Introduction

The presence of both macro and microvascular disease in diabetes contributes to declining tissue health and the pathogenesis of ulceration in the presence of other complications. \[1\] Increased pressures under the foot when walking have been shown to be significantly associated with an increased plantar ulcer formation in patients with diabetes. \[2, 3\] Boulton et al. (1983) reported increased plantar pressures in 17% of patients with diabetes. \[4\] Lack of joint mobility has been shown to be a primary risk factor for ulceration and can be assessed using video imaging in clinical practice. Generally people with diabetes mellitus and peripheral neuropathy are at increased risk of plantar foot ulceration especially during walking. Ulceration has been shown to be associated with reduced joint mobility in the first metatarsophalangeal joint and increased peak plantar pressure. \[5-8\] However, assessment of the first metatarsophalangeal joint’s range of motion (ROM) to assess the risk of ulceration has traditionally been carried out using a non-weight bearing (passive/static movement) technique and goniometric measure. \[9, 10\]

Using a plantar pressure measurement device provides an accurate indicator of diabetic patients developing ulceration but is not in
common use clinically due to the high variance in results.\textsuperscript{7, 11-14} In addition recent findings have shown that people with diabetes often have reduced passive ankle dorsiflexion ROM but this has no significant correlation to increases in plantar pressure findings.\textsuperscript{15}

A limited number of studies exist that focus on the measurement of dynamic ROM of the first metatarsophalangeal joint in patients with diabetes mellitus and risk of ulceration. Debate continues over the relationship between passive and dynamic measures, peak plantar pressure and ulceration in people with diabetes. Turner et al. reported no correlation between results of static ROM and 1st metatarsophalangeal joint motion measures. However these authors did not investigate dynamic ROM.\textsuperscript{16}

This paper addresses whether (i) a difference exists between static and dynamic dorsiflexion range of motion of the first metatarsophalangeal joint in subjects with diabetes and controls, and ii) whether there is a relationship between dynamic range of motion and peak plantar pressure.

\textbf{Patients and Methods}

Fifteen female participants with at least a six year history of type 2 diabetes mellitus and an age matched group of fifteen females without diabetes mellitus were recruited by convenience sampling from the Charles Sturt University Allied Health Podiatry Clinic inpatients database and from the Diabetes Complications Screening Initiative. This study gained approval from the Charles Sturt University School of Community Health Ethics Committee (Approval # EC/04/12). Possible participants were initially excluded if they reported a history of lower limb injury, fractures, obvious foot deformity or other disease states that limit or impair movement in the lower limb. Each participant had a finger prick test for blood glucose levels at time of the biomechanical testing using a Medisense 2® Blood Glucose Sensor. HbA1c values were obtained from fasting blood samples collected at the local pathology laboratory.

\textbf{Biomechanical Assessments}

Biomechanical assessment was carried out using the Novel EMED-ST pressure plate system (Novel GmbH, Munich, Germany) recessed in a 10 meter long walkway. All biomechanical assessments were carried out on the left and right foot of the participants. The Novel EMED-ST provides a measurement of the level of pressure exerted through the plantar surface of the foot by the participant when a step is placed on the mat. The Novel EMED-ST transducer mat system measures plantar pressure with sensor platform dimensions of 475 x 320mm. The platform has 6080 sensors, four per square centimetre that sample at a rate of 100Hz. The transducer mat system is mounted in the center, and flush with the floor of a five-meter walkway. Pressure data displayed is limited to a range of 10 to 1275 KPa.\textsuperscript{17}

\textbf{Passive Weight bearing Range of Motion Assessment}

Participants were assessed for first metatarsal movement on the platform by placing their feet so that the first metatarsal head came to rest on the edge of the walkway. A goniometer held against the metatarsal bisection and the hallux of the right and left first metatarsophalangeal joint was then used to measure passive dorsi and plantar flexion. Three measures were recorded on both the left and right foot and the average recorded for both feet for dorsiflexion.
Video Camera

A Panasonic™ NV-GS400 digital video camera was used to collect dynamic range of motion data. The video collection interval was set to 1/500th of a second which corresponds to the data collection speed of the Novel EMED-ST plantar pressure system and positioned approximately 1 meter from the walkway. To reduce error the same camera and position was used to record dynamic range of motion data for all participants. The camera was linked to the Novel Player® software via USB cable. The camera used was also compatible with the siliconCOACH-Pro® program and enabled video data to be recorded and stored directly on to the computer.

Dynamic Dorsiflexion Range of Motion Assessment

Three retro reflective markers were placed on the right and left foot at the bisection of the metatarsal and hallux and on the medial border of the first metatarsal head. Each marker provided an identifiable point for analysis on videorecording. A camera located directly opposite from the centre of the walkway, with a full view of the sensor mat and connected to a computer was used to record dynamic dorsiflexion data. Participants were asked to walk, starting at a marker stepping off with the right foot first and return to the far end of the walkway to the adjusted marker. Only records containing the entire foot were collected. Three trials were recorded and the results averaged for dynamic dorsiflexion of the first metatarsophalangeal joint.

All video recordings were stored and analysed with the siliconCOACH – Pro® software Version 6.0 for calculation of the joint angle during walking. The lifting of the first metatarsal head from the ground was used for angle analysis providing the image that exhibited the maximum amount of dynamic dorsiflexion of the first metatarsophalangeal joint for three consecutive images and for both the left and right foot.

Peak Plantar Pressure Assessment

The Novel Player® program depicts a numerical value of pressure in KPa across the joint at and each sensor site. Peak plantar pressures were obtained for the first metatarsal head and the hallux for each of three consecutive frames that were recorded. Values which indicated the highest level of pressure within the first metatarsal head and hallux region were recorded and an average value was then calculated for each foot and used in data analysis.

Statistical Analysis

The reliability and validity of all methods used in this study have previously been assessed and are not covered here.[13, 18, 19] The Statistical Package for Social Sciences (SPSS) Version 14.0 was used to analyse data (SPSS, 2008). Mean data have been included for static and dynamic range of motion of the first metatarsophalangeal joint. Median values were used for peak plantar pressure (PPP) under the first metatarsal head and hallux. Statistical analysis for PPP was undertaken using the Kolmogorov-Smirnov nonparametric test on median values.

Results

There was no significant difference for body mass index (BMI) between the groups. However HbA1c values were elevated in the diabetes group (p = 0.006) but within the range of good control. (Table 1)

Table 1- Body Mass Index, Blood Glucose Level and HbA1c values.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Diabetes</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Mass Index</td>
<td>31.10±5.14 kg/m²</td>
<td>33.32±9.19 kg/m²</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>HbA1c</td>
<td>5.98±0.56</td>
<td>7.08±0.95</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>
Passive weight bearing dorsiflexion measures indicated that dorsiflexion range of motion (ROM) was significantly lower (33.88±12.98º and 40.56±14.57º, p<0.05) in the diabetes group compared to control. However, we found no significant difference between the diabetes and control group dynamic range of motion (45.53±9.06º and 43.78±12.56º, p=0.27).

(\textit{Table 2})

\textbf{Table 2-} Passive and Dynamic Weight Bearing Dorsiflexion Range of Motion.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Diabetes</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>40.56±14.57º</td>
<td>33.88±12.98º</td>
<td>0.033</td>
</tr>
<tr>
<td>Dynamic</td>
<td>43.78±12.56º</td>
<td>45.53±9.06º</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Comparison between passive and dynamic ROM is shown in \textit{Table 3}. The dynamic range of motion for all groups is greater with the diabetes group having statistically significant different results for the passive compared to dynamic ROM measure (p < 0.001).

\textbf{Table 3-} Comparing Static and Dynamic Dorsiflexion Range of Motion

<table>
<thead>
<tr>
<th></th>
<th>Static (\textit{mean±sd})</th>
<th>Dynamic (\textit{mean±sd})</th>
</tr>
</thead>
<tbody>
<tr>
<td>ND**</td>
<td>40.56±14.57º</td>
<td>43.78±12.56º</td>
</tr>
<tr>
<td>DM##</td>
<td>33.88±12.98º</td>
<td>45.53±9.06º</td>
</tr>
<tr>
<td>ND + DM#</td>
<td>37.22±14.09º</td>
<td>44.66±10.84º</td>
</tr>
</tbody>
</table>

º = degrees; ND = nondiabetic; DM = diabetic

# p < 0.01; ## p <0.001; ** p>0.05

Peak plantar pressure (PPP) can be measured at the first metatarsal head or at the hallux. For the first metatarsal head, the PPP was reduced in the diabetes group but was not statistically significant (360.8 N/cm² and 299.16 N/cm², p=0.39). Analysis of the PPP values for the hallux indicated similar results for the data distribution, with the statistical analysis for nonparametric data showing no significant difference between the two groups (478.33 N/cm² and 416.66 N/cm², p = 0.39) (\textit{Table 4})

\textbf{Table 4-} First Metatarsal Head and Hallux Peak Plantar Pressure.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Diabetes</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Metatarsal Head</td>
<td>360.83 (266.67-675)</td>
<td>299.16 (221.67-390) *</td>
</tr>
<tr>
<td>Hallux</td>
<td>478.33 (410-685.33)</td>
<td>416.66 (343.33-513.33) *</td>
</tr>
</tbody>
</table>

*p>0.05 for both comparisons

In this study no statistically significant correlation was noted between either passive or dynamic range of motion and diabetes status (correlation; p value: -0.2388; p = 0.06 and 0.08; p = 0.53 respectively) nor was there a significant difference between passive and dynamic dorsiflexion (0.203; p = 0.11).

The correlation between mean peak plantar pressure and diabetes status was -0.22 (p = 0.09). However a statistically significant negative correlation (-0.339) was seen for mean passive dorsiflexion and HbA1c (p = 0.024) but not for dynamic dorsiflexion and HbA1c.

Similarly a statistically significant negative correlation (-0.269; p = 0.037) was observed between mean passive dorsiflexion and body mass index but not for dynamic dorsiflexion and BMI. No correlation was observed between peak plantar pressure and either passive or dynamic dorsiflexion range of motion (p > 0.05).

\textbf{Discussion}

This study differs from previous studies because it considered patients with well controlled diabetes and only considered female subjects. In a study by Tinley and Taranto the authors did not have any HbA1c measures to verify the level of diabetes control.[20] Our study reports the level of HbA1c that indicates reasonable control of diabetes. A significant reduction in passive dorsiflexion of the first metatarsophalangeal joint in the diabetes group (p = 0.033) was noted and would indicate from current assessment procedures an increase in risk of ulceration. However ulceration of the foot is more a function of increased plantar pressure, which is associated with limitations of dynamic dorsiflexion, which can occur in early diabetes with no apparent complications such as peripheral neuropathy due to altered gait.[21] Therefore our study also investigated dynamic dorsiflexion and found that in this group of well controlled diabetic females the dynamic dorsiflexion was not significantly different to that of age matched controls.
This suggests normal functional capacity in this patient group of subjects with diabetes. A similar finding was reported by Rao et al. who found that a reduction in passive ankle joint mobility did not influence mobility during gait.\[22\]

No significant reduction (p = 0.39) in peak plantar pressure in the diabetes group was seen when compared to controls. This follows previous findings \[18, 23\] and suggests that no increase in risk of ulceration can be assumed. No correlation with either passive or dynamic range of motion and peak plantar pressure was found and is similar to the finding of Rao et al.\[22\]. This may suggest that subjects with diabetes utilize strategies such as shortening their stride length and reducing their push-off power to modulate plantar loading.\[22\]

Our study agrees with previous findings in that the passive range of motion was significantly lower in the diabetes (33.88±12.98º) than the control (40.56±14.57º) group. Based on this finding, conventional differential diagnosis indicates an increased risk of ulceration. However when dynamic range of motion was tested no significant difference was noted between the control (43.78±12.56º) and the diabetes (45.53±9.06º) group. Since dynamic range of motion is related to change in peak plantar pressure and risk of ulceration, the results suggest that although the passive ROM is lower in individuals with diabetes, the reduction in ROM does not affect dynamic range of motion and therefore did not influence peak plantar pressure. In the literature the reduced amount of dorsiflexion range of motion used during ambulation has been attributed to the increased functional requirements placed on the joint by body weight, soft tissue, and loading of osseous structures.\[24-26\]

The similarities in peak plantar pressure between the two groups in our study, with the diabetes group having a slightly lower median peak plantar pressure reflects previous reports. This may be partially due to the similarity in body mass index between the two groups tested as this factor strongly influences peak plantar pressure.

However the lack of a significant statistical result may be due to the large range of results for PPP in both groups even though the study was adequately powered at 80%. A larger sample may identify a subgroup, however in our cohort there was a normal distribution.

The clinically important finding is that in a cohort of diabetic women with HbA1c indicating well controlled blood glucose, passive dorsiflexion was significantly lower in the diabetes group, whereas the two stronger indicators for risk of ulceration, namely dynamic range of motion and peak plantar pressure were within the normal range and did not differ between the diabetic and nondiabetic group.

More importantly, there is no correlation between passive ROM and peak plantar pressure and therefore passive ROM may not be useful clinically for assessment of foot function. However further research is required to confirm our findings, especially with consideration for different clinical situations such as a more chronic patient group and male subjects. Passive range of motion of the metatarsophalangeal joint may be important and a correlation with change in dynamic range of motion and peak plantar pressure could be found in other patient groups. In the diabetic group lower passive dorsiflexion ostensibly appears early, rather than loss of dynamic motion or reduced peak plantar pressure.

A longitudinal study will be required to determine whether passive dorsiflexion or dynamic range of motion function is a better predictor of foot ulcer outcomes. Our conclusion is that individuals with well controlled diabetes should be tested using a dynamic range of motion test when assessing risk of future range of motion reduction and therefore prediction for plantar ulcer risk.
References


