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 h. Body postures (sitting, standing, and lying) and locomotion (walking, number of steps, and postural transition) were extracted.

RESULTS — Patients daily spent twice as much time standing (13 ± 5%) as walking (6 ± 3%). They spent 37 ± 6% of time sitting and 44 ± 8% lying down. The average number of steps per day was 7,754 ± 4,087, and the number of walking episodes was 357 ± 167 with maximum duration of 3.9 ± 3.8 min.

CONCLUSIONS — The large portion of DPN patients' time spent standing with the feet loaded requires further consideration when treating and preventing foot ulcers.

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Clinicians are cautious about advising extra activity in patients at risk of developing diabetic foot ulcers (DFUs). There is concern about excessive loading of the foot causing DFUs. 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 DFUs have found these individuals to be less active than healthy counterparts (1–3). Maluf and Mueller (1) stratified steps per day in patients with diabetes and varying levels of foot complications. Patients with diabetic peripheral neuropathy (DPN) took ~8,000 steps/day whereas patients with a history of DFUs took ~5,500 steps/day (1). Armstrong et al. (4) corroborated diminished steps per day in high-risk patients, reporting ~4,500 steps/day in this population.

In trying to obtain a more complete picture of the trauma associated with physical activity of patients at high risk of DFUs, 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 per day (1). Patients with a history of DFUs 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 DFUs used pedometers to measure steps per 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 DFUs 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 institutional review board approved consent form prior to participating. DPN was defined by clinical exam using a 10-g monofilament and biothesiometer (9). The patient age was 59 ± 8 years, and BMI was 34.6 ± 4.2 kg/m^2. Patients were asked to wear a comfortable shirt containing an unobtrusive body-worn sensor (PAMSys; BioSensics, Cambridge, MA) for 48 h. 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 triaxial accelerometer housed in a single portable sensor allowing for continuous collection of 3D acceleration data for up to 5 days at sample frequency of 50 Hz. The sensor unit was positioned in the middle of the chest close to the sternum. This sensor unit enables the extraction of spontaneous daily physical activity, including body postures (sitting, standing, and 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 caused by respiration. If the sensor was worn at the chest level, it could detect an acceleration signal caused by respiration. However, if the sensor was not worn, the SD 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 predefined set of activities including com-

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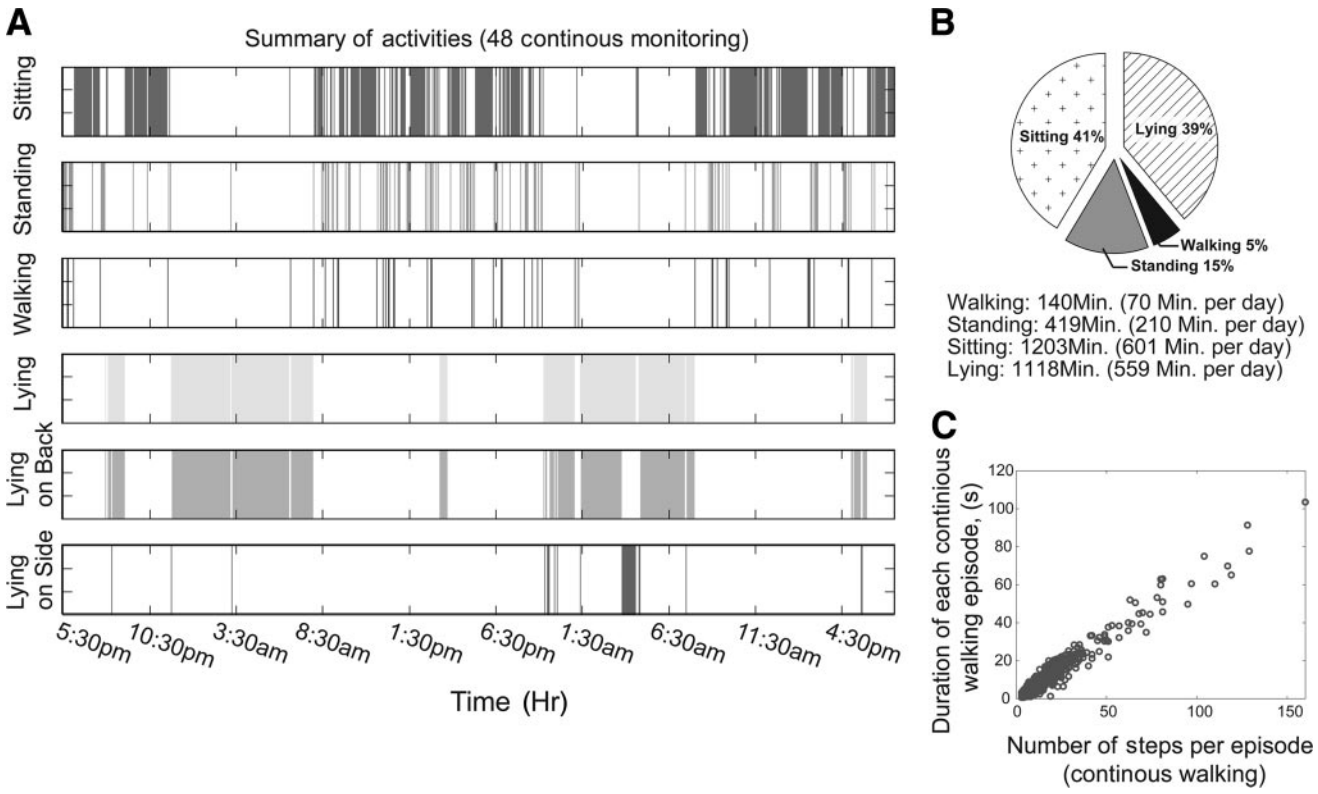

Figure 1 —A*: Spontaneous daily physical activity of a typical DPN subject with monitoring over 48 h.* B*: Relative percentage of major activities.* C*: Duration (in seconds) of each continuous walking episode (walking without stop) as a function of number of steps per each walking episode.*

plete 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 were recorded between March and May 2009 thus limiting seasonal variations in activity.

RESULTS — On average, 17.5 ± 29.89 min (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 because the sensor was not properly inserted in the shirt resulting in noisy data. Results demonstrated that the period of standing is almost twice the period of walking (Fig. 1). On average, DPN patients spent 13.5 ± 5.3% of time 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 min 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/day (13% of total activity) on average. The least active patient walked 4,013 steps/day (3.3% of total activity) on average. 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 s 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 nonclinical 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 DFUs. 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.

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