ORIGINAL ARTICLE

Measuring the effect of incremental angles of wheelchair tilt on interface pressure among individuals with spinal cord injury

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Study design: This study was a repeated measures study.

Objectives: The objective was to systematically measure the relative reduction in interface pressure (IP) at the ischial tuberosities (IT) and sacrum through 10° increments of tilt in a manual wheelchair among individuals with motor complete spinal cord injury (SCI).

Setting: This study was carried out in Manitoba, Canada.

Methods: A total of 18 adults with ASIA A or B level of injury were recruited through an out-patient SCI clinic. Using a standardized protocol, participants were tilted in 10° increments between 0° and 50°, and IP readings were obtained at the IT and sacrum using pressure mapping technology. Relative pressure reduction from baseline was calculated and compared between tilt angles.

Results: Tilt angle had a highly significant effect on pressure reduction at the IT ($P=0.000$) and the cosine relationship between these variables was expressed as quadratic. Reduction in sacral pressure did not occur until 30° tilt, with increased loading at smaller tilt angles. Pressure reduction at the IT and sacrum was not significantly different for tetraplegic and paraplegic participants.

Conclusion: Small tilt angles are more suitable for postural control than pressure management. A minimum tilt of 30° is required to initiate unloading the sacrum and to achieve a clinically important reduction in pressure at the IT. Larger tilt angles resulted in more substantial pressure reduction than previously reported. Tilt-in-space appears to have similar benefits for individuals with paraplegia and tetraplegia.

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Introduction

Pressure ulcers are a significant and costly problem for individuals with a spinal cord injury (SCI), who use a wheelchair. Prolonged sitting, without intermittent weight-shifting and pressure relief, creates a high risk for ischemia.¹ Sensory and motor impairment can impede anticipation of pressure and independent performance of repositioning. Tilt-in-space (TIS) wheelchairs are used as one strategy to address the risk of pressure damage. With a TIS configuration, the entire seating system rotates backwards within the wheelchair frame, while keeping the seat-to-backrest angle fixed. By changing the orientation of the individual relative to gravity, the normal force between the seat cushion and buttocks is reduced. Reducing the intensity of pressure at the

human–seat interface is expected to extend the duration of time before ischemia occurs.² Tilting the wheelchair backwards allows the user to assume a more recumbent position, taking the pressure off of the buttocks.

While TIS wheelchairs are regularly employed to address issues of pressure redistribution, there are also other indications for their use. Research and clinical evidence suggest that TIS may address changes in body structure and function to enable outcomes, such as improved postural control and stability, comfort, pain relief, digestion and biomechanical efficiency of propulsion.^{3–5} However, TIS has also been reported to impede upper extremity function, elicit abnormal reflexes and limit accessibility.^{5,6} Wheelchairs configured for TIS are typically larger, heavier and more expensive than traditional wheelchairs.⁷ Furthermore, specific models of wheelchairs are required to achieve large angles of tilt. For example, over 15% of the funding-approved TIS wheelchairs in Ontario do not tilt to 30°; 40% do not tilt to 40° and 85% do not reach 50°. Given these accessibility, functional and

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economic implications, the effectiveness of these wheelchairs must be demonstrated in order to justify their prescription.

Currently, there is limited empirical evidence to inform clinicians about the relative benefit in interface pressure (IP) reduction obtained as tilt angle increases. Previous studies have employed small sample sizes and explored a few select angles of tilt, often in conjunction with other interventions such as recline. Hobson⁸ explored nine different combinations of sitting posture, tilt and recline, reporting an 11% reduction in peak IP at 20° of tilt. Vaisbuch *et al.*⁹ found a 22% reduction in peak pressure at the ischial tuberosities (IT) when children with paraplegia were tilted to 25°. Burns and Betz¹⁰ combined three different cushions in a horizontal and 45° tilt position, with the latter resulting in a 33% reduction in peak IP, whereas Henderson *et al.*¹¹ compared tilt at 35° and 65° and found 27% and 47% reductions, respectively. Comparisons between these results are challenging owing to differences in study design and measurement tools.

Intuitively, larger angles of tilt are expected to result in greater reduction of IP and should be more effective in addressing the risk of pressure ulcers. Clinicians often prescribe TIS wheelchairs and specific tilt angles based on clinical experience; additional empirical evidence would inform their professional reasoning. Therefore, the purpose of this study was to systematically measure the relative reduction in IP at the IT and sacrum through 10° increments of tilt in a manual wheelchair among individuals with motor complete SCI. Specific objectives included establishing the nature of the relationship between tilt angle and relative pressure reduction and identifying clinically significant differences between angles of tilt. In addition, we compared the effect of TIS between paraplegic and tetraplegic participants.

Materials and methods

Study design and participants

A repeated measures design was used, allowing each participant to act as his/her own control. Participants were exposed to a reference position (0° tilt, seat-to-backrest angle 100°), followed by five conditions of the TIS intervention (10° increments of tilt from 10°–50°). Differences in IP between tilt angles were compared within individuals. In all, 18 participants were recruited through the out-patient SCI clinic at a tertiary care rehabilitation hospital (see Table 1). To be included, participants must have been 18–65 years of

age, SCI (paraplegia or tetraplegia) at American Spinal Injury Association (ASIA) A or B level of completeness and not using a ventilator. Substantive scoliosis or fixed deformity that prevented central alignment in sitting was an exclusion factor. The study was approved through the University of Manitoba Health Research Ethics Board and all participants provided informed consent.

Instrumentation

The Force Sensitive Applications (FSA; VISTA Medical, Winnipeg, Manitoba, Canada) pressure mapping system was used to collect data on IP values between the buttocks and seat surface. The FSA consists of 256 individual pressure sensors (each 2.4 cm²) configured in a 16 by 16 array. The FSA has demonstrated strong reliability and validity as a measure of IP, and integrates software to compensate for creep and hysteresis error.¹² The FSA was calibrated to 300 mm Hg by the manufacturer before data collection. IP was measured in mm Hg, and values obtained from each sensor were transcribed into an Excel spreadsheet for analysis. The location of the ITs and sacrum for each participant were identified by finding the peak values and were confirmed through visual inspection of the pressure map. Single sensor peak pressure values show poor repeatability and high within-session variation, and are therefore unstable measures.¹³ Consequently, peak pressure index (PPI) was used as the primary measure. PPI is the average value of four adjacent sensors covering a 9–10 cm² area; the highest PPI under the sacrum and each IT was used. PPI provides greater stability in measurement over single-sensor maximum values. Furthermore, it demonstrates good reliability for within and between sessions and has been recommended for inclusion in ISO standards.¹³

A Quickie Iris (Sunrise Medical, Longmont, CO, USA) TIS wheelchair was selected for use in this study, because it provided a large range of tilt angle compared with other commercially available products. The rocker mechanism for tilting provided discrete increments of tilt, allowing consistent tilt position between participants. A Jay2 (Sunrise Medical) seat cushion was used, as it provides acceptable pressure redistribution and does not require individual adjustment between study participants.

Procedure

A protocol, based on a review of the literature and pilot study, was developed to standardize positioning in the wheelchair. Consistent with other related studies,^{8,14} the seat-to-back angle was fixed at 100° and participants sat as far back as possible in the TIS wheelchair, with their hands on their lap, and the footrests were adjusted to ensure that the femurs were parallel to the floor. A six minute settling period was enforced to allow for creep in the buttocks and cushion, as recommended in the literature.¹⁵ The participant was asked to sit as motionless as possible and a pressure reading was obtained over a 10 s period at the 6-min mark. The wheelchair was then tilted back 10° and another pressure reading was taken after a 1-min settling period. This process was repeated up to, and including, the maximum tilt of 50°.

Table 1 Participant demographics (mean ± s.d., if applicable)

	All	Tetraplegic	Paraplegic
N	18	10	8
Male	17	9	8
Age (years)	42.6 (8.3)	44.9 (8.5)	41.9 (5.5)
Years post-injury	18.2 (8.3)	19.0 (9.7)	17.3 (6.7)
Weight (kg)	74.7 (12.7)	78.4 (10.2)	68.5 (14.9) ^a
BMI	24.1 (3.7)	25.2 (2.3)	22.3 (5.1) ^a

Abbreviation: BMI, body mass index.

^aWeight and BMI for two paraplegic participants were not obtainable.

Tilt positions were marked on the wheelchair rocker mechanism for verification and confirmed with an inclinometer. The FSA was sampled at four frames per s, providing 40 data points for each tilt angle.

Data analysis

Differences in mean and relative reduction IP values for the left and right IT were compared by paired *t*-tests. Total and relative pressure reductions for right IT, left IT and sacral positions in response to increasing tilt angle were analyzed by a repeated measures analysis of variance. Linear and quadratic within-subjects contrasts were computed if the repeated measures factor (angle) was statistically significant to determine the nature of the relationship. Differences between tetraplegic and paraplegic participants in mean IP scores for each tilt angle were compared by the independent group's *t*-test. A *P*-value <0.05 was set for statistical significance in all analyses and the data was analyzed by SPSS, version 13.0 (SPSS Inc., Chicago, IL, USA).

Results

Pressure on ITs

When mean IP (mm Hg) for the left and right IT at each tilt angle was compared, values on the right were somewhat higher but there was no statistically significant difference between the two sides. Likewise, there were no statistically significant left-right differences for relative pressure reduction from baseline for each tilt angle.

Figures 1 and 2 show the relationship between total and relative pressure reduction as tilt angle increases. The theoretical predictive values, based on the cosine of the tilt angle, are provided for reference. The repeated measures analysis of variance indicated that tilt angle had a highly significant effect on pressure reduction for both right IT ($F(4,17)=165.1$, $P=0.000$) and left IT ($F(4,17)=202.7$, $P=0.000$). The cosine relationship between these variables was expressed as a quadratic relationship (right: $P=0.001$; left: $P=0.000$), with each successive tilt producing a larger relative reduction. The statistical curve fit showed cubic and order 4 higher order terms to be non-significant. Tilt at 10° did not result in a significant reduction in IP (right: $P=0.492$; left: $P=0.054$) whereas 20° of tilt showed a modestly significant change (right: $P=0.034$; left: $P=0.001$). All remaining angles demonstrated a highly significant change from baseline ($P=0.000$).

Participants were also considered separately as tetraplegic and paraplegic groups. The two groups were not significantly different based on the demographic variables of age ($P=0.395$), years since injury ($P=0.672$), weight ($P=0.136$) or body mass index ($P=0.146$). There was no statistically significant difference in mean IP at baseline between groups for the right IT (tetraplegic (T): 131.4 ± 11.2 ; paraplegic (P): 129.5 ± 25.2 , $P=0.899$) or the left IT (T: 124.8 ± 26.3 ; P: 110.3 ± 49.4 , $P=0.404$). The tetraplegic group demonstrated a slightly larger relative reduction in pressure at each tilt angle, but the difference between the two groups was not significant.

Figure 1 Total pressure reduction with increasing tilt angle.

Figure 2 Relative pressure reduction with each incremental tilt.

Table 2 Comparison of mean IP values for tetraplegic and paraplegic groups at the sacrum

Tilt angle	Mean IP (± s.d.)	P-value
0°	T 125.2 (53.3) P 76.4 (30.8)	0.036 ^a
10°	T 127.0 (51.6) P 80.0 (26.1)	0.025 ^a
20°	T 117.2 (50.0) P 77.6 (29.9)	0.067
30°	T 102.3 (40.8) P 65.3 (25.6)	0.044 ^a
40°	T 72.9 (35.7) P 51.3 (23.9)	0.169
50°	T 37.4 (23.9) P 34.0 (12.6)	0.725

Abbreviations: IP, interface pressure; P, paraplegic; T, tetraplegic.

^aStatistically significant.

Pressure on sacrum

The results of the repeated measures analysis of variance indicated that the mean sacral IP did not change significantly from baseline at tilt angles of 10° or 20°. However, there was significant reduction in sacral pressure from baseline at tilt angles of 30° ($P=0.002$), 40° ($P=0.000$) and 50° ($P=0.000$). The comparison of mean sacral IP values for the tetraplegic and paraplegic groups (Table 2) showed that pressure scores were significantly higher for the T group at 0°, 10° and 30° tilt, with a trend toward significance at 20°.

As well, the tetraplegic group evidenced a slightly larger reduction in IP across angles, but this did not reach statistical significance ($P = 0.246$).

Discussion

A key finding of this study is the quadratic relationship between wheelchair tilt angle and pressure reduction at the pelvis among individuals with SCI. As might be expected, progressive tilt angle resulted in lower pressure at the weight-bearing prominences of the pelvis; however, the outcome of each successive increment of tilt was significantly beneficial in reducing pressure. The primary loading surfaces of the pelvis are the ITs and sacrum, and present the highest risk for pressure ulcer development. The left and right ITs were comparable in terms of mean IP and pattern of pressure redistribution. Smaller tilt angles had limited value in addressing pressure. The outcome of initial tilt to 10° was largely inconsequential, with $<5\%$ reduction. In fact, this adjustment appears to have loaded the sacrum, which may be a result of a posterior shift in the center of mass during rotation of the wheelchair around its axis. While tilt to 20° resulted in a statistically significant change in pressure from baseline, the effect size is around 0.5 and the clinical value of $<15\%$ pressure reduction would be limited at best. These results are consistent with previous studies that considered small tilt angles.^{8,9,16} These small tilt angles seem best suited for improving function, such as wheelchair propulsion¹⁷ or increasing stability and reducing postural demands.¹⁴ In the current study, no pressure reduction occurred at the sacrum during the smaller tilt angles of 10° and 20° .

Our study results indicate that a tilt angle of at least 30° is required to produce a clinically valuable reduction in pressure. This threshold has been suggested elsewhere in the literature.^{4,18} However, at larger angles of tilt, our results indicate a more substantive benefit than previously reported.^{10,11,19} Several reasons may exist for these differences. The current study used the most up-to-date pressure mapping hardware and software, which has been substantially improved to accommodate for error such as hysteresis and creep. The current study also employed PPI as the outcome measure, rather than maximum (peak) pressure. Although PPI results in a lower IP value than maximum pressure, it provides a more stable measure and is less susceptible to error. It is also important to note that each 10° increment of tilt had a substantially greater impact on the overall pressure reduction. For example, the benefit from tilting $20\text{--}30^\circ$ is $\sim 15\%$ IP reduction, $30\text{--}40^\circ$ around 20% reduction and $40\text{--}50^\circ$ results in nearly 25% additional change. Clinically, this would suggest that any opportunity to achieve additional tilt has substantive benefits for pressure reduction. Practically speaking, many TIS wheelchairs do not have the capacity to achieve 40° or 50° of tilt. These large tilt angles require a longer wheelbase to achieve stability, which can impact accessibility. Alternatively, a rocker-style articulating mechanism can be used to achieve tilt, but it may also increase purchase cost. Recognizing that pressure redistribution is one of several outcomes that must be

considered when prescribing a wheelchair, clinicians should consider products that have a large tilt angle capacity where feasible. Prescribing TIS for pressure management would be most applicable to individuals with tetraplegia, given that limitations in trunk and upper extremity motor function typically restrict independent repositioning; however, some paraplegics with weakness or pain due to repetitive injury might also be good candidates.

Within the study sample, the impact of tilt angle was comparable between individuals with tetraplegia and paraplegia. No significant difference was identified in either raw IP values or relative pressure reduction at the ITs. The tetraplegic group generally had higher sacral pressures at the smaller angles of tilt. This was likely due to increased posterior pelvic tilt resulting from greater impairment of motor control in the trunk with higher-level injury. Despite higher IP values, the rate of pressure reduction at the sacrum remained consistent between these groups. Future studies should consider physiological measures such as blood flow and tissue oxygenation to determine the degree to which they accompany these relative pressure reduction results.

The use of a preconfigured seating system in the study wheelchair provided a consistency between participants; however, individual adjustments were limited and the use of participants' own seating products would have better reflected the true effects of tilt. Randomizing the application of tilt angle and obtaining multiple measures for test-retest reliability would have been optimal; however, limitations in sitting tolerance and the potential for changes in pelvic positioning posed challenges to this approach. Most participants in the study were males and this should be considered when generalizing the results.

This study confirms that small tilt angles may support posture and positioning, but tilt of 30° or more is required to significantly impact pressure redistribution. Furthermore, increasing TIS angle provides substantially greater pressure reduction at the pelvis and the benefit at large tilt angles is greater than previously thought.

Conflict of interest

The authors declare no conflict of interest.

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