ABILITY OF EPIDERMAL SENSORS TO MEASURE LOWER LIMB TEMPERATURE DURING ACTIVITY WITH A PROSTHESIS SIMULATOR

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INTRODUCTION
Clinicians and researchers lack easy-to-use instruments to evaluate the socket-limb interface in a non-invasive manner during every day activities1. Interface temperature and pressure are critical considerations in socket design, fit, comfort, and residual limb health1,2. Hafner & Sanders2 suggested that incorporating sensing and monitoring technologies within prostheses could create opportunities for exchange of timely, relevant, and meaningful health information between patients, their prosthetists, and other healthcare providers. Unfortunately, instruments currently available to measure inside the socket include wires, cables, bulky/rigid sensors, or require mounting through holes in the socket, which is not clinically practical. Recent development of thin, flexible, wireless, ‘skin-like’ epidermal sensors3 may be one way to address these problems, leading to the development of a residual limb monitoring system. The purpose of this study was to assess temperature readings from these epidermal sensors by comparing them to thermocouples, which have been previously used to collect data from the socket-limb interface4.

METHOD
A prosthesis simulator was fabricated by a certified prosthetist to fit the left leg of an able-bodied individual (female, 26 years, 162.6 cm, 56.3 kg). The simulator comprised the following components: a gel liner (Ottobock, Germany), a prosthetic sock, and a transtibial vacuum-suspension socket. Data were collected simultaneously from both legs using 8 thermocouples (Omega Engineering, Stamford, CT) and 8 epidermal temperature sensors (Materials Research Lab, UIUC) placed on top of the thermocouples on 4 sites on each leg: tibial tubercle, fibular head, distal tibia, and medial gastrocnemius. Data were collected during: (1) 5 min. of seated rest with bare limb, (2) donning of simulator, (3) 10 min. of seated rest with simulator donned, (4) 30 min. of treadmill walking at 0.53 m/s, (5) 5 min. of seated rest with simulator donned, (6) 30 min. of treadmill walking at 0.53 m/s, (7) 30 min. of seated rest with simulator donned, (8) doffing of simulator, and (9) 25 min. of seated rest with bare limb.

RESULTS
Temperature readings from both sensor types at all locations corresponded reasonably well (±1.1°C) but were generally better on the contralateral limb (Figure 1). Temperature from the limb within the simulator were generally greater than the contralateral limb. Contralateral limb temperatures were generally constant throughout testing while temperature within the simulator continuously increased by 5-7°C once donned and did not return to near initial temperature until the simulator was doffed. Donning the gel liner caused a drop in temperature, while doffing the simulator caused an instant drop in temperature. The epidermal sensors were durable to socket conditions and did not cause any adverse skin problems.

DISCUSSION
Thermocouples have been used previously to measure transtibial residual limb temperature using a similar protocol5. Our data compared well and was similar both in magnitude and pattern to that previously published for transtibial amputees4. While these initial results suggest that the epidermal sensors are suitable for assessing temperature from within a prosthetic socket, additional work is needed to better understand the variation in correspondence between the two sensors at different locations.

CONCLUSION
Epidermal sensors provided temperature magnitudes and trends during initial testing that are reasonable.

CLINICAL APPLICATIONS
Using epidermal sensors to monitor residual limb conditions within prosthetic sockets may lead to improved healthcare for persons with limb loss.

REFERENCES
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