The Importance of Time Spent Standing for those at Risk of Diabetic Foot Ulceration

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**Objective:** Despite the high cumulative plantar stress associated with standing, previous physical activity reports of diabetic patients at risk of foot ulceration have not taken this activity into account. This study aimed to monitor spontaneous daily physical activity in diabetic peripheral neuropathy (DPN) patients and examine both walking and standing activities as important foot-loading conditions.

**Research Design and Methods:** Thirteen DPN patients were asked to wear a body worn sensor for 48 hours. Body postures (sitting, standing, lying) and locomotion (walking, number of steps, postural transition) were extracted.

**Results:** Patients daily spent twice as much time standing (13±5%) as walking (6±3%). They spent 37±6% sitting and 44%±8 lying down. Average steps/day was 7,754±4,087 and the number of walking episodes was 357±167 with maximum duration of 3.9±3.8 minutes.

**Conclusion:** The large portion of DPN patients’ time spent standing with the feet loaded requires further consideration when treating and preventing foot ulcers.

Clinicians are cautious about advising extra activity in patients at risk of developing diabetic foot ulcers (DFU). There is concern about excessive loading of the foot causing DFU. However, the published data regarding this association are not clear. Contrary to expectations, previous studies looking at physical activity levels in individuals at high risk for DFU have found these individuals to be less active than healthy counterparts. (1-3) Maluf and Mueller stratified steps/day in patients with diabetes and varying levels of foot complications. (1) Patients with peripheral neuropathy (DPN) took approximately 8,000 steps/day whereas patients with a history of DFU took approximately 5,500 steps/day. (1) Armstrong and colleagues corroborated diminished steps/day in high risk patients, reporting approximately 4, 500 steps/day in this population. (4) In trying to obtain a more complete picture of the trauma associated with physical activity of patients at high risk of DFU, a means of calculating cumulative plantar stress from steps taken was suggested. (1) Cumulative stress was described as the product of the forefoot pressure-time integral and the number of strides/day. (1) Patients with a history of DFU actually demonstrated 41% less cumulative plantar stress than control and DPN patients matched for age and BMI. (1) With previous studies indicating a lower volume of total physical activity in DFU patients, variability in physical activity has been identified as a likely contributor to DFU formation. (5) These previous studies assessing physical activity in patients at risk of DFU used pedometers to measure steps/day. Until recently, it has not been possible to unobtrusively assess other types of foot loading activities such as standing or bouts of activity using a single wearable sensor. (6-8) A greater understanding of the complete physical activity of those at risk of DFU, may provide greater insight into DFU development and prevention. This study aimed to describe the quality
and quantity of activities of daily living in DPN patients.

RESEARCH DESIGN AND METHODS

Thirteen DPN patients were studied; all patients signed a local IRB approved consent form prior to participating. DPN was defined by clinical exam using a 10g monofilament and biothesiometer. (9) The patient age was 59±8 years and BMI was 34.6±4.2. Patients were asked to wear a comfortable shirt including an unobtrusive body worn sensor (PAMSys™, Biosensics LLC, MA, USA) for 48 hours. Subjects were instructed to remove the shirt prior to bathing. They were also told to record the time period for any episodes that the shirt was removed. PAMsys contains a single tri-axial accelerometer housed in a single portable sensor allowing for continuous collection of 3D acceleration data for up to 5 days at sample frequency of 50Hz. The sensor unit was positioned at the middle of the chest close to the sternum. This sensor unit enables extracting spontaneous daily physical activity including body postures (sitting, standing, lying) and locomotion (walking, number of steps, speed, postural transition, etc). (8; 10; 11) An algorithm that detected when the shirt wasn’t worn permitted exclusion of those times from final analysis. The algorithm was based on measuring acceleration variation due to respiration. If the sensor was worn at the chest level, it could detect an acceleration signal due to respiration. However, if the sensor was not worn, the standard deviation value of the frontal accelerometer signal (i.e. accelerometer with axis perpendicular to the subject’s chest) would be close to zero. The algorithm was validated based on activity observation of a pre-defined set of activities including complete rest during all postures in a typical subject wearing the sensor unit. Another sensor unit was synchronized with the sensor worn by the subject and placed on a table. The developed algorithm could discriminate when the sensor wasn’t worn by the subject versus when it was worn during all activities. All data was recorded between March and May 2009 thus limiting seasonal variations in activity.

RESULTS

On average 17.5±29.89 minutes (1.2%±2.1%) of the data per day was excluded for subjects not wearing the sensor. This was slightly higher than the subjects’ self-reported value (11±16.5 min.). In addition, data from one subject was excluded due to the sensor not being properly inserted in the shirt resulting in noisy data. Results demonstrated that the period of standing is almost twice the period of walking (Figure 1). On average, DPN patients spent 13.5±5.3% in standing, 6.1±3.1% in walking, 37.3±6.3% in sitting, and 44.3±8.1 in lying posture per day. The average total number of steps per day was 7,754±4,087 and the number of episodes of continuous walking without stopping was 357±167 with maximum duration of 3.9±3.8 minutes or 422±403 steps. No significant correlation was found between the total number of steps per day and the duration of longest continuous walking episode (r=0.32, p=0.30). The most active patient walked 17,856 steps (13% of total activity) on average. The least active patient walked 4,013 steps (3.3% of total activity). The duration of standing for the most and least active patients was 21% and 9.1%, respectively. On average, 77±15 sit-to-stand postural transitions with an average duration of 2.6±0.07 sec were recorded per day.
CONCLUSIONS
To our knowledge, this is the first study to describe both the quality and quantity of physical activities of daily living in DPN patients. Physical activity has been traditionally defined as the total number of steps per day. However, this study suggests that walking may cover as little as 3–13% of a person’s daily physical activity and hence might not be representative of what the subject is doing during activities of daily living. The technology can also be used to objectively monitor DPN patients’ risk of falling after intervention through measurement of the sit-to-stand transition under non-clinical observation or coaching. (11;12) This study demonstrates that standing period is a very important foot loading condition that requires further attention when treating and preventing patients with foot ulcers. Additionally, this study suggests that the duration of the longest bout of continuous walking, which is assumed to be an important cumulative foot stress, is independent of total number of steps per day.

Author contribution paragraph: BN researched data, wrote manuscript, reviewed/edited manuscript, contributed to discussion; JW reviewed/edited researched data, wrote manuscript, reviewed/edited manuscript; contributed to discussion and RC researched data, reviewed/edited manuscript, contributed to discussion.

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Figure Legend:
Figure 1: (A) Spontaneous of daily physical activity of a typical DPN subject monitoring over 48 hours, (B) Relative percentage of major activities, (C) Duration (in second) of each continuous walking episode (walking without stop) as a function of number of steps per each walking episodes.

REFERENCES

![Figure 1](image-url)