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ORIGINAL ARTICLE

Remote monitoring of sitting behaviors for community-dwelling manual wheelchair users with spinal cord injury

Y-S Yang[1], G-L Chang[2], M-J Hsu[3] and J-J Chang[1]

[1]*Department of Occupational Therapy, College of Health Science, Kaohsiung Medical University, Kaohsiung City, Taiwan;* [2]*Department of Biomedical Engineering, National Cheng Kung University, Tainan City, Taiwan and* [3]*Department of Physical Therapy, College of Health Science, Kaohsiung Medical University, Kaohsiung City, Taiwan*

Study design: A case series study.
Objectives: To describe the sitting behaviors in community-dwelling manual wheelchair users (MWUs) with spinal cord injury (SCI) by using a custom data logger and to compare the sitting time parameters between the groups with paraplegia and tetraplegia.
Setting: Data were collected from the MWUs living in the community area of Kaohsiung, Taiwan.
Methods: A custom data logger with six force sensor resistors was designed and installed on a personal daily-use wheelchair. Twenty MWU participants were instructed to disregard the activation of data logger and pursue their regular activities of daily living. Cumulative sitting time, averaged uninterrupted sitting time, lift-off frequency, and the symmetry ratio of sitting weight distribution for 24 h per day over a 1-week period were recorded.
Results: Manual wheelchair users spent an average of 9.2 h (median 9.7, range 3.2–12.2 h) per day in their own wheelchair. They sat for an average of 97 min (median 62, range 24–284 min) without displaying any lift-off behavior. The average lift-off frequency was 9.4 times (median 9.2, range 2–20 times) per day. During sitting, the median value of symmetrical right-left and front-rear weight distribution ratio was 0.9 (range 0.5–1.4), and 0.5 (range 0.01–1.6), respectively. There was no significant difference in sitting time parameters between MWUs with paraplegia and those with tetraplegia.
Conclusion: Community-dwelling MWUs spent long periods of time in their wheelchairs and did not engage frequently in pressure relief activities. Regardless of their neurological levels, education on the pressure relief activity is still a core component for all MWUs.
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Introduction

Many people with spinal cord injuries (SCIs) living in the community rely on wheelchairs for mobility. Sitting in their own wheelchair becomes the sole position for the majority of the day. Decreased mobility and immobilization are significant risk factors for pressure ulcers in these people.[1–3] The reported prevalence of pressure ulcers among spinal cord-injured manual wheelchair users (MWUs) ranges from 14 to 85%, and the most common site is the ischial tuberosity.[4–6]

In sitting, the study showed that 18% of the body weight is distributed over each ischial tuberosity region.[7] Able-bodied people are able to sense physical discomforts associated with prolonged sitting and are able to reposition their body positions frequently, thereby protecting their tissues from ischemic damage. However, people who suffer loss of sensation and motor ability due to SCI are unable to initiate the body movements for protecting the skin tissue. Consequently, the area surrounding the ischial tuberosity is therefore particularly vulnerable to higher pressures. Body tissues can generally tolerate high pressures within a short period of time. However, if such high pressures are maintained, blood supply and lymphatic drainage may be impaired. Therefore, monitoring of the sitting time at the interface between the soft tissues of the body and a support surface are critical in preventing the occurrence of pressure ulcers for MWUs with SCI.

To prevent pressure ulcers, people with SCI are routinely advised to undertake a pressure relief movement every 15–30 min to encourage tissue reperfusion and maintain tissue integrity.[8,9] They are also advised to self-inspect their skin for

Correspondence: Dr J-J Chang, Department of Occupational Therapy, Kaohsiung Medical University, 100, Shi-chuan 1st Road, Kaohsiung, Taiwan, R.O.C.
E-mail:jjchang@kmu.edu.tw
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pressure sores daily. However, many MWUs either did not perform such pressure relief activities or did not adhere to the advice, although they were physically capable of performing pressure-relieving movements without help. Merbit *et al*.[10] found that participants typically sat more than 20 min without having any pressure relief behavior. A similar finding was also observed by Bain and Ferguson-Pell.[11] Stockton and Parker[12] reported that 20.8% of community-dwelling wheelchair users did pressure relief activity only once an hour, and a further 54.7% MWUs moved less than once per hour. However, no further insight information has been provided in the above studies, such as the length of sitting time in MWUs' wheelchairs and the frequency of doing a pressure relief activity per day.

There is still very little information about the actual pressure relief behavior of wheelchair users, especially for those living in the community. Therefore, the purpose of this study was to describe sitting behaviors of community-dwelling MWUs. The sitting time parameters were collected in MWUs' own wheelchairs over a 1-week period, while they did their regular activities of daily living.

Materials and methods

Twenty community-dwelling MWUs were recruited and provided informed consent in accordance with the procedures approved by the Institutional Review Board of the Kaohsiung Medical University Hospital before participation in the study. The criteria for selection in this study were as follows: (1) SCI between the levels of C4 and L2, American Spinal Injury Association Impairment Scale (AIS) score A or B; (2) use a manual wheelchair as a primary mode of mobility within the community; (3) absence of any other clinical signs of pressure ulcers for at least 1 year; (4) between the ages of 18 and 65 years. Exclusion criteria were as follows: (1) use more than one manual wheelchair as a personal daily-use wheelchair during study; (2) unable to perform a lift-off or transfer activity from their wheelchairs either by themselves or with the help of other assistants.

Instrumentation

The data logger used in this study included a microcontroller (Tattletale model TFX-11, Onset Computer, Bourne, MA, USA) with six force sensor resistors (FSRs, $3.8 \times 3.8\,cm^2$, Interlink Electronics, Camarillo, CA, USA) (Figure 1). Six FSRs were sealed within a plastic mat in two rows: two in the front row and four in the rear row to record any change of weight distribution around the thigh and ischial tuberosity regions, respectively. Custom circuits were constructed and connected between FSRs and the microcontroller TFX-11 through a rubber serial cable. Any force data on FSRs were recorded with the time of the event in the flash memory of the microcontroller TFX-11. The data logger was designed to collect up to 11 days at a sample rate of 10 s or 100 000 time stamps. The sampling rate was selected as 10 s so that six FSRs could be recorded without running the risk of the memory overflowing during the collection period. Besides, we defined that if any lift-off activity was longer than 10 s, it would be accounted for as a pressure relief behavior. The mass of data logger including batteries and sensors is less than 2 kg. The data logger was attached to each participant's wheelchair by a waist bag and loop band (Figure 1).

Figure 1 A custom data logger with six force sensor resistors (FSRs).

Procedure

Participants were asked a series of standardized questions to collect descriptive characteristics about personal information and about their regular activities of daily living. Afterward, the data logger and a plastic mat with FSRs were installed on each participant's personal daily-use wheelchair. To ensure that each of the FSRs were located around the ischial tuberosity and thigh region, the placement of the plastic mat was verified by investigators while participants were sitting on their own wheelchairs. As many MWUs used a folding wheelchair owing to the transportability and storage benefits, the plastic mat was attached to the wheelchair by a pair of velcro strips to ensure the initial position without moving while folding the wheelchair. If a participant used a cushion on his/her wheelchair, the plastic mat with FSRs was mounted under the cushion. Otherwise, a thin foam cushion

(2 cm height) would be provided for the participant to cover the plastic mat for protecting circuits and cosmetic appearance.

Participants were instructed to disregard the activation of the data logger and pursue their regular activities of daily living. Data were downloaded after 7 days post-installation of the data loggers. Data collection was started on a monday and ended on either the next monday or next tuesday, whichever was most convenient for the participant. The end time was the same as the start time to ensure data collection over the 24 h of the transition day.

Data reduction

Once downloaded from each participant, data were analyzed using software written in MATLAB 6.1 (The Mathworks Inc., Natick, MA, USA). Each raw data contained the time stamp and reading of each FSR during sitting. If the participant performed a lift-off by pushing up on the armrests of the wheelchair or if he or she vacated the wheelchair, the sum of all six FSR readings was zero. Then, it was accounted for as a pressure relief behavior. In addition, the ratio of symmetrical sitting weight distribution (right to left, and front to rear) was calculated by dividing the resultant force on the right or front arrays by the resultant force on the left or rear arrays. A ratio of 1.00 indicated perfect symmetry. A right-left and front-rear symmetric ratio less than 1.00 indicated an asymmetrical weight distribution between the right and left and an increased weight distribution on the ischial tuberosity (rear) compared to the thigh region (front).

Statistical analyses

Descriptive statistics were completed for sitting time parameters (for example, sitting time and lift-off frequency) over a 24-h period of a 7-day trial period. To obtain a typical daily profile, nonparametric repeated measurement Friedman test was performed to test any differences between 7 days across a week in sitting time parameters. Afterward, to explore the differences in sitting time parameters between MWUs with paraplegia (T1-L2, AIS grade A or B) and those with tetraplegia (C5-C8, AIS grade A or B), nonparametric Mann–Whitney *U*-test was performed. Furthermore, Mann–Whitney *U*-test was used to examine whether using a cushion might increase the sitting tolerance or not. All statistical analyses were completed using SPSS 11.0 software (SPSS Inc., Chicago, IL, USA), and the significance level was set at $\alpha = 0.05$.

Results

The general demographic information of participants is presented in Table 1. The average years in the wheelchair was 5.5 years. There were neither age-related changes nor duration of injury-related changes in any sitting parameters ($P > 0.05$). Figure 2 shows the cumulative sitting time and lift-off frequency per day obtained over a 1-week period. The analysis of repeated measurement with Friedman test indicated no significant differences in sitting time parameters between 7 days across a week. Therefore, these parameters of 7 days can be pooled together and averaged to formulate a daily profile. The average cumulative time spent in the wheelchair per day was around 9.2 h (median 9.7, range 3.2–12.2 h). The mean of the longest period of uninterrupted sitting time without leaving their wheelchairs was 3.7 h (median 3.5, range 1.1–7.6 h), and the average time of uninterrupted sitting in a wheelchair was around 97 min (median 62, range 24–284 min). Participants showed an average of 9.4 times of lift-off behaviors (median 9.2, range 2–20 times). Furthermore, participants showed a symmetrical right-left sitting weight distribution with an average of 1.06 ratio (median 0.9, range 0.5–1.4). An asymmetrical front-rear sitting weight distribution with an average of 0.6 ratio (median 0.5, range 0.01–1.6) can be found among participants (Table 2).

Table 2 shows a daily profile of sitting behaviors between participants with paraplegia and those with tetraplegia. There were no significant differences between participants with tetraplegia and those with paraplegia in sitting behaviors, in terms of cumulative sitting time, uninterrupted sitting time, and lift-off frequency. The sitting behaviors were not significantly influenced by the injury levels. However, participants with cushions on their wheelchair

Table 1 Participant demographic information

Variable	*Mean (s.d.) (n = 20)*
Age (years)	37.0 (10.3)
Years in wheelchair	5.5 (6.0)
Weight (kg)	68.9 (14.7)
Self-reported sitting time per day (hours)	9.6 (2.5)
Gender (male/female)	18/2
Neurological level (paraplegia/tetraplegia)	11/9
Wheelchair with cushion (with/without)	16/4

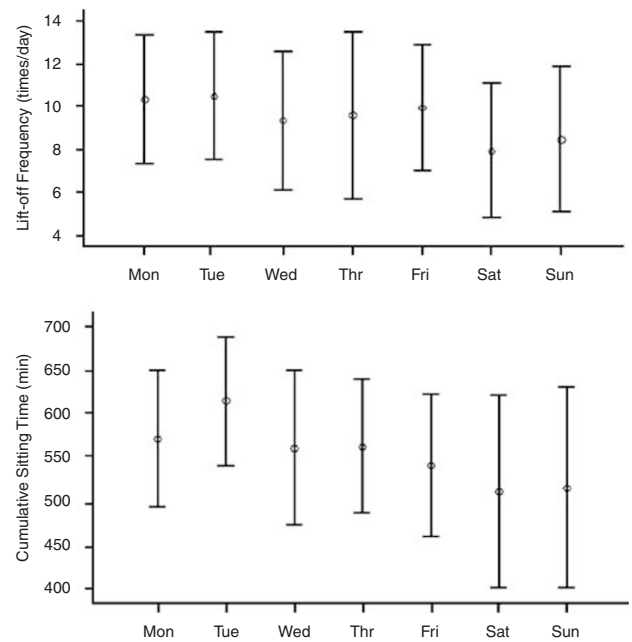

Figure 2 The lift-off frequency and cumulative sitting time across over a week (95% confidence interval for mean).

Table 2 Comparison of sitting behaviors between paraplegia, tetraplegia and a combined result for MWU participants

	Paraplegia (n = *11*) *median (range)*	*Tetraplegia* (n = *9*) *median (range)*	P-*value*	*Combined* (n = *20*) *median (range)*
Cumulative sitting time (min)	563.4 (191.3–734.1)	596.5 (336.0–642.8)	0.849	579.9 (191.3–734.4)
Longest period of uninterrupted sitting (min)	198.6 (66.7–455.4)	210.2 (171.7–353.1)	0.270	208.9 (66.7–455.4)
Average time of uninterrupted sitting (min)	53.5 (23.67–284.3)	92.2 (49.3–228.7)	0.160	62.2 (23.7–284.3)
Frequency of lift-off (times per day)	10.0 (2–19.7)	8.4 (2.0–12.6)	0.270	9.2 (2.0–19.7)
Right-left symmetric sitting ratio	1.0 (0.5–1.3)	0.8 (0.8–1.3)	0.676	0.9 (0.5–1.4)
Front-rear symmetric sitting ratio	0.6 (0.02–1.6)	0.3 (0.01–0.9)	0.210	0.5 (0.01–1.6)

Abbreviation: MWU, manual wheelchair user.

Table 3 Comparison of sitting behaviors between MWUs with and without cushion

Variable	*With cushion* (n = *16*) *median (range)*	*Without cushion* (n = *4*) *median (range)*	P-*value*
Cumulative sitting time (min)	597.5 (191.3–725.6)	542.1 (364.7–734.4)	0.925
Longest period of uninterrupted sitting (min)	211.0 (79.0–455.4)	167.5 (66.7–198.6)	0.029**
Average time of uninterrupted sitting (min)	92.9 (26.9–284.3)	45.9 (23.6–61.9)	0.072
Frequency of lift-off (times per day)	7.9 (2.0–19.7)	13.2 (7.9–14.0)	0.098
Right-left symmetric sitting ratio	0.8 (0.5–1.3)	1.0 (0.9–1.3)	0.850
Front-rear symmetric sitting ratio	0.5 (0.01–1.6)	0.4 (0.04–0.8)	0.108

Abbreviation: MWU, manual wheelchair user.
**Denoted <0.05.

showed a significant increase of uninterrupted sitting time ($P = 0.029$) than those without cushion. Consequently, an increased tendency of cumulative sitting time ($P = 0.072$) and a decreased tendency of lift-off frequency ($P = 0.098$) was observed (Table 3).

Discussion

In this study, our result found a wide range of sitting behaviors among community-dwelling MWUs (Table 2). MWUs spent almost 9 h a day sitting in their own wheelchair and performed a pressure relief movement once in an average of every 1–2 h. These findings were consistent with previous studies.[10–12] Bloemen-Vrencken *et al.*[13] found that individuals with SCI in the community did not frequently engage in pressure relief movements when sitting/driving in their wheelchair. Only 20.9% of the 410 responders always did some type of pressure relief every 30 min. Our finding indicated that most MWUs did not do pressure-relief activities at the advised frequency of every 15–30 min, although they were physically capable of performing pressure-relieving movements. This seems to put them at high risk of pressure ulcer. However, all participants in our study do not have any pressure ulcer history for at least 1 year. The possible explanation could be that most participants (16/20) used a cushion in their own wheelchair. Participants having a cushion sat longer with less lift-off frequency compared to those without a cushion. Cushions can provide effective pressure relief because they spread the weight, allowing users to sink down into them and distribute the pressure of sitting over a larger surface area. Therefore, even if users sat in their wheelchair for more than 20 min without any lift-off behavior, using a cushion might protect them from the risk of pressure ulcer.

Although MWUs with paraplegia showed shorter sitting time interval with high lift-off frequency due to better mobility function as compared to MWUs with tetraplegia, no statistical differences were noted in our presented study. MWUs with paraplegia spent almost the same amount of time in the wheelchair as MWUs with tetraplegia did. Individuals with SCI are advised to perform pressure-relief activities at the frequency of every 15–30 min.[8–9] In our study, the frequencies of lift-off in most MWUs with paraplegia and tetraplegia were 10 and 8.4 times per day, respectively, which are much lower than the advised frequency. Therefore, if MWUs did not perform the pressure-relief behavior regularly, they could expose themselves to a high risk of developing pressure ulcers regardless of their neurological injury levels. Raghavan *et al.*[14] found that neurological injury level is not a significant predictor of pressure scores. A multicenter study by Cardenas *et al.*[15] further indicated that pressure ulcers were a more common cause of rehospitalization in those with paraplegia than tetraplegia. Our result showed that both groups did not frequently display lift-off behavior when sitting in their wheelchairs, although the group with paraplegia was more capable of performing the activity. This result implied that the importance of regular lift-off or other forms of pressure relief to prevent pressure ulcer should be emphasized among MWU groups regardless of their neurological injury levels.

In the present study, a high symmetry ratio of right-left weight distribution demonstrated that MWUs sat in their wheelchairs with symmetrical right-left sitting posture. The more symmetrical the sitting pattern is, the closer to 1 is the value of the symmetrical ratio. However, the symmetry ratio of front-rear weight distribution appears to be low. This may be explained by the fact that higher sitting pressure is located in the ischial tuberosity region in comparison with the thigh region. Another explanation may be that people with SCI due to the absence or impairment of trunk muscle control

usually show a 'C'-shaped kyphotic posture.[16] This slumped sitting posture allows people with SCI to shift more weight backward and secure the trunk within their base of support without losing balance in a wheelchair. Therefore, with prolonged sitting time and the large magnitude of pressure involved, a high probability of developing a pressure ulcer around the ischial tuberosity region could be expected. Many types of wheelchair cushions have been developed in an attempt to relieve sitting pressure. A hybrid wheelchair cushion that is combined with two or more of the materials might conform better to sitting behaviors, distributing pressure more evenly and reducing peak pressures. Further research could be done to investigate the possible benefits of the hybrid design emphasizing on reducing pressure distribution over the buttocks, especially around the ischial tuberosity region, rather than the whole seating interface.

The results of this study described precise sitting behaviors of community-dwelling MWUs. However, there are a number of limitations that require consideration. First, the present study utilized a data logger with a sampling rate of every 10 s. If any lift-off activities less than 10 s occurred, these would not be accounted for in our results. Consequently, the number of lift-off frequencies might be somehow underreported. Second, a plastic mat with FSRs was mounted in a participant's daily-use wheelchair to detect the occurrence of force. Our results could only represent the sitting behavior while MWUs were in their wheelchair. We were unable to tell any sitting behavior once MWUs left their wheelchair. Third, the small number of participants used might have led to insufficient power to detect differences in many of the measured variables. Although we used non-parametric statistical analyses, it is probable that the statistical analyses failed to find effects that may have actually existed in the underlying population. Furthermore, with such a relatively small number of participants, the reader should be aware that our sample might not reflect the general spinal cord-injured population.

Given the information from this study, future studies might involve using an audio or visual feedback device to wake up the MWUs when they sit for more than 15–30 min and test whether it will increase the pressure relief behaviors frequently. Furthermore, research of MWUs' sitting time might extend the follow-up period to better determine the influence of continuous prolonged sitting and less lift-up frequency on the incidence of pressure ulcers.

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