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Determining frictional properties of pants and cushion cover materials using human soft tissue and a rigid sled and how they affect seated shear forces

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ABSTRACT

Shear forces on the buttocks while seated are directly linked to friction, yet the frictional properties at the seat interface are unknown. Shear forces are one of the factors related to increase risk of pressure injury formation. The goals of this study included determining coefficients of friction between three cushion covers and two clothing fabrics using a mechanical system as well as human participants and to evaluate the impact of the cushion covers on shear loading on the buttocks while seated. A chair with separate seat pan tilt and back recline movements was built and instrumented with reflective markers and a load cell. A motion capture system and load cell were used to determine the angles of seat pan tilt at which the sled and participants started sliding, as well as shear forces at three recline angles for three cushion covers (vinyl, one-layer nylon, and two-layer nylon). Results showed the vinyl and two-layer nylon cushion covers respectively had the largest and smallest coefficients of friction for both pants materials. The coefficients of friction calculated with the human participants and rigid sled were within 10% of each other, demonstrating similar results. Further, increasing back recline increased shear load on the buttocks, while the two-layer nylon cover reduced shear forces seen on the buttocks. This work furthers the understanding of shear loading on the buttocks, will aid in the protocols for reducing pressure injuries, and suggests that coefficients of friction found using rigid bodies may be applied to deformable bodies.

1. Introduction

There are over 3 million wheelchair users living in the United States, each of whom have as high as an 80% lifetime risk of experiencing at least one pressure injury (PI) (Brault, 2012; Hubli et al., 2020). Incidences of PIs are highly disruptive; treatment involves extended time in the prone position to offload the area around the wound, debridement of the wound, and dressings, among other treatment strategies (Whitney et al., 2006). Further, treatment costs of PIs total about $27 billion in the United States each year (Padula & Delarmente, 2019). Thus, PIs are widespread, disruptive, and expensive.

Shear loading on the skin is consistently cited in the development of PIs (Bergstrom et al., 1987; Bouten et al., 2003; Hanson et al., 2010; Hoogendoorn et al., 2017; Reichel, 1958). Shear forces have been implicated in PI formation because they cause internal tissue stresses. Finite element models have been used to estimate these internal stresses (Lachenbruch et al., 2015; Linder-Ganz & Gefen, 2007; Macron et al., 2018; A. Manorama et al., 2013; Ming Zhang & Roberts, 1993; Oomens et al., 2016; Verver et al., 2004; Wu et al., 2004). Further, experimental work has shown that shear decreases blood perfusion. Both internal stress and reduced blood perfusion contributed to tissue necrosis over time, leading to PI formation.

Soft tissues in the buttocks and thighs have been shown to experience shear loading while seated, creating a higher risk for PI development (Bush, 2006; A. Manorama et al., 2013). Almost half of all pressure injuries occurred in the buttocks and thighs, indicating a need to address loading in those regions (Horn et al., 2002). Despite evidence showing that the buttocks and thighs experienced increased shear forces while sitting in reclined positions, studies showed they were the most popular positions for wheelchair users and were commonly prescribed for pressure relief (Dicianno et al., 2009; Ding et al., 2008; Harrand & Bannigan, 2016; Hobson, 1992; Kobara et al., 2014). The popularity of reclined positions, paired with increased shear forces and prevalence of PIs, underscore a need to reduce the shear loading on the buttocks and

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thighs while seated. Other common positions in which shear may be increased, such as positions during transfers from a chair to another surface, may further be affected by changing the friction properties of the cushion cover. Since manual transfers between surfaces rely on the person sliding across the chair, reducing the friction on the cushion cover may make it easier to slide and therefore, reduce shear force simultaneously. There are multiple activities that highlight the importance of the frictional properties of the cushion cover, pants material, and the interaction between the two.

Shear load may be reduced is by selecting materials for the cushion covers that have low coefficients of friction. Materials with low coefficients of friction support relatively small shear forces before they start to slide. While decreasing shear on the seat pan may increase the likelihood of an occupant sliding out of position, supports can be added to facilitate positioning while reducing shear in the buttocks region. By using materials with low coefficients of friction for a cushion cover, the maximum amount of friction is reduced, which provides a mechanism by which shear on the buttocks and thighs can be reduced, thus addressing one factor related to PI risk.

Friction is generated by contact between two surfaces; and thus the interaction between the cushion cover material and that of clothing is an important factor to understand. Numerous studies investigated friction between skin and textiles commonly used to make clothes (Bergstrom et al., 1987; Gerhardt et al., 2008; Klaassen et al., 2016; Schwartz et al., 2018; Tiell et al., 2021). These have shown that coefficients of friction between skin and cotton are approximately 0.54 (Zhang & Mak, 1999) and that several factors such as knit or woven fabric construction affect friction (Ajayi', 1992a,b). Additionally, factors like skin moisture increase friction (Schwartz et al., 2018). Understanding the frictional properties of skin, clothing, seat cover fabric, and how they change with environmental factors like moisture, is integral to understanding which pair of materials will sustain more shear force before sliding, which one will slide on each other, and the potential results on the skin. However, there is a dearth of literature describing the friction generated between cushion cover materials and materials commonly used to make pants, particularly while in the seated position. Shear forces generated between the pants and cushion cover are transferred to the tissue making this interaction between directly related to the generation of shear force on the buttocks and thigh tissues. Studies have shown that shear forces on the external surfaces of wound dressings result in proportional shear forces experienced at the skin surface, which ultimately related to shear forces in the subcutaneous tissues (Nakagami et al., 2006; Ohura et al., 2008). As such, there is a need to evaluate the frictional properties of cushion covers when paired with different clothing materials.

Therefore, the goals of this study were 1) to determine the coefficients of friction between three cushion covers (vinyl, one-layer nylon, and two-layer nylon) and two fabrics commonly used to make pants (cotton denim and cotton-polyester blend sweatpants) using a mechanical system, 2) to compare the coefficients of friction found using the mechanical system to those obtained with human participants, and 3) use a chair with back recline to evaluate the ability of the cushion covers to reduce shear loading on the buttocks and thighs while seated in *reclined positions*.

2. Materials and methods

2.1. Overview

Three specific hypotheses were tested in this work. The first hypothesis was that the coefficients of friction with covers made from nylon had smaller coefficients of friction than those with vinyl covers. This was tested using a weighted sled to simulate the buttocks. The second hypothesis was that coefficients of friction could be determined using humans and that the frictional coefficients would be the same with either the sled or the humans, even though humans have deformable soft tissue in their buttocks and thighs. The third hypothesis was that the seat pan covers would affect the shear forces on the buttocks and thighs while seated **in reclined positions**. A custom articulating chair capable of measuring shear and normal forces on the seat pan with independent seat pan tilt and recline was used to conduct all experiments. All experiments were conducted with three materials that are either commonly used in current cushion covers (vinyl) or being proposed as an alternative (one layer of nylon and two layers of nylon) paired with two pants materials (cotton denim and cotton-polyester blend sweatpants). The cotton denim was a twill weave with a thickness of 0.84 mm, and the sweatpants were a knit fabric with a fleece backing and an uncompressed thickness of 2.2 mm (1.5 mm with fleece compressed).

2.2. Articulating chair design

A custom articulating chair was manufactured for this research with independent, motor-driven back recline and seat pan tilt movements. The back was able to recline rearward from vertical to 20°, and the seat pan was able to tilt up to 40° from horizontal such that the anterior edge of the seat pan was higher than the posterior edge. The seat pan was mounted on a six-axis load cell (AMTI, Watertown, MA) to collect normal and shear force data on the seat pan during testing. Calibration of the load cell confirmed that it was accurate to within two Newtons of force in each direction.

2.3. Determination of coefficients of friction via a Non-Deformable system

Static and kinetic coefficients of friction were determined for all pant materials and cushion covers using a sled (Table 1). The sled had a square cross-sectional area of 225 cm^2, was designed to hold 45 N of weight, equivalent to the weight carried by the ischial tuberosities while seated, and had interchangeable fabrics securely attached (Mendes et al., 2019; Sprigle et al., 2003). Cover materials were secured with Velcro. For the two-layer nylon cover, the top layer of nylon was only attached to the posterior edge of the seat pan to ensure that it could freely slide on top of the bottom layer. Four reflective motion capture markers were attached to the sled to determine its position in space (markers S1-4 in Fig. 1).

To determine the static and kinetic coefficients of friction of the different material pairings, motion capture data were obtained (60 Hz) to determine the position of the sled and the orientation of the seat pan. The sled position ($\vec{s}$) was the average position of the four markers on the sled. The orientation of tilt of the seat pan was determined using two of the markers (Front left (FL) and back left (BL) in Fig. 1) and Eq. (1).

$$\hat{e}_1 = \frac{\vec{FL} - \vec{BL}}{\| \vec{FL} - \vec{BL} \|} \quad (1)$$

where $\vec{FL}$ was the position vector of marker FL, $\vec{BL}$ was the position vector of marker BL, and $\hat{e}_1$ was the unit vector that represented the orientation of the seat pan. The angle of tilt of the seat pan was determined using vector $\hat{e}_1$ and Eq. (2).

$$\theta_{spt} = \tan^{-1}\left(\frac{\hat{e}_{1,z}}{\hat{e}_{1,y}}\right) \quad (2)$$

where $\hat{e}_{1,y}$ was the y-component of the seat pan orientation vector, $e_{1,z}$ was the z-component of the seat pan orientation vector, and θ_{spt} was

Table 1
Pants materials and seat pan cover materials. Material pairings included all combinations between the two columns.

seat pan cover material	sled bottom material
vinyl	denim (100 % cotton)
one-layer nylon	cotton (60 %)-polyester (40 %) blend
two-layer nylon	

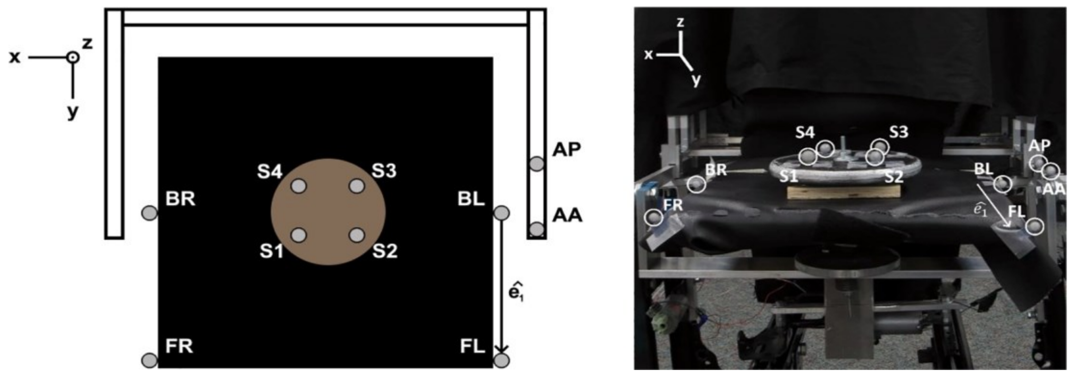

Fig. 1. Top down (left) and front (right) views of the articulating chair setup for the sled testing. The markers on the front right (FR), front left (FL), back left (BL), and back right (BR) were used to determine the orientation of the seat pan (e_1). The markers on the sled, S1-4, were used to determine the sled's position. The anterior (AA) and posterior (AP) markers on the chair back were used to determine the angle of back recline. All positions were given in the coordinate systems in the top left of the views.

the angle of tilt of the seat pan. The sled position along the seat pan was calculated using the orientation of the seat pan and the positions of the sled and marker BL in space. This is described in Eq. (3).

$$\vec{r} = e_1 \bullet \left(\vec{s} - \vec{BL}\right) \quad (3)$$

where r was the sled position along the seat pan.

The sled was placed on the seat pan while it had 0° of tilt (horizontal). The seat pan was then tilted until the sled started to slide. Just after the sled started to slide, the angle of tilt ($\theta_{spt,max}$) was held constant. The only forces acting on the sled were gravity, friction parallel to the seat pan, and the force normal to the seat pan (Fig. 2). As such, the static coefficient of friction (μ_s) for the material pairing was determined using Eqs. (4) through Eq. (6).

$$\Sigma F_t = \mu_s mg\cos\left(\theta_{t,max}\right) - mg\sin\left(\theta_{t,max}\right) = 0 \quad (4)$$

$$\mu_s mg\cos\left(\theta_{t,max}\right) = mg\sin\left(\theta_{t,max}\right) \quad (5)$$

$$\mu_s = \tan\left(\theta_{t,max}\right) \quad (6)$$

Motion of the sled was along the seat pan orientation vector (e_1). Thus, the acceleration (a) was determined by using changes in the position of the sled along the seat pan (r) to determine mean acceleration between frames. Velocity was first calculated from the change in position along the seat pan between frames. With a known data collection frequency, the change in position was divided by the time between frames to determine the sled velocity. Changes in velocity between frames were then divided by the time between frames to determine the sled acceleration. The sled acceleration while sliding was used to determine the kinetic coefficient of friction (μ_k) for the material paring using Eq. (7).

$$\mu_k = \tan\left(\theta_{t,max}\right) - \frac{|a|}{g\cos\left(\theta_{t,max}\right)} \quad (7)$$

where g was the gravitational constant (9.81 $\frac{m}{s^2}$). Ten trials were conducted for each material pairing, and the coefficients of friction were averaged across the trials.

2.4. Coefficients of friction with human participants

Coefficients of friction were computed with data sets collected with human participants. Ten able-bodied individuals (5 male, 5 female) consented to participate (IRB #16−681). People who weighed over 250 lb (1110 N) were excluded from this study due to restrictions on motor capacity.

As with the prior hypothesis, four reflective markers were attached to the seat pan. Movement data were obtained from reflective markers attached bilaterally on the participants' greater trochanters (Fig. 3). Participants were tested in two pairs of pants: denim jeans and cotton-polyester blend sweatpants, the same fabrics used with the sled. Additionally, the same three cushion covers were tested for a total of six testing conditions (Table 1).

Participants all started in the same seated configuration. The seat pan had 0° of tilt, and the back of the participants' buttocks were 15 cm from the posterior edge of the seat pan, with their hands placed in their laps. Participants were instructed to sit in an upright posture and not contact the back of the chair with any part of their back (Fig. 4a and Fig. 4b). The seat pan was then tilted until the participant slid (Fig. 4c). The orientation and angle of the seat pan tilt were calculated using Eqs. (1) and (2). The average position of the lateral epicondyles was recorded relative to the seat pan, similarly to the position of the sled in the previous section. The average position of the markers on the lateral epicondyles was used to determine when the participant slid (Eq. 8).

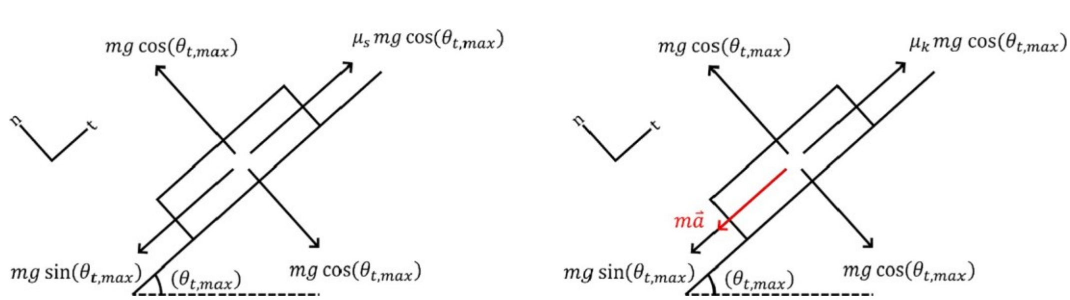

Fig. 2. Free body diagrams for the sled before (left) and after (right) it starts to slide. The friction before the sled starts to slide is determined by the static coefficient of friction (μ_s), and the friction after it starts to slide is determined by the kinetic coefficient of friction (μ_k).

Fig. 3. Reflective marker placements on the greater trochanters.

$$\vec{q} = e_1 \bullet \left(\vec{k} - \vec{BL}\right)$$

where k was the average position vector of the markers attached to the lateral epicondyles, and q was the average position of lateral epicondyles along the seat pan. The acceleration of the knees was found using the same process that was used to obtain the acceleration of the sled, and the static and kinetic coefficients of friction were calculated using Eqs. (6) and (7), respectively. Three trials were conducted for each participant wearing each pair of pants on each cushion cover, and coefficients of friction were averaged across trials.

2.5. Evaluating the effects of seat pan cover on the shear forces while seated

Motion capture data of the participant and chair, and shear force data on the seat pan, were collected while participants sat in the articulating chair at multiple recline angles. All six material pairings were tested. Participants sat on the articulating chair with their buttocks touching the chair back, their hands in their laps, and their feet resting on a footrest with 90° of flexion in the knees. The back was reclined to 17° past vertical and then moved back to the 0° recline (vertical) position while the seat pan remained horizontal. Participants then stood to prepare for the next trial. Three trials were conducted for each material pairing.

Motion capture and shear force data were used to determine the recline angle of the back and shear force on the seat pan. Two markers (AA and AP, Fig. 1) were used to determine the angle of back recline. The shear forces in the anterior-posterior direction of the seat pan were recorded by the load cell continuously throughout recline and incline motions. Shear data were obtained at 5°, 10°, and 15° of back recline for each trial.

2.6. Statistical analysis

A three-way repeated measures ANOVA was used to determine the effects of recline angle, pants material, and seat pan cover material on the shear forces on the seat pan. Different levels (3) of recline, pants materials (2), and seat pan covers (3) were all treated as classes. The effects of interactions between the pants materials and seat pan covers

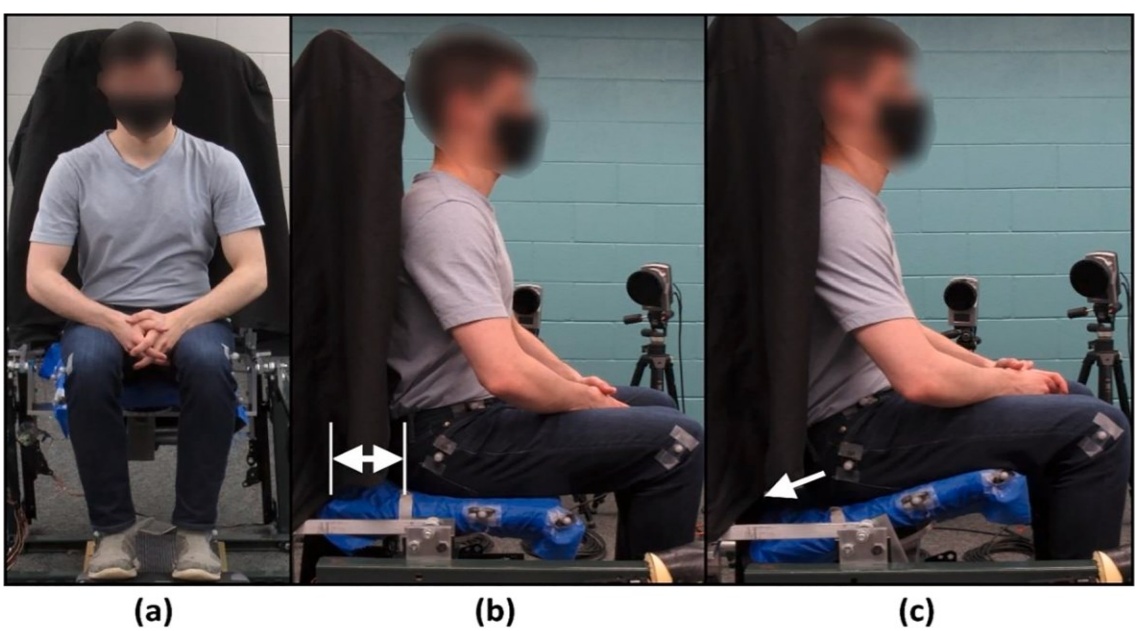

Fig. 4. (a) Front view of a participant sitting on a flat seat pan, (b) side view of a participant sitting on a flat seat pan, with the arrow indicating the space between the participant and the chair back, (c) participant sitting on a tilted seat pan just before starting to slide.

on shear force were also investigated. Tukey tests were used to identify significant differences between the shear forces with different recline angles, pants materials, and seat pan covers with p values less than 0.05. Effect sizes for the differences in seated shear forces with the different material pairings were determined using Cohen's D method.

3. Results

3.1. Coefficients of friction with the sled

The coefficients of friction as found from the weighted sled are reported in Fig. 5 and Table 2. The static and kinetic coefficients of friction were largest for the vinyl cover, regardless of pants material; and the coefficients of friction were smallest for the two-layer nylon cover for both pant materials. The reduction in both *static* and *kinetic* coefficients of friction when switching the cover from vinyl to the one-layer nylon cover was 10% for the denim pants material and 26% for the cotton-polyester blend. The two pants materials had similar coefficients of friction when interacting with the two-layer nylon seat pan cover. For all material pairings, the *kinetic* coefficients were smaller than the *static* coefficients of friction by a range of 2–9%, with the smallest change occurring in the denim on two-layer nylon cover and the largest change occurring in the cotton-polyester blend on one-layer nylon cover.

3.2. Coefficients of friction with human participants

Five able-bodied males (average age 22.4 ± 3.1 years, average height = 181.4 ± 5.0 cm, average weight = 754.7 ± 85.9 N) and five able-bodied females (average age 23.0 ± 6.2 years, average height = 162.6 ± 10.5 cm, average weight = 607.9 ± 39.3 N) participated in this study. The coefficients of friction as found from the human participants are reported in Fig. 6 and Table 2. Coefficients of friction were not found with human participants when a vinyl seat pan cover was tested because the angle of tilt needed start the participant sliding was too great (>30°), so participants were unable to keep their backs from contacting the back of the chair, affecting friction computations.

For both pairs of pants, the coefficients of friction were smaller on the two-layer nylon cover than on the one-layer nylon cover. The kinetic coefficients of friction determined from the human trials were between 2.5 and 3.5% smaller than the static coefficients of friction.

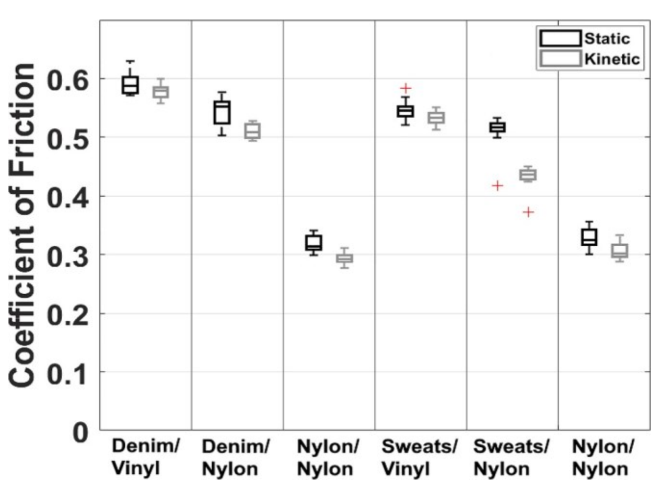

Fig. 5. Box plots of the coefficients of friction for each of the material pairings, found using the sled to simulate the buttocks. Darker boxes represent static coefficients of friction, while lighter boxes are kinetic coefficients of friction. The center nylon/nylon boxes were determined with denim pants fabric, and the rightmost nylon/nylon boxes were determined with sweats pants fabric. Plusses (+) indicate outliers.

3.3. Effects of back Recline, pants Materials, and seat pan covers on shear forces

The shear forces on the seat pan with all three covers and both pants materials at three recline angles are reported in Fig. 7. All shear forces reported are in the anterior direction of the seat pan (+y in Fig. 1). The data indicated that increasing back recline increased the shear force on the seat pan **regardless of seat pan cover** ($p < .0001$). Data also indicated that there were no significant differences ($p = .220$) between pants material with respect to the shear forces on the seat pan, though there was a trend towards denim reducing shear force. Further, the seat pan cover did not significantly affect the shear force on the seat pan, either ($p = .2838$). However, the two-layer nylon cover reduced shear force on the seat pan by about 20% relative to the vinyl cover across the pants materials. Interaction effects between the recline angle and material pairing were investigated, but there were no significant findings.

Interactions between the pants materials and seat pan covers were also investigated, and the data showed that shear forces on the seat pan decreased when participants wore the cotton-polyester blend pants and sat on the vinyl, one-layer nylon, and two-layer nylon cover, respectively. This trend mirrored the decreases in coefficients of friction observed with these material pairings, however the same trend did was not observed with the denim pants on the three seat pan covers. Specific pants and seat pan cover material interactions showed that denim on vinyl had less shear force than cotton-polyester blend on vinyl ($p = .0071$) and denim on one-layer nylon ($p = .0370$). Denim on two-layer nylon ($p = .0258$) and cotton-polyester blend on two-layer nylon ($p = .0487$) also had less shear force than cotton-polyester blend on vinyl. No other statistically significant interactions were found.

4. Discussion

This study developed a method to investigate the interaction between the materials of the pants and seat covers for the application of wheelchairs and their users, resulting in datasets with implications for seat cover material choice. Data indicated that the nylon covers had smaller coefficients of friction compared to the vinyl cover. This was significant as many standard wheelchairs have a sling made from vinyl. Consideration to using nylon covers should be given as data showed that shear forces supported were smaller than those that of the vinyl cover, providing one mechanism by which shear may be reduced on the buttocks and thighs of wheelchair users.

The results of this study show promise that rigid sleds may be used as an approximate deformable tissue analog because the coefficients of friction calculated with both the humans and rigid sled were within 10% of each other and had the same trends. Experiments with rigid sleds were more repeatable than those with human participants, as evidenced by the smaller standard deviations of the coefficients of friction found using the sled. It is important to note that there are larger variations when testing with humans, and it is expected that these variations will be related to body habitus including health condition that the sled may be unable to capture. Thus, a range of people will need to be tested to describe frictional variations. Because the sled removes human variation, it provides a method to consistently determine coefficients of friction for materials, but understanding marginal variations in friction due to body habitus necessitates studying a range of people.

This work also impacts current clinical care and best practices. Current practices include the use of back recline to redistribute pressure while seated. Although a global analysis might indicate that the *total normal force on the seat pan* is reduced as more normal force goes onto the seat back, when we focus on the region of high PI incidence, which is the ischial tuberosity region toward the back of the buttocks, this trend is not true. Previous work has shown that between the recline angles of 0° and 30°, normal forces on the buttocks, specifically over the ischial tuberosities, increased with back recline (Hobson, 1992; Scott & Bush, 2021). This increase in the normal force on the buttocks was due to a

Table 2
Coefficients of friction for all material pairings of pants and cover materials.

		Cover Material					
		Vinyl	One-Layer Nylon	Two-Layer Nylon			
		μ_s	μ_k	μ_s	μ_k	μ_s	μ_k
Sled Trials							
Pants Material	Denim	0.61 ± 0.02	0.58 ± 0.02	0.55 ± 0.05	0.52 ± 0.03	0.27 ± 0.01	0.27 ± 0.01
	Sweatpants	0.58 ± 0.02	0.53 ± 0.01	0.43 ± 0.02	0.39 ± 0.01	0.27 ± 0.01	0.26 ± 0.01
Human Trials							
Pants Material	Denim	–	–	0.50 ± 0.04	0.48 ± 0.06	0.29 ± 0.06	0.29 ± 0.06
	Sweatpants	–	–	0.44 ± 0.07	0.43 ± 0.07	0.30 ± 0.04	0.29 ± 0.04

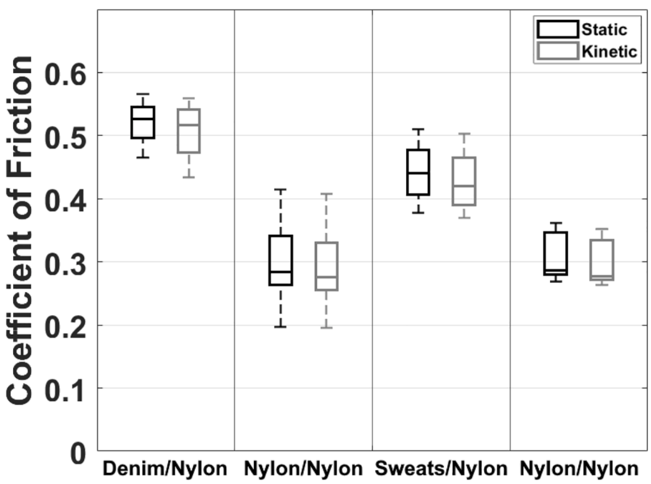

Fig. 6. Box plots of the coefficients of friction for each of the material pairings, found using human participants. Darker boxes represent static coefficients of friction, while lighter boxes are kinetic coefficients of friction. The center nylon/nylon boxes were determined with denim pants fabric, and the rightmost nylon/nylon boxes were determined with sweats pants fabric.

shift of the load from the thighs on the front of the seat pan to the buttocks/ischial region. When there is an increase in normal force over a region, and friction is present, there is potential for the shear force to also increase. Thus, use of back recline was also shown to increase shear forces on the buttocks. Together, these findings suggest that the current practice of using back recline as a prevention method for PIs in the buttocks should be reconsidered (Hobson, 1992). As stated, this is in contrast to current clinical practice and *some* evidence provided by other researchers (Jan et al., 2010; Zemp et al., 2019). However, our data suggests that these increases in normal and shear pressures increase tissue stress and decrease perfusion, thereby increasing the risk of PI formation (A. A. Manorama et al., 2010; Ming Zhang & Roberts, 1993; Zhang et al., 1994). To remedy this, alternative seated positions or strategies should be explored to mitigate risk factors associated with pressure injuries.

From a PI prevention perspective, it was essential to identify material pairings that could reduce shear force on the buttocks and thighs while seated. In this study, the three material pairings with the smallest amount of shear on the buttocks were denim on vinyl, denim on two-layer nylon, and cotton-polyester blend on two-layer nylon. The denim and cotton-polyester blend on two-layer nylon were both material pairings with low coefficients of friction as found with the sleds and human participants, and they indicated that the two-layer nylon cover has the potential to yield small shear forces on the buttocks and thighs while seated. The two-layer nylon cover decreased the shear force on the buttocks and thighs by about 20% relative to the vinyl cover. The lack of

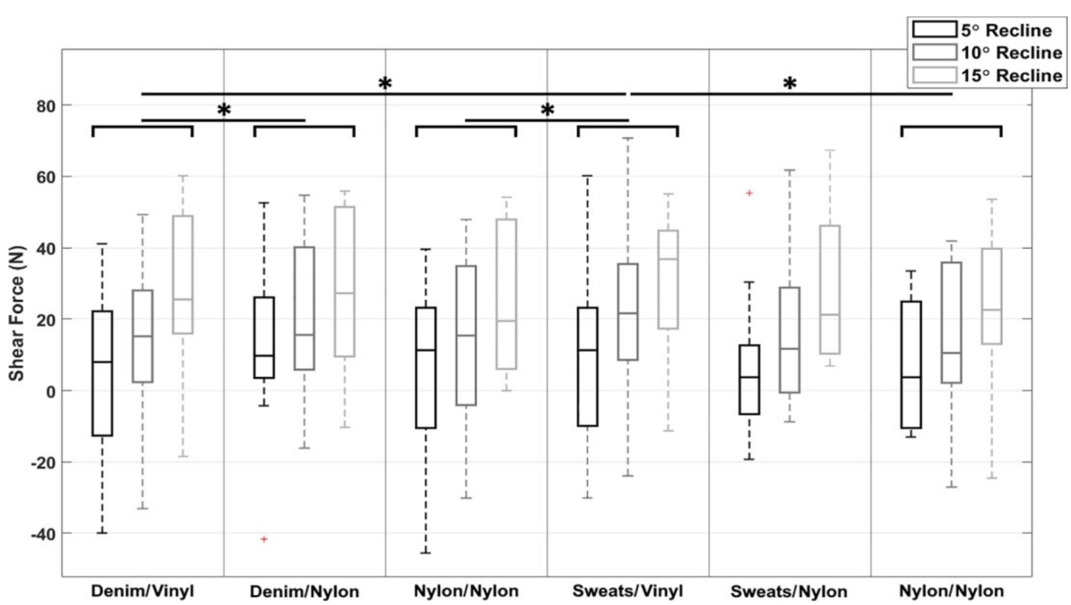

Fig. 7. Shear forces on the seat pan of each material pairing at each angle of recline. All shear forces are in the anterior direction of the seat pan. Recline increased shear force on the seat pan, regardless of the material pairing. Asterisks (*) indicate significant differences in shear forces between material pairs, and plusses (+) indicate outliers. The center nylon/nylon boxes were determined with denim pants fabric, and the rightmost nylon/nylon boxes were determined with sweats pants fabric.

a statistically significant difference was due to large standard deviations of the shear force measurements and a small sample size. An examination of the effect sizes, particularly for the seated position with the largest shear force (15°reline) demonstrated medium effect sizes (~0.4 -0.5) between the two-layer nylon seat pan cover and vinyl cover, which indicated a larger sample would yield statistically significant differences. Now that initial data are available for work related to shear and friction, these can be used to formulate a sample size calculation guiding future work. Nevertheless, that decreasing trend in shear force is likely to reduce tissue stresses in the buttocks and thighs, which results in increased perfusion in the skin in those regions, helping protect the tissues from PI formation.

To implement a shear reducing cover of any kind in a wheelchair, precautions must be taken to ensure that chair occupants do not slide into an unintended position or even out of their chair. Most manual and powered wheelchairs have foot plates mounted in front of the seat pan that provide some protection against the chair occupant sliding forward, and lateral pads and support straps can be implemented as well. The combination of shear reducing covers and wheelchair supports can reduce the risk of PIs and unintended repositioning at the same time.

As an initial study of frictional properties of materials related to friction and shear on the buttocks with seated, there were several limitations in this study. The first limitation was that the sled was not buttock shaped, which may have affected the measured coefficients of friction. Related to that, the weight carried by the sled was consistent with that carried by the ischial tuberosities instead of the entire buttocks. A future study could use a buttocks shaped sled with a realistic distribution of weight that represents that carried by the human buttocks. A second limitation to this work is that the coefficients of friction were not found for pant materials *on the vinyl cover using human participant*s. This was because participants contacted the back of the chair at the large tilt angles needed to overcome static friction with the vinyl cover. The participants touching the back of the chair instead of sliding indicated that the tilting surface method of determining coefficients of friction may not be used for humans and materials with high coefficients of friction. Although the sled was oriented in a consistent fashion, and the cushion fabric was oriented the same throughout all testing, the orientation of the fabrics' weave relative to the participants' sliding were not recorded. How weave and weave orientation affect this interaction should be addressed in future research. While the coefficients of friction are not limited for methods using a sled on a tilting surface, experiments that use human participants need to limit the magnitude of the coefficients of friction tested. This knowledge can be used to help find coefficients of friction for other material pairs that could be used clinically for shear reduction. Finally, expansion of this work to include more factors can potentially differentiate between friction and shear forces experienced by different groups. Future work can explore whether age, racial identity, or disability status might affect the results of friction tests involving skin and textiles. The inclusion of persons with disabilities in particular is necessary to accurately characterize the shear forces experienced by the populations most at risk for developing PIs.

One Sentence Summary:

Initial computations of frictional properties of pants and seat cover materials using human participants and rigid sled suggested that they produced similar results to one another, and the different materials' effects on seated shear forces were studied.

CRediT authorship contribution statement

Justin Scott: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Tamara Reid Bush:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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