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Microclimate evaluation of strap-based wheelchair seating systems for persons with spinal cord injury: A pilot study

Christine M. Olney^{a,*}, Amanda Simone^a, Kristin Hanowski^a, Thomas S. Rector^a, Gary D. Goldish^{a,b}, Andrew H. Hansen^{a,b}, and John E. Ferguson^{a,b}

^a1 Veterans Drive (151), Minneapolis VA Health Care System, Minneapolis, MN, 55417, USA

^bDepartment of Rehabilitation Medicine, University of Minnesota, Minneapolis, MN, 55455, USA

Abstract

Study purpose: The purpose of this pilot study was to assess microclimate characteristics of two versions of a strap-based wheelchair seating system (perforated and solid straps) and to conduct preliminary microclimate comparisons of subjects' current wheelchair seating systems.

Materials and methods: In this pilot study, the microclimate properties of two variations (solid and perforated) of a strap-based seating system were compared with two commonly used seating systems. Six subjects sat on three different seating systems each for 100-min test periods, while temperature and relative humidity were measured with a single sensor adjacent to the skin-seat interface. Additionally, thermal images of the seat interface were collected before and after each test period.

Results: The thermal images revealed that the maximum surface temperature of the solid-strap-based seating system was significantly lower than the other seating systems, -1.21°C . (95% CI -2.11 to -0.30 , $p = 0.02$), immediately following transfer out of the seat. Five minutes after transferring out of the seat, the perforated-strap seat was significantly cooler than the other seats -0.94°C . (95% CI -1.59 to -0.30), $p = 0.01$, as was the solid-strap-based seat, -1.66°C . (95% CI -2.69 to -0.63), $p = 0.01$. There were no significant differences in interface temperature or relative humidity measured with the single sensor near the skin-seat interface.

Conclusion: This pilot study offers preliminary evidence regarding the microclimate of the strap-based seating systems compared with other common seating systems. Clinically, the strap-based seating system may offer another option for those who struggle with microclimate management.

Keywords

Wheelchair seating; Spinal cord injury; Seating; Microclimate; Strap-based seating

*Corresponding author. Christine.Olney@va.gov (C.M. Olney).

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jtv.2018.06.001>.

1. Introduction

Persons with spinal cord injury (SCI) spend about 10 h a day seated in their wheelchairs on average, putting them at high risk for pressure injury [1,2]. Pressure injury to the seated area is primarily attributed to one or more risk factors occurring at the interface between the skin and seating system: mechanical pressure, shear, and microclimate [3]. In his review of the literature, which included human and animal studies, Gefen (2008) found evidence suggesting that pressure injuries can occur in less than 1 h, not specifically considering moisture and temperature [4]. The National Pressure Ulcer Advisory Panel defines microclimate as “the local tissue temperature and moisture (relative humidity) level at the body/support surface interface” [5]. Both factors are known to affect the physiological resilience of skin and underlying tissue [6], thus, we believe it is most likely, an increase in either or both microclimate factors can lead to a decreased time to pressure injury occurrence and possibly increased incidence. Further, for persons with a higher-level SCI (T6 or above), the normal autonomic feedback loop for internal temperature control can be compromised [7], thus their response to environmental, e.g. microclimate of seating system, heating and cooling is different from that of a neurologically intact person’s response. A well-fitted wheelchair seating system can provide protection against incurring a pressure injury [8,9] by: 1) off-loading the seated area’s bony prominences of the ischial tuberosity and the sacral-coccyx-trochanter region; 2) preventing shear; and 3) maintaining desirable microclimate (temperature and moisture) of the seated area.

There are numerous wheelchair seating systems on the market comprised of components such as air-cells, gels, foam beads, and combinations thereof, primarily focused on off-loading the bony prominences of the seated area. Unfortunately, pressure injuries continue to occur, implying a continued need for innovative seating design, materials and fabrication methods to manage load and other risk factors [10]. Minimal knowledge exists regarding existing wheelchair seating microclimate properties and management of those properties. Clinically, seating specialists are challenged to match a specific seating system to a patient when it is known that persons who sit for extended periods of time experience increased risk for pressure injury [11] due to temperature and moisture factors of the seated area [12,13].

A tabby-weave strap-based seating system (Tamarack Habilitation Technologies Inc., Blaine, Minnesota) has been designed to address risk factors associated with pressure injury development, including microclimate management. The strap-based seating system uses 11 to 14 horizontal straps and 13 longitudinal straps (depending on frame size) that are interwoven and connected to a perimeter frame contoured to accommodate the skeletal anatomy. The length of these straps can be adjusted to obtain a clinically acceptable fit [14]. A seat cover is used on top of the straps and is made of a polyester spacer fabric and a nylon/spandex fabric layer with low-friction zones located under the pelvis. Because no additional fabrics or cushioning is used on the seating surface, the strap-based seating system may allow for increased airflow, which may potentially reduce heat and moisture buildup in the seated area.

The purpose of this pilot study was to gather preliminary data regarding the microclimate characteristics of two versions of the strap-based wheelchair seating system (perforated and

solid straps). These microclimate characteristics were also measured in the subjects' current wheelchair seating systems for comparison.

2. Materials and Methods

2.1. Materials

The strap-based seating system has been previously described in detail [14]. The interwoven straps have spaces between them designed to allow airflow around the wheelchair user's seated area (Fig. 1). Both strap systems are made of 100% polyester. The difference between the two strap-based seating systems is that the perforated version has an array of small holes throughout the strap length, whereas the other is a solid woven strap.

Quantitative measures included thermal images of the seating systems, as well as temperature and moisture measured at one site near the skin-seat interface. An infrared thermal imaging camera (T450sc, FLIR Systems Inc., Wilsonville, Oregon) was used to capture each seating system's heating and cooling characteristics at three times: Pre-seating (at room temperature), immediately after the subject transferred out of the seat after sitting for 100 min, and 5 min after transfer. A sensor was placed adjacent to the skin-seat interface to continuously measure temperature (°C) and moisture (measured as relative humidity [RH]) (MSR Electronics GmbH, Seuzach, Switzerland, FH2). This small, capsule-shaped sensor (approximately 6 mm in diameter and 21 mm long) was connected to a digital data logger (MSR Electronics GmbH, Seuzach, Switzerland, MSR145WD) with a thin cable (approximately 1 mm in diameter). The accuracy of temperature measurements is ± 0.5 °C for measurements between 10 °C and 65 °C, and the accuracy of RH measurements is $\pm 2\%$ for measurements between 10% and 85% and $\pm 4\%$ for measurements above 85%, as stated by the sensor manufacturer. Although other studies have used multiple sensors [15–17] preliminary testing verified that a single sensor, placed on the medial thigh, forward of the ischial tuberosity and adjacent to the skin-seat interface, provided consistent reliable data to test between seat variability, without causing tissue injury during the prolonged testing periods. We also found in preliminary testing that using multiple sensors and their wires were difficult to manage when transferring the subject from bed to seat, interfering with data integrity.

This study was approved by the Minneapolis VA Health Care System's Institutional Review Board (a research review and ethics board) and was conducted at the Minneapolis VA Spinal Cord Injuries and Disorders (SCI/D) Center. The study rooms had environmental controls to regulate air flow, ambient temperature, and humidity, to help ensure these factors had minimal effects upon the seat comparisons.

2.2. Recruitment

For this pilot study, our goal was to recruit at least six subjects currently using a customized foam based seating systems (RIDE, Aspen Seating, Littleton, Colorado) to gain a sense of the strap-based seating system's relative micro-climate characteristics. At the time the study was conducted, only three users of that type of seating system met the study's inclusion criterion. Therefore, we added three subjects who were sitting on an often-used seating

system for Veterans with troublesome pressure issues (ROHO[®], Permobil, Lebanon, Tennessee). Again, the foam-based and air-cell-based seating systems were used *to gain a sense of the strap-based seating system's microclimate characteristics* compared to other commercially available seating systems.

2.3. Study visits

We included Veterans between 18 and 71 years of age with SCI at C5 or below who could operate a manual wheelchair and were currently using either air-cell-based or foam-based seating systems. We excluded persons with lower limb amputation or active pressure injury. We conducted skin checks of the seated area at enrollment, at each visit, and during the testing of each seating system to catch any threats to tissue integrity.

Three study visits for each subject were required to complete the microclimate testing. At the first visit, after informed consent was gained, seating specialists ensured the subject's currently used seating system pressure mapped within safe, acceptable ranges. If the subject's seating system did not map well at this first visit, the seating specialist invoked our standard clinical process to modify the system. Once modified, the study proceeded. The purpose of the second visit was to fit both strap-based seating systems to the subject in their own wheelchair. The third visit consisted of three testing sessions to capture temperature and moisture adjacent to the skin-seat interface for both strap-based seating systems and the subject's usual seating system. Random block assignment of the seat order was used to help control any effects of testing order. For each subject, all three visits were conducted in the same room which had controlled temperature and humidity. The subject donned a provided pair of cotton shorts. The sensor was taped in place (on the right medial thigh, forward of the ischial tuberosity, adjacent to the skin-seat interface). The subject started each of the three seating system test periods by lying on their side on a bed for 15 min to allow time for the sensor to reset to a common starting point. The subject then either did a self-transfer or was lifted to the test seat. Once the subject was in the test seat, the sensor placement was rechecked and adjusted if needed to ensure it was adjacent to the skin-seat interface. Preliminary testing with the sensors determined there were minimal changes in skin interface temperature and humidity after 95 min of sitting, therefore for an efficient study session timeline, the subjects sat upright in their wheelchair for 100 minutes in each of the three test seats. Every fifteen minutes the subject was reminded to perform a 2-minute forward-lean pressure relief maneuver.

2.4. Data analysis

Measurements of seat temperatures, via thermography, taken 5 min after transferring out of the seats were compared (separately) using clustered longitudinal regression analyses, with both the pre-seating and immediate post-seating measurements included as covariates. Having only three subjects currently using either a foam-based or air-cell-based comparator they were combined into one reference group for comparisons to each of the two new strap seats. The analyses were clustered by subject to obtain robust standard errors and 95% confidence intervals for the average differences between seats.

Each subject's continuous temperature measurements via the sensor placed near the skin-seat interface during each of the three 100-min sessions were plotted for visual comparison. These plots along with preliminary data indicated the measurements were relatively stable during the last 95–100 min. To reduce variation in the skin-seat interface temperature measurements during the last 5 min of continuous measurement, the measurements recorded after 95, 99 and 100 min of being seated in each seat were averaged for comparison using fixed effects longitudinal regression analysis with the measurement made immediately after being seated as a covariate. Again, the comparator seats were combined into one reference group for comparisons to each of the two new strap seats. The analyses were clustered by subject to obtain robust standard errors and 95% confidence intervals for the average differences between seats. A separate regression analysis was used to compare skin-seat interface temperatures after 5 min of sitting as the measurements increased to a relatively stable level after approximately 95–100 min. Measurements of skin-seat interface moisture (RH) were compared in the same manner as the skin-seat interface temperatures.

Because this was a pilot study to obtain preliminary estimates of differences between newer seats with straps and current types of seats, reported p-values and confidence intervals are not adjusted for the number of comparisons being made. The regression analyses were done using Stata software (version 13.0; College Station, TX).

3. Results

3.1. Demographics

For this pilot study, six male subjects were recruited and all six subjects completed the three required visits. Individual characteristics are reported in Table 1.

3.2. Seating system thermal images

Thermal images of the four seating systems at three different phases of the testing are shown in Fig. 2.

3.3. Seating system temperatures

Table 2 depicts mean seat temperatures (the average of the maximum temperature of the subjects sitting surface at three times: preseated, immediately after and 5 min after the subject had sat for 100 min and then transferred out of the wheelchair.

Seat temperatures (adjusted) immediately after the subject transferred out of the perforated-strap seat was not statistically different than the combined comparator seats, 0.14 °C. (95% CI –1.69 to 1.98), $p = 0.85$, whereas the solid strap-based seat was significantly cooler than the comparator seats, –1.21 °C. (95% CI –2.11 to –0.30), $p = 0.02$. After 5 min of cooling the perforated-strap seat was significantly cooler than the combined comparator seats, –0.94 °C. (95% CI –1.59 to –0.30), $p = 0.01$, as was the solid-strap-based seat, –1.66 °C. (95% CI –2.69 to –0.63), $p = 0.01$.

3.4. Temperature and moisture near the skin-seat interface

Fig. 3 graphically depicts each subject's temperatures (°C) and moistures (RH) near the skin-seat interface.

Each subject sat on three different seats (perforated strap, solid strap and either foam or air-cell based). The random seat order for testing is noted next to subject number. For actual values please see Supplemental Data Set.

3.5. Temperatures near the skin-seat interface

There was little difference between average temperatures adjacent to the skin-seat interface immediately after the subject transferred into each of the three seating systems and relatively stable differences between 95, 99 and 100 min (See Table 3).

Adjusting for the small difference in the initial temperature, the temperature while sitting in the perforated strap-based seat for 5 min, was not different [-0.13°C , (95% CI -1.08 to 0.81), $p = 0.73$] than the temperature while sitting in the comparison seating systems, as was the temperature while sitting in the solid strap-based seat not different than the comparators [-0.16°C , (95% CI -0.72 to 0.39), $p = 0.48$]. At the end of the sitting periods (average of minutes 95, 99, and 100) the adjusted temperatures near the skin-seat interface in the perforated strap-based seat was not different [-0.34°C , (95% CI -0.99 to 0.32), $p = 0.24$] than the comparison seating systems. The temperature sitting in the solid strap-based seat was not different [-0.21°C , (95% CI -0.82 to 0.40), $p = 0.42$] than the temperature while sitting in the comparison seating systems.

3.6. Relative humidity (RH) near the skin-seat interface

Like the temperature, there was little difference between RH immediately after the subjects transferred into the wheelchair and relatively stable differences between 95, 99 and 100 min, Table 4.

The RH while sitting for 5 min in the perforated strap-based seat was non-significantly higher by 6.7 RH (95% CI -5.3 to 18.7), $p = 0.21$ than sitting in the comparison seating systems. The RH in the solid strap-based seat was about the same on average as the comparison seating systems, -0.04 RH (95% CI $-0.8.3$ to 8.2), $p = 0.99$. The RH at the end of the session (average of minutes 95, 99, and 100) while sitting in the perforated strap-based seat was non-significantly more humid on average than the RH while sitting in the comparison seating systems, 4.4 RH (95% CI -10.4 to 19.2), $p = 0.48$. The RH while sitting in the solid strap-based seat was also non-significantly higher than the RH while sitting in the comparison seating systems, 2.0 RH (95% CI -7.0 to 11.0), $p = 0.59$.

4. Discussion

This pilot study measured temperature of seats pre- and post-use, and microclimate characteristics adjacent to the skin-seat interface in two strap-based seating systems as well as in subjects' current wheelchair seating systems. Heat transference occurs from human to the seat during the 100-min testing period, reaching near equilibrium of skin and seat. The measurement of the seat temperature at the moment the participant moved out of the seat

acts as a proxy for skin temperature. Further, the room (ambient air temperature) was cooler than the participant skin temperature. Pron et al. (2017) used thermography to explain the influence of the cushion on heat losses and proposed a convective-radiative model that explains the relationship between the wheelchair user and their cushion and how thermography can capture that relationship [18]. We suggest the faster the cooling capability of the seat, the better opportunity the seat has to reset towards ambient temperature when not fully loaded e.g. during the forward lean pressure relief. Our thermography images demonstrate the solid strap based system cooled faster than the foam based or air cell based systems. Specifically, the temperature of the solid strap-based seating system was significantly lower immediately following transfer out of the wheelchair compared to subjects' usual seating systems. Assuming near equilibrium of temperature at the skin-seat interface [at the end of the trial], this immediate temperature measurement using the thermal camera may provide the best estimate of the temperatures at the skin-seat interface over the entire seating area. Thermal image measurements also showed that the strap-based seats cooled significantly faster than the subjects' usual seating systems, which may be clinically relevant to seat cooling during a 2-min forward lean pressure relief.

We did not find significant differences in the temperature or moisture adjacent to the skin-seat interface in this small ($n = 6$) pilot study. While the environmental temperature and relative humidity were controlled, the initial temperatures near the skin-seat interface varied between subjects; a range of 28.04 °C to 34.71 °C. The initial moistures near the skin-seat interface ranged from 30.07% RH to 68.83% RH. This initial variation in temperature and moisture between subjects can be partially explained by their individual basal metabolisms and autonomic functions. Skin temperature and moisture trends usually correlate positively (i.e., as temperature goes up, so does moisture). In this pilot study, over the course of the 100-min test sessions, the temperature-moisture data did increase in parallel, except for case S3. Where his temperature appeared relatively steady throughout the test sessions, the percent relative humidity rapidly climbed and maxed out by the end of the session in one session (one of the strap-based seats). This may be due to moisture other than the subject's normal skin moisture (e.g. excess sweat) entering the sensor. Interestingly the pressure reliefs (forward lean) conducted every 15 min were visibly evident in Fig. 3, particularly for S3 and S6. A short durational drop in the trend every 15 min signifies a pressure relief, for both temperature and moisture. Sprigle and Eicholtz's (2009) study demonstrates similar breaks in the trend lines with pressure reliefs [19].

Previous studies have varied in their methods measuring temperature and moisture of the seated area [15–20], such as by type of sensor, sensor placement, and length of time sensing. For this pilot study, we conducted extensive preliminary testing to ensure our data gathering methods were sensitive to microclimate changes and safe for the subjects. For example, like Hsu and colleagues we found that changes in temperature on one side of the body correlated with changes on the other side, thus validating conducting measurement on one side [15]. Also, we were trying to measure differences *between seats* so it was more important to use a consistent location. For safety purposes, to limit skin integrity issues for this high-risk population who lack sensation, and for practical management during transfers of the wires attached to the sensor, we chose the one sensor placed on the right medial thigh, forward of the ischial tuberosity, adjacent to the skin-seat interface. A limitation to note is that our

single sensor measurement of temperature and moisture was adjacent to the skin-seat interface, not between the skin and seat. This placement was important for safety of the subjects, but may not provide reliable measurement of seating microclimate properties to other studies that place the sensor between the skin and the seat. We chose methods based on our preliminary work and this method appeared to be the best pathway for testing these three seating systems in a safe manner. We also want to clarify that we did not adjust the covers to be the same for each seat. It is known that fabric affects the wicking of moisture away from the skin, therefore one seat cover may have made a difference over the other. The reason for not standardizing covers is that we wanted to measure the seats as they are used in the real world. Therefore, we used the standard seat covers for each seating system. To expand, the strap-based seating systems use a silklike, breathable fabric (<https://glidewear.com/shop/pressure-ulcer-wheelchair-cushion-cover/>), the foam-based seating system uses a spacer mesh fabric (<http://www.ridedesigns.com/ride-custom-2-cushion-wheelchairs>), and the air-cell based system uses a two-way stretch, fluid-resistant polyurethane-coated polyester fabric (<https://www.permobilus.com/product/roho-standard-heavy-duty-cushion-cover/>). Again, this limits comparability to studies that have removed the covers [15] or standardized the covers for lab testing purposes [16].

Future work is needed to develop thin sensors that are safe to use at the skin-seat interface, rather than near the interface. In the meantime, thermal images of seating systems may provide useful insight into wheelchair seating microclimate properties. Further it is possible that these data can be verified by using finite element modeling [21] to better inform the research community about the properties of the tested seating systems.

5. Conclusion

Using thermal imagery, we found that the solid strap-based seating system was cooler immediately after use, and that both strap-based seating systems cool down faster after being vacated than the standard seating systems tested. There were no conclusive findings regarding the strap-based seating systems temperature and moisture management compared to the other seating systems, as measured by a single sensor near the skin-seat interface. This small pilot study demonstrates the wide variability in individual body temperature and moisture, underlining a need for safe, effective wheelchair seating options. Further testing is needed to understand fully the microclimate management capabilities of the strap-based systems and their full effects on clinical outcomes. For now, it appears that the strap-based system does allow for more rapid cooling when vacated, meaning that a full forward lean pressure relief maneuver may allow more air flow to cool off, more than that of the comparator foam based or air cell based seating system.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Declarations of interest

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Abbreviations

C	Celsius
C-5-7	Cervical spine, 5th through 7th vertebrae level
RH	Relative humidity
S	Subject
SCI	Spinal cord injury
SCI/D	Spinal cord injuries and disorders
T-5	Thoracic spine at 5th vertebrae level

References

- [1]. Sonenblum SE , Sprigle SH . Some people move it, move it... for pressure injury prevention. J Spinal Cord Med 2016; 11 4:1–5.
- [2]. Martin JS . Everyday sitting behavior of full-time wheelchair users. J Rehabil Res Dev 2016 53(5):585.27898157
- [3]. Dealey C , Rrindle CT , Black J , Alves P , Santamaria N , Call E , Clark M . Challenges in pressure ulcer prevention. Int Wound J 2015 6 1;12(3):309–12.23786251
- [4]. Gefen. 2007 How much time does it take to get a pressure ulcer? Integrated evidence from human, animal, and in vitro studies. Ostomy/Wound Manag 2008 10;54(10):26–8.
- [5]. National Pressure Ulcer Advisory Panel. European pressure ulcer advisory Panel and Pan pacific pressure injury alliance In: Emily Haesler , editor. Prevention and treatment of pressure ulcers: clinical practice guideline. Osborne Park, Australia: Cambridge Media; 2014.
- [6]. Yusuf S , Okuwa M , Shigeta Y , Dai M , Iuchi T , Rahman S , Usman A , Kasim S , Sugama J , Nakatani T , Sanada H . Microclimate and development of pressure ulcers and superficial skin changes. Int Wound J 2015 2 1; 12(1):40–6.23490303
- [7]. Krassioukov AV , Karlsson AK , Wecht JM , Wuermser LA , Mathias CJ , Marino RJ . Assessment of autonomic dysfunction following spinal cord injury: rationale for additions to International Standards for Neurological Assessment. JRRD (J Rehabil Res Dev) 2007;44(1):103–12.
- [8]. Sprigle S , Sonenblum S . Assessing evidence supporting redistribution of pressure for pressure ulcer prevention: a review. JRRD (J Rehabil Res Dev) 2011;48(3):203–14.
- [9]. Moore Z , van Etten M . Ten top tips: seating and pressure ulcer prevention. Wounds Int 2015;6(2): 6–11.
- [10]. Regan M , Teasell RW , Keast D , Aubut JL , Foulon BL , Mehta S . Pressure ulcers following spinal cord injury In: Eng JJ , Teasell RW , Miller WC , Wolfe DL , Townson AF , Hsieh JTC , Connolly SJ , Mehta S , Sakakibara BM , editors. Spinal cord injury rehabilitation evidence. 2010 Version 3.0.
- [11]. Gefen A How do microclimate factors affect the risk for superficial pressure ulcers: a mathematical modeling study. J Tissue Viability 2011 8 31;20(3):81–8.21115351
- [12]. Angelidis IK , Lidman D , Sjöberg F , Thorfinn J . Decubitus ulcer development: pressure alone increases tissue temperature. Eur J Plast Surg 2009;32:241–4.
- [13]. Ferguson-Pell . Thermodynamic rigid cushion loading indenter: a buttock-shaped temperature and humidity measurement system for cushioning surfaces under anatomical compression conditions. J Rehabil Res Dev 2009 8 10;46(7):945.20104417

- [14]. Ferguson JE , Wittig BL , Payette M , Goldish GD , Hansen AH . Pilot study of a strap-based custom wheelchair seating system in persons with spinal cord injury. *JRRD (J Rehabil Res Dev)* 2014;51(8):1255–64.
- [15]. Hsu TW , Yang SY , Liu JT , Pan CT , Yang YS . The effect of cushion properties on skin temperature and humidity at the body-support interface. *Assist Technol* 2016 9 29:1–8.27184731
- [16]. Liu Z , Cascioli V , Heusch AI , McCarthy PW . Studying thermal characteristics of seating materials by recording temperature from 3 positions at the seat-subject interface. *J Tissue Viability* 2011 8 31;20(3):73–80.21646019
- [17]. McCarthy PW , Liu Z , Heusch AI , Cascioli V . Assessment of humidity and temperature sensors and their application to seating. *J Med Eng Technol* 2009 1 1;33(6):449–53.19479607
- [18]. Pron H , Taiar R , Rui HT , Lestriez P , Polidori G . Infrared thermography applied to the study of the thermal behavior of wheelchair cushion. *Comput Meth Biomech Biomed Eng* 2017 10 30;20(supl):167–8.
- [19]. Sprigle S , Eicholtz M . Temperature and Humidity at the Buttock-Wheelchair Cushion Interface. 2013 Available from: <http://rearlab.gatech.edu/publications/TempHumidity.pdf>.
- [20]. Stockton L , Rithalia S . Pressure-reducing cushions: perceptions of comfort from the wheelchair users' perspective using interface pressure, temperature and humidity measurements. *J Tissue Viability* 2009 5 31; 18(2):28–35.19329031
- [21]. Zeevi T , Levy A , Rauner N , Gefen A . Effects of ambient conditions on the risk of pressure injuries in bedridden patients—multi-physics modelling of microclimate. *Int Wound J* 2017 12 17:1–15.

Fig. 1.

Images of the four seating systems tested for microclimate characteristics including two strap-based seating systems, a foam-based and an air cell-based seating system.

Fig. 2. Thermal images of four test seats.

First row: Pre-seating thermal images (at room temperature), Second row: Thermal images immediately after the subject transferred out of the seat after sitting for 100 min, and Third row: Thermal images 5 min after the transfer. For actual values please see Supplemental Data Set.

Fig. 3. Temperatures (°C) and moistures (RH) near the skin-seat interface.

Table 1

Subject demographics.

Subject ^b	Age	Sex	BMI	Level Of Injury	AIS	Cause of Injury	Years Since Injury	Current Seat
S1 ^a	55	M	22.96	T-5	A	MVA	34	Foam
S2	43	M	21.72	T-4	A	Fall off ladder	8	Foam
S3 ^{ab}	71	M	22.68	T-12	A	MVA	52	Foam
S4	70	M	31.08	T-10	@	Spastic paraplegia	20	Air-cell
S5 ^a	56	M	26.91	C-5-7	A	Diving Accident	36	Air-cell
S6	65	M	23.14	T-11	A	MVA	10	Air-cell

@ Not applicable to this subject.

BMI: Body mass Index; AIS: American Spinal Injury Association Impairment Scale; MVA motor vehicle accident.

^a Adjustments to subjects' current seating system needed prior to initiating this study.

^b Visits 2 and 3 delayed due to a discovered small Stage II pressure injury.

Table 2

Mean (SD) seat temperatures (°C) (n = 6).

Seating system	Seat Temperature (SD)		Seat Temperature (SD)		Temperature Change	
	Pre-seated	Immediately after transfer	Five-minutes after transfer	Pre-seated to Immediately after transfer	Immediately after to five- minutes after transfer	
Perforated Strap-Based	23.68 (1.48)	31.48 (1.00)	26.07 (0.96)	7.8 (0.98)	-5.42 (1.05)	
Solid Strap-based	23.97 (1.08)	30.23 (1.70)	25.87 (0.45)	6.27 (1.9)	-4.37 (1.68)	
Combined Air-cell/Foam-Based	24.57 (1.28)	31.65 (1.26)	27.25 (0.86)	7.08 (1.61)	-4.4 (1.27)	

Table 3

Temperatures (°C) near the skin-seat interface immediately after transfer to wheelchair and at 5, 95, 99 and 100 min (n = 6).

Seating system	Temperature (SD)	Temperature (SD)	Temperature (SD)	Temperature (SD)	Temperature (SD)
	After Transfer	At Minute 5	At Minute 95	At Minute 99	At Minute 100
Perforated Strap-Based	31.96 (1.9)	32.76 (1.86)	34.23 (1.2)	34.27 (1.23)	34.28 (1.21)
Solid Strap-Based	32.4 (2.1)	33.03 (1.81)	34.49 (1.05)	34.49 (1.02)	34.51 (1.01)
Combined Air-cell/Foam-Based	31.82 (2.15)	32.81 (1.47)	34.52 (1.27)	34.57 (1.26)	34.6 (1.27)

Table 4

Relative humidity near the skin-seat interface immediately after transfer to wheelchair, and at 5, 95, 99 and 100 min (n = 6).

Seating system	RH (SD)	RH (SD)	RH (SD)	RH (SD)	RH (SD)
	After Transfer	At Minute 5	At Minute 95	At Minute 99	At Minute 100
Perforated Strap-Based	51.22 (13.37)	69.54 (12.48)	84.16 (12.1)	84.21 (12.83)	84.25 (12.82)
Solid Strap-based	50.86 (5.1)	62.89 (7.37)	81.93 (9.42)	82.16 (9.43)	82.21 (9.49)
Combined Air-cell/Foam-Based	47.90 (12.53)	63.59 (9.07)	81.53 (7.7)	82.24 (8.53)	82.4 (8.6)