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ORIGINAL RESEARCH

# Orthotic-Style Off-Loading Wheelchair Seat Cushion Reduces Interface Pressure Under Ischial Tuberosities and Sacrococcygeal Regions

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**Abstract**

**Objective:** To assess the efficacy of an off-loading wheelchair seat cushion in removing pressure from high-risk ischial tuberosities and the coccyx/sacrum in wheelchair sitting.

**Design:** Repeated-measures design.

**Setting:** Private research laboratory.

**Participants:** Manual wheelchair users with chronic spinal cord injuries (N = 10).

**Interventions:** Three configurations of an off-loading wheelchair seat cushion compared with a flotation style (10-cm air inflation) wheelchair seat cushion.

**Main Outcome Measures:** Outcome measures included peak pressure index (PPI), ischial tuberosity peak pressures, and the dispersion index or ratio of pressures under the ischial and sacral regions to the total of all pressures recorded.

**Results:** PPI and ischial tuberosities peak pressure ranged from a low of 39±18 and 68±46mmHg in the fully off-loaded cushion to a high of 97±30 and 106±34mmHg, respectively, for the flotation style cushion (2-way analysis of variance main effect across 4 conditions, $P<.001$). Dispersion index ranged from a low of 8%±3% in the fully off-loaded cushion to a high of 16%±3% in the flotation style cushion. Pairwise comparisons yielded significance in all cushion-pair analyses ($P<.05$ after multiple corrections).

**Conclusions:** The force-removal approach of this orthotic off-loading cushion design effectively reduces a known extrinsic risk factor for pressure ulcers—interface pressure—in the high-risk ischial tuberosity and sacral/coccygeal regions of the buttocks.

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Pressure ulcers remain one of the most challenging problems faced by wheelchair users.[1] For many wheelchair users, pressure ulcer risk can be substantially reduced by the selection of an optimal seat cushion.[2-5] Wheelchair seat cushion selection is particularly important for its effect on 2 factors: tissue interface pressure[3] and sitting posture[6,7]; in addition to the implications of body posture on musculoskeletal health and upper extremity mobility, posture itself has indirect influence on interface pressure.[6,8-10]

Cushion technologies that rely on a flotation principle[11] minimize interface pressures under bony prominences by distributing pressure as evenly as possible over the largest contact area possible, thereby reducing peak pressures under the bony prominences of the pelvis, particularly the ischial tuberosities.[12,13] Although these cushions are useful in reducing pressures under these bony prominences,[14-16] pressures in these areas may remain unacceptably high.[17,18] Therefore, it may be necessary to completely off-load these high-risk areas of the anatomy to effectively reduce the risk of pressure ulcers in these critical regions.[17,19,20]

Although the off-loading concept is not completely novel,[18] there has been limited inquiry into the effect of an off-loading design on seating interface pressures.[19,20] Additionally, this body of work is not recent and predates the characterization of

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interface pressure parameters currently used in cushion assessment, including the peak pressure index (PPI) and dispersion index, both of which are used in this study. Nevertheless, there is indication that a previously tested off-loading cushion design has also yielded significantly lower interface pressures in the area of the ischial tuberosities.[18]

In this study, we test the ability of an off-loading cushion design to reduce external pressures in key areas of the pelvic anatomy. This wheelchair seat cushion is designed using orthotic principles to intentionally and completely off-load high-risk bony prominences. By redistributing contact pressure away from the ischial tuberosities, sacrum/coccyx, and greater trochanters and toward the posterior gluteal muscles and proximal femurs (distal to the greater trochanters), this cushion system is designed to significantly decrease peak pressures immediately under these highly sensitive bony regions of the pelvis. Our main objective was to measure the interface pressure characteristics of this off-loading cushion and compare them to the flotation style seat cushion that is commonly used for pressure ulcer prevention in wheelchair users.[2,16,21]

# Methods

## Participants

All study procedures were approved by the institutional review board prior to recruitment or testing, and all participants provided informed consent. Participants included 10 adults with chronic spinal cord injury (3−42y postinjury; average, 20y). Exclusion criteria were presence of a pressure ulcer or subject hip width >48cm. Participants were all tested in a laboratory environment using their own wheelchairs or a suitable surrogate.

## Materials

All testing was completed using a properly inflated (according to the manufacturer's instructions) 10-cm-high air flotation cushion[b] and a newly developed off-loading cushion. The air flotation cushion is comprised of a grid of interconnected air chambers, each 4in in height, with a single valve provided for adjusting the air inflation level. This system is designed to allow the buttocks to immerse into the cushion and for the cushion to envelop the bony regions of the pelvis.[12] This cushion is commonly used to manage interface pressure in persons with chronic spinal cord injury and has demonstrated effectiveness in interface pressure reduction, particularly under the bony prominences of the pelvis.[16,22-25] The off-loading cushion[a] used uses a firm, generically shaped closed cell foam base, a 2-n molded soft polyurethane foam overlay, and a moisture wicking outer cover. Wedges can be selectively inserted into the posterior-lateral support structures (ie, cantles) of the cushion to correct postural asymmetries and/or increase the amount of ischial off-loading (fig 1). Although complete off-loading of the bony prominences is the primary intended use of this cushion, optional reticulated foam well inserts can be added to provide increased ischial contact and reduce the sensation of rapid transitions from supportive contours to off-loaded tissue if desired by the clinician or wheelchair user.

*List of abbreviations:*
**PPI peak pressure index**

## Study design

To assess the potential effectiveness of the off-loading design, we compared this design against the flotation style cushion, which is believed to minimize extrinsic risk factors for pressure ulceration and is commonly used in wheelchair seating among a high-risk population (eg, individuals with chronic SCI).[3,11,14,16,23] Because the off-loading cushion can be reconfigured to allow for 2 semi-loading conditions, we tested 3 configurations, each with different loading characteristics: fully off-loading (C0-off), which was determined through clinical evaluation, which included or excluded posterolateral wedges according to the manufacturer's instructions[26]; addition of the top well insert (C1-off); and addition of both well inserts (C2-off). The comparator condition (flotation-style cushion) was labeled C3-float.

## Instrumentation

Seat pressure measurement was conducted using an interface pressure mapping system. The system consisted of a flexible mat (46×46cm) containing an array of 1296 pressure sensors (36×36 array of 1-cm$^2$ sensors). The mat was placed between the cushion being tested and the seated person. The mat electrical output was connected to a laptop computer for data reduction. The system incorporates software for mapping of pressure distributions and export of data.

## Protocol

The pressure mapping system mat was calibrated and validated according to the interface pressure mapping system manufacturer's instructions and to a standard range of 0 to 220mmHg. The manufacturer's recommended validation procedure was used at the start of each testing day, and if the calibration was not found to be adequate (ie, outside the validation range recommended by the system manufacturer), the mat was recalibrated. Special care was taken to assure that the sensing mat was not suspended on any of the cushion configurations tested, which would create a hammocking effect and interfere with the accuracy of the interface pressure readings.

Participants sat in the same wheelchair (either their own wheelchair or a comparable substitute on which a solid back support had been installed) under all 4 conditions in a randomized order. For each condition, subjects sat for 2 minutes after visual verification by the researcher of proper sensor mat placement and adequate functioning of all sensors.[27,28] Pressure data were recorded at a sampling rate of 1Hz for 2 minutes, collecting a minimum of 120 frames of data per trial. Subjects completed 5 trials for each condition, performing a complete pressure relief maneuver (ie, wheelchair push-up) to unweight the cushion fully between trials.

When each participant was initially seated on each cushion, the locations of both ischial tuberosities, both greater trochanters, and the sacrococcygeal region were verified via palpation by an experienced physical therapist. The sensor locations of the ischial tuberosities and the sacrum were recorded for use in data processing, and the ischial tuberosities and sacrococcygeal region were selected on the pressure map image using the appropriate pressure mapping system manufacturer's software feature. Region size was standardized across all participants and all conditions,

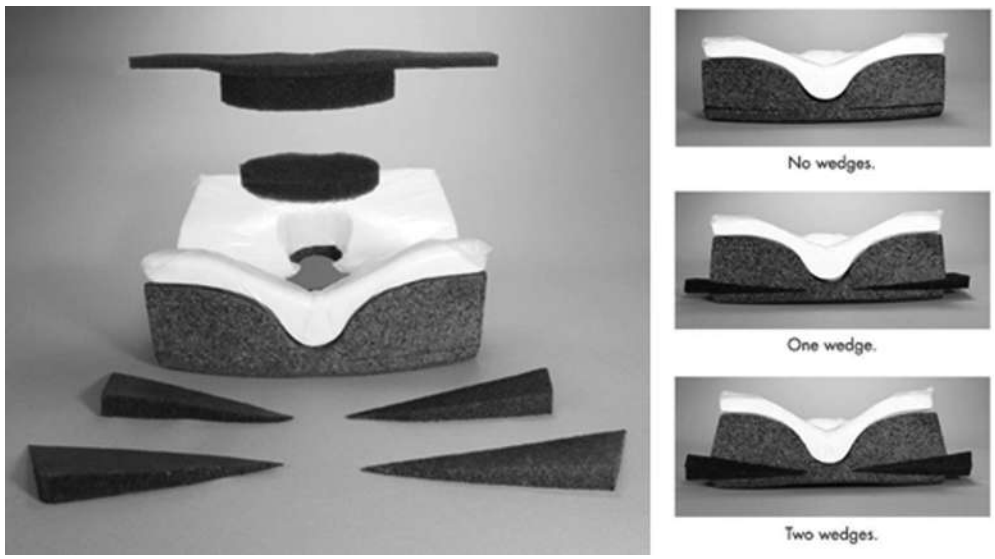


**Fig 1** Ride Deigns Java cushion. Full system including wedges and 2 well inserts (*left*) and posterolateral wedge inserts (*right*).

selecting a 3×3 sensor region for each of the ischial tuberosities and for the sacroccygeal region.[28] The region of the mat encompassing the 2 ischial tuberosities and the sacral region was used in the calculation of the dispersion index as described by Sprigle et al[28]; we note that although Sprigle is the first to have reported on the dispersion index, the dispersion index was developed by International Organization for Standardization TC173 SC1 WG11 (in 2002) during the development of the International Organization for Standardization 16840 standards. This region was identified based on the palpated locations of the ischial tuberosities and the sacrum/coccyx. This region was also standardized in size across cushion configurations so that it contained the same number of sensors for each configuration tested. For this reason, the region used (area B in fig 2) did not necessarily contain all sensors under the ischial tuberosities and the sacrum; however, it was necessary to standardize the size of the region for fair comparisons.

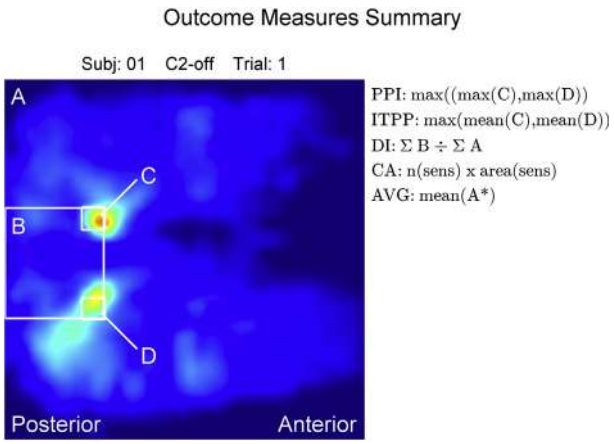


**Fig 2** Outcome measures used in this study. Abbreviations: AVG, average pressure; CA, contact area; DI, dispersion index; ITPP, ischial tuberosity peak pressure; sens, sensor; Subj, subject; C2, condition 2 (off-loading cushion with both well inserts).

## Outcome measures

Primary outcome measures used in this study included the PPI, ischial tuberosity peak pressure, and the dispersion index.[28] The dispersion index characterizes the percent of pressure distributed under the bony prominences (ischial tuberosities and sacrococcygeal region) of the pelvis compared with the total pressure under all areas of the seat[28]; this measure was selected for its unique ability to evaluate the effectiveness of the off-loading properties of the wheelchair seat cushion. Although the dispersion index is a newer measure and has not yet been fully validated as an extrinsic pressure ulcer risk factor, the more commonly used PPI and ischial tuberosity peak pressure and have been widely used to assess interface pressure risks in a seated environment.[18,27,29-32] Finally, we included 2 additional summary measures (contact area and average pressure) with only modest relevance to a focal study on pressure redistribution, but whose reporting helps to provide valuable context related to general efficacy of a pressure management seat cushion. All outcome measures analyzed for this study are described in table 1 and depicted in figure 2.

## Data processing and analysis

Data were extracted from frame 120 of each trial, unless there was a visually obvious sensor recording anomaly, in which case the frame nearest to frame 120 was used and the frame number was noted. Pressure matrix data were processed according to published standards, in the following order: nonlinear filtering with a 20% width 2-dimensional Gaussian window and then 2-dimensionally triplicate interpolation with a cubic spline.[33,34] A custom routine was prepared in the MATLAB[d] numerical computation environment for all data processing.

Three configurations of the off-loading cushion were examined, along with the flotation cushion. We tested the hypotheses that the PPI, ischial tuberosity peak pressure, and dispersion index variables (PPI, ischial tuberosity peak pressure, and dispersion index) (see table 1 and fig 2) would show significant differences in the 4-way cushion comparison,

**Table 1** Outcome measures used in this study

| Metric | Descriptor | Units | Definition | Mat Region Used |
|---|---|---|---|---|
| 1 | PPI | mmHg | Average of 9 sensors in the neighborhood around the IT peak pressure | IT regions |
| 2 | IT peak pressure | mmHg | Maximum measured pressure across all sensors in the 2 ischial tuberosity regions | IT regions |
| 3 | Dispersion index | % | Total pressure in the mat region containing the ITs and sacrum divided by the total pressures across the entire mat | Sacral and both IT regions compared with whole mat |
| 4 | Contact area*,† | $cm^2$ | Active sensors multiplied by the area of each sensor | Whole mat |
| 5 | Average pressure* | mmHg | Average of all active sensors | Whole mat |

Abbreviation: IT, ischial tuberosity.
* Indicates threshold of 5mmHg applied prior to calculation.
† Increased values of this measure indicate improvement.

indicative of progressive reduction of interface pressure in these critical regions and off-loading of the high-risk areas of the pelvis; our null hypothesis was that there was no significant difference among the 4 cushion configurations.

Because of the nature of the off-loading cushion, it was anticipated that the contact area might be reduced in the off-loading cushion, given that the off-loading is intentional and that the whole mat average pressure would be similar across all conditions. For each outcome measure, we tested the hypothesis of significant difference among conditions via 2-way analysis of variance with condition and subject identification as factors; $P$ values were reported for condition only. The multiple comparison analyses were corrected for multiple testing within condition pair via Bonferroni correction. All variables were computed via the customized data processing routine; all statistical analyses were performed in a statistical computing environment.[e]

# Results

## Demographics

Ten subjects (1 woman and 9 men) with chronic spinal cord injuries completed all testing (table 2). Average height of the subjects was 179±9cm, average weight was 80±10kg, and average hip width of the subjects was 41±4cm.

Representative data samples are shown in figure 3.

## Outcome measures

The average pressure (among nonzero sensors) ranged from 31±14 (C0-off) to 68±37mmHg (C3-float), and the contact area ranged from 2071±33 (C3-float) to 2091±25$cm^2$ (C0-off).

Mean and SD values for all outcome measures are reported in table 3. All analysis of variance results were found significant at the $P<.001$ level. The PPI values ranged from a low of 39±18mmHg (C0-off) to a high of 97±30mmHg (C3-float); the averages were 39±18, 61±19, 78±30, and 97±30mmHg in C0 to C3, respectively. These differences were significant at $P<.001$ (fig 4).

Where all hypothesis tests yielded significant differences, we report on pairwise comparisons in table 4.

We note that the PPI and dispersion index covary. Although a linear model is significant ($P<.001$), the $R^2$ value is also low ($R^2=.19$), indicating a significant trend of the PPI with dispersion index, albeit imprecise and nondeterministic (fig 5).

# Discussion

## Study validity

Here, we hypothesized that the 4 cushion configurations would yield significantly different results in a set of interface pressure outcome measures, including the PPI, which is the outcome

**Table 2** Subject demographics

| Subject Identification | Sex | Height (in) | Height (cm) | Weight (lb) | Weight (kg) | Hip Width (cm) |
|---|---|---|---|---|---|---|
| 1 | M | 71 | 180 | 160 | 73 | 38 |
| 2 | M | 74 | 188 | 200 | 91 | 38 |
| 3 | M | 74 | 188 | 210 | 95 | 45 |
| 4 | M | 74 | 188 | 185 | 84 | 43 |
| 5 | M | 70 | 178 | 200 | 91 | 48 |
| 6 | M | 66 | 168 | 165 | 75 | 36 |
| 7 | M | 70 | 178 | 180 | 82 | 40 |
| 8 | F | 64 | 163 | 135 | 61 | 41 |
| 9 | M | 70 | 178 | 165 | 75 | 43 |
| 10 | M | 72 | 183 | 170 | 77 | 38 |

Abbreviations: F, female; M, male.

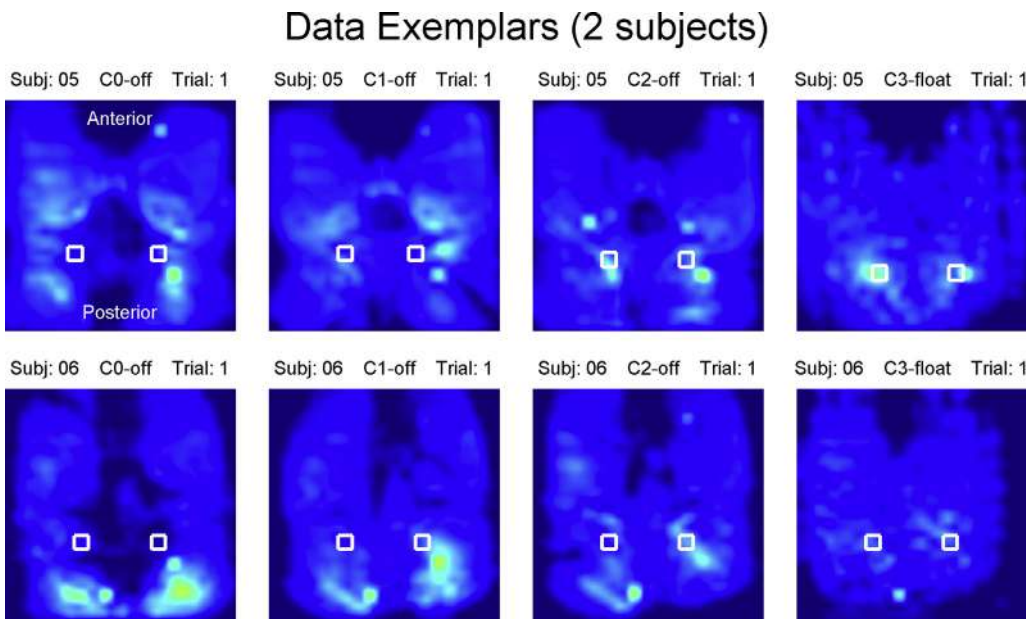


**Fig 3** Exemplars of data collected from 2 patients in 4 conditions (far left: C0-off; left: C1-off; right: C2-off; far right: C3-float). Abbreviations: C0-off, condition 0 (fully off-loading cushion); C1-off, condition 1 (off-loading cushion with top well insert); C2-off, condition 2 (off-loading cushion with both well inserts); C3-float, condition 3 (flotation-style cushion); Subj, subject.

measure most closely linked with extrinsic pressure ulcer risk factors. Although we considered a more conventional comparative effectiveness study of a single representative off-loading configuration, we elected instead to test all 3 configurations of this off-loading cushion for 2 reasons: (1) it was unclear which single configuration would be most informative and clinically relevant, and (2) there are no existing validation studies on the off-loading seat cushion design tested. Therefore, the hypothesis that the 3 configurations yield different pressure parameters has yet to be formally tested; we believed it to be important to incorporate this test into our study.

This study incorporated a sufficiently large and diverse pool of outcome measures, either as a direct variable of seat cushion performance or as a measure for context. In particular, this included the PPI, ischial tuberosity peak pressure, and dispersion index (a measure of how much of the interface pressure is concentrated under the ischial tuberosities and sacral region of the pelvis). We also measured 2 parameters for context—the average of all nonzero pressure readings across the full mat (ie, average pressure) and the full contact area—to identify differences on these additional, commonly reported interface pressure measures associated with determining clinical efficacy of various cushion designs.[3,22,35]

The performance of the off-loading cushion on the primary outcomes was as hypothesized. Commonly used correlates of extrinsic pressure ulcer risk (ie, PPI, peak pressure under the ischial tuberosities) were significantly higher with the flotation style cushion than with the various configurations of the off-loading cushion. Additionally, the dispersion index, a measure of the percent of total pressure distributed under the ischial and sacral regions, was significantly lower for the off-loading cushion, which is indicative of the efficacy of this cushion in reducing pressures in these highly sensitive anatomic regions. All parameters were compared against a flotation style cushion, which is the most commonly used cushion for reduction in these very critical interface pressure characteristics.[36] The novel seating configurations studied here make it difficult to compare these results with the existing body of literature; however, these values may provide valuable context for understanding the interface pressure characteristics of this cushion and comparing them with existing research.

**Table 3** Outcome measure results

| Metric | Descriptor | Off-Loading C0 | Off-Loading C1 | Off-Loading C2 | Flotation C3 | *P* |
|---|---|---|---|---|---|---|
| 1 | PPI (mmHg) | 39±18 | 61±19 | 78±30 | 97±30 | <.001 |
| 2 | IT peak pressure (mmHg) | 68±46 | 81±34 | 98±43 | 106±34 | <.001 |
| 3 | Dispersion index (%) | 8±3 | 13±3 | 14±3 | 16±3 | <.001 |
| 4 | Contact area*,† ($cm^2$) | 2091±25 | 2094±22 | 2096±16 | 2071±33 | <.001 |
| 5 | Average pressure* (mmHg) | 31±14 | 45±18 | 54±25 | 68±37 | <.001 |

NOTE. Values are mean ± SD or as otherwise indicated.
Abbreviations: C0, condition 0 (fully off-loading cushion); C1, condition 1 (off-loading cushion with top well insert); C2, condition 2 (off-loading cushion with both well inserts); IT, ischial tuberosity.
* indicates threshold of 5mmHg applied prior to calculation.
† Increased values of this measure indicate improvement.

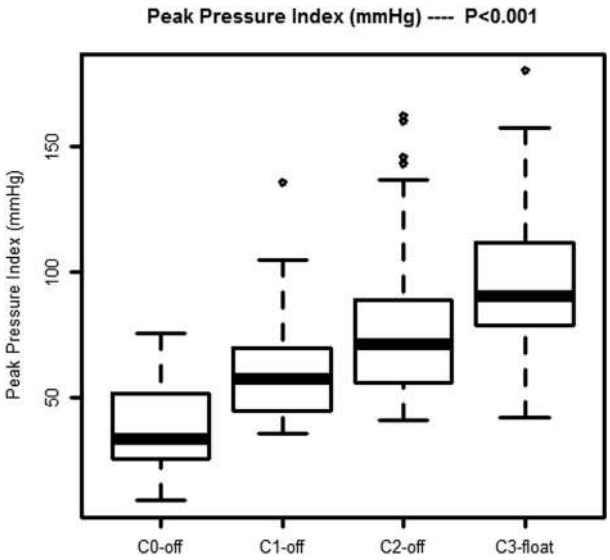


**Fig 4** PPI results. Abbreviations: C0-off, condition 0 (fully off-loading cushion); C1-off, condition 1 (off-loading cushion with top well insert); C2-off, condition 2 (off-loading cushion with both well inserts); C3-float, condition 3 (flotation-style cushion).

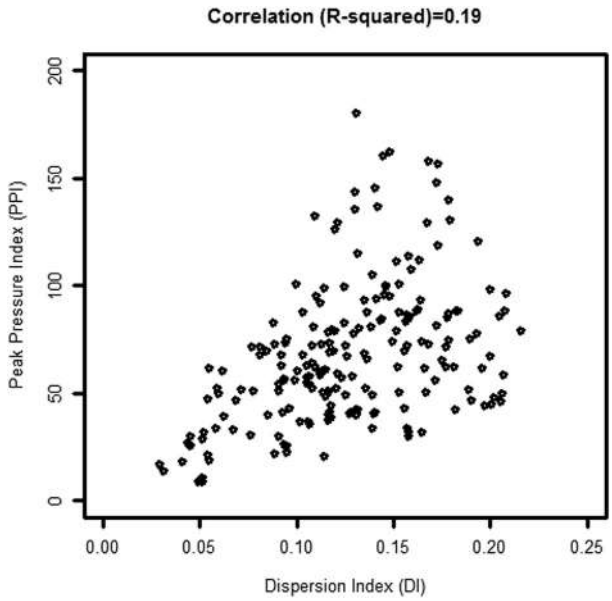


**Fig 5** Correlation of PPI and dispersion index results.

Results from the present study indicate that the off-loading cushion effectively reduced interface pressure under the ischial tuberosities and sacrum of the pelvis, as indicated by a significant difference in the PPI, ischial peak pressure, and dispersion index. This result is similar to the findings of Rosenthal et al[18] in their testing of a similarly designed wheelchair seat cushion.

## Study limitations

This study is limited by the lack of a universally accepted interface pressure parameter directly tied to pressure ulcer risk. Although several measures were used here, each with wide use by the community, and each with some support in the current literature for metric validity, there is simply no criterion standard measure definitively tied to pressure ulcer risk.[21,30,32] Moreover, many of the measures used to describe interface pressure do not inform the discussion of pressure redistribution, but they are important for context and as freestanding measures to inform the broader discussion on seating technology. Consequently, our study is somewhat diffuse. Our primary outcome measure, PPI, is the metric most closely tied to extrinsic risks of developing pressure ulcers; however, the newer dispersion index measure, first defined by Sprigle[28] in 2003, has also been incorporated into a number of studies over the last 10 years.[29,31,37] Prior to this, multiple studies also examined interface pressures under various defined regions—particularly high-risk regions such as those under the ischial tuberosities and the sacrum/coccyx.[17-20,27] As the applied research into interface pressure mapping matures, more focal studies will be possible.

Additionally, our study design was structured in such a way that the 3 off-loading cushion configurations were considered 3 distinct seating systems and compared along with the flotation style cushion. It could be argued then that the significant differences seen could be attributable to differences among the 3 off-loading cushions, and not because of differences between the off-loading cushion and the flotation cushion. Although this is a fair point, the manufacturer makes the assertion that the off-loading cushion can be considered to be 3 different cushions, depending on the particular cushion configuration selected, and that the 3 configurations provide quite different profiles in the degree of off-loading of the pelvic region. Furthermore, our pairwise comparisons show that each of the 3 off-loading cushions consistently yield significant differences versus the flotation style cushion.

Although our sample size for this study was small, our findings, although certainly preliminary, could well be argued as generalizable. Although our study participant pool comprised a narrow demographic (mostly men with spinal cord injury), we studied only those variables related to interfacial pressure; we have no evidence that the parameters measured here vary by diagnosis or sex. We believe that the off-loading cushion paradigm would have potential utility in populations broader than those subjects studied here; however, more testing would be required to support this conjecture. These are fair and valid characterizations: given the relative lack of literature base for seating technologies (eg, off-loading cushion), this work will be

**Table 4** *P* values for pairwise comparisons between conditions for 5 outcome measures

| Metric | C0—C1 | C0—C2 | C0—C3 | C1—C2 | C1—C3 | C2—C3 |
|---|---|---|---|---|---|---|
| 1 | <.001 | <.001 | <.001 | <.05 | <.001 | <.001 |
| 2 | <.001 | <.001 | <.001 | <.05 | <.001 | <.001 |
| 3 | <.001 | <.001 | <.001 | <.01 | <.001 | <.01 |
| 4 | <.001 | <.001 | <.001 | <.01 | <.001 | <.01 |
| 5 | <.001 | <.001 | <.001 | <.05 | <.001 | <.001 |

NOTE. *P* values are corrected for multiple comparisons.
Abbreviations: C0, condition 0 (fully off-loading cushion); C1, condition 1 (off-loading cushion with top well insert); C2, condition 2 (off-loading cushion with both well inserts); C3, condition 3 (flotation-style cushion).

inherently exploratory. Nevertheless, despite the relatively small sample, we identified several parameters for which the null hypothesis was rejected at $P<.001$. Therefore, we believe that our study design was appropriate and adequate. Further investigation with other patient populations may also be warranted, and we made no effort in this study to quantify or assess seated posture characteristics (eg, pelvic tilt in the sagittal plane); however, this may also be useful in the investigation of the potential benefits of an off-loading seat cushion designed based on orthotic principles.

## Conclusions

All metrics indicated reduction in a key extrinsic risk factor for pressure ulceration—pressure at the buttock-cushion interface. This was demonstrated through significant changes in the PPI, ischial region peak pressure, and the related parameter, the dispersion index. Additionally, the off-loading cushion did not demonstrate reductions in the contact area or increased overall average pressure, further reinforcing its potential for mitigating likelihood of developing pressure ulcers in a high-risk population, those with chronic spinal cord injury.

## Suppliers

a. Java Cushion; Ride Designs.
b. Single Valve, High Profile Roho Cushion; Roho.
c. XSENSOR interface pressure mapping system; XSENSOR Technology.
d. MATLAB Release R2012a; MathWorks.
e. R version 3.1.0; The R Foundation for Statistical Computing.

## Keywords

Pressure ulcer; Rehabilitation; Spinal cord injuries; Wheelchairs

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