Research Article

Trunk Function and Ischial Pressure Offloading in Individuals with Spinal Cord Injury

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Objective: To determine if there is a relationship between trunk function and offloading of the ischial tuberosities in individuals with Spinal Cord Injury (SCI).
Design: Prospective cross-sectional evaluation.
Setting: Sub-acute rehabilitation hospital.
Participants: Fifteen non-ambulatory participants with complete or incomplete traumatic and non-traumatic SCI, American Spinal Injury Association Impairment Scale (AIS), Classification A-D.
Outcome Measures: Isometric trunk strength using a hand held dynamometer, the ability to reach using the multidirectional reach test and offloading times of the ischial tuberosities using a customized pressure mat.
Results: Participants who were able to engage in the multidirectional reach test were defined as "Reachers", whereas individuals who were unable to engage in the multidirectional reach test were defined as "Non-Reachers". Trunk strength was significantly higher in Reachers compared with Non-Reachers ($P < 0.05$). Offloading times over the left and right ischial tuberosities were lower in Non-Reachers when compared with Reachers, however the results were statistically significant only for offloading over the right ischial tuberosity ($P < 0.05$). There was no correlation between trunk strength and pressure offloading times for both groups.
Conclusions: Regardless of an individual's ability to engage in a reaching task, participants with spinal cord injury spent more time offloading the left ischial tuberosity compared with the right ischial tuberosity. The study highlights the need to identify factors that may contribute to offloading behavior in individuals with spinal cord injury who lack sufficient trunk strength.

Keywords: Ischium, Spinal cord injuries, Pressure ulcer, Wheelchairs, Rehabilitation

Introduction

Pressure ulcers occur from prolonged unrelieved pressure[1] and are a costly medical complication leading to morbidity, reduced quality of life and possible mortality.[2] The estimate of pressure ulcers in all Canadian healthcare settings is 26%.[3] The prevalence for pressure ulcers in adults with spinal cord injury (SCI) has been reported to be up to 66%.[4]

Preventative programs have been developed to mitigate the development of seated acquired pressure ulcers, including regular skin checks, pressure offloading and proper seating assessment and prescription. Guidelines for pressure ulcer prevention include engaging in pressure relief every 15–30 minutes for a period of 30–120 seconds.[5] Pressure offloading over the weight-bearing surfaces has focused on spatial and temporal redistribution of pressure.[6] However, there is inconsistency regarding the frequency and method of repositioning[7] for the prevention of seated acquired pressure ulcers. It has also been recommended that pressure relief frequency, length and type be customized for each individual with spinal cord injury using pressure mapping.[5] Despite recommendations for pressure relief, patient adherence is low.[8]

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There are multiple methods to engage in pressure relief for the individual with SCI. Depending on motor impairments, individuals who spend prolonged periods sitting in a wheelchair can engage in pressure relief through a push up, side lean, and forward lean. Furthermore, pressure offloading can occur under the ischial tuberosity during forward and cross body reaches with the greatest pressure offloading on the contralateral tuberosity of the reaching arm.[9,10] Individuals with SCI who lack adequate trunk or upper extremity function may be unable to engage in frequent offloading due to impaired neural control of the trunk and upper extremity muscles, reduced trunk and upper extremity strength and reduced sensory input[11] and therefore may rely on wheelchair tilts or recline to engage in pressure offloading which have been found to be effective in reducing interface pressures over the ischial tuberosity.[9,12]

Pressure relief in individuals with SCI can be captured through several technologies including time loggers,[13] interface mapping technologies,[14] and flexible pressure monitoring systems.[15,16] Furthermore, there are several interventional strategies used to promote pressure relief including educational tools and pressure offloading reminding systems[6] to promote self-managed care. While trunk function is essential for engaging in daily activities including reaching and has been reported as a high priority for functional recovery in individuals with both tetraplegia and paraplegia,[17] individuals with SCI who are unable to engage in a functional reach, may also be unable to engage in effective ischial offloading.

The seated reach test, measured by trunk excursion during forward, backward and lateral reaches has been found to be highly reliable ($r \geq 0.71$) in individuals with motor incomplete SCI and also related to seated centre of pressure excursion.[18] The seated reach test has been used as a surrogate measure of trunk function when sophisticated electromyography (EMG), kinematic and kinetic data are not available to determine trunk control ability for offloading in individuals with SCI. The purpose of this study was to measure temporal pressure offloading and to explore the relationship between trunk function and pressure offloading in individuals with traumatic and non-traumatic SCI. We used the seated reach test and trunk strength as indices of trunk function. Participants were classified by their ability to engage in the reaching task without losing their balance as "Reachers". Those participants who were unable to engage in the reaching task and demonstrated a protective mechanism (i.e. moving their arm) to prevent them from losing their balance or demonstrated a loss of balance were defined as "Non-Reachers". We hypothesized that in individuals with SCI, reaching ability and trunk strength would correlate with pressure offloading of the ischial tuberosities.

Methods

Participants with Spinal Cord Injury

Twenty non-ambulatory participants with complete or incomplete traumatic and non-traumatic SCI, American Spinal Injury Association Impairment Scale (AIS), classification A-D were recruited for the study by convenience sampling. Eligible participants were approached by a central recruiter at the sub-acute rehabilitation hospital where they were receiving inpatient rehabilitation at which time they were advised of the nature, purpose, risks and benefits of the study. Participants who were medically stable, participating in in-patient rehabilitation and using a wheelchair as their primary means of mobility for at least two hours per day were eligible to participate. Participants were excluded from the study if they presented with an existing pressure ulcer, significant musculoskeletal conditions (e.g. inflammatory arthritis), impaired neurological status affecting their sitting balance due to conditions other than SCI (e.g. Parkinson's disease), or documented brain injury impacting their ability to follow instructions. All participants provided informed consent to participate in the study, which was approved by the hospital Institutional Review Board.

Evaluation of Trunk Function

Trunk strength

Trunk strength testing was conducted as per the method reported by Larson *et al.*[19] Testing was done by an experienced physical therapist (SG) with training and expertise in muscle strength testing in individuals with SCI. A hand-held dynamometer (MicroFet, Hoggan Health, Salt Lake City, UT, USA) was used to assess isometric trunk strength in the forward flexion, extension and lateral flexion directions in random order. The lever arm was determined from the point of resistance to the iliac crest (for flexion and extension strength) or the greater trochanter (for lateral flexion strength). The participant was instructed to push "as much as you can" into the dynamometer and hold this position for five seconds in order to obtain a maximum voluntary isometric contraction. The peak force was recorded in newtons (N) for three contractions and the mean of three peak force measures was multiplied by the lever arm to convert the value into newton meters (Nm).

Multidirectional Reach Test (MDRT)

Multidirectional reach testing was conducted according to the method as described in Gabison *et al.*[20] Participants were asked to remain in the same seated position as during the trunk strength testing. Participants were asked to reach in one of six different directions (forward, back, left, right, forward right, forward left) in random order, towards a target situated at the level of their acromion, with their opposite hand across their chest. Participants were instructed to reach using their preferred arm as far towards the target without losing their balance. A passive marker was placed over the T1 vertebrae, and the vertical and horizontal displacements were recorded using a telemetric laser distance meter (Fluke 411D, Fluke Corporation, Everett, WA, USA). The resultant displacement was calculated using the Pythagoras theory. Participants were monitored during this task to prevent them from falling or losing their balance. Participants were required to demonstrate the ability to reach in all six directions to be classified as "Reachers". Participants who were unable to engage in reaching in all six directions were classified as "Non-Reachers".

Evaluation of pressure offloading during sitting

A pressure mat, "SensiMAT™" (SensiMAT Systems, Woodbridge, Ontario, Canada) with six (43.7 mm by 43.7 mm, 0.55 mm thick) standard force sensors (actuation force 0.1 N, force sensitivity 0.1–10.0[2] N) was placed under the participants' wheelchair cushions. To ensure that the SensiMAT™ would capture offloading behavior under the wheelchair cushion, we ensured that the size of the SensiMAT™ corresponded to the same size of the wheelchair cushion for each individual, in order to make certain that the pressure sensors were within the participant's weight bearing area. The SensiMAT™ sampled offloading from each of the six sensors at a sampling rate of 1 Hz. Analog signals were collected using an iPhone via Bluetooth link, and subsequently transferred to a secure server via Wi-Fi (Fig. 1). Analog signals were processed with MATLAB Version R2013a (MATLAB, Mathworks, Natikc, MA, USA) to capture pressure offloading duration. Offloading behaviour was characterized when the pressure sensors registered a force equivalent in value to that when no pressure was applied for a minimum of at least 2 seconds (s). The feasibility of capturing offloading behavior using the SensiMAT™ was pilot tested on 10 individuals without SCI, and one individual with SCI prior to the study to ensure that the characterization of offloading could be described as demonstrated in Figure 1.

Participants were instructed to engage in their usual activities over a two-hour period while sitting during the time that pressure offloading behavior was collected. Activity logs were completed by each participant to capture the activities they participated in for the duration of the data collection period. Activity logs were used to detect the duration of prolonged offloading, which occurred when the participants were not in their wheelchairs (i.e. during transfers). SensiMAT™ data were compared with activity logs to confirm offloading activities that should not be included in the sitting analysis. Due to the participants' differences in sitting durations, cumulative pressure offloading time data were converted to seconds per hour (s/hour).

Testing for trunk function and pressure offloading were conducted on two separate days.

Data Analysis

SPSS Version 23 (SPSS, IBM Corp, Armonk, NY, USA) was used for data analysis. An Analysis of Variance (ANOVA) was conducted to compare demographic data between the Reachers and Non-Reachers. χ^2 analysis was conducted to determine if AIS classifications were significantly different between Reachers and Non-Reachers. The Shapiro Wilk test was used to assess for normalcy for trunk strength measures and offloading durations. Since the data was not normally distributed, the Mann-Whitney *U* Test was used to determine significance between the Reachers and Non-Reachers with respect to trunk strength and pressure offloading times. Spearman's Rank Correlation Coefficients were computed to determine if there were associations between trunk strength and pressure offloading times. Correlation coefficients were interpreted according to the following criteria: $\kappa = 0.21–0.40$ representing fair correlation, $\kappa = 0.41–0.60$ representing moderate correlation, $\kappa = 0.61–0.80$ representing good correlation, and $\kappa > 0.81$ representing very good correlation.[21]

Participants with missing data were excluded in the full analysis.

Results

Of the 20 participants who were recruited for the study, one participant dropped out due to the required time commitment for the study. Two participants were deemed as ineligible to participate in the study due to their progression to an ambulatory status following recruitment into the study. Seventeen participants had trunk strength entered for analysis. SensiMAT™ data was lost from two participants due to technical difficulties. As such, data from 15 participants were entered into the full analysis.

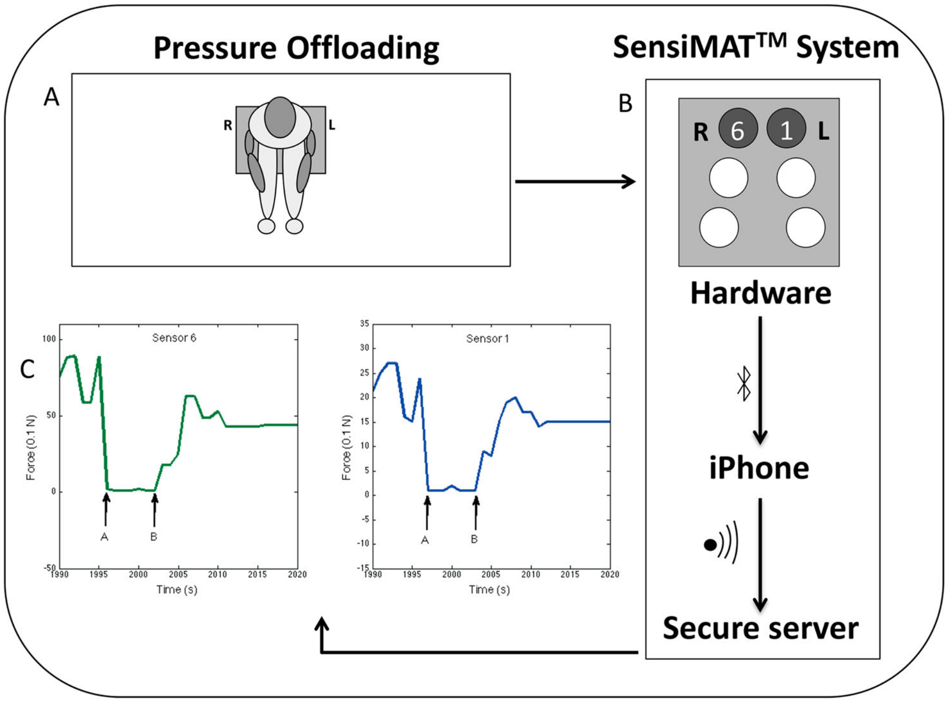

Figure 1. Total seconds of offloading time over the right (R) and left (L) ischial tuberosities were captured using a pressure mat, "SensiMAT™". The participant sat on the SensiMAT™ in their wheelchair during their usual daily activities (A). Data from the rear two sensors (sensors 6 and 1, denoted by black circles), located under the R and L ischial tuberosities were captured via Bluetooth technology onto an iPhone and then uploaded onto a secure server for data processing (B). MATLAB was used to extract offloading durations in seconds (C) (time between arrows A and B)

Participants' demographics and clinical status

Table 1 presents the demographic and clinical characteristics of the Reachers and Non-Reachers. All participants were right hand dominant. Six individuals were manual wheelchair users in the Reachers group whereas seven individuals were manual wheelchair users in the Non-Reachers group. Statistical analysis revealed that Reachers and Non-Reachers were similar with respect to age, height and weight. AIS classifications were not significantly different between Reachers and Non-Reachers.

Trunk strength

Figure 2 presents the trunk strength results for the Reachers and Non-Reachers. Left sided trunk flexion strength was highest in both the Reachers and Non-Reachers. Right sided trunk strength was lowest in both the Reachers and Non-Reachers. Between group comparisons revealed that trunk strength was higher in Reachers when compared with Non-Reachers. The Mann-Whitney U test demonstrated that significant differences existed between Reachers and Non-Reachers for all trunk strength measures ($P < 0.05$).

Pressure offloading

Figure 3 presents the pressure offloading results for the Reachers and Non-Reachers. In general, Reachers spent more time offloading over the left and right ischial tuberosities than Non-Reachers (94.40 s/hour and 34.35 s/hour vs. 18.25 s/hour and 6.85 s/hour respectively). However, significant differences existed between the Reachers and Non-Reachers for offloading only for the right ischial tuberosity ($P = 0.029$). While offloading for the left ischial tuberosity was lower in Non-Reachers than Reachers, the results did not reach significance ($P = 0.232$).

Relationship between trunk strength and pressure offloading

There were no significant correlations found between isometric trunk strength (flexion, extension, and lateral flexion) and pressure offloading duration of the right and left ischial tuberosities (Spearman's Rank Correlation: 0.083–0.434, P = 0.134–0.769).

Discussion

This study demonstrated that ischial offloading could be assessed in individuals with SCI using SensiMAT™ technology in a paradigm when individuals with SCI were performing normal daily activities. Although

Table 1 Participant Characteristics (n=17)

Demographics					Clinical Status			
ID	Age (yrs)	Sex	Height (cm)	Weight (kg)	AIS Score	Injury Level	T/NT	WC
Reachers								
17	39	M	152	104.5	A	C7	Traumatic	EL
2	48	F	172	77.0	A	T11	Traumatic	MA
3	52	M	174	74.0	A	L3	Non-traumatic	MA
6	21	M	182	72.7	B	T10	Traumatic	MA
15	53	M	180	82.0	B	T10	Traumatic	MA
9	16	F	165	47.6	B	T12	Traumatic	MA
14	65	M	175	84.5	D	C5	Non-traumatic	EL
16	78	F	157	68.0	D	C6	Non-traumatic	MA
Mean	46.5	-	169	76.3	-	-	-	-
SD	20.9	-	10.7	16.1	-	-	-	-
Non-Reachers								
4	53	M	172	68.2	A	C4	Traumatic	EL
12	35	M	170	68.2	A	T3	Traumatic	MA
1	36	M	175	74.0	A	T4	Traumatic	MA
8	25	M	176	54.5	A	T4	Traumatic	MA
5	25	M	173	70.0	A	T9	Traumatic	MA
10	32	M	180	98.2	A	T10	Traumatic	MA
7	44	M	173	80.0	B	C4	Traumatic	EL
11	50	M	170	77.3	B	C4	Traumatic	EL
18	60	M	175	65.9	C	T11	Non-traumatic	MA
Mean	40.0	-	173.7	72.9	-	-	-	-
SD	12.4	-	3.1	16.1	-	-	-	-
Grand Mean	43	-	171.8	70.4	-	-	-	-
SD	16.7	-	7.7	22.0	-	-	-	-

*F=Female, M=Male, T=Traumatic, NT=Non-Traumatic, WC = Wheelchair, MA=Manual, EL=Electric

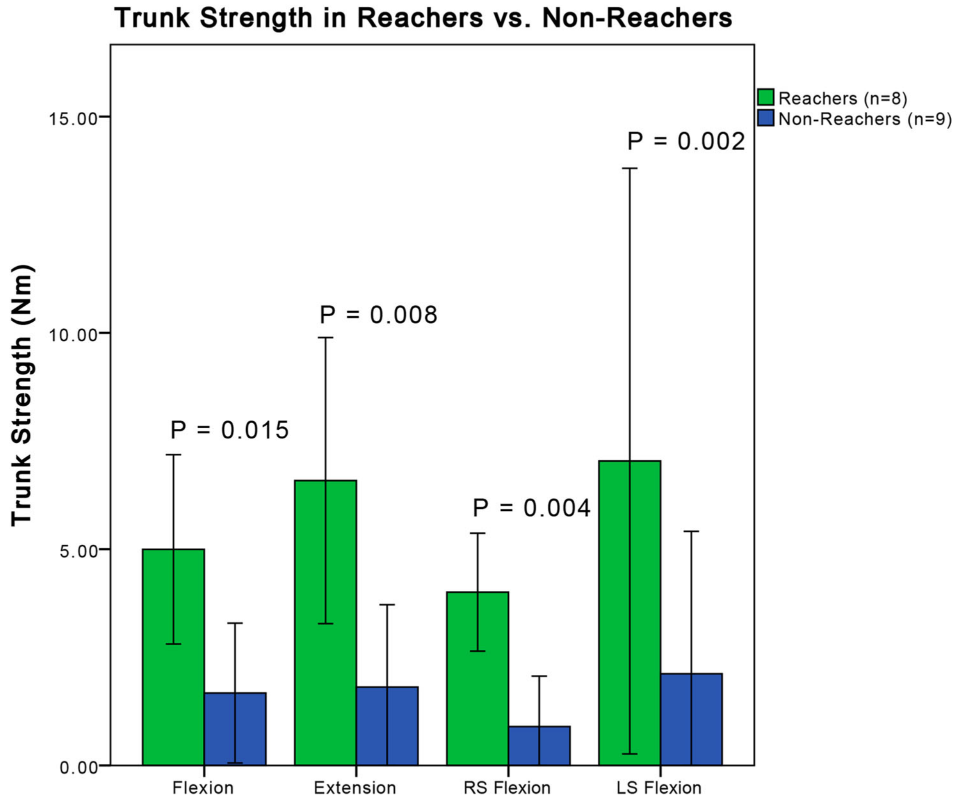

Figure 2. Mean isometric trunk strength (expressed as Nm) with 95% Confidence Intervals for Reachers (n=8) and Non-Reachers (n=9). Non-Reachers demonstrated significantly lower trunk strength for all directions ($P < 0.05$). Trunk extension strength was the highest in the Reachers whereas trunk LS Flexion strength was highest in the Non-Reachers (RS=Right Side, LS=Left Side)

data were collected over a two-hour period, no participants developed a pressure ulcer during this period or the course of the study, despite the fact that offloading frequency and duration were less than best practice recommendations[5] suggesting that pressure relief may not be the only contributing factor in the maintenance of tissue health. Other factors need to be monitored longitudinally.

Trunk strength was significantly lower in Non-Reachers compared with Reachers. Individuals with SCI, who were unable to engage in a reaching task, had significantly lower trunk strength in all directions. In earlier work we demonstrated that trunk strength was significantly lower in wheelchair users compared to walkers in individuals with SCI,[20] however, trunk strength was not characterized in wheelchair users in relationship to reaching ability. Given that trunk muscle activation is required to maintain trunk stability during perturbed sitting,[22] it is likely that reduced trunk muscle strength may preclude an individual's ability to reach and generate reactive compensatory balance strategies through the activation of trunk muscles, which are required when the centre of mass is displaced beyond the base of support. This study adds to the current literature by characterizing trunk strength in wheelchair users, however additional studies using EMG may help shed light on the required generation of muscle forces and synergies to maintain upright stability in wheelchair users with varying reaching abilities and the relationship to offloading behaviours.

Because the ability to reach while sitting and maintain upright stability involves synergistic trunk muscle activity, individuals with SCI who present with sensorimotor impairments of the upper and lower extremities and trunk muscles, which are dependent on both the injury level and completeness of the injury,[23,24] will use different offloading strategies. Furthermore, individuals with traumatic SCI demonstrate lower functional independent measures scores than those with non-traumatic SCI, suggesting greater disability in individuals with traumatic SCI.[24,25] Shin *et al.*[26] demonstrated that individuals with high traumatic SCI (T10 and above) exhibited smaller "functional" boundaries in sitting compared with individuals with low SCI (T11-L4), suggesting that there may be varying degrees of reaching ability depending on injury level. In addition, Chen *et al.*[27] found that individuals with low thoracic SCI demonstrated greater dynamic seated stability than those individual with a

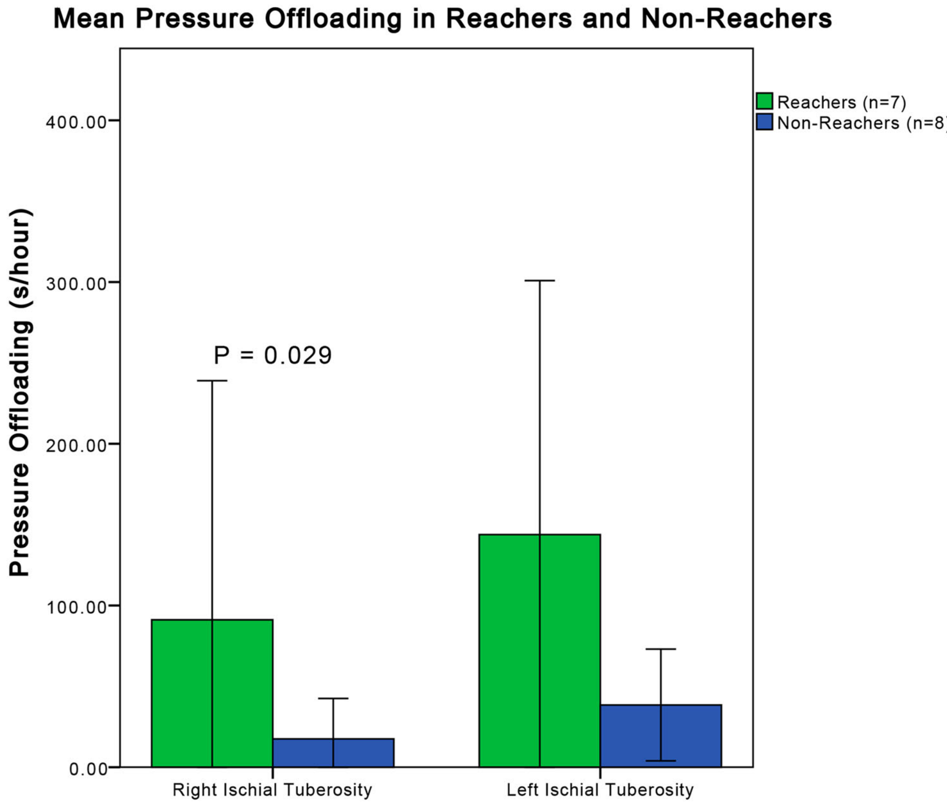

Figure 3. Mean offloading times (expressed as s/hour) with 95% Confidence Intervals for Reachers (n=7) and Non-Reachers (n=8). The right ischial tuberosity was offloaded less than the left ischial tuberosity in both Reachers and Non-Reachers. Non-Reachers spent less time offloading the right and left ischial tuberosities compared with Reachers however the results were significant only for the right ischial tuberosity ($P < 0.05$)

high-level thoracic SCI. Earlier Seelan *et al.*,[11] had noted that individuals with high thoracic injury tend to rely on their latissiumus dorsi, lower fibres of trapezius, pectoralis major, and serratus anterior and high thoracic parts of their erector spinae, while able bodied individuals rely more on their erector spinae for seated stability, also suggesting that trunk muscle activation depends on level of injury. Based on the work of Shin *et al.*,[26] we decided to use T10 as the threshold as we expected this level would be a neurological level of injury that might explain some of the variance.

Due to our sample size we could not use injury level, AIS impairment scale nor etiology of SCI as variables to account for reaching ability. When considering seated stability and injury level, four of the eight Reachers in our study had injury levels at or below T10, whereas only two of nine participants in the Non-Reachers group had an injury at the level of T10 or lower. Three Reachers had a non-traumatic SCI, whereas only one of the Non-Reachers sustained a non-traumatic SCI. Participant ID18 was unable to engage in a reaching task despite an incomplete non-traumatic injury at the level of T11 and two of the participants (ID14 and ID16) were able to engage in a reaching task despite incomplete Non-Traumatic injuries at C5 and C6, suggesting that while an injury level of T10 may characterize those who can perform a reach vs. those who are unable to, the completeness and nature of the injury must be considered in the context of injury level. These differences in the etiology of SCI (i.e. traumatic and non-traumatic SCI) and time course of pathology could not be factored into our analysis due to our limited sample size. Furthermore, data on participants were collected post SCI, hence their pre-injury reaching profile was not assessed which could influence their post-injury reaching status. Ideally, a larger sample would have enabled us to stratify participants by injury level and etiology, and would have allowed us to explore further the relationship between injury level, etiology, reaching ability and offloading behavior.

We did however stratify the participants into two groups based on their reaching ability as we expected that individuals who would be unable to engage in a reaching task would also present with reduced pressure offloading times in comparison to those who could engage in reaching tasks. Interestingly participants in this study engaged in pressure offloading over their left ischial tuberosity approximately 50% longer than their right ischial tuberosity. Although Reachers spent more time offloading compared to Non-Reachers, the results showed significance only for the right side. All participants were right hand dominant, suggesting that reaching dominance might play a role in offloading. Our findings are in agreement with Grangeon *et al*.[28] who suggested that individuals with SCI may prefer to reach with their dominant limb, and while reaching, use their non-dominant limb for support. Consequently, individuals with SCI may prefer to reach towards their dominant side when engaging in daily activities,[9] thereby offloading their non-dominant side making it plausible that non-dominant limb support also relates to side offloading. Offloading the right ischial tuberosity would have required participants to reach towards their non-dominant (left) side, obviously a more difficult task for non-Reachers as they were unable to reach without losing their balance. We recommend further studies using a larger sample size to determine if and how the ability to engage and dominance in reaching tasks has an effect on offloading times for both the left and right ischial tuberosities.

In previous work we demonstrated a relationship between right-sided trunk strength and left reach distance,[20] however pressure offloading was not assessed during the reaching task. Cabanas-Valdes *et al*.[29] have demonstrated that trunk training exercises improve both trunk performance and dynamic sitting balance in individuals post stroke. However, in SCI, where trunk strength is usually reduced bilaterally, particularly for those with complete injuries, the bilateral reduced trunk strength may preclude an individual's ability to reach and offload the ischial tuberosity when sitting, while attempting to maintain functional sitting balance. Our data suggest that the greatest variability of trunk strength occurred with left side flexion in both Reachers and Non-Reachers as indicated by the largest confidence intervals. At present, we are unable to explain these findings and suggest that future studies examine potential contributors of both trunk strength and hand dominance. Understanding the interrelationships might elucidate whether there is a need to target rehabilitation programs that address functional reaching for specific individuals who may be unable to engage in pressure offloading as suggested by Chen *et al*.[27] Given that we could not demonstrate that trunk strength was correlated with offloading times, further studies, with a larger sample using specific thoracic levels and degrees of completeness of injury may be required to explore if and how trunk stability, reaching ability and pressure offloading behaviours are related. Furthermore, examining the trunk musculature during various pressure offloading paradigms i.e. forward or side leans as well as reaching alone, may shed light on the influence on offloading behaviors during different functional activities.

As our study did not examine the trajectories of either trunk or arm movement during pressure offloading while participants engaged in their daily activities, we are unable to determine the method of offloading that participants used to engage in pressure relief. Additionally, we did not consider upper limb function, which could potentially influence offloading behavior. Three of the Reachers and one Non-Reacher simultaneously offloaded both ischial tuberosities, which could be achieved by a forward lean or vertical lift. Future studies in carefully designed cohorts of individuals with SCI should capture video monitoring or kinematics of the trunk and upper extremities, and motor scores of the upper extremities to characterize the relationship between trunk kinematics, arm kinematics and strength, and pressure offloading in the laboratory setting and during various functional daily activities.

We defined full offloading as pressure relief. However, the offloading process can be broken down into three distinct phases: offloading (where the tissue is offloading), offloaded (the tissue is completely offloaded) and reloading (the tissue is reloaded as the individual returns to the loaded condition). It is documented that seated functional movements facilitate the redistribution of pressure and increase circulation to weight bearing surfaces[30] suggesting that during the offloading process, ischemic tissues are reperfused. Further studies should examine if partial offloading is significant between Reachers and non-Reachers.

Recently Tederko *et al*.[31] demonstrated that increased wheelchair footrest height increases pressure under the ischial tuberosity. As we did not account for footrest height during our study we do not know how it influences our findings. Future studies should examine if footrest height has an effect on the degree of our technological approach to monitor offloading.

Conclusions

Although the results of the study demonstrated that those who were able to reach, offloaded their right ischial tuberosity more than those who were unable to reach, there was not a significant correlation between isometric trunk strength and ischial offloading. If reaching is an important factor for offloading, assessing reaching abilities and the corresponding trunk muscle activation patterns becomes paramount before targeted rehabilitation strategies for offloading pressure can be designed. We have demonstrated that the SensiMAT™

technology is capable of tracking the pressures over the ischial tuberosities for prolonged periods of time and during different activities. The data acquired are a first step in establishing a baseline for patient specific customized training for pressure offloading during the course of their rehabilitation. The participants in our study did not develop pressure ulcers during the sub-acute rehabilitation phase even though we could not demonstrate adherence to best practice recommendations for pressure offloading. These findings are consistent with what has been reported in the literature suggesting other factors that contribute to pressure ulcer development should be explored during the rehabilitation phase.

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Disclaimer statements

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Conflict of Interest The authors report no conflicts of interest.

Short Title Ischial pressure offloading in spinal cord injury

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