Imaging of differential reactivity of the vascular tree in the human forearm by optical tomography

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Abstract: We demonstrate that different components of the vascular tree can be identified in a cross–sectional view by their reactivity to simple manipulations (*e.g.*, deep breathing) and by the existence of different naturally occurring beat frequencies.

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

1. Introduction: The functional properties of the vascular tree vary in accordance with its principal anatomic structures. For instance, metabolic nutrient exchange and modulation of vascular resistance is restricted mainly to the microvessels. The arteries and veins on the other hand have various structural features that facilitate directional flow. Currently, noninvasive imaging studies of the vasculature are limited mainly to investigations of large vessels. MR angiography can differentiate veins from arteries in accordance with the direction of flow by performing a time–averaged measurement. Real–time measurement of flow can be obtained by duplex ultrasound. Recently, we have described how the method of optical tomography can be adopted to detect dynamic features in dense scattering media [1]. In the current report we extend these studies and have explored the ability to detect different temporo–spatial properties of the vasculature in the human forearm. Two different experiments were performed. One involved a series of deep breathing exercises to produce temporal variations in tissue blood volume. The second recorded time–dependent variations in blood volume following release of a pressure cuff. Results obtained indicate that analysis of dynamic imaging data can provide a wealth of information regarding the differential reactivity of the vascular tree.

2. Methods: Single–wavelength (810 nm), multi–detector parallel optical measurements were collected at ~3 Hz using a previously described iris imaging system [2]. A serial source–multiplexing scheme was used to collect tomographic data from the right forearm. Data from 240 consecutive time points (84 sec real–time) were collected, and normalized to the temporal mean value determined during the resting phase for the occlusion study and throughout the time series for the respiration study. Variations about the mean were used as input for image reconstruction. Images were computed by simultaneously solving for perturbations in the absorption and diffusion coefficients. The resulting image data were analyzed using appropriate time–series analysis methods [1].

3. Results: *Occlusion Study*. The natural occurrence of vascular frequencies due to respiratory and cardiac activity can be exploited to produce a spatial map revealing the presence of different components of the vascular tree.

Figure 1

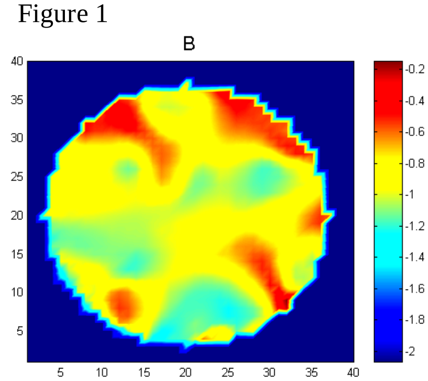


Figure 2

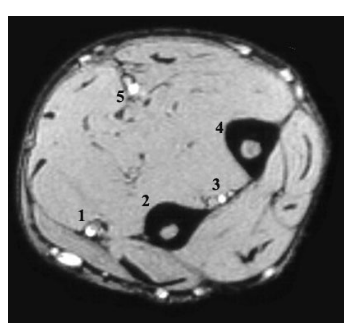


Figure 3

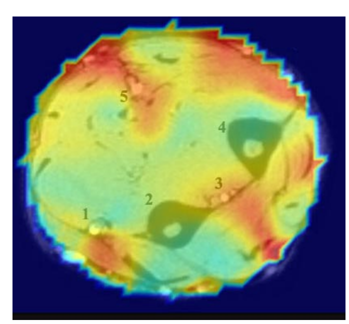
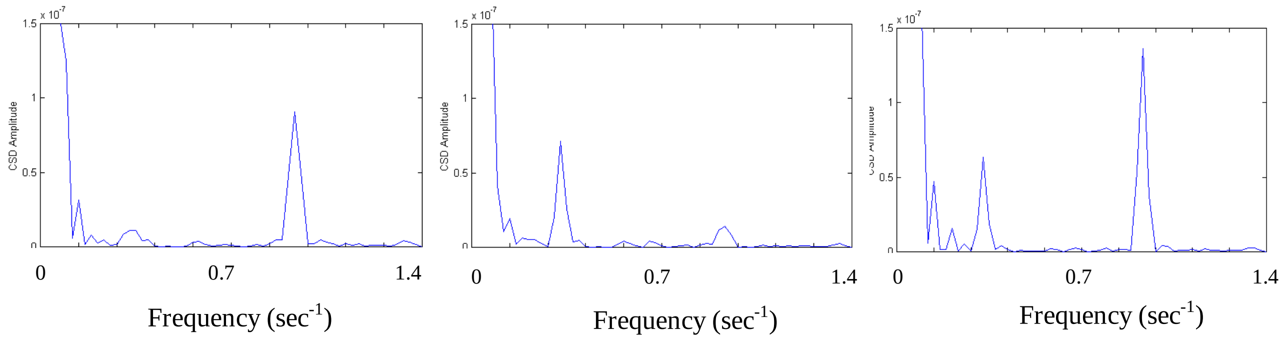


Figure 1 shows a map of the log of the ratio of the computed Fourier amplitudes at the cardiac and respiratory frequencies obtained from the time series. Figure 2 is a representative MR slice in the same region of forearm. An overlay of the two maps is shown in Figure 3. Inspection reveals that in the vicinity of the radial (1), interosseous (3) and ulnar (5) arteries, the ratio of the Fourier amplitudes (cardiac to respiratory) is nearly ten times larger than it is in other regions. This response can be seen more clearly in Figure 4, which shows the frequency spectrum derived from a temporal correlation computation on the image series (*i.e.*, cross–spectral density response), where the time course of one index pixel is compared to all others.

Figure 4. A B C



Legend: Amplitude of cross–spectral density for different positions in the computed image. Locations of pixels are A, row 20, column 29; B, row 9, column 10; C, row 9, column 14.

Respiratory study: The fixed architecture of the vascular tree can also be exploited to produce a spatial map revealing particular features of the vasculature. Upon inspiration, enhanced return of blood to the heart occurs, causing net emptying of blood from the tissue. Upon expiration, net filling occurs in the peripheral blood vessels. The positions in the cross section where these cyclic events are occurring can be estimated by computing the temporal derivative of the image series and identifying the *location* of the maximum and minimum values of the derivative for each time point. In the case of larger vessels, it is expected that these will be spatially coincident. We have computed the frequency of coincident events for a series of deep breathing exercises. A spatial map of these is shown in Figure 5. The color scale identifies the number of "hits" (*i.e.*, maximum or minimum values) in a given pixel. Significantly, we do observe a number of regions that have significantly greater number of hits than in other regions. Also of interest are regions where no maximum or minimum values are detected. In other locations, the frequency of these events is low, but not zero. We believe this might be the action of vasomotion, which serves to redirect blood flow to different regions of tissue over time. Figure 6 is an overlay of the image onto a representative MR map. While specific interpretation is difficult, it is worth noting that maximum values are observed in the vicinity of the three major arteries. In other studies to be reported, we have computed similar measures in response to vasoocclusion. Here too we observe a pattern that is consistent with vasoengorgement in the periphery of the arm upon cuff inflation and a net emptying upon cuff deflation. These results underscore the flexibility of studies that can be introduced to monitor the reactivity of the vasculature to simple manipulations.

Figure 5

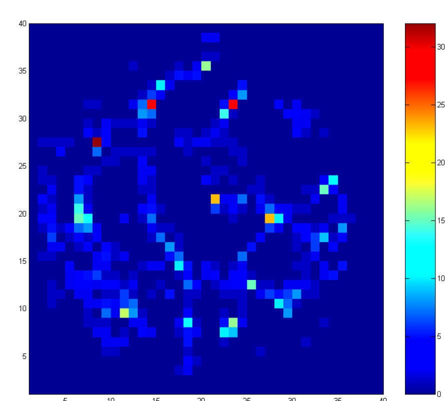
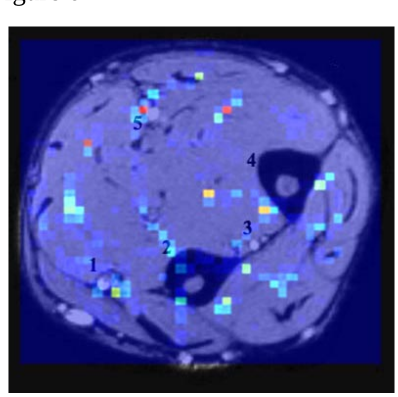


Figure 6



4. Summary: The reactive properties of the vasculature and the existence of natural beat frequencies support the use of time series imaging methods to differentiate the reactivity of different components of the vascular tree.

5. References:

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[3] J. S. Bendat and A. G. Piersol, "Engineering Applications of Correlation and Spectral Analysis", John Wiley and Sons, NY, 1993.

6. Acknowledgements: This study was supported in part by NIH grant no. RO1–CA66184 and by the New York State Science and Technology Foundation.