

Pressure Distribution Comparison among Standard Seating Surfaces and Strap Seating System

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Abstract

Aims: Pressure injuries (PIs) are common issues that can be minimized through the use of pressure-redistributing support surfaces. Cushions that provide immersion and contour are considered the most effective for pressure relief; however, others are readily available on the market. The aim of this study is to determine how a wheelchair equipped with Comfort Tension Seating®(CTS) compares to standard sling seating, foam, and a high-end pressure redistributing contoured cushion.

Materials and Methods: Pressure redistribution qualities as measured through peak pressure index (PPI) using pressure mapping technology were gathered on four different seating surfaces -standard sling seat, CTS, and two cushion types flat cross-section foam, contoured-cushion, and CTS. Twenty non-disabled participants trialed each cushion for five minutes each. The methods of this study are described and outcomes analyzed by comparing the PPI and comfort of the four cushions.

Results: A Wilcoxon signed-rank test, and related samples Friedman's two-way analysis of variance by ranks (ANOVA) was calculated. The results show that there is a significant difference between each of the cushions in comfort and pressure redistribution. There was a statistically significant difference in mean PPI between the three groups in which the CTS performed better than the sling and flat cross-section foam, but not quite as good as the high-end contoured cushion ($p < .001$).

Conclusion: While not as optimal as the contoured M2 foam cushion, the CTS seating surface appears to provide superior pressure-redistributing performance compared to sling and flat cross-section foam. This suggests that the CTS could be used as a support surface for many applications, except for individuals with high-level PI risk, without using tilt and recline features.

Keywords: pressure distribution, standard seating surfaces, strap seating system

1. Introduction

Pressure injuries (PIs) are defined as a localized injury to the skin and/or underlying tissue, usually over a bony prominence such as the ischial tuberosity, heels, sacrum, and trochanters in the body, caused by long periods of pressure or shearing forces. PIs are often associated with pain and vary among four stages of intensity. The stages range from tissue redness, partial tissue loss, full tissue loss, exposed bone and/or muscle, and unstageable depth due to the presence of slough (Porter-Armstrong et al., 2018). Patients with PIs have significant physical, social, and self-care dysfunction and may experience certain complications such as depression, pain, topical infection, osteomyelitis, sepsis, and even death (Borojeny et al., 2020).

PIs are the third most costly disease after cancers and cardiovascular disease, resulting in approximately 60,000 deaths annually (Borojeny et al., 2020). In the United States, the average cost of treating a stage four hospital-acquired pressure injury alone has been reported as 129,248 USD and a stage four community-acquired pressure injury as USD 124,327 (Porter-Armstrong et al., 2018).

Risk factors may include low physical activity, decreased consciousness, malnutrition, and aging, as well as diagnoses such as spinal cord injuries (SCI), multiple sclerosis (MS), cerebral palsy (CP), spina bifida (SB), and other conditions that may reduce movement/sensation. According to Hubli et al. (2021), it is estimated that

50-80% of individuals with SCI may develop a PI at least once in their lifetime. PIs can severely impact the performance of an individual in a rehabilitation facility, work, school attendance, and overall quality of life.

PIs are in most cases, treatable; however, long-term prevention requires client and caregiver education, dedication, and routine management, through a holistic process (Damiao, 2020). On a physical level, pressure redistribution can occur through the implementation of pressure-redistributing mattresses, cushions, and repositioning of the body. Repositioning movements can include lateral and forward leans and vertical push-ups to lift the buttocks from the wheelchair. As part of the rehabilitation process, the individual, family, and caregivers should be educated in PI risk factors, strategies, and skin care (Hubli et al., 2021). Since every individual is different, considerations for optimal repositioning such as levels of mobility, skin integrity, tissue tolerance, and comfort must be evaluated.

2. Literature Review

For the wheelchair user population, the ischial tuberosities (ITs) and sacrum (tailbone) are commonly vulnerable areas. The ITs are the sitting bones that come in contact with the surface area when a person is sitting upright, thus, resulting in frequent deep tissue injuries for those with limited mobility and those bound to one specific position, such as being seated in a wheelchair (Shabshin et al., 2010). As described above, the aging population is also at considerable risk for PIs. Older adults are at increased risk for the formation of PIs due to skin changes associated with aging, including thinning of the dermis and epidermis, resulting in decreased resistance to shear forces. Complications such as increased pain, infection, additional surgeries, and even death are heavily correlated with the geriatric population because of limited physical capabilities (Mondragon & Zito, 2021).

However, PIs are largely preventable with the use of appropriate support surfaces. Prevention management strategies include daily skin examination to enable early detection of problems, good skin hygiene, frequent postural change, and active support surfaces such as pressure cushions (Damiao, 2020). Additionally, cushions are prescribed to relieve, redistribute, and reduce pressure to prevent PIs, and can be a predominant factor in PI occurrence if these support surfaces lack immersion and/or contour (Damiao, 2020; Sprigle & Pubillones, 2020).

Preventative measures are addressed through moving the body, weight-shifting activities, and the use of dynamic surfaces that actively redistribute pressure on the body surfaces (Sonnenblum et al., 2020). Wheelchair cushion prescriptions are appropriate in pre-wound, wound, and post-wound phases (Damiao, 2020). Pressure mapping is a commonly available tool used clinically to help identify optimal support surfaces by measuring the mechanical interface load between the individual and a specific cushion. These pressure mats are often used to aid the prescription/evaluation process (Peko Cohen & Gefen, 2017).

Pressure redistributing wheelchair cushions vary by material and design. Air-cell-based (ACB) cushions are often considered the most effective, and use a rubber bladder-like structure to provide maximal immersion of the buttocks. The rubber material means that this type of cushion is durable against incontinence. Yet, ACB also has negative features such as precise inflation monitoring and risk for punctures. Over-inflation can decrease PI protection, while also decreasing postural stability. Similarly, under-inflation can also impact PI protection if the user 'bottom's-out', which is particularly risky for those with decreased sensation and/or communication capacities (Damiao, 2022).

Another material commonly used is viscoelastic fluid or gel, typically combined with a foam base. In this configuration, a gel pad is placed over a firm foam base contoured with a deep well to help keep the gel pad in place and protect the ischial tuberosities (ITs) and sacrum. Benefits from this type of cushion include pressure relief, cooling properties, and a good base of support. However, some flaws include added weight, and require precise sizing; as a mismatch between the user and the gel overlay can incorrectly cause a bottoming-out effect (Damiao, 2022).

There are also foam cushions made of polyurethane and viscoelastic (memory foam). While these are generally lightweight and inexpensive, they are most effective when designed with contours to match the user's contours. Foam is considered most effective at providing optimal postural support, particularly when custom-contoured shape capture is integrated into the design. Custom-contour cushioning provides individualized cushions to accommodate specific deformities and provide a more supportive foundation. Two types are off-loading cushions (OLC) and standard cushions. OLC are built to relieve pressure under the bony prominences for the buttocks, thighs, and/or back areas. Unlike OLC, the standard custom-contoured cushions are shaped to match the user as accurately as possible to provide a firm and stable support surface, while simultaneously providing an even pressure distribution across the contact surface area (Damiao, 2022).

The strap seating system utilizes Comfort Tension Seating®(CTS), a design characteristic of Broda wheelchairs, is based on multiple straps that individually conform to the user's body. The CTS design aspires to provide

positioning support and comfort by suspending weight evenly distributed via an array of straps (Broda, 2022). This technology is an outlier in the medical device equipment (DME) realm, and its effects toward providing pressure redistribution have gone uninvestigated in the literature. Thus, this study will evaluate how the CTS design compares to commonly used seating surfaces regarding pressure redistribution and comfort.

2. Methods

This study used a single cohort within-subjects research design. The study was conducted in accordance with approval from the Pace University Institutional Review Board. An informed consent form was provided to each subject prior to participation. This study was a double-blind experiment in which the subjects and the data gatherer were unaware of which seating surface/ cushion was being trailed at any given time.

2.1 Participants

Convenience sampling was used to conduct the present study by recruiting 20 non-disabled first-semester Pace University occupational therapy graduate students. Inclusion criteria consisted of each participant being within one standard deviation for the average height and weight of male and female adults over 18. Exclusion criteria excluded any individual with sensory impairment, previous history of extended wheelchair use and prior knowledge of cushion characteristics and expected outcomes.

2.2 Procedures

The participants sat on each cushion for 5 minutes, with a 5-minute break between each trial. Cushions consisted of a) a standard sling seat wheelchair, b) a standard chair with a 3inch foam insert, c) a moderately contoured 'pressure relieving' Comfort Company M2 foam cushion, and d) the Broda CTS wheelchair with a thin foam chair pad. In total, each subject participated for approximately 30 minutes. Participants were asked to sit relatively static with minimized movements on each cushion. After 5 minutes, the researcher recorded the pressure map readings. The participant was provided a 5-minute standing break prior to continuing onto the next cushion until all three seating surface/cushions were sat upon and data was collected. At the conclusion of each cushion trial, participants were asked to rate their level of comfort.

2.3 Measures

A pressure mapping system was used to record each cushion's peak pressure index (PPI), and a Likert Scale to measure the comfort level to determine which cushion had the most pressure distribution. PPI is an objective measure used to identify the highest-pressure values within the contact area on the pressure map (Crane et al., 2016).

2.4 Peak Pressure Index

In order to increase the validity of the pressure mapping system, researchers have used PPI to measure pressure distribution for sitting surfaces (Damiao, 2022). The mapping system uses a pressure sensor pad with 1024 sensors. However, individual sensors are limited to an accuracy of up to approximately 200 mmHg of pressure. Due to this, actual peak pressure experienced under bony prominences may not be accurately measured. Thus, researchers have commonly used a *peak pressure index (PPI)* to account for this inaccuracy. The PPI is measured by identifying the 'hot spot' and adding up all nine sensors with the highest pressure within that area. The mean of this pressure, measured in mmHg, creates the PPI (Damiao, 2022).

2.5 Comfort

Comfort is another crucial component related to wheelchair seating. Participants were asked to report any discomfort associated with the seat cushion, which ultimately indicates poor pressure redistribution or compliance with use (Tasker et al., 2014). Comfort levels were measured by participants reporting on a scale from 1 to 5; '1' being the 'low comfort', and '5' being 'high comfort'.

2.6 Data Collection Process

During this study, participants sat in a seated upright position on each of the four cushions. Their hips, knees, and ankles were measured using goniometers to ensure they were all flexed at 90 degrees to increase the consistency of weight distribution among all cushions. Each cushion was trialed for 5 minutes at a time with a 5-minute gap in between to give the participant a 'rest' period to allow the buttocks to return to the natural shape when unweighted. The pressure mapping sensor array was placed over the cushion, with the participant sitting directly on it. At the five minute mark, pressure readings were gathered by an investigator who identified the 'hot spot' of the highest pressures and recorded the data, without knowing which cushion was being trailed. That data was recorded onto a spreadsheet by an investigator who did know which cushion was being trailed so that the appropriate readings

could be accurately linked to the correct cushion. Lastly, the participant was asked to rate their level of comfort.

2.7 Analysis

Both PPI and comfort data were analyzed through descriptive and inferential statistics. A non-parametric Wilcoxon signed-rank test (due to small sample size), as well as a Freidman's two-way analysis of variance by ranks (ANOVA), were performed to determine if there was a statistically significant difference in the mean PPI of each seating surface compared to the CTS system. All analyses were calculated through SPSS, Version 28 (IBM, 2021).

3. Results

Descriptive statistics are shown in Table 1 to display the results of each cushion's average PPI. The lowest PPI average was the M2 cushion which had 107.24 (SD = 34.64), followed by the Broda/CTS system which had an average of 144.63 (SD= 41.54). This revealed that the M2 cushion and the Broda CTS had the best pressure redistribution among the seating surfaces.

Table 1. Descriptive and inferential statistical analysis of Broda/CTS compared to other cushions

IP parameters and statistical result at 5 min (n=20)

Original (mean±SD)				Relative (mean±SD)			Statistical results on relative data			
B	Sling	Foam	M2	Sling (relative to B)	Foam (relative to B)	M2 (relative to B)	df	Non-parametric (Wilcoxon)		
				Cushion	z	p				
PPI	144.63±41.54	168.65±40.03	162.65±48.02	107.24±34.64	24.02	18.02	-37.39 (1,20)	Broda-Sling	-3.32	<.001
								Broda-Foam	-3.22	0.001
								Broda-M2	-4.02	<.001

Note. B: Broda Comfort Tension Seating®(CTS); df: degree of freedom; PPI: Peak Pressure Index; Significance: p = .05.

Table 1 further highlights the comparison of each cushion's average PPI to the CTS. A Friedman's test was calculated, suggesting a significant difference in PPI among all four cushions ($p < .001$). Descriptive results and inferential results through the Wilcoxon signed-rank test suggest that there was a significant difference in PPI between the CTS system and the comparison cushions ($p < .001$), with the M2 demonstrating the highest level of pressure redistribution and the sling seating providing the worst performance. While the CTS underperformed compared to the M2 ($p < .001$); it was statistically significantly better than the sling ($p < .001$) and the foam ($p = .001$) surfaces. Similarly, the CTS and M2 cushions had the highest comfort results ($M = 3.3$, $M = 4.6$, respectively) when compared to the foam ($M = 3.1$) and sling surface ($M = 2.2$).

4. Discussion

This data provides evidence that while the CTS may not be the most effective surface-to-PI treatment or prevention when left in a 90-degree position without the tilt and recline features, it might provide moderate protection and comfort, particularly in comparison to commonly used alternatives such as a sling-seat and simple cross-section foam. As with any seating system, incorporating tilt and recline can significantly improve PI protection (Damiao, 2020).

The results suggest that the seating cushion design greatly influences the amount of pressure distribution on the buttocks and possibly other high-risk PI areas. It is unsurprising to discover that sling seating provides poor pressure redistribution; however, what was surprising from these results, was how poorly the cross-section foam performed, especially in comparison to the CTS system, consisting of a very thin foam overlay. This suggests that the CTS system, aside from the foam overlay, plays a significant role in providing immersion. When paired with the foam overlay, the CTS provides pressure redistribution significantly better than plain foam and sling surfaces in a system that can be universal to many users, unlike the highly contoured M2, which must be appropriately matched to the individual. Similar results were noted with comfort, as the participants rated the CTS on average

better than the foam and much more so than the sling seat.

The authors would like to emphasize that the inference and generalizability of these results are limited. Further research is indicated to provide all stakeholders with meaningful data to prevent pressure injuries, and improve comfort. PI prevention research is extremely limited when it comes to measuring actual PI incidence. As is most common, this type of research is typically conducted using proxy measures such as magnetic resonance imaging (MRI), finite element (FE) modeling, and pressure mapping, as was done in the present study (Damiao, 2020). This measure can be used to identify problem areas and/or optimal seating surfaces but cannot be reliably used as a PI prediction or prevention tool (Stinson et al., 2003). Thus, the authors do not imply that the CTS or M2 will provide better PI prevention outcomes; rather, it appears the CTS and the M2 cushion provide superior performance in pressure redistribution, which are believed to be factors associated with PI incidence.

Future research should explore CTS surfaces in relation to comfort and pressure distribution in conjunction with the tilt and recline among dependent-wheelchair users. Furthermore, additional research should be done to investigate the effects of posture, height, and weight (BMI) on these outcomes.

4.1 Limitations

A relatively small sample size of 20 non-disabled participants impacts the generalizability of the present study. A larger sample size and/or wheelchair-dependent users as participants can provide researchers with more generalizable results. Lastly, these trials should occur over extended periods to ascertain a more accurate interpretation of comfort.

5. Conclusion

Pressure injuries are a continuing healthcare problem that impacts wheelchair users' well-being and participation in daily activities. Many seating cushions and surfaces are available, yet choosing which is best for the user can be a clinically daunting task. This study suggests that the M2 cushion and CTS surfaces, compared to the standard sling and foam cushions, have superior peak pressure index and comfort level. These results can -improve healthcare professionals' decision-making when prescribing DME, such as wheelchairs.

Competing Interests Statement

The authors declare that there are no competing or potential conflicts of interest.

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