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ARTICLE

Seated pressures in daily wheelchair and sports equipment: investigating the protective effects of cushioned shorts

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Abstract

Study design The primary study design was a pretest and posttest study performed in a single session with subjects as their own control. We summarize three integrated and sequential studies.

Objective The objective of this study was to investigate whether commercially available cushioned shorts would add skin protection when used in adaptive sports equipment (AE).

Setting Community in Tacoma Washington, USA.

Methods TekScan Pressure Mapping System for recording average (AP) and peak (PP) seating pressures.

Part 1. Pretest/posttest design, subjects as own control. Eight adults with SCI (C5–T6) mapped in daily wheelchair and AE with and without bicycle shorts.

Part 2. Sixteen able-bodied subjects were mapped with and without an impact short and full-coverage short in a hand-cycle.

Part 3. One individual with T5 SCI was mapped with and without a full-coverage short in personal basketball chair and mountain hand-cycle.

Results *Part 1*. Significant differences between the daily wheelchair and AE in the static condition for AP and PP and AP in the dynamic condition. Bicycle shorts showed no significance.

Part 2. Impact shorts increased static PP and AP. The full-coverage short decreased static AP.

Part 3. The full-coverage short increased AP and PP in the basketball chair. In the mountain hand-cycle, AP decreased but PP increased.

Conclusion Athletes who are static in their AE may be at greater risk of tissue breakdown than those actively playing. Cushioned shorts had highly variable effects on seated pressure in adaptive equipment. Pressure mapping is recommended prior to using any cushioning in AE by the SCI population.

Introduction

Following spinal cord injury (SCI), individuals undergo physiologic changes that increase the risk for metabolic and cardiovascular diseases, such as heart disease, hypertension, diabetes, and obesity [1–5]. These risk factors for cardiovascular disease and coronary artery disease include arterial changes, lipid profile changes, decreased physical activity, obesity, and psychosocial factors such as depression [6]. A study by Hatchett et al. demonstrated that 40–66% of their study participants were overweight or obese 0–5 years post-injury when evaluated with SCI-modified body mass index [7], while another study by Locatelli et al. estimated that 70% of individuals with SCI are overweight or obese [8]. Nash et al. recently analyzed risk factors for cardiometabolic disease in the SCI population and found that 83% of participants were overweight or obese, 62% were pre-hypertensive, and 76% were at moderate-to-high risk for insulin resistance [1]. SCI has been associated with a more than two-fold increased risk for heart disease and stroke when compared to an able-bodied population [9]. Physical inactivity can further compound the risk for cardiometabolic diseases and individuals with SCI reportedly engage in less activity than able-bodied individuals [10]. The National Spinal Cord Injury and Statistical Center reported in 2016

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Fig. 1 Mesh bicycle short with ischial padding used in Part 1 of study. Shorts did not have a significant effect on peak and average pressure under static and dynamic conditions in adaptive equipment. (4ucycling short, $10.99)

that mortality rates due to endocrine disorders, metabolic diseases, musculoskeletal disorders, and mental disorders have been rising in recent years [11].

Given the high incidence of obesity and other cardiometabolic diseases in the SCI population, the literature strongly supports physical activity as a way for individuals with SCI to decrease their risk of developing such diseases [2, 5, 12–15]. Frequent exercise has been associated with favorable changes in lipid profiles for the SCI population that correlate to decreased risk of cardiovascular disease [2, 3, 5, 16]. A 2017 systematic review found moderate-to-high confidence that frequent exercise can improve fitness and overall health in the SCI population [12]. Recent guidelines have been published to assist with recommending exercise for this population [17].

Adaptive sports provide an excellent opportunity for individuals with SCI to engage in physical activity. However, use of adaptive equipment may place individuals at risk of pressure ulcer. Customized seat cushions are recommended for individuals in their daily wheelchairs to prevent pressure ulcers, but the lack of specialized cushioning in adaptive sport equipment raises concern [18]. Pressure ulcers often lead to recurrent hospital stays, surgery, infection, and immobility and can be incredibly costly to the patient and the health-care system in general [19]. Pressure, shear forces, moisture, and immobility are extrinsic factors that may increase the risk of pressure ulcer development [19]. Although adaptive sports expose individuals to these extrinsic factors, the overall systemic benefits of physical activity are associated with decreased risk of developing pressure ulcers [20].

Recent studies found the presence of deep tissue injuries on 62.8% of female athletes on the Japanese Women's Wheelchair Basketball team [21]. Focusing specifically on athletes with SCI on the Japanese Men's Wheelchair Basketball team, deep tissue injuries were found on 69% of these athletes [22]. Research in the sport of sledge hockey found static seated pressures that greatly exceed clinically accepted values for daily wheelchairs in physically disabled populations [23]. Berthold et al. compared pressure distribution with and without the presence of a Vicair® All-Rounder cushion and failed to show any significant decrease in pressure when the cushion was in place [24]. Although the research regarding skin breakdown for adaptive athletes is limited, these studies highlight the importance of finding a pressure relieving option for the adaptive athlete. Our study assesses seated pressures across multiple types of sports equipment with and without the presence of a cushioned short. We predicted that a cushioned short could provide pressure-relieving properties and, when worn close to the skin, will not impact an athlete's function during play. Over-the-counter cushioned shorts are easily accessible and might provide an affordable pressure-relieving option for people with disabilities.

Our study is novel in that we analyzed seated pressure distribution in both static and dynamic sport-specific positions, with and without the presence of a cushioned short, in multiple types of adaptive equipment including handcycles, basketball, and quad rugby chairs. We anticipated that a short that has cushioning would reduce seated pressures in adaptive equipment. Our study tested the following hypotheses:

1. Seated average pressures are greater in adaptive sports equipment as compared to daily use wheelchairs.
2. Seated peak pressure are greater in adaptive sports equipment as compared to daily use wheelchairs.
3. A short with cushioning over sitting surface anatomy will decrease peak and average pressures in adaptive sports equipment.

Methods

This paper summarizes three integrated and sequential studies. The primary study design was a pretest and posttest study performed in a single session with subjects as their own control. Consent was obtained from all participants. IRB approval was obtained through the University of Puget Sound IRB committee.

Part 1. Participants were recruited from the Seattle–Tacoma region via flyer and direct recruitment through adaptive sports teams. Participants were included if they had SCI, participated in adaptive sports either competitively or leisurely, and owned their own adaptive equipment. Individuals were excluded if they possessed any ambulatory function or had any current skin breakdown.

Fig. 2 Impact shorts used in part 2 of study. This short significantly increased peak and average pressures on static conditions in a hand-cycle in able-bodied participants. (JBM Hip Padded Short, $12.99)

Fig. 3 Full-coverage padded short used in parts 2 and 3 of the study. Short decreased average pressures and had no effect on peak pressures in able-bodied subjects in hand-cycle under static conditions. In single subject with T5 SCI, the short increased peak and average pressures in the basketball wheelchair, while in a mountain hand-cycle, average pressures decreased but peak pressures increased with the presence of the short. (Seirus Innovation 5656, $21.29)

Eight individuals participated in this study, seven males and one female, who ranged in age from 26 to 54 years and presented 5–35 years after acquiring their SCI. Five individuals had cervical injuries (C5–C7) and three had thoracic injuries (T4–T8). All participants self-reported absence of sensation below the level of SCI. Sports equipment tested included quad rugby chairs, basketball chairs, and hand-cycles.

Participant's seating pressures were mapped in static and simulated dynamic motions in the following conditions:

1. Daily WC
2. Adaptive equipment
3. Adaptive equipment+bicycle short (Fig. 1)

Part 2. Because we found no effect of the first shorts and higher static pressures in part one, the second study compared two different shorts, an impact short (Fig. 2) and a full-coverage short (Fig. 3), to a condition with no shorts in an able-bodied population under static conditions in a hand-cycle. A total of 16 participants, 10 females and 6 males, ranged in age from 23 to 57 years. Only the static condition was measured because the first part of the study found the static condition to be most concerning. Able-bodied individuals were utilized since recruitment was easier and would allow for us to quickly rule out any shorts that were not candidates for a follow-up in SCI participants.

Part 3. The third study was a single subject design to measure average and peak pressures in static and dynamic conditions, with and without the presence of the full-coverage short (Fig. 3). The full-coverage short was found to decrease average pressures in able-bodied subjects in part two of the study and was tested in part 3 for this reason. One participant from part 1 was recruited for this final study. This individual had a T5 SCI, was 27 years old, and was tested in a daily wheelchair, a basketball wheelchair, and a mountain hand-cycle.

TekScan data collection methods used across all parts of study

The TekScan pressure-mapping procedure was performed following the manufacturer's instructions. The TekScan pressure-mapping sensor was calibrated to the participant's weight utilizing a calibration file within 5 pounds of their body weight. The sensor was placed on the seating surface. Each condition mapped was recorded 400 frames over 60 s. For dynamic recordings, participants were cued to simulate movements that would typically be performed in the type of chair they were in. For static recordings, the participants were instructed to sit still for 60 s. Participants were instructed to wear the specified test shorts in their usual manner. For example, if it was typical for the individual to not wear undergarments beneath their clothing, then they would wear the shorts as such. Participants were instructed to wear the sport-specific gear they would normally wear during their sporting event over top of the shorts.

Data analysis

Average pressure of the contact area and peak pressure were pulled from the data for each recorded mapping movie. One researcher recorded the data from the TekScan program and recorded it onto data extraction sheets. The researcher then entered it into excel data sheet. A second researcher then entered data from the data extraction sheets into a second tab in excel. This was done so a comparison of the data entered in excel could be monitored for errors. Data were analyzed in SPSS version 23 and graphed in Microsoft Excel 2011. Paired *t*-tests were used to compare average pressures and peak pressures in each condition with a 95% confidence interval.

The authors certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Results

Part 1: Paired *t*-tests showed significant differences between the daily chair and sports equipment for both average ($p = 0.023$) and peak pressures ($p = 0.052$) in the static position, as well as average pressure ($p = 0.046$) in the dynamic condition (See Fig. 4). However, no significant difference was found between daily chair and adaptive equipment for peak pressures ($p = 0.248$) in the dynamic condition. In the sports equipment, the static condition had notably higher pressures than the dynamic condition (See Fig. 5). No significant differences were found when the shorts were added.

Part 2: The results of paired *t*-tests showed that, when compared to no short, the impact short increased peak and average pressures ($p = 0.00$, $p = 0.00$), while the pull-on short decreased average pressures ($p = 0.029$) but had no effect on peak pressures ($p = 0.756$) (See Fig. 6).

Part 3: Graphic analysis shows the full-coverage cushioned short increased peak and average pressures in the basketball wheelchair. In the mountain hand-cycle, average pressures decreased but peak pressures increased with the presence of the short (See Fig. 7).

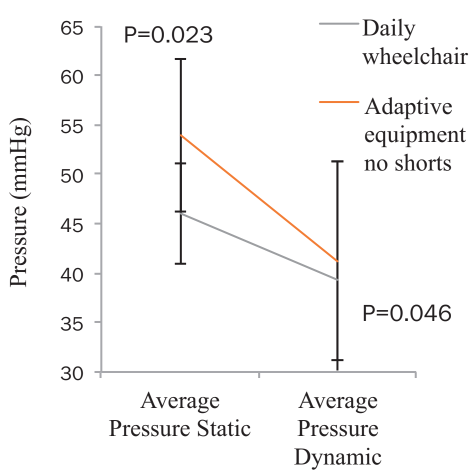

Fig. 4 Comparison of average pressures between daily wheelchair and adaptive equipment in static and dynamic conditions

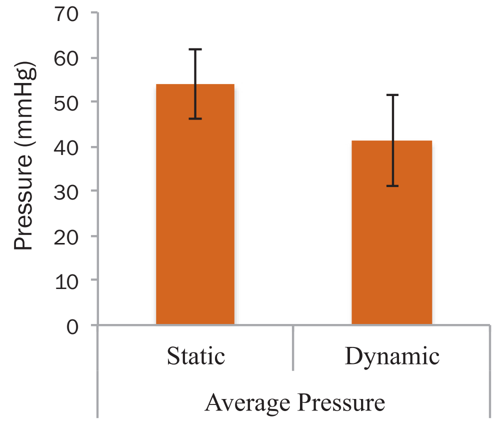

Fig. 5 Comparison of average pressures in adaptive equipment under static and dynamic conditions

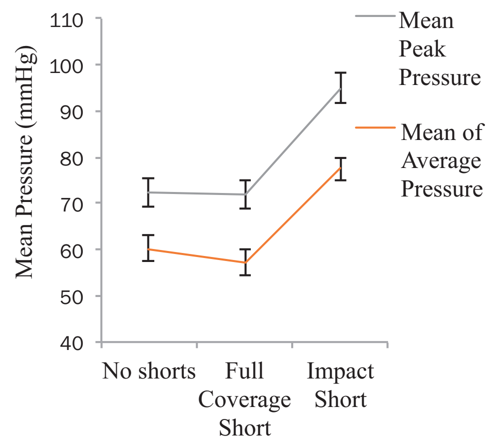

Fig. 6 Mean average and mean peak pressures between no short, full-coverage short, and impact short in a hand-cycle in a static condition in able-bodied participants

Post-hoc analysis

In a post-hoc analysis, we regrouped the data from the first part of our study to compare seated pressures in different seating positions within sports equipment: knee extension ($n = 4$), compared to knee flexion ($n = 6$). Paired *t*-test showed no significant difference between the groups for average and peak pressure in any condition.

Discussion

This study measured both average and peak pressures; however, since prior research has shown that peak pressures are transient and currently have no established cutoff

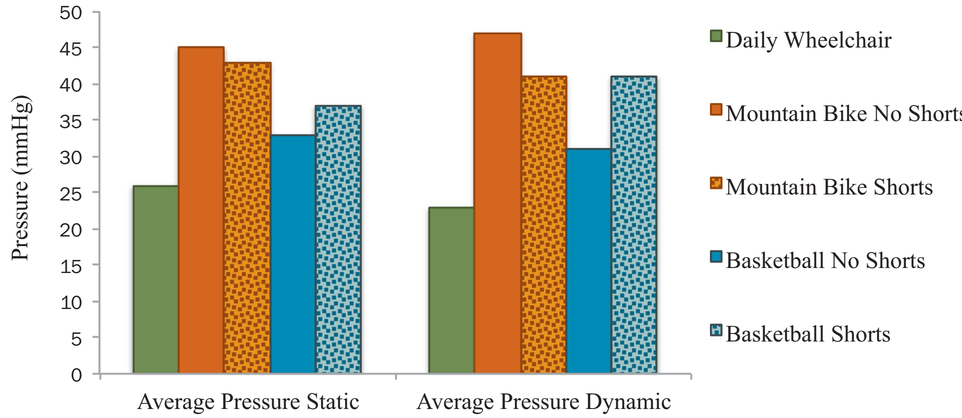

Fig. 7 Effects of a full-coverage short on average pressures in static and dynamic conditions in two different types of adaptive equipment in a single subject with T5 SCI

denoting risk of pressure ulcer or skin breakdown, we chose to emphasize average pressures in our analysis [24]. Across all parts of our study, we found average and peak pressures in different types of sports equipment in both static and dynamic conditions that exceeded clinically accepted pressure values. Other studies evaluating the pressure and efficacy of different daily wheelchair cushions and pressure-relieving positions have utilized a safe pressure cutoff of 100 mm Hg [18, 25–27] Earlier research suggests 30 mm Hg for the cutoff value for tissue safety, with up to 60 mm Hg allowed, provided increased pressure-relieving movements are performed [26, 27]. The studies analyzing sledge hockey pressures used 32 mm Hg as a clinically accepted cutoff [23, 24]. Both sledge hockey studies found higher than acceptable pressures for sports equipment and this study supports those findings. The greater pressures that were demonstrated in sports equipment indicate a need for pressure-relieving options for athletes and suggest that cushioning should specifically focus on relieving pressure for static conditions.

Static pressures were significantly higher in sports equipment than daily wheelchairs and indicate that athletes might be at the greatest risk for skin breakdown when they are sitting still. Athletes may be exposed to the greatest pressures when they sit too long on the sideline or stop to take an extended rest in their equipment. In the dynamic condition, however, pressures in sports equipment were similar to pressures seen in daily use wheelchairs. These findings demonstrate that athletes might relieve their pressure enough during play, so that the pressures they experience are no different than pressures they would experience while using their daily chairs. The nature of sports equipment is to allow for active play and movement, and static sitting does not appear to be as safe in this type of equipment. The authors of this study stress the importance of frequent pressure reliefs as often or more often than an individual typically performs relief when in their daily chair. Coaches of adaptive teams should be mindful to frequently rotate players so that athletes on the bench do not sit for too long.

We found that the pressure-relieving effects of cushioned shorts behaved differently depending on movement condition, type of sports equipment, and brand of short. The bicycle shorts used in the initial study had no significant effect in any condition tested. The impact short used with the able-bodied participants in part 2 of our study greatly increased pressures in all conditions tested. In the single-subject study, the full-coverage short showed greater pressures in the basketball wheelchair and lower pressures in the hand-cycle (Fig. 7). At this time, the authors cannot recommend one specific over-the-counter short for pressure-relieving effects. These findings indicate that the type of sports equipment used might influence the effectiveness of a cushioned short.

This study incorporated mountain hand-cycles, road hand-cycles, basketball wheelchairs, and quad rugby wheelchairs which all place athletes in varying positions of knee flexion. Mountain and road hand-cycles position the athlete's knees in a more extended position, when compared to quad rugby and basketball chairs with knee flexion. In a post-hoc analysis, we analyzed the results from the first portion of our study in order to compare seated pressures according to seating position within sports equipment: knee extension for mountain and road hand-cycles ($n = 4$), compared to knee flexion for rugby and basketball chairs ($n = 6$). Comparison of seated position showed no significant difference between the groups for average and peak pressure in static or dynamic conditions, with or without the addition of a cushioned short.

Although no significant difference was found, the athletes in hand-cycles trended toward higher seated peak and average pressure values than athletes sitting with knee flexion. Recent studies on seated pressures in sledge hockey equipment showed higher pressure values when athletes were seated in greater degrees of knee flexion than extension for able-bodied control subjects but failed to show significant differences between knee angles for individuals with neurologic conditions [11, 12]. The authors of these studies note that the lack of significant results for the neurologic group could have been due to asymmetrical seating in the sledge hockey bucket. Our findings suggest that changes in knee angle or seating position may alter the force per unit area between the seating surface and the individual and may focus the pressure over bony prominences (increasing pressure) or displace the force and distribute the weight over greater contact area (reducing pressure).

Our findings did not show any specific short that significantly reduced seated pressures in *all* types of sports equipment. The problem still remains that seated pressures in adaptive equipment exceed clinically supported values. The full-coverage short used in our single subject study reduced pressure for a hand-cycle, but more research is needed to assess the pressure-relieving effects of this short across different types of sports equipment and with a larger population. Sports equipment positions athletes in different angles of hip and knee flexion to best suit the demands of the specific sport and is thus highly variable. Further research should continue to explore wearable pressure reducing equipment for adaptive athletes and should also focus on whether specific types of sports equipment expose individuals to different amounts of seated pressure based on seating position.

The small number of individuals in part 1 of our study limited our ability to see significant relationships in our post-hoc analysis. Larger group sizes might have led us to a more definitive statement with our post-hoc analysis regarding seated posture.

The structure of the TekScan pressure map required continuous connection to a computer and thus limited the available range of motion for dynamic movements. A wireless system would allow for dynamic motions that more accurately reflect play during sports. The size of the TekScan map also restricted the variety of equipment that could be included in the study. A monoski was originally tested but the map could not fit the contour of the bucket seat. Hand-cycles, basketball chairs, and quad rugby chairs fit with the TekScan system and were thus included in the study.

This study supports the finding that adaptive athletes may be at greatest risk for skin breakdown when they are sitting still in their sports equipment. The results demonstrated highly variable effects on seated pressure between the three different cushioned shorts tested, and for this reason, no single short can be recommended for sports equipment pressure relief at this time. Because of this variability, the authors of this study stress the importance of performing pressure mapping before any type of cushioning is added to sports equipment and also recommend frequent pressure reliefs when athletes are in their sports equipment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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