

# Heel blood perfusion responses to pressure loading and unloading in women

*The use of laser-Doppler imaging and fluxmetry in assessing heel blood perfusion before, during, and after 40 minutes of continuous heel loading in 11 female volunteers.*



## THE SYMPOSIUM ON ADVANCED WOUND CARE

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### Abstract

Heel pressure ulcers are significant and costly problems causing suffering and potential limb loss from infection and compromised blood flow. Heel blood perfusion (HBP) deficits accompanying loading likely affect the skin breakdown process, but little is known about the loading and off-loading changes. To clarify this issue, combined laser-Doppler Imaging (LDI) and Fluxmetry were used to assess HBP before, during, and after 40 minutes of continuous heel loading in 11 female volunteers (32-60 years). During loading, an initial decrease in HBP was followed by a gradual small recovery ( $p < 0.001$ ). Off-loading resulted in a significant hyperemic response with HBP exceeding baseline by a factor of  $4.72 \pm 0.63$  ( $p = 0.001$ ) and remaining elevated for about 10 minutes. Spatial LDI data showed that hyperemic responses are maximum near the pressure center and diminish radially. These results suggest a localized, pressure-related tissue trauma, which is compensated for by a substantial hyperperfusion. The dependence (and adequacy) of this response on clinical variables including heel pressure and duration, limb vascular status, and patient health are unknown. The present seminal data and associated methods provide a platform from which these and other important clinical parameters can be systematically studied and compared.

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### Introduction

Pressure ulcers are frequent and costly problems in acute, long term, and home care populations. Skin breakdown caused by continuous pressure over bony prominences is a hazard in all patients, particularly in those assessed as being at high risk for

skin breakdown. Prolonged localized pressure over these prominences, combined with frictional and shear forces, impacts local blood perfusion laying the foundation for tissue ischemia and potentially subsequent necrosis. Localized heat and humidity are additional factors that increase breakdown risk in part due to the

associated metabolic effects on blood flow demand, which may already be compromised. The heel under pressure is often prone to tissue breakdown in part because of its small surface area of contact, high local pressures and limited basal blood flow. Heel breakdown incidence has been reported as high as 29.5 percent,<sup>1</sup> and other studies have indicated that the heel is one of the most common locations of pressure ulcer occurrence.<sup>2,3</sup> Though it is likely that local, mechanically-induced blood flow deficits play a central role in the heel-breakdown process, little is known about the details of the blood perfusion changes which accompany heel-loading and subsequent off-loading. The purpose of the present pilot study was to investigate and provide seminal information regarding these local heel blood perfusion dynamics. Heel blood perfusion was measured by laser-Doppler imaging before, during and after sustained (40 minutes) heel loading in 11 healthy females.

## Methodology

### *Study population*

Eleven healthy women gave Institutional Review Board approved informed consent and served as volunteer subjects. Subjects ranged in age from 31 to 60 years (mean  $\pm$  sem,  $42 \pm 7$  years) and were of mixed ethnic backgrounds (five Caucasians, five Hispanics, and one African-American).

### *Preparatory sequence*

On entry into a temperature controlled laboratory maintained

at 22° to 23° Celsius, subjects assumed a supine position on an examination table with a foam overlay mattress. Each subject was positioned so that both heels extended over the edge of the table and were not influenced by external pressure. A laser-Doppler imaging (LDI) system,\* was placed under the right (experimental) heel at a distance of 19 cm and set to scan an area of 40 x 40 mm. Initially, the right heel was placed briefly on a clear plastic plate (3 mm thick), which was later used as the pressure loading surface. This surface was supported across a specially constructed stand at a distance of 19 cm from the LDI head. The center of the pressure area, defined as the area of the heel in contact with the plastic plate, was determined visually and marked with a 2 x 2 mm felt square to assure consistency. The clear plastic plate was removed, and the subject remained in a supine position. The subject's feet were covered with a black sheet which served as a backdrop for the LDI scans, and the subject was also covered with a light blanket. Overhead room lights were turned off to minimize ambient light. Finally, the LDI head was aligned with the beam centered at the 2 x 2 mm felt target site on the heel.

### *Instrumentation*

Blood perfusion at the heel was determined by LDI, which is a non-contact method similar to standard laser-Doppler fluxmetry (LDF). Whereas LDF requires placement of probes on the skin, LDI is non-contact and provides perfusion data over a larger

area.<sup>4-8</sup> The present system emits a low power laser beam (635 nm) that penetrates the tissue to a variable depth ranging from 300 to 1000 micrometers to provide spatial perfusion data.<sup>9</sup> In the presence of moving blood cells, the laser-light is Doppler-broadened, partially backscattered, and the reflected light collected by a photodetector within the solid state laser head. The signal is processed according to an algorithm that results in an output proportional to tissue blood perfusion. Based on relative perfusion in each of the sampled areas of the scanned region (expressed in arbitrary units, a.u.), a color-coded image is generated in which spatial regions having perfusions within specified limits are similarly colored. In general, deep red corresponds to the highest perfusion and deep blue to the lowest. In between colors from lowest to highest are light blue, green and yellow. Further details on LDI use and applications may be found in the literature.<sup>10-13</sup>

### *Protocol*

The subject remained still throughout the experiment, and the LDI head was re-aligned prior to each scan. With both feet protruding over the edge of the exam table, and thus off-loaded, the experiment was started with a 10 minute baseline period. During the period, four LDI scans were taken of the right heel. At the completion of the baseline period, the right heel was loaded by placing it in contact with the supported clear plastic plate. The left heel remained off-loaded. LDI scans were taken at 2, 4, 6, 8, 10, 15, 20, 30, and 40 minutes after initial loading. After 40 min-

\*LISCA Development AB, Linköping, Sweden



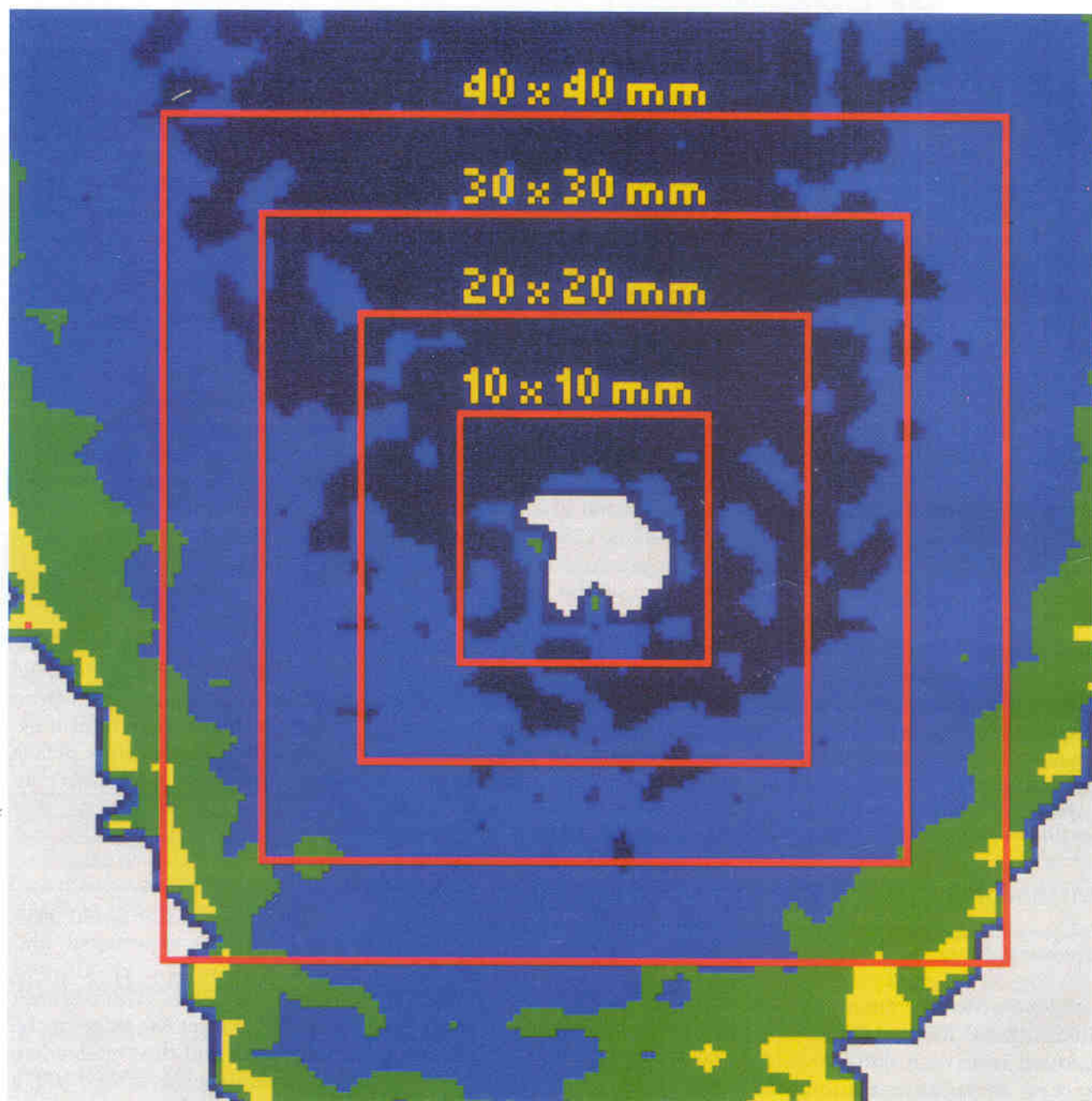


Figure 1. Heel LDI analysis model. An example of an LDI scan with superimposed square areas indicating the 10 x 10, 20 x 20, 30 x 30, and 40 x 40 mm areas used for mean blood perfusion computations. The 2 x 2 mm felt target site used to align the laser is seen as the irregular gray region at the center of each analyzed area. Printed with permission from H.N. Mayrovitz, PhD.

utes of heel loading, the plastic plate was removed and the right heel was again off-loaded. LDI scans were then taken at 30 seconds, 2, 4, 6, 8, 10, 15, and 20 minutes after off-loading.

At the end of each experiment, LDI scans were taken of a background calibration white card\* with and without the plastic plate interposed. This provided for an offset calibration value which

was subtracted from the raw collected data to account for any effects associated with light transmission through the plastic plate.

\*Gray Card, Eastman Kodak Company, Rochester, NY

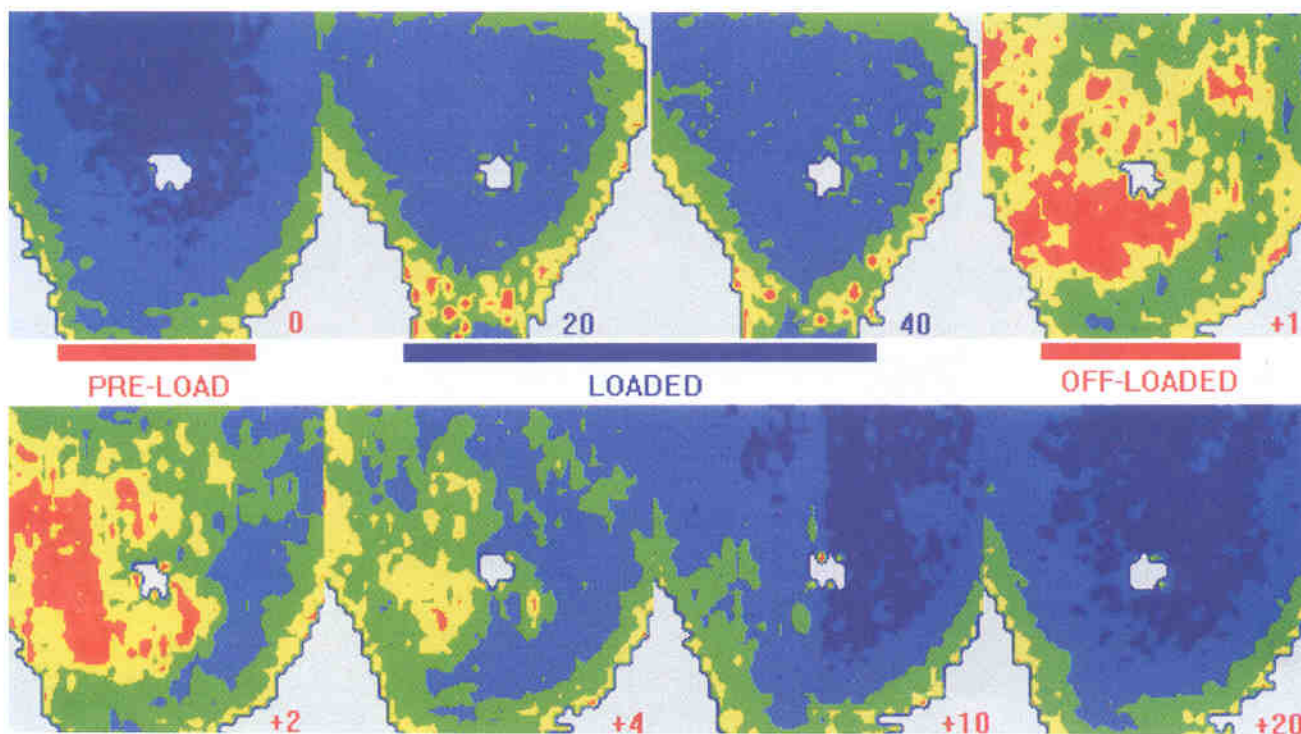


Figure 2. Sequential heel LDI scans. Example of one subject's perfusion response to loading and off-loading is illustrated as color-coded images. In order of increasing perfusion values, colors are dark blue, light blue, green, yellow and red. A rapid hyperemic reperfusion is noted upon off-loading and the non-uniformity of intra-zone perfusion is clearly demonstrated during the early phases of the hyperemic responses. Printed with permission from H.N. Mayrovitz, PhD.

## Analyses

The LDI-generated images were analyzed by computing the average perfusion among areas of 10 x 10 mm, 20 x 20 mm, 30 x 30 mm, and 40 x 40 mm around the center of the pressure area as shown in Figure 1. This procedure assigned a single numerical value for each average perfusion in the designated areas in arbitrary units. The calibration "zero-flow" background values were subtracted for each subject to yield a perfusion value. The analysis allowed for an investigation into the distribution of blood flow around the center of the pressure area and the possible variations in flow both spatially and temporally.

## Results

### Composite response to compression and off-loading

A typical colorized perfusion image sequence for one subject is shown in Figure 2. In this composite figure, contours of the same color correspond to heel regions having similar relative blood perfusion levels. Red contours represent the greatest perfusion, yellow and green intermediate perfusion, and deep blue the lowest. This type of representation is useful to rapidly observe spatial variations in perfusion bands within different heel regions. The overall temporal sequence for the entire group is shown in Figure 3. Each data

point represents the mean blood perfusion measured in the 10 x 10 mm area centered around the central heel-compression site. These data points are connected by a spline curve, which represents a best fit to the composite data with error bars showing  $\pm 2$  sem at each time point.

### Response to compression

When compared with baseline heel blood perfusion values, reduction in perfusion upon compression loading was seen in all subjects. In Figure 4, LDI perfusion data for the central area are separated in terms of three critical intervals: pre-load baseline, a 40 minute heel-loading, and a 20 minute recovery interval after



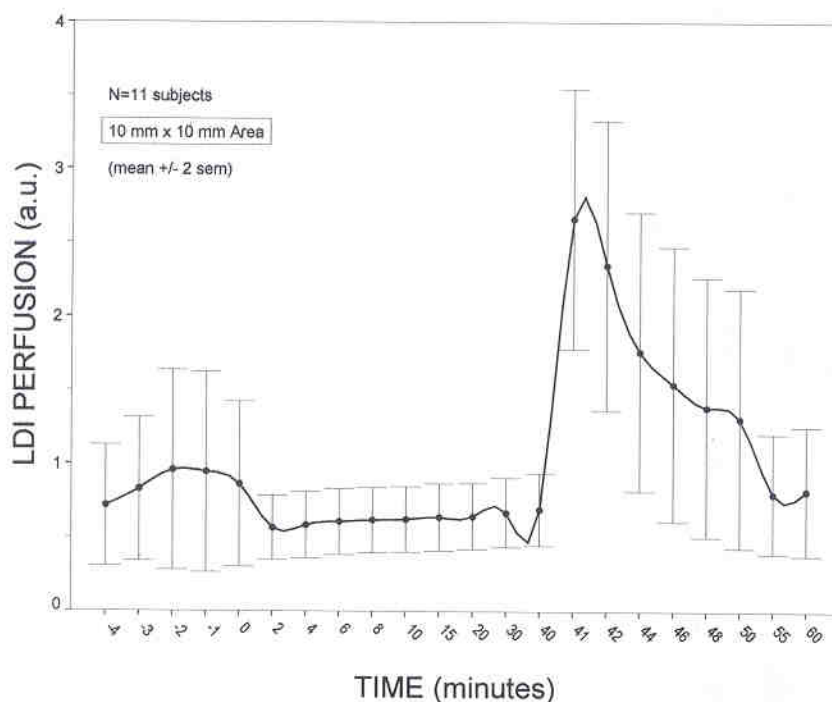


Figure 3. Perfusion response to pressure and release. Overall temporal response for all evaluated subjects. Data points are means connected by a spline curve representing the "best fit" to the data; error-bars are  $\pm 2$  sem. Data is for the 10 x 10 mm area around the center of pressure. Loading begins at time = 0 and off-loading at time = 40 minutes. Printed with permission from H.N. Mayrovitz, PhD.

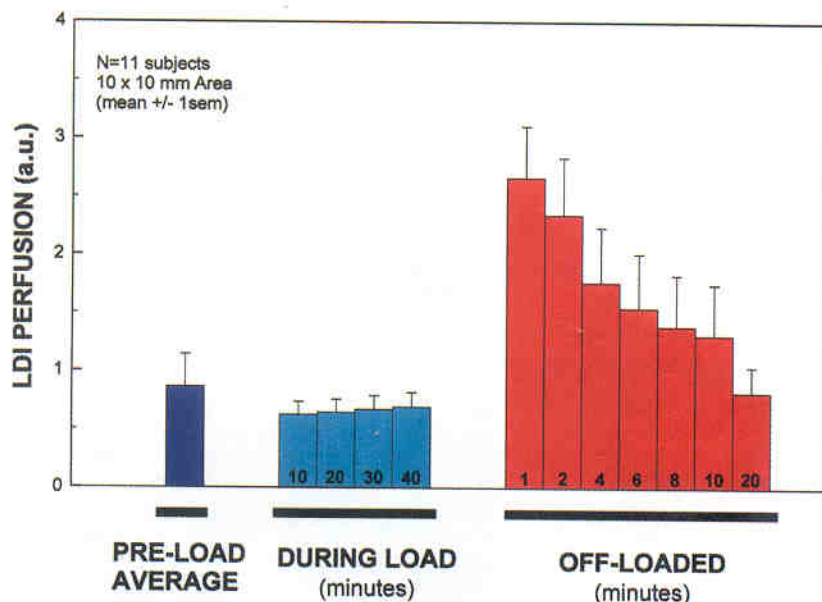


Figure 4. Perfusion response by key intervals. Upon loading, a significant reduction in heel blood perfusion is evident. During load, there is a non-significant trend toward an increased perfusion over time. Off-loading creates a significant hyperemic response which dissipates after approximately 10 minutes. Printed with permission from H.N. Mayrovitz, PhD.

off-loading. Perfusion during loading was significantly less than the pre-loaded baseline ( $p < 0.01$ ). During loading there appeared to be a slight progressive increase but this trend was

not significant; mean perfusion at the end of loading did not differ from the perfusion during the first 10 minutes of loading.

Analysis of baseline perfusions for each of the four assayed areas

showed no significant differences in heel perfusion values among the respective assayed areas with mean values as shown in Figure 5. During heel-loading, the central 10 x 10 mm area sur-

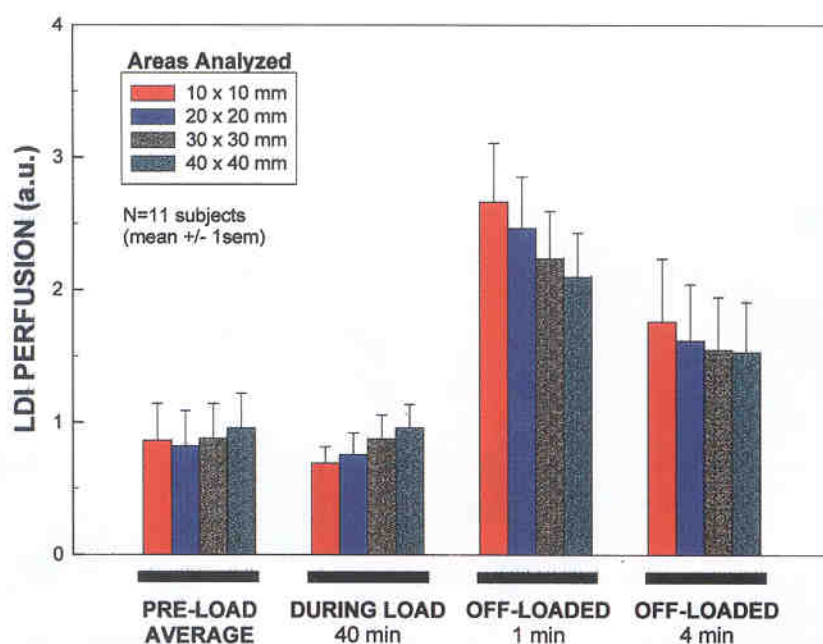


Figure 5. Spatial differences in heel blood perfusion. For each area, average perfusion values are indicated for different times within key intervals. The perfusion decrease when the heel is loaded and its increase when it is off-loaded is inversely proportional to the size of the area around the center of pressure. For example, the 10 x 10 mm area surrounding the center of applied pressure shows the greatest decrement upon loading and the greatest reperfusion upon off-loading. Printed with permission from H.N. Mayrovitz, PhD.

rounding the center of applied pressure showed the largest perfusion decrement, and the largest area (40 x 40 mm) showed the smallest perfusion decrement as compared with baseline.

#### *Hyperemic response to off-loading*

Upon pressure-release, a rapid increase in perfusion was observed. Initially, off-loaded perfusion far exceeded ( $p < 0.01$ ) the baseline values for each assayed heel-area but the central area had the largest response as shown in Figure 5. These results thus show a significant hyperemic response which remained elevated as compared with baseline ( $p < 0.01$ ) for up to and including 10 minutes after pressure-release.

## Discussion

In the present seminal study, dynamic changes in heel skin microcirculation associated with loading and off-loading were investigated as a first step in the process of gaining insight into potential blood-perfusion linkages to the development of heel pressure ulcers. The findings of this inquiry demonstrate the following main points: (1) Heel-blood perfusion, even in healthy individuals, is rapidly and significantly reduced upon loading with the greatest effort occurring within the central loading area; (2) Blood perfusion remains depressed throughout the loading duration with only a hint of an adaptive vasodilatory re-

sponse during the sustained loading of 40 minutes; and (3) Off-loading is associated with a rapid and significant hyperemic response which is a signature of a heel blood flow functional deficit present during the loading interval.

The potential implications and future extensions of the present findings include the following: If, as is likely, the hyperemic response serves to off-set relative flow deficits during loading, then a greater hyperemic response would likely be needed with longer durations of loading. However, it is unknown if longer durations of loading cause cumulative injurious effects, which may serve to suppress vasodilatory reserve, thereby compounding and exacerbating dependent tissue injury and integrity if not off-loaded in a timely fashion. This may be an issue even in vascularly healthy individuals as herein studied but is likely an important aspect in patients with already compromised lower extremity vascular status. When these aspects are better characterized in on-going studies, it may be possible to develop suitable hyperemic risk-assessment procedures to better classify relative heel breakdown-risk on a patient-by-patient basis.

## Acknowledgment

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