A Wearable Diffuse Optical Tomography Patch for Investigating Pressure Injuries

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Abstract: Pressure injuries are wounds to skin and underlying tissues potentially originating from reduced tissue oxygenation. To elucidate pressure injuries' initiation mechanisms, we developed a body-conforming diffuse optical imaging patch to measure tissue hemodynamics in real time.

1. Introduction

Pressure injuries (PIs), also known as pressure ulcers or more commonly bedsores, are wounds caused by prolonged pressure exerting on the skin and underlying tissues. Most frequently, PIs develop over bony prominences such as the sacrum (lower back), heels, shoulders and neck, but they can potentially form in any part of the body. Although all populations with limited mobility are at risk of developing PIs, the highest prevalence rates occur in non-ambulatory patients without self-ability to reposition their body, especially those who are bed-bound recovering from trauma, surgery or acute illness in intensive care units (ICUs), terminally ill patients and wheelchair users. Severe PIs are extremely painful, may require surgery(ies) that take months to heal and leave permanent scars, and place patients at risk of developing potentially fatal infections.

Although prolonged pressure is known to alter the normal physiology of tissues, the origination mechanism of PIs is still poorly understood. Recent studies speculate that PIs result from a series of additive damages, namely pressure-induced cell deformation, inflammation and ischemia [1]. These adverse events occur within minutes of one another but then progress at different rates and cumulatively produce damage from the death of few cells to the necrosis of tissue. Despite the undetermined pathogenesis of PIs, measuring relevant tissue alterations in real time has the potential of elucidating these origination mechanisms and ultimately allow detecting PIs at the earliest stage.

In this work, we present a diffuse optical imaging (DOI) device with the form factor of a wearable patch that achieves a twofold goal. First, from a scientific perspective, it measures and monitors moment-to-moment optical changes of skin and underlying tissues, especially in relation to hemodynamic processes, in an attempt to better understand the effects of prolonged pressure on these tissues. To our knowledge, using diffuse optical imaging for capturing the spatial and temporal characteristics of alterations in tissues under pressure, in-vivo and in real time is an unprecedented effort. Second, from a clinical perspective, this device aims at establishing a relationship between optical changes in susceptible tissues and clinical evidence of PI development, with the long-term goal of identifying PIs at their earliest stage and prompting human intervention to prevent damage aggravation.

2. Methods

We designed and fabricated a wearable optical patch as a flexible PCB embedding 128 dual-wavelength LEDs (emitting at 730 and 850 nm) and 128 silicon photodetectors (PD) forming a 150 x 150 mm gridded matrix with a LEDs-PD separation of 10 mm (Fig. 1). This arrangement resulted in 1,736 unique channels for each wavelength with emitter-detector distances of 10 mm (480 channels in total), 22 mm (840 channels), and 30 mm (416 channels) that allowed to interrogate all tissues at risk for PIs, namely the skin, the underlying adipose tissue and the muscle deep down to its interface with the bony prominence (i.e., sacrum). Near infrared light emission was time multiplexed to avoid crosstalk between optical channels, and, for every channel, a subtraction of detected ambient light was performed during time intervals when the LEDs were inactive. Also, an opaque, 3D-printed flexible lattice was mounted on the grid to prevent direct light-piping between LEDs and adjacent PDs. To ensure comfort and safety, the optical probe was coated with a layer of optically clear, biocompatible material. The recording of all 1,736 channels at each wavelengths could be performed as frequently as every 5 seconds, thus providing more than sufficient temporal resolution to observe significant hemodynamic changes due to prolonged pressure. Tomographic image reconstruction for oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) was performed using NIRFAST, i.e. a finite-element method often utilized for functional brain imaging, on a 168 x 168 x 12 mm volume with a voxel size of 1 mm^3.

To test the device and evaluate the feasibility of study on a larger population of humans, we recruited five healthy subjects (4 males, 24.6 ± 4.4 yrs.) with no history of tissue damage to the sacrum or any persistent open wound on the body and with different race and skin complexion (2 White, 2 Black or African-American, 1 Asian). The experimental protocol consisted of three sequential steps: 1) an initial unloaded baseline (5 min) with subject laying on their side, followed by 2) loading of the sacral tissues (120 min) with subject laying supine, followed by 3) unloading with subject laying on their side (20 min). Hemodynamic images were collected from the sacral area (Fig. 1) every minute during the entire experimental protocol.

3. Results

Hemodynamic images for HbO and HbR computed from a representative subject are shown in Figure 1, alongside a picture of the device and the schematic placement on the sacral tissues.

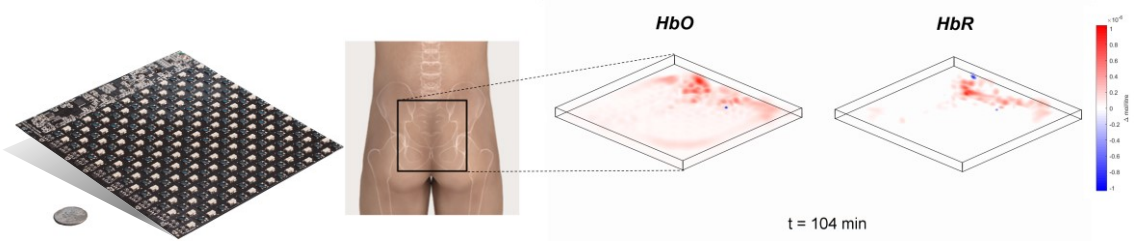

Figure 1: Uncoated optical probe (left) and examples reconstructed hemodynamic images at a specific time point (right).

To facilitate the assessment of hemodynamic changes due to prolonged pressure, we averaged tomographic layers within three separate depth ranges, namely 1-4 mm, 5-8 mm and 9-12 mm. As shown in Figure 2, tissue hemodynamics changed significantly from the initial application of pressure (5 minutes from laying supine) to the end of the prolonged effect (120 minutes after). Of relevance, different hemodynamic patterns were also noticeable across depths, possibly denoting different effects of pressure onto superficial (skin, fat) and deep (muscle) tissues. This is of particular interest to the investigation of pressure injuries, as muscle tissues are believed to be less resilient to prolonged pressure than skin [2].

In summary, diffuse optical imaging successfully captured hemodynamic changes induced by prolonged pressure and, in the future, it may provide meaningful information towards a greater understanding of the origination mechanisms of pressure injuries.

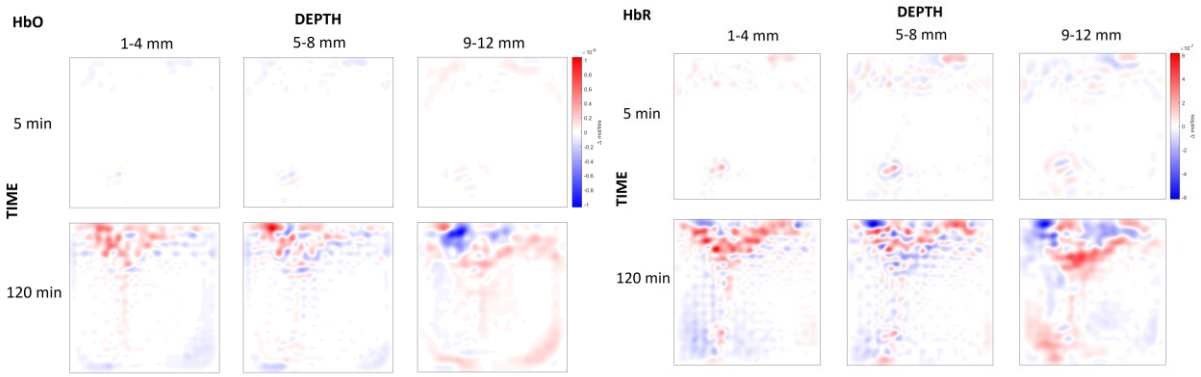

Figure 2: Hemodynamic images for HbO (left) and HbR (right) captured at the beginning (5 min) and end (120 min) of body-weight pressure at different depths.

4. Acknowledgements

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5. References

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