Imaging of tissue reperfusion by dynamic optical tomography

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Abstract: We have explored the real–time response of the forearm vasculature to partial obstruction and subsequent restoration of blood flow. Dual–wavelength measurements were collected at 2 Hz, and the resulting image series (120 images per wavelength) was analyzed using appropriate time–series analysis methods. The temporal properties of the absorption coefficients' spatial distributions gave clear evidence of coordinated reperfusion among well–separated zones of peripheral tissue.

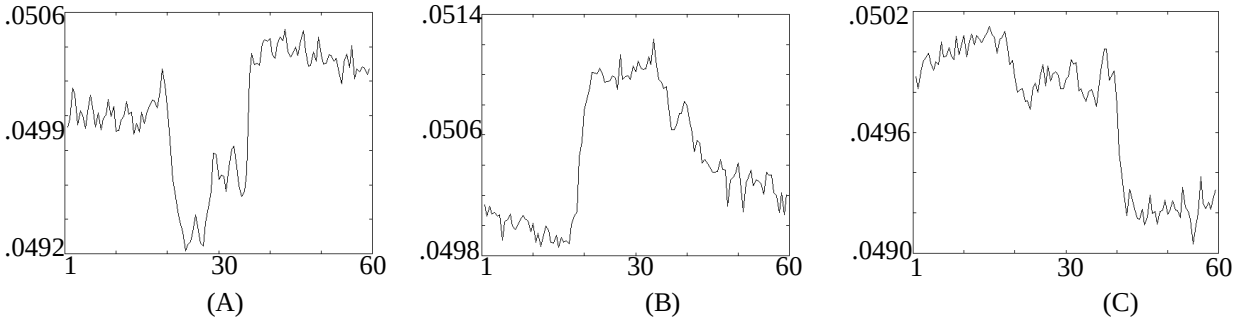
OCIS codes: (170.6960) Tomography; (170.5280) Photon migration

1. Introduction: Systemic interruption of blood flow can occur in various surgical procedures. For example, during cardiopulmonary bypass, blood flow to the peripheral tissues can be halted for several hours before reperfusion injury occurs. Adequacy of restoration of blood flow to the periphery is not easily assessed and often is made by simply assessing the warmth of the tissue by manual palpation. More useful would a noninvasive method capable of assessing temporal variations in both tissue blood volume and blood oxygenation. Optical methods can provide this information. In this report we demonstrate the ability to image tissue reperfusion from analysis of time series image data. Results obtained suggest that dynamic imaging studies may represent a new approach to characterizing perfusion states in large tissue structures.

2. Methods: Data collection was accomplished by performing dual–wavelength (780, 810 nm) parallel optical tomographic measurements at rate of 2 Hz using an iris imaging head [1] on the right forearm. For each of six source positions, a three–phase measurement protocol was followed. Following an initial 15–sec rest period, a sphygmomanometer cuff, located proximal to the measuring site, was rapidly inflated to a pressure of 150 mm Hg. After an additional 20 seconds, rapid deflation was initiated, and monitoring continued for an additional 25 sec. Variations in intensity readings about the temporal mean value were used as input for image recovery [2]. For each wavelength, images for 120 consecutive time points (60 sec real–time) were computed by simultaneously solving for perturbations in the absorption and diffusion coefficient. The resulting image data were analyzed using appropriate time–series analysis methods [3].

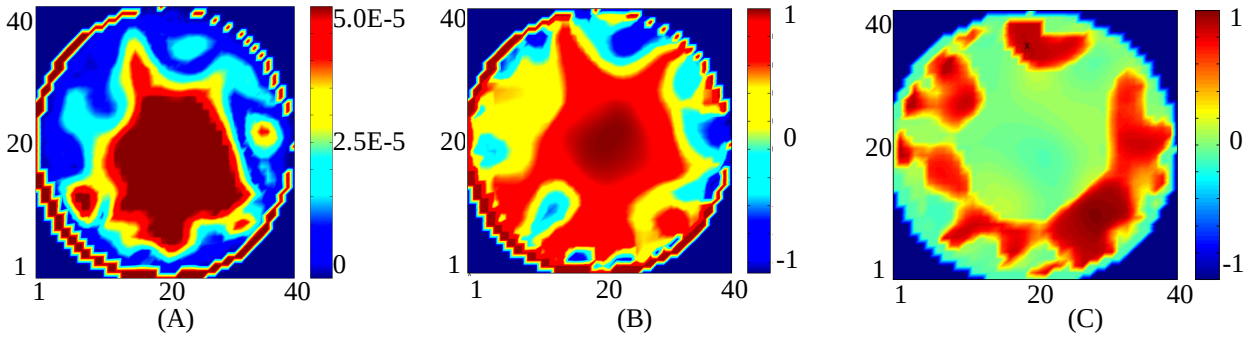
3. Results: Time trends revealing relative variations in hemoglobin levels in response to inflation and deflation of a pressure cuff at various locations in the cross–section are shown in Figure 1. Panel A shows an expected rapid vasoengorgement upon inflation of the cuff, followed by a slower return to baseline levels. Panel B shows that in other regions essentially the opposite tend occurs, indicating that redistribution of blood in the tissue is taking place simultaneously. The expected hyperemic overshoot is present in the selected pixel. A still different trend is revealed in Panel C, indicating that not all regions of the tissue have recovered within the time frame of measurement. Panels A and B in Figure 2 show cross–sectional images of the forearm derived by using Fourier (Panel A) and time–correlation (Panel B) analysis methods. Note the spatial coincidence between the large–amplitude response in panel A and the strong positive inter–correlated central region in panel B, indicating that all pixels within this region are *simultaneously* experiencing a low frequency change (*i.e.*, reperfusion). Panel C shows that coincident with these events is a time–correlated change in blood oxygenation levels. This was estimated by taking the difference between the computed absorption coefficient values at the two wavelengths (780 and 810 nm) for each time point. Interestingly, we observe that the regions experiencing a relative improvement in oxygenation are all highly correlated. Comparison of these to Panel B shows that they are the same regions that had experienced a relative vasoengorgement upon inflation of the pressure cuff.

Figure 1



Legend: Reconstructed absorption coefficient at 810 nm (Hb isosbestic wavelength) *vs*. time of measurement (seconds), for two specific pixels. Pixel coordinates are (row,column) = (27,32) in Panel (A), (14,30) in Panel (B), (18,20) in Panel (C). See Fig. 2 for maps showing row and column numberings.

Figure 2



Legend: Results of time–series analysis procedures applied to the reconstructed images from the reperfusion portion of the experimental time sequence (final 25 seconds of 60–sec total measurement duration). Panel (A), amplitude of Fourier transform, at f = 0.09 Hz. Panel (B), map of cross–correlation between a central pixel and all pixels, at Δt = 0 s, for the reconstructed 810 nm absorption coefficient. Panel (C), map of cross–correlation between a peripheral pixel and all pixels, at Δt = 0 s, for the difference between the reconstructed 780 nm and 810 nm absorption coefficients.

4. Summary: We have studied the real–time response to a transient occlusion event on the forearm by analyzing time series image data obtained from optical tomographic measurements. One of the measurement wavelengths is close to a hemoglobin isosbestic point, and the reconstructed absorption coefficient at this wavelength clearly shows redistribution of blood within the affected forearm. Inter–pixel temporal correlation studies show a sharp separation of the forearm tissue into central and peripheral zones, each of which exhibits strong positive intra–zone coordination of reperfusion response, while the correlation between the zones is essentially zero. The differences between the absorption coefficients at the two wavelengths employed, which is a useful qualitative measure of shifts in Hb oxygenation, also is markedly different in the two zones. These results corroborate well–known physiological responses, suggesting that optical tomography may have significant utility as a noninvasive real–time monitoring tool for vascular responsiveness and reactivity.

5. References:

[1] R. L. Barbour *et al.*, "Development and Evaluation of the IRIS OPTI Scanner, a General Purpose Optical Tomographic Imaging System," OSA TOPS vol. 21, p. 251–255, 1998.

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[3] R. L. Barbour *et al.*, "Optical Tomographic Imaging of Dynamic Features of Dense Scattering Media," 1999 JOSA–A, submitted.

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