

Measuring peripheral vascular reactivity with diffusive optical imaging

Michael A. Khalil¹, Molly Flexman¹, Joseph Youssef¹, Ritu Aparajita², In-Kyong Kim², Rajeev Dayal²,
Andreas H. Hielscher¹

¹Dept. of Biomedical Engineering, Columbia University, New York, NY, 10025

²Dept. of Vascular Surgery, New York-Presbyterian Columbia University Medical Center, New York, NY, 10032

Abstract— Diffuse optical imaging of the peripheral vascular reactivity is implemented at the major arteries of the foot. Transmitted light intensities are recorded in response to vascular occlusions induced by pressure cuffs. These dynamic measurements promise to help identify various peripheral vascular diseases.

I. INTRODUCTION

The primary task of peripheral vasculature is to supply organs and extremities with blood. To monitor vascular function, and to diagnose and monitor vascular disorders it is important to be able to measure and evaluate basic vascular parameters, such as arterial and venous blood flow, arterial blood pressure, and vascular compliance [1]. Dynamic optical imaging is increasingly applied to clinically relevant areas such as brain and cancer imaging. In this approach, an external stimulus is applied and changes in relevant physiological parameters such as oxygenated and deoxygenated hemoglobin concentrations are extracted [2].

Here we present the application of this method to measuring the vascular response in the major arteries of the foot. Optical imaging is capable of evaluating basic vascular parameters, such as arterial and venous blood volume and measuring the relaxation process of the foot relative to stimulus. Monitoring vascular function in the lower extremities can potentially be used to diagnose and monitor pathologies such as peripheral vascular disease.

II. METHODS

A. Instrumentation and Experimental Setup

Optical transmission measurements on the foot were performed with a digital, dynamic near-infrared optical tomography imager [3]. A combined optical beam consisting of two laser diodes (wavelength $\lambda = 765$ nm and 830 nm) acts as an illuminating source. This source is sequentially coupled into different optical fibers that bring the light to different injection points of the surface of the ankle and foot (Fig. 1).

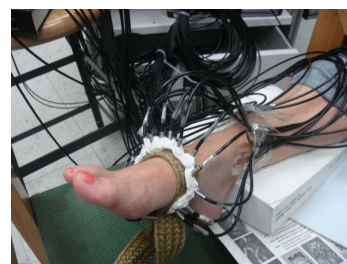
B. Protocol for Dynamic Measurements

The experiments were designed to study the vascular reactivity in the lower extremities by

targeting the major arteries of the foot (posterior tibial artery and the dorsalis pedis artery).



(a)



(b)

Fig 1: Location of the optical fibers around (a) the ankle and (b) the foot.

Volunteers were asked to place their foot on a stable holding platform while sitting upright on a chair. Once the patient was seated comfortable the measuring head was placed around the ankle or the foot as shown in Fig. 1. The instrument then ran a self-calibration where it determined and stored the ideal gain settings for each channel at every source position.

To illicit a controlled vascular response a pressure cuff was applied to the upper thigh. First a baseline measurement was taken for one minute. Then, the pressure cuff was inflated to 120 mmHg to induce venous occlusion in the foot. The pressure was maintained for one and a half minutes at which point the pressure was rapidly released. Data was acquired for another minute during the rest period before pressure was reapplied. This cycle was repeated four times lasting a total of approximately 10 minutes.

III. RESULTS

Examples of dynamic time traces corresponding to the detector readings around the foot are shown in Figs. 2 and 3. The traces depict the transmission profile over select detector channels for a single illumination position at one wavelength each. The response is plotted as a change in intensity versus time t in minutes. All traces are normalized to the mean of the initial rest period, which defines the baseline for the experiment.

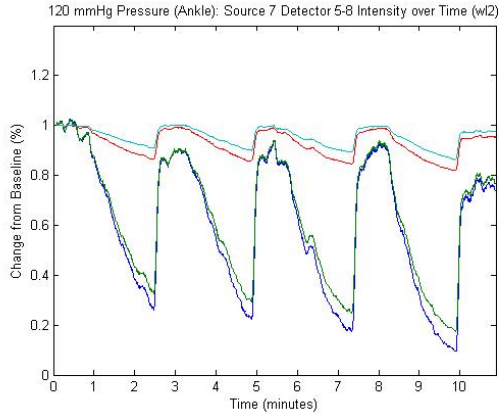


Fig. 2: Temporal response of lateral detector intensities at the ankle.

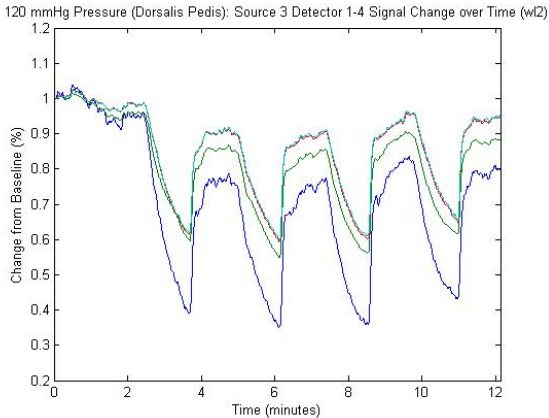


Fig. 3: Temporal response of lateral detector intensities at the foot.

The observed signal changes can be readily explained by some well-known physiologic responses. When the pressure cuff is engaged, venous return is engaged, venous return is discontinued while arterial supply is still active, causing blood to pool in the vascular network throughout the clocked region. As a result, the optical attenuation, which is sensitive to blood volume, increases causing a decline in transmitted intensities. Subsequent to the pressure being released, the accumulated blood volume begins to diminish, at first rapidly, due to the elevated pressure gradient in the vascular system, and

then more gradually as the gradient eases toward equilibrium. Consequently, the attenuation is reduced and the optical signal returns towards baseline [4].

Another interesting dynamic feature that emerges from analyzing the temporal response of the detectors is rate at which the signal recovers when the pressure is released from the thigh. Variations in signal slope and time sift can potentially be used as biomarkers to diagnose vascular pathologies within the lower extremities.

IV. CONCLUSION

We have shown that dynamic diffuse optical imaging enables the detection of vascular changes within the lower extremities. We have identified potential biomarkers that could vary between healthy and diseased vasculature, these include the change of amplitude with response to occlusion from a pressure cuff, as well as the rate of recovery after the pressure is removed.

These biomarkers have the potential to diagnose vascular pathologies such as peripheral artery disease (PAD). PAD typically manifests itself early in the legs and foot. If undetected, it can progress to cause foot ulcerations, poor wound healing, gangrene, and ultimately amputation. The detection of PAD is difficult in diabetic patients where co-morbidities such as calcification of the arteries and neuropathy alter the blood pressure measurements. Diffuse optical imaging has the potential to enable physicians to image vascular function independently from vascular compressibility and can serve as a safe and accurate method for diagnosing PAD.

ACKNOWLEDGEMENTS

This work is funded in part by the Society of Vascular Surgery Clinical Research Seed Grant and the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS; grant #2R01 AR46255), which is part of the National Institutes of Health.

REFERENCES

1. G.S. Landis, T.F. Panetta, S.B. Blattman, H.L. Graber, Y. Pei, C.H. Schmitz, R.L. Barbour, "Clinical Applications of Dynamic Optical Tomography In Vascular Disease," *Proc. SPIE* **4250**, 130 (2001).
2. A.H. Hielscher, A.Y. Bluestone, G.S. Abdoulaev, A.D. Klose, J. Lasker, M. Stewart, U. Netz, J. Beuthan, "Near-infrared diffuse optical tomography," *Disease Markers* **18** (2002) 313-337
3. J.M. Lasker, J.M. Masciotti, M. Schoenecker, C.H. Schmitz, A.H. Hielscher, "Digital-signal-processor-based dynamic imaging system for optical tomography," *Rev. Sci. Instrumentation* **78**, 083706 (2007)
4. J.M. Lasker, C.J. Fong, D.T. Ginat, E. Dwyer, A.H. Hielscher, "Dynamic optical imaging of vascular and metabolic reactivity in rheumatoid joints," *J. Biomed Optics* **12**(5), 052001 (2007)