. This confirmed the immediate vasoconstrictive response followed by an ~15–30 sec delay of a decrease in blood oxygenation. Overall, a wealth of time-varying responses were observed throughout the cross-section.

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**OCIS codes:** (170.6960) Tomography; (170.5280) Photon migration

**Introduction:** A critical component essential to health is the moment-to-moment reactivity of the vasculature. This is controlled both locally in response to the release of various tissue factors, and centrally by the autonomic nervous system. A broad range of disease processes are known to adversely influence vascular reactivity. For instance, in diabetes mellitus, blockage of small vessels can result in hypoperfusion states; neovascularization with an altered architecture is common in solid tumors; vasospastic states, in the form of Raynaud's phenomenon (*i.e.*, excessive vasoconstriction in response to cold), are associated with a range of disease processes, including certain autoimmune disorders, such as lupus and rheumatoid arthritis. The vascular response to a cold shock is a common test used for diagnosing vasospastic disorders and is an elegant demonstration of the control exerted on the vasculature by the autonomic nervous system.

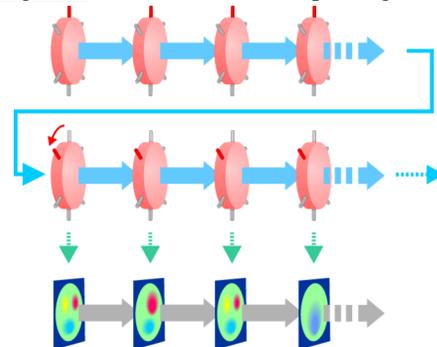
While much basic physiology regarding tissue/vascular coupling is known, suitable noninvasive methods capable of evaluating this process in large tissue structures have been lacking. Recently, we have described the feasibility of performing fast optical tomographic measurements as a means of exploring tissue/vascular coupling [1]. Also, in an accompanying report we describe new instrumentation we have developed that is suitable for investigating this interaction [2]. For this report, we explored the influence that a contralateral cold shock has on the dynamics of vascular coupling in the human forearm. Examples of other measures of tissue/vascular coupling are reported in accompanying reports [3,4].

**Methods:** *Instrumentation:* The instrumentation used for these studies is described in an accompanying report [2]. Basically, data collection was accomplished using a dual-wavelength (780 and 810 nm) parallel detection system with a geometrically adaptive iris measuring head (Figure 1). Measurements were performed at a rate of 2 Hz, using the serial source multiplexing scheme sketched in Figure 2.

Figure 1. Iris imaging head.



Figure 2. Serial-source multiplexing scheme.



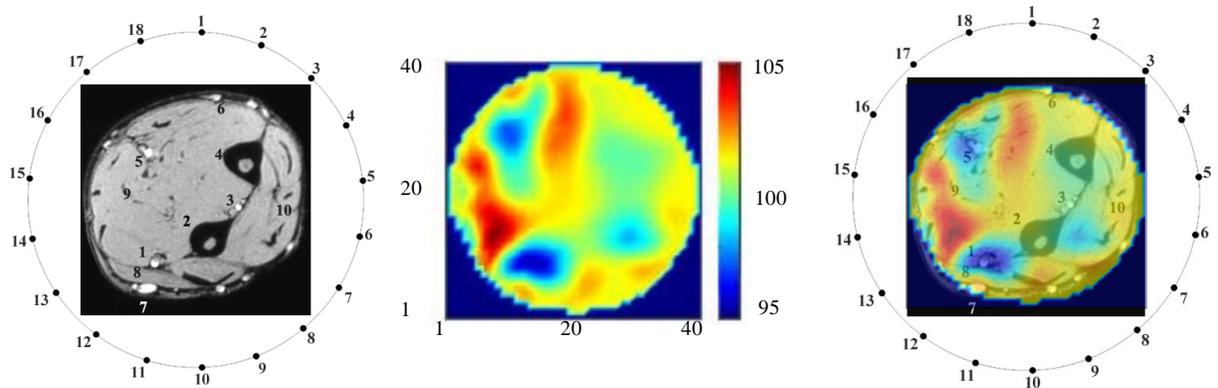
**Data collection protocol:** The protocol comprises three time periods. A 30-sec rest period is first, followed by a 60-sec exposure of the left hand to an ice slush, and then a 60-sec exposure to warm water. All during this time

period the right forearm arm is surrounded by and in contact with the iris measuring head. This protocol is repeated for each source position. In all, data from a total of six sources and eighteen detectors per source (108 S–D pairs) were used for the reconstruction of one image at each time point and each wavelength. The entire time series contained 300 images per wavelength.

*Image reconstruction.* Image reconstruction was accomplished by solving a linear perturbation equation, using a previously described CGD method limited to the first-order Born solution. The data vector for each image consisted of detector values normalized to the mean value of the initial segment (*i.e.*, the 30-sec rest period) of the time series. This value was then multiplied by the reference intensity value, as described elsewhere [5].

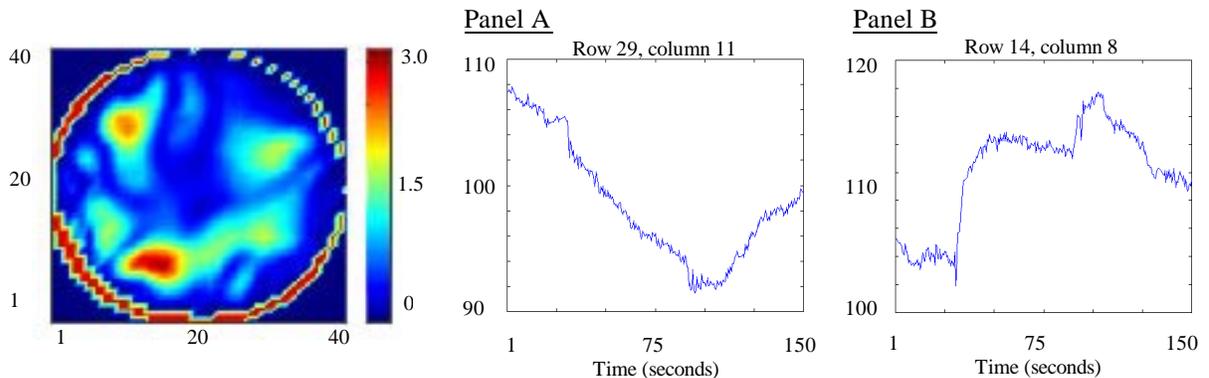
**Results:**

Figure 3 shows a MR image of the right forearm, an image of the mean value of hemoglobin concentration throughout the time series and overlay of the two images. Inspection shows that maximal vasoconstriction is observed in the regions of the radial, ulnar and interosseous arteries. Relative vasoengorgement is seen in the regions corresponding to different muscle groups (flexors digitorum profundus, carpi radialis and digitorum superficialis).



**Figure 3.** Panel A. MR image of right forearm. Legend: 1) radial artery, 2) radius, 3) interosseous artery, 4) ulna, 5) ulnar artery, 6) basilic vein, 7) cephalic vein, 8) brachioradialis, 9) flexor digitorum superficialis, 10) extensor digitorum. Panel B. Reconstructed mean image of 300 images of variations in hemoglobin concentration ( $\mu\text{M}$ ). Values shown assume a mean tissue blood volume of 5%. Panel C, overlay image. Shown are the positions of the optical fibers.

Figure 4 shows a map of the coefficient of variation of the computed hemoglobin levels during the time series. Comparison of panel B in Figure 3 to Figure 4 shows substantial overlap between those regions exhibiting the extreme mean values and those having the largest overall CV. Interestingly, however, quantitative variations are evident. Figure 5 shows the time course at various locations within the computed image series. Most evident is an abrupt change in hemoglobin levels upon exposure to the cold shock and to warm water.

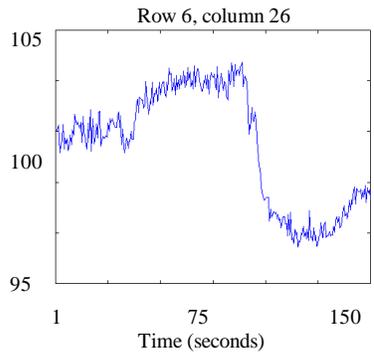


**Figure 4.** CV image of hemoglobin concentration.

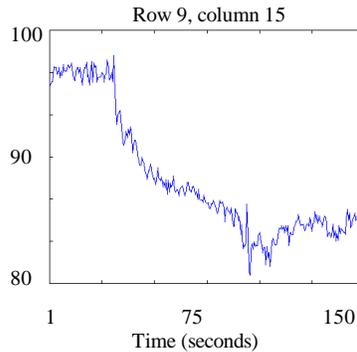
**Figure 5A–E.** Time trends at selected positions in the image map. Ordinate axis is hemoglobin concentration in  $\mu\text{M}$ .

Figure 5 continued

Panel C



Panel D



Panel E

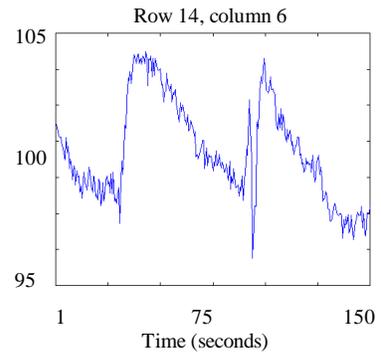


Figure 6 shows a map of mean value of variations in hemoglobin oxygenation levels during the time series. A resting level of 30% is assumed. Time trends at specific locations in the image map are shown in Figure 7. Interestingly, unlike the abrupt response seen in tissue hemoglobin levels (*i.e.*, blood volume), changes in hemoglobin oxygenation are delayed by approximately a 15–30 sec following exposure to the cold shock.

Figure 6

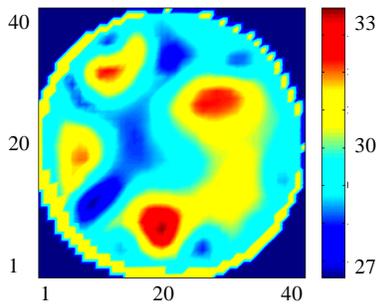
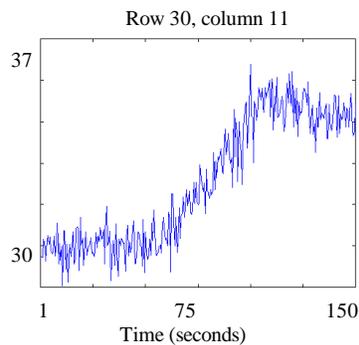
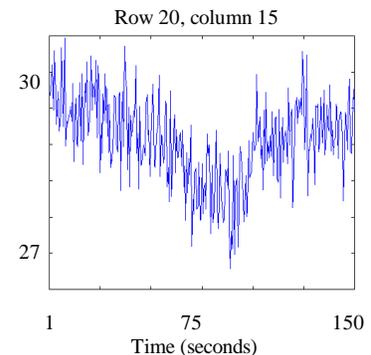


Figure 7A



7B



**Summary and conclusions:** Analysis of time-series image data have identified site-specific variations in hemoglobin concentration and its oxygenation state in response to a cold shock. The principal changes seen coincide with major vascular structures and muscle.

#### References:

- [1] H. L. Graber *et al.*, "Dynamic imaging of muscle activity by optical tomography," accompanying report.
- [2] C. H. Schmitz *et al.*, "A fast versatile instrument for dynamic optical tomography," accompanying report.
- [3] S. Blattman *et al.*, "Imaging of tissue reperfusion by dynamic optical tomography," accompanying report.
- [4] H. L. Graber *et al.*, "Dynamic imaging of muscle activity by optical tomography," accompanying report.
- [5] Y. Pei *et al.*, "Model-based imaging of scattering media based on a modified perturbation formulation using relative detector values," *Optics Express*, submitted.

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