Non-contact hematoma damage and healing assessment using reflectance photoplethysmographic imaging

Robert Amelard[*a,b], Kaylen J. Pfisterer[b], David A. Clausi[a], Alexander Wong[a]

[a]Department of Systems Design Engineering, University of Waterloo, 200 University Ave W, Waterloo, Canada [b]Schlegel-University of Waterloo Research Institute for Aging, 250 Laurelwood Dr, Waterloo, Canada

ABSTRACT

Impact trauma may cause a hematoma, which is the leakage of venous blood into surrounding tissues. Large hematomas can be dangerous as they may inhibit local blood flow. Hematomas are often diagnosed visually, which may be problematic if the hematoma leaks deeper than the visible penetration depth. Furthermore, vascular wound healing is often monitored at home without the aid of a clinician. We therefore investigated the use of near infrared (NIR) reflectance photoplethysmographic imaging (PPGI) to assess vascular damage resulting from a hematoma, and monitor the healing process. In this case study, the participant experienced internal vascular damage in the form of a hematoma. Using a PPGI system with dual-mode temporally coded illumination for ambient-agnostic data acquisition and mounted optical elements, the tissue was illuminated with a spatially uniform irradiance pattern of 850 nm wavelength light for increased tissue penetration and high oxy-to-deoxyhemoglobin absorption ratio. Initial and follow-up PPGI data collection was performed to assess vascular damage and healing. The tissue PPGI sequences were spectrally analyzed, producing spectral maps of the tissue area. Experimental results show that spatial differences in spectral information can be observed around the damaged area. In particular, the damaged site exhibited lower pulsatility than the surrounding healthy tissue. This pulsatility was largely restored in the follow-up data, suggesting that the tissue had undergone vascular healing. These results indicate that hematomas can be assessed and monitored in a non-contact visual manner, and suggests that PPGI can be used for tissue health assessment, with potential extensions to peripheral vascular disease.

Keywords: Photoplethysmography, photoplethysmographic imaging, non-contact, hematoma

1. INTRODUCTION

A hematoma is blood pooling outside of a blood vessel into surrounding tissues and can be caused by impact trauma, needle pricks, and bacterial infections.[1] Under normal circumstances, the pooled blood is slowly resorbed into the bloodstream. However, the healing process is often assessed visually and in an unconstrained environment, potentially leading to untreated vascular damage. Photoplethysmographic imaging (PPGI) systems are non-contact light-based imaging systems capable of assessing blood pulse waveforms from a distance.[2–5] However, their use as vascular damage assessment tools has been largely unexplored. The purpose of this case study was to determine whether near infrared (NIR) reflectance PPGI can be used to assess vascular damage and healing by monitoring changes in pulsatility over time.

2. METHODS

Let $x_i(t)$ denote the incident illumination on pixel i at time t. Using the Beer-Lambert law, reflectance can be converted to absorbance to model changes in blood volume:

$$a_i(t) = -\log\left(\frac{x_i(t)}{x_i^0(t)}\right) \tag{1}$$

*Corresponding author: ramelard@uwaterloo.ca

where $x_i^0(t)$ is the illumination incident on the tissue at time t. Since $x_i^0(t)$ is unknown, a detrending method was used to remove illumination trends deviating from the baseline incidence:[6]

$$z_i(t) = \arg\min_{\hat{z}} \left\{ ||a_i(t) - \hat{z}(t)||^2 + \lambda^2 || \frac{\partial^2}{\partial t^2} \hat{z}(t)||^2 \right\} \tag{2}$$

where $\hat{z}$ is the estimated baseline-corrected absorbance signal and λ is a tuning parameter. This was solved using a regularized least-squares approach.[6]

In order to identify the locations that exhibit hemodynamic pulsations, the heart rate frequency was found using a photoplethysmography (PPG) finger cuff. The temporal PPG signal $s(t)$ was converted to the frequency domain using the Fourier transform:

$$S(f) = \int s^*(t) e^{2\pi j t f} dt \tag{3}$$

where $s^*(t) = s(t) - \frac{1}{T}\int_0^T s(t)dt$ is the zero-DC offset PPG signal. The heart rate frequency f_{hr} was then computed as the frequency which exhibited the maximum spectral power:

$$f_{hr} = \arg\max_f \left\{ S(f)\overline{S(f)} \right\} \tag{4}$$

where $\overline{\cdot}$ is the complex conjugate. The areas in the frames which exhibited strong pulsing at the heart rate frequency were highlighted. Given the absorbance signal $z_i(t)$, the Fourier transform was used to convert it to the frequency domain:

$$Z_i(f) = \int z_i^*(t) e^{2\pi j t f} dt \tag{5}$$

where $z_i^*(t) = z_i(t) - \frac{1}{T}\int_0^T z_i(t)dt$ is the zero-DC offset absorbance signal. Then, for each pixel i, the correspondence with the heart rate frequency was computed as:

$$\Omega_i = \frac{Z_i(f_{hr})\overline{Z_i(f_{hr})}}{\max_f \left\{ Z_i(f)\overline{Z_i(f)} \right\}} \in [0, 1] \tag{6}$$

3. EXPERIMENTAL RESULTS

A case study was conducted to assess vascular damage in one of the authors (KJP) caused by intravenous needle insertion during routine blood draw in the cubital fossa. Data were collected 90 min post-procedure, as well as three days later. A novel Coded Hemodynamic Imaging (CHI) system[2] was used to image the damage site, consisting of a near infrared (NIR) sensitive camera (GS3-U3-41C6NIR-C, Point Grey) fitted with an 850–1000 nm optical bandpass filter, and a spatio-temporally coded 850 nm high powered LED illuminated at a 20:1 temporal code for ambient compensation and spatially coded for uniform illumination.[2,7]

Figure 1 shows an RGB image of the damaged area 90 min following the procedure. A boundary was drawn identifying the painful areas based on participant feedback.

Figure 2 shows the results at the initial data collection. Figure 2(a) shows the raw NIR image. A dark area in the fossa was observed, representing a localized increased in light absorption due to blood pooling from the vascular damage. The NIR image exhibited increased contrast compared to the RGB image, making it visually easier to identify the blood pooling. Figure 2(b) shows the computed Ω map overlaid onto the NIR image. Reduced pulsatility (blue) was observed in the damaged area (white boundary), showing reduced observable pulsatility due to blood pooling and vascular damage.

Figure 3 shows the result at the three-day follow-up. Figure 3(a) shows reduced contrast in the cubital fossa, indicating vascular healing and reduced blood pooling. Figure 3(b) shows the computed Ω map overlaid onto the NIR image. A higher number of pulsatile areas were observed in the damaged area (white boundary) as compared to the original data. However, a small structurally cohesive track of low pulsatility was observed near the fossa consistent with the remaining dark area in Figure 3(a), indicating that the tissue had not yet fully healed.

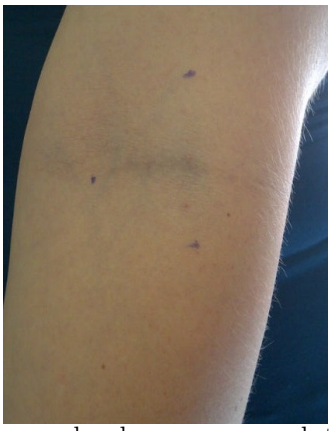
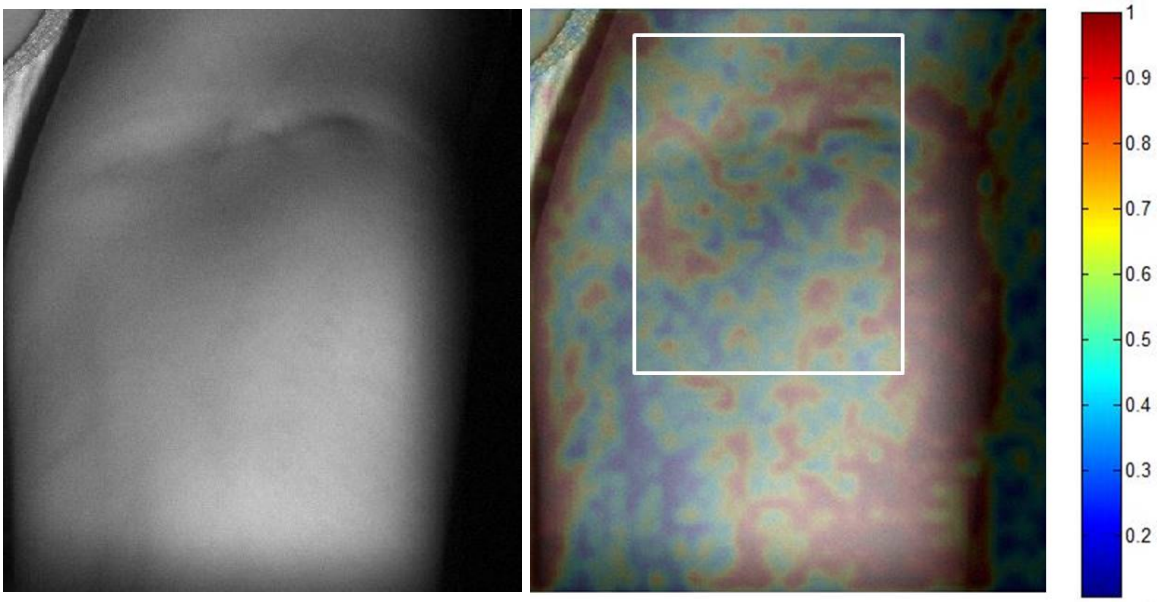


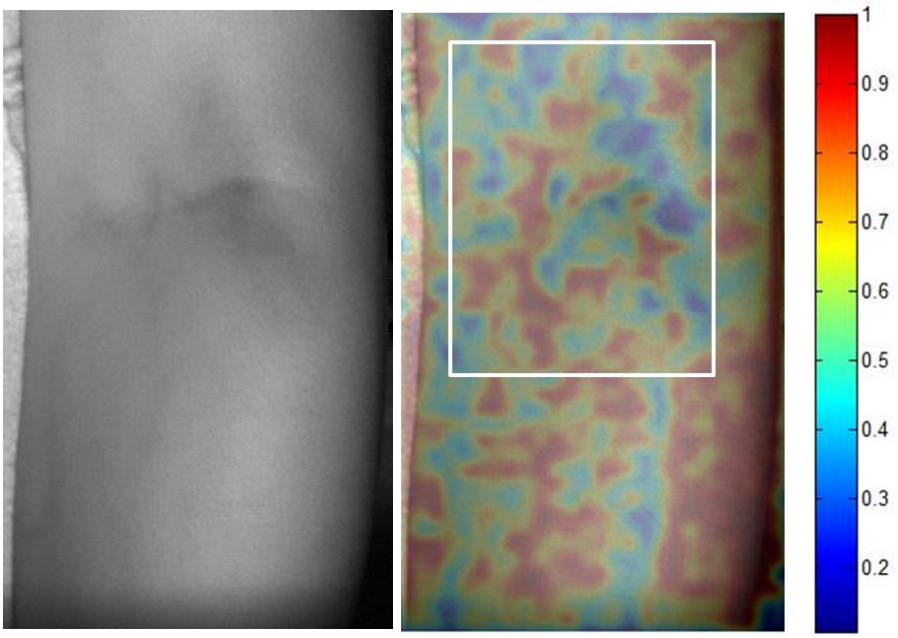
Figure 1: Image of the cubital fossa where vascular damage occurred, taken 90 min post-procedure. A boundary was drawn around the area where the participant experienced pain.



(a) NIR image

(b) Ω map overlay

Figure 2: Results of imaging 90 min post-procedure. The raw NIR image (a) shows a dark area in the fossa, representing increased blood volume from pooling. The computed Ω map overlay (b) shows reduced pulsatility (blue) in the damage site (white boundary).



(a) NIR image

(b) Ω map overlay

Figure 3: Results of imaging three days post-procedure. Compared to this first post-procedure data, the raw NIR image (a) shows reduced contrast in the fossa, indicating vascular healing and blood resorption, and the Ω map overlay (b) shows increased pulsatility in the damage site (white boundary). The vascular healing was not complete, as indicated by reduced pulsing in the small dark area on the right side of the fossa.

4. CONCLUSIONS

In this case study, Coded Hemodynamic Imaging (CHI) was used to assess the healing process of a subdermal hematoma. The damage site shows reduced pulsatility immediately post-procedure, which were largely restored three days post-procedure. These results show promise for monitoring temporal changes in pulsatility for assessing vascular healing.

ACKNOWLEDGMENTS

This work was supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada, AGE-WELL NCE Inc., the Canada Research Chairs program, and the Ontario Ministry of Research and Innovation.

REFERENCES

[1] WedMD Inc., "Hematoma." `http://www.emedicinehealth.com/hematoma/article_em.htm` (2016). Accessed: 17 Jan 2016.

[2] Amelard, R., Scharfenberger, C., Kazemzadeh, F., Pfisterer, K. J., Lin, B. S., Clausi, D. A., and Wong, A., "Feasibility of long-distance heart rate monitoring using transmittance photoplethysmographic imaging (PPGI)," *Scientific Reports* **5**(14637) (2015).

[3] Sun, Y., Hu, S., Azorin-Peris, V., Greenwald, S., Chambers, J., and Zhu, Y., "Motion-compensated noncontact imaging photoplethysmography to monitor cardiorespiratory status during exercise," *Journal of Biomedical Optics* **16**(7), 077010–1–077010–9 (2011).

[4] Kumar, M., Veeraraghavan, A., and Sabharval, A., "Distanceppg: Robust non-contact vital signs monitoring using a camera," *Biomedical Optics Express* **6**(5), 1565–1588 (2015).

[5] Wang, W., Stuijk, S., and de Haan, G., "Exploiting spatial redundancy of image sensor for motion robust rPPG," *IEEE Transactions on Biomedical Engineering* **62**(2), 415–425 (2015).

[6] Tarvainen, M. P., Ranta-aho, P. O., and Karjalainen, P. A., "An advanced detrending method with application to HRV analysis," *IEEE Transactions on Biomedical Engineering* **49**(2), 172–175 (2002).

[7] Amelard, R., Scharfenberger, C., Wong, A., and Clausi, D. A., "Illumination-compensated non-contact imaging photoplethysmography via dual-mode temporally-coded illumination," in *Proc. SPIE*, **9316**, 931607–1–931607–5 (2015).