INTRODUCTION

Diabetic ulcers continue to burden the US Healthcare System with thousands of amputations every year. It is known that in the presence of peripheral neuropathy, a common complication in Diabetes Mellitus, repetitive moderate stresses acting on or under the foot lead to these hard-to-heal sores. The normal component of the plantar stresses (i.e., pressure) has been studied extensively and eventually this factor has been labeled as a “poor tool” in predicting plantar ulcers [1]. Plantar shear stresses are thought to be a major factor in diabetic ulceration; however they were not studied extensively. The purpose of this study was to collect plantar shear stress data using a custom-built stress plate in three subject groups; diabetic neuropathic (DN), diabetic control (DC) and healthy control (HC) and compare the results.

METHODS

The study was approved by the Institutional Review Board. Subjects gave informed consent before participation. Group DN consisted of 12 diabetic neuropathic patients (12M, 65.7±6.9 years, 31.4±5.2 BMI), whereas Group HC included 11 individuals (7F/4M, 65.5±6.0 years, 27.8±5.9 BMI) without diabetes, any foot disorder or major deformities. The third group (DC) served as the diabetic control group and comprised 12 diabetic patients (8F/4M, 51.8±13.3 years, 28.7±7.9 BMI) without neuropathy. Peripheral neuropathy was tested by vibration perception and 5.07 Semmes-Weinstein monofilaments. Each subject walked on the stress plate, which was installed on a 12-ft walkway and set flush, multiple times. Detailed specifications of the device are given elsewhere [2]. Data from three trials were averaged and used in statistical analysis.

Figure 1: Peak plantar pressure (top) and shear (bottom) profiles of a representative DN subject. Note the difference between the sites of peak pressure (medial forefoot) and peak shear (central forefoot).
method. Four major stress variables were identified in each subject; peak pressure (PP), peak shear (PS), peak pressure-time integral (PTI) and peak shear-time integral (STI). Data analyses were based on global peak values and regional peak values. For the second type of analysis, pressure and shear profiles of the enrollees were masked into five regions by a custom Matlab® script; hallux, lesser toes, medial forefoot, central forefoot and lateral forefoot. Data were analyzed by a General Linear Model. Pairwise comparisons were conducted via Bonferroni tests. Alpha was set at 0.05.

RESULTS AND DISCUSSION

Global peak pressure and peak shear occurred at different plantar sites in 75%, 50% and 33% of the DN, DC and HC subjects, respectively (Figure 1). This confirms the findings of an earlier report [3].

Global stress analysis: PP was not significantly different across the three groups (p=.124), whereas PS (p=.043), PTI (p=.006) and STI (p=.006) were. Table 1 displays the results for each group. Group-wise significant differences were observed in; DN-DC: PTI and STI, DN-HC: PS, PTI and STI, DC-HC: none.

Regional stress analysis: Only a few region-wise significant differences were detected. Peak pressure (PP) and pressure-time integral was significantly higher in the medial forefoot of the DN patients when compared with both control groups. p value in the comparison of PS under the hallux of DN and HC subjects was calculated as borderline (0.052). On the other hand, STI was significantly higher at this region in DN patients (p=.001).

It is thought that the results demonstrate the clinical importance of plantar shear in diabetes related foot ulcers. The observation that peak pressure and shear may occur at different anatomical sites of the DN foot may explain why most ulcers do not develop at peak pressure locations [4]. While many previous manuscripts reported significantly higher pressure magnitudes in patients with neuropathy the results of this study revealed non-significant changes, which may be tied to the relatively smaller sample size. It was interesting to observe however that while pressure magnitudes remained similar, shear magnitudes were significantly higher in the diabetic neuropathic group. Comparison of results between the diabetic control and healthy control groups did not disclose significant differences, which indicate that biomechanical alterations in the diabetic foot occur with the onset of neuropathy. To our knowledge, this constitutes the first study that reported on the comparison of plantar shear stresses between diabetic neuropathic patients and a diabetic control group. Also for the first time, this study reported a statistically significant shear stress increase at various anatomical regions of the diabetic neuropathic foot. Further investigation of plantar shear stresses is expected to lead to better understanding of the complication and development of more effective prevention methods.

REFERENCES


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Table 1: Mean (standard deviation) values of global peak pressure and shear stress variables in three groups. * denotes a significant group-wise difference.