Plantar Shear Stress in Individuals With a History of Diabetic Foot Ulcer: An Emerging Predictive Marker for Foot Ulceration

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Plantar shear stress has been held accountable as a causative factor in diabetic foot ulcers (DFU) (1,2). Delbridge et al. (2) recognized shear stress as a major causative factor by stating that it is shear rather than vertical load that is responsible for tissue breakdown that occurs deep to the skin. Historically, research in this area has been hampered by an underestimation of the importance of shear stress and the lack of technology to measure it. Emerging evidence within the past decade has demonstrated the clinical significance of shear to foot ulceration (3–5). We previously revealed that individuals with diabetic neuropathy (DN) experience higher plantar shear compared with control subjects (5). However, to our knowledge, no study has compared peak shear in individuals with a history of DFU to those patients with DN but no history of DFU.

We quantified peak plantar shear (PS) in 9 subjects with (DFU) and 16 DN subjects without previous ulcers (DN) using the Cleveland Clinic shear plate (5). Ulcer history was confirmed by the collaborating physicians (A.G.G. and L.A.L). We collected peak pressure (PP) and shear data while barefoot subjects walked across the device at self-selected speeds. Two-sample *t* tests were used to analyze the group differences.

PP was not significantly different between the two groups (DFU 738.6 $\pm$ 322.3 kPa, DN 568.0 $\pm$ 123.8 kPa, $P = 0.2075$); however, PS was significantly higher in the DFU group (DFU 135.3 $\pm$ 60.6 kPa, DN 86.4 $\pm$ 30.3 kPa, $P = 0.0465$).

This study revealed, for the first time, that PS is significantly higher in patients with a history of DFU, representing a risk factor for development of DFU (Fig. 1). Although the study was likely underpowered to detect a significant difference in PP between the two groups, we believe that the higher PP in DFU subjects is clinically meaningful. The difference in PS was sufficient to generate an effect size >0.9, and hence a small sample size was sufficient to capture the statistical significance.

Shear stresses act tangentially in anteroposterior and mediolateral directions at the foot-ground interface, transmitting a complex stress–strain pattern to the sublayers of the plantar tissue. These stresses are applied in alternating directions and are abrasive to the plantar surface, particularly during walking. An analogy is a running chainsaw. A running chainsaw applies abrasive shear forces that will easily sever the limb of a tree. When shear force is removed, i.e., when the engine is off, it may be impossible to

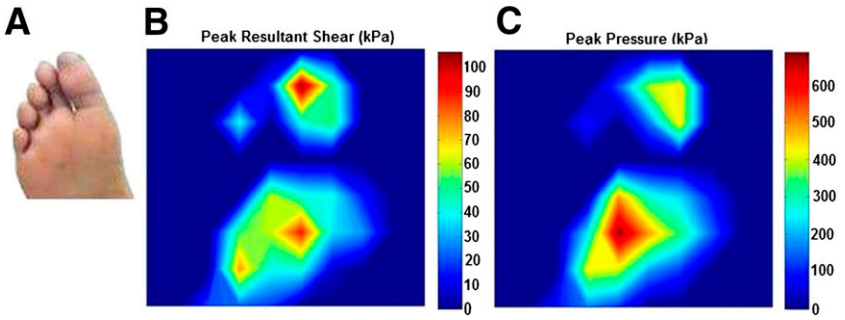

Figure 1—Peak pressure (*C*) and shear stress (*B*) profiles of a representative subject who had a previous ulcer under his right hallux (*A*). Mirror images of stress profiles were provided for easier visualization.

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break the same branch by applying pressure alone. Shear stress may not only lead to abrasion of the skin and plantar tissue but also damage the sublayers of the tissue and contribute to frequent formation of calluses under the diabetic foot, which are well-known risk factors.

Emerging evidence suggests that peak shear should be used jointly with pressure to better predict risk for developing a DFU. Future research should investigate the clinical implications of shear in a large longitudinal cohort study. With better biomechanical markers at hand, engineers and clinicians can work together to identify developing ulcers and design novel methods and devices to effectively prevent them.

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