

Effect of Stride Frequency on Plantar Loading in Type 2 Diabetes.

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ABSTRACT

Neuropathy and high plantar pressure are two prevalent risk factors associated with diabetes mellitus (DM) that may lead to foot ulceration. Commonly, neuropathy, or the gradual loss of nerve function, limits the amount of sensation on the plantar aspects of the feet. Increased plantar pressure occurs due to alteration of musculoskeletal and soft tissues in patients with DM. Once ulceration has occurred, DM also contributes to a reduced ability to heal. A pendulum-based model has been used to predict preferred stride frequency (PSF). PSF is appropriate for healthy populations in order to keep plantar pressures at the lowest levels. However, PSF may not be appropriate for the DM population considering the neuropathy and plantar pressure concerns. Therefore, the purpose of this study was to examine how stride frequency above or below PSF alters plantar loading. Twenty volunteers with diagnosed Type 2 DM walked on a treadmill at PSF and four randomly sequenced bouts at $\pm 5\%$ and $\pm 10\%$ of PSF, on two separate occasions. Plantar pressures were recorded from Pedar™ insoles placed in running shoes. Stride frequency from PSF to 10% above PSF may decrease CT and PTI in Type 2 DM patients lowering ulceration risks.

Keywords: Diabetes mellitus, ulceration, stride frequency, plantar pressure

INTRODUCTION

Type 2 diabetes mellitus (DM) patients have an elevated risk of plantar ulceration compared to the normal population. Higher susceptibility in these individuals' results from their increased likelihood of having one or more factors associated with ulcer development. Neuropathy and higher than normal plantar pressure are two prevalent risk factors associated with DM that may lead to ulceration (Cavanagh and Ulbrecht 207).

Commonly, neuropathy, or the gradual loss of nerve function, limits the amount of sensation on the plantar aspects of the feet (*The American Orthopaedic Foot and Ankle Society*). Decreasing this sensation level disables DM individuals from being able to feel the onset or occurrence of injury to the foot. As a result, these patients are more inclined to experience a plantar ulceration.

Also, increased plantar pressure due to alteration of musculoskeletal and soft tissue is common among patients with DM (Cavanagh and Ulbrecht 207). These conditions increase the probability of tissue damage. One common factor that influences this type of degradation is atrophy of the intrinsic muscles that control the position of the phalanges. Additionally, as shown by Cavanagh and Ulbrecht (207), nonenzymatic glycosylation of many proteins in the body may play a role in plantar soft tissue dysfunction leading to higher risks of ulceration.

Once ulceration has occurred, it becomes increasingly difficult to propagate healing. Certainly, there is a high probability that plantar regions under high pressure become ischemic when the foot is loaded (Cavanagh and Ulbrecht 209). Consequently, the slow restoration of blood flow to the forefoot during the last portion of the gait cycle may be the cause of delayed recovery from ulceration as stated by Cavanagh and Ulbrecht (209). In fact, conditions slowing flow rate in blood restoration have recently been displayed as common abnormalities, even in early DM (Cavanagh and Ulbrecht 209).

Agreement on the pressure threshold for ulceration has yet to be determined (Cavanagh 206). It is known however, that patients with DM on average have higher pressure under their feet than individuals without DM (Cavanagh and Ulbrecht 199). It is frequently at these sites of high pressure where most ulcerations in patients with DM occur (Cavanagh and Ulbrecht 199). As a result, plantar pressure assessment is a topic of great interest. Plantar pressures in these patients could then lead to a reduced risk of ulceration.

Average plantar pressure is calculated by dividing applied force by the area over which it acts (Cavanagh and Ulbrecht 202), but the average pressure that places individuals at risk for ulceration has yet to be determined. Several calculations lacking validity have been performed in search of determination of this average pressure (Cavanagh and Ulbrecht 202). This lack of validity stems from the fact that the “effective foot area” is much smaller than the area of the footprint (Cavanagh and Ulbrecht 202). Therefore, plantar pressure must be directly measured rather than estimated whenever possible. Several in-sole devices are currently commercially available for direct in-shoe pressure measurement enabling the information from multiple steps to be obtained (Cavanagh and Ulbrecht 202). Of course, when this instrumentation is used, care must be taken to consider things that could influence pressure readings such as stride length (natural or mandated), speed of walking (natural or mandated), and first step or midgait data collection (Cavanagh and Ulbrecht 204).

It is not advisable to simply analyze the foot pressure distribution of a healthy population and consider similar values safe for non-healthy individuals (Cavanagh and Ulbrecht 206). Specifically, PSF may not be appropriate for the DM population considering the neuropathy and plantar pressure concerns. Therefore, the purpose of this study was to examine how stride frequency above or below PSF alters plantar loading. Alterations in gait frequency to decrease plantar loading may result in prescriptive procedures for lowering plantar ulceration risks of patients with Type 2 DM.

METHODS

Subjects

A sample size of twenty individuals with Type 2 DM, age 40-65, was used. Factors for exclusion from this study included current ulcerations, history of cardiac problems, and greater than Grade 2 obesity. Prior to participation, subjects were asked to read and sign an informed consent form approved by the University of Wisconsin-La Crosse Institutional Review Board. Any questions or concerns that the participants had were addressed prior to testing.

Instrumentation

In-shoe plantar loading was measured by the Pedar™ system (Novel GMBH, Munich, Germany). The Pedar™ system consists of a set of insoles that are sized to an individual's shoe size. The insoles are 2 mm thick and were easily placed into the bottom of the New Balance® running shoes provided for the subjects. Each insole consists of 99 pressure sen-

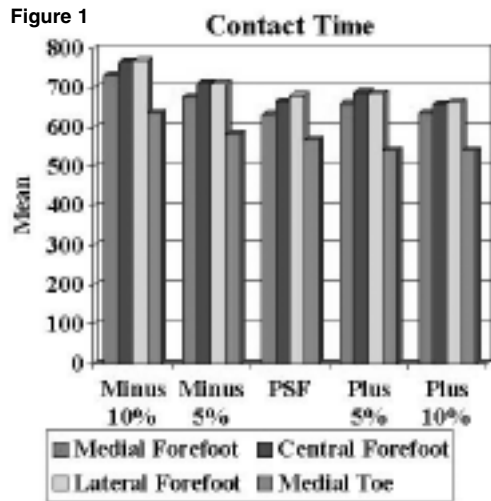
sors that measure the normal forces over the entire insole. The pressure insoles were connected to an 8 bit analog-to-digital converter box. The leads were secured to the subject's legs as previously described by Zimmer and Kernozek. In-shoe loading was measured bilaterally at a sampling rate of 50 Hz. The analog-to-digital converter box was connected to a personal computer for data collection and storage. Contact times (CT), peak pressures (PP) and pressure-time impulse (PTI) served as the dependent variables in this study while the independent variable was stride frequency (-10% of PSF, -5% of PSF, PSF, +5% PSF, and +10% PSF). An increase in either PP or PTI may lead to tissue degradation. These in-shoe measurement variables during treadmill walking have been shown to have a high amount of reliability using the Pedar system (Zimmer and Kernozek).

Protocol

Each subject participated in a total of two sessions. The first session allowed subjects to become accustomed to walking on a treadmill, and the second session was used for actual testing. Height and weight was recorded for calculation of Body Mass Index (BMI = weight (kg) / height (m)). Subjects were allowed to warm-up on the treadmill at a self-selected pace for four minutes. To obtain the subject's stride frequency, he or she walked on the treadmill at self-selected walking speed for four minutes. Subjects then walked on a treadmill at PSF and four randomly sequenced bouts at ±5% and ±10% of PSF. A Seiko Digital Metronome was used to aid the subjects in maintaining the appropriate stride frequency. Subjects were allowed to rest for 1-minute intervals between each test frequency to minimize any effects of fatigue if they so chose. Data were collected by the Pedar™ System at minute 3 of each testing frequency, in a manner previously performed by Zimmer and Kernozek and analyzed using RM MANOVA statistical analysis. The dependent variables were calculated for 7 different plantar regions. The analysis did not focus on the heel region, arch region, or lateral toe region based on the fact that ulceration rarely occurs in these regions. Therefore, the medial toe region and the medial forefoot, central forefoot, and lateral forefoot regions were analyzed statistically.

RESULTS

Analysis displayed that changing stride frequency did not significantly affect PP on the foot. However, walking at PSF, +5% PSF, and +10% PSF significantly decreased contact time in the medial forefoot region while walking at -5% PSF and -10% PSF produced a significantly higher CT (Figure 1). Slight variations did exist between PSF, +5% PSF, and +10% PSF, but the differences between these were not significant. However, a significant linear trend was found. Similar results were found across all regions analyzed. The same pattern was seen in the central forefoot, lateral forefoot, and the medial toe (Figure 1). Consequently, significant linear trends



were present across these regions as well.

Consistent with these findings, PTI of the medial forefoot displayed significant differences between -5% PSF and -10% PSF compared to PSF, +5% PSF, and +10% PSF (Figure 2). Central and lateral forefoot regions and the medial toe region displayed similar results (Figure 2). Differences were found between PSF, +5% PSF, and +10% PSF, but these differences were not significant. An overall significant linear trend was found.

DISCUSSION

It can be concluded increasing stride frequency linearly decreases CT in the lateral, medial, and central forefoot regions as well as in the medial toe region. Increasing stride frequency also linearly decreases PTI in the lateral, medial, and central forefoot regions as well as the medial toe region. Consequently, stride frequency from PSF to 10% above PSF may decrease CT and PTI in the lateral, medial, and central forefoot regions as well as in the medial toe region. This may be especially beneficial for those with a history of medial toe ulceration, callus, or elevated plantar pressures. As a result, those with Type 2 DM may benefit from walking at their normal speed but using faster, shorter steps (faster cadence) rather than slower, longer steps (slower cadence).

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Figure 2

