AN ACTIVE INSOLE SYSTEM TO NORMALISE PLANTAR LOADING USING FINITE ELEMENT DRIVEN SOFT HYDRAULIC ACTUATORS

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Introduction

537 million people have diabetes worldwide, and 19-34% of this population will develop diabetic foot ulceration (DFU) in their lifetimes [1,2]. Patient specific pressure offloading insoles are commonly used to prevent ulceration [3]. However, patient specific offloading insoles (static offloading insoles) cannot adapt to dynamic plantar loading experienced through activities of daily living. This paper aims to create and evaluate an active insole system effectively minimising peak loading and normalising overall plantar loading.

Methods

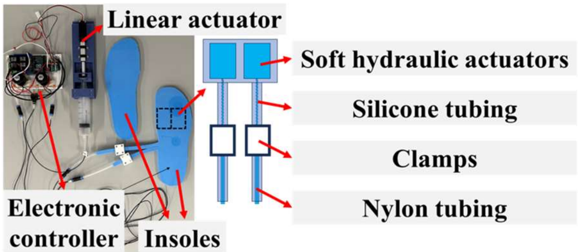

Figure 1: The active insole system hardware.

An active insole was created using silicone with two soft hydraulic actuators embedded in the medial and lateral metatarsal head region (Figure 1). A single healthy and diabetic participant wore the active insole system while sitting and walking on a treadmill. The system measured plantar pressure (PP) for the neutral active insole shape

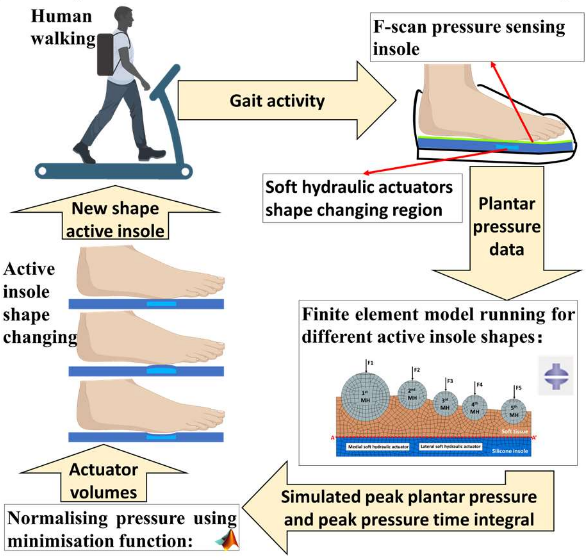

Figure 2: The active insole system optimisation process.

(initial shape). Measured plantar pressure was then used in an approximate finite element foot-insole model to predict PP and pressure time integral (PTI) for a range of active insole shapes while the subjects were sitting and took less than 6 minutes to run. The rough optimal active insole shape to normalise pressure by minimising both the peak PP and peak PTI was then predicted. The system then changed the shape of the active insole (Figure 2). These steps were then repeated on a smaller range of shapes to further refine the plantar loading.

Results

Table 1 shows the results from the healthy and diabetic participants. It shows that the active insole system was able to reduce both the peak PP and the peak PTI at the high-risk plantar region of the participants. Gait symmetry was not adversely affected.

ID.	Neutral insole	First optimisation	Second optimisation	Reduction
Average peak plantar pressure (kPa)				
H	683	656	620	**63(9%)**
D	359	234	172	**187(52%)**
Peak pressure time integral (kPa·s)				
H	135	132	127	**8(6%)**
D	97	61	56	**41(42%)**

Table 1: Participates' peak PP and peak PTI at high-risk plantar region (A-A' in Figure 1). H is a healthy participant and D an individual with diabetes.

Discussion

This study showed an active insole system was able to reduce peak PP and peak PTI by 52% and 42% for an individual with diabetes respectively. It demonstrates for the first time, the feasibility of using an active insole system to reduce peak pressures, normalising loading, and proving the feasibility of such technology to potentially manage DFU. Further work is needed to collect data on more participants and to refine the system.

References

1. Magliano et al, IDF diabetes atlas. (IDF, 2021).
2. Armstrong et al, N. Engl. J. Med. 376:2367–2375, 2017.
3. Penny et al, J. Wound Care 29:S18–S26, 2020.

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