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Seat-Interface Pressure: A Pilot Study of the Relationship to Gender, Body Mass Index, and Seating Position

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ABSTRACT. Stinson MD, Porter-Armstrong A, Eakin P. Seat-interface pressure: a pilot study of the relationship to gender, body mass index, and seating position. *Arch Phys Med Rehabil* 2003;84:405-9.

Objectives: To investigate the relationship between interface pressure and gender, body mass index (BMI), and seating positions, and to evaluate the implications for clinical practice.

Design: Group design.

Setting: Pressure mapping laboratory.

Participants: Sixty-three student volunteers (44 women, 19 men; mean age, 22.2 ± 5.1 y).

Interventions: Seated-interface pressure was measured using the Force Sensing Array pressure mapping system. Seating positions used included recline (10° , 20° , 30°), foot support, and foot elevation.

Main Outcome Measures: Interface pressure in the form of both average pressure (mean of the pressure sensor values) and maximum pressure (highest individual sensor value).

Results: Both average and maximum pressures were independent of gender, while average pressure had a significant positive correlation with BMI ($r = .381$, $\alpha = .01$ level). Recline of the chair by 30° significantly reduced average pressure ($P < .001$), whereas recline by 10° or 20° had no significant effect. Recline by 10° , 20° , and 30° did not significantly alter maximum pressure. Elevation of the feet on a footstool reduced average pressure to a level approaching statistical significance, while supporting participants' feet versus leaving them unsupported significantly increased average pressure at a 0° , 10° , 20° , and 30° recline ($P < .01$) and maximum pressure at 0° , 10° ($P < .01$), and 30° ($P < .05$).

Conclusions: Elevating clients' feet and reclining their chair by 30° reduced interface pressure and the associated risk of pressure ulcer development. Additional research is required, however, to replicate this study with participants at increased risk of pressure ulcer development.

Key Words: Pressure; Pressure ulcer; Rehabilitation.

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PRESSURE ULCERS PRESENT a major problem for the National Health Service, costing up to £755 million per annum in England,¹ as well as immense personal cost to the individuals experiencing them. Many factors contribute to their

development. Reduced mobility is a significant risk factor.² Any condition or disease that impairs movement will increase the risk of developing pressure ulcers,³ including pain, excessive sedation, psychiatric illness, orthopedic injury, and neurologic disease.⁴ Sensory impairment may also contribute to pressure ulcer development, for example, in patients with stroke,⁵ diabetes, or spinal injuries.⁶ Reduced sensation leads to insensitivity to pain or discomfort and results in decreased or absent stimulus to move in order to relieve pressure.⁶

Age is another contributing factor, with elderly people having increased susceptibility due to reduced skin elasticity, loss of subcutaneous fat, muscle atrophy, reduced cell proliferation, and collagen disposition.⁷ Elderly people may also experience severely compromised nutrition,⁸ another feature linked to pressure ulcer development. Malnutrition may increase the risk of pressure ulcer development through various pathways, including depletion of lymphocytes and serum proteins,⁹ increased risk of organ failure and serious illness,⁶ and emaciation.² Fecal and urinary incontinence also incur risk toward pressure ulcer development,^{10,11} as well as vascular disease³ and any history of pressure ulcers.¹²

Shear, friction, and pressure are important factors involved in pressure ulcer development. Shear occurs when the deep fascia and skeleton move over the skin and upper fascia, resulting in damage to the vascular supply in the subcutaneous tissues. Shearing forces are an integral part of the effect of pressure and occur, for example, when a patient slides down in bed.⁶ No satisfactory method of measuring shear has been developed.¹³ Friction occurs when 2 surfaces move across each other, often causing damage to superficial layers of skin and is frequently because of poor moving and handling techniques.¹⁴

Although numerous factors are implicated in the development of pressure ulcers, many of which have been outlined previously, the most important is unrelieved pressure.^{13,15-17} Pressure results in compression and possible capillary occlusion and can lead to ischemia if prolonged.⁶ The probability of developing a pressure ulcer is known to increase with the duration and the magnitude of pressure involved,¹⁸ and this in turn depends on the individual's tissue tolerance.¹⁴ It is known that both low and high pressures can lead to pressure ulcer development, depending on duration.¹⁹

Animal studies conducted by Kosiak¹⁵ in 1959 and Daniel et al²⁰ in 1981 and a human study by Reswick and Rogers²¹ in 1976 described an inverse parabolic relationship between pressure and time. That is, high pressure exerted over a short period of time could lead to deep tissue damage, whereas lower pressures exerted over a longer period of time may result in skin and muscle damage.²⁰ It is frequently stated that any load greater than 32mmHg is harmful because it exceeds capillary pressure, thus causing occlusion.²² Sprigle,²² however, emphasizes that this value is a misinterpretation of a 1930 study by Landis²³ and that no specific threshold has yet been identified at which pressure can be considered harmful. Indeed, no controlled investigations have been carried out on pressure and the application time needed to cause pressure ulcers.²⁴ The relationship between interface (or contact) pressure, and pressure

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Table 1: Gender, Height, Weight, and BMI of Participants

Participants	Height (cm)	Weight (kg)	BMI (kg/m ²)
Men (n=19)	179.63±5.24	61.00±10.37	20.29–31.00
Women (n=44)	164.63±5.63	48.50±7.59	17.00–27.84

NOTE. Values are mean ± SD or range.

ulcer prevention, including such variables as acceptable time and pressure limits, requires further research.²⁴

Nevertheless, it is accepted that pressure monitoring at the interface between the body and support surface is important in the assessment of tissue viability²⁵ and in the selection of appropriate pressure-relieving cushions.²⁶ Recent work by Geyer et al²⁷ has shown that higher interface pressures are associated with higher incidence of pressure ulcers in elderly, at-risk clients.²⁷ Interface-pressure measurement may be achieved through pressure mapping techniques. One such pressure mapping system, the Force Sensing Array^a used in our study, has been favorably described by several authors.²⁸⁻³⁰

Measurements from pressure mapping are subject to the influence of many variables. Previous research studies have investigated the relationship between interface pressure and variables such as body mass index (BMI) and seating position^{1,31,32} by using systems other than the Force Sensing Array. Our study attempted to examine the effect of such variables on interface pressure by using the Force Sensing Array system. Furthermore, because several researchers have included male gender as a risk factor for pressure ulcer development,^{11,33} the relationship between gender and interface pressure was also considered.

The purpose of this pilot study was to investigate whether pressure in seating was related to gender or BMI. In addition, this study examined whether changes in seating position (foot elevation; foot support; recline by 10°, 20°, 30°) significantly altered interface pressure readings.

METHODS

Participants

This pilot study was performed with 63 student volunteers (44 women, 19 men), whose mean age ± standard deviation (SD) was 22.2±5.08 years, mean height was 69.2±8.79cm, and mean weight was 67.0±12.4kg. Further details regarding the respective height, weight, and BMI of the participants are included in table 1. The criteria for selection were being able-bodied, aged between 18 and 40 years, and giving written informed consent. Any volunteers fulfilling these criteria were included.

Instrumentation

The Force Sensing Array is a clinical tool used in the assessment of pressure distribution at an interface, that is, between subject and seat. It is comprised of a pressure-sensing mat connected by an interface module to a computer. Data computed from the sensors are presented in various forms, including a color-coded map, 3-dimensional grid, and numeric pressure values.

Procedure

Before the study began, the seat pressure mat was calibrated according to the manufacturer's product manual. The same calibration was used throughout the study to maximize comparability of results. The study took place over a 10-day period. Before pressure measurements were made, the height and

weight of each participant was measured and recorded, and BMI was subsequently calculated (kg/m²).

Interface-pressure readings recorded included both average and maximum pressures, which may be defined as follows: average pressure is the measure of the mean of the sensor values, and maximum pressure is the highest individual sensor.

Procedure for pressure measurement in relation to recline of chair and foot support. During assessment, the pressure mat was placed between the participant and the support surface, an armchair with seat height of 51cm and a manually adjustable ratchet back which reclined by 10°, 20°, and 30° from the neutral position. The chair surface was made from upholstered foam (grade R650F on seat, grade 400H on back). Participants were seated in a relaxed position with arms placed on the armrests and at 90° of flexion at hips, knees, and ankles. In cases in which participants' feet did not reach the floor, feet were supported on blocks to achieve the above posture. Pressure readings were taken at a 0°, 10°, 20°, and 30° recline. The comparative effects on interface pressure between supporting participants' feet on blocks and leaving them unsupported was investigated by recording another set of pressure readings at a 0°, 10°, 20°, and 30° recline with feet unsupported (n=45).

Procedure for pressure measurement in relation to foot elevation. Pressure was recorded with the participants' feet elevated on a 30cm high footstool, legs straight, hips at 90° of flexion, with the chair back at a 0° recline (n=59). Four participants were excluded from this part of the study because of incomplete data collection.

Statistical Analysis

Statistical analysis was performed by using SPSS.^b The Student *t* test was applied to differences in average and maximum pressures with gender, foot support, foot elevation, and various degrees of seat back recline. The Pearson correlation coefficient was used to examine the correlation between interface pressure and the following parameters: height, weight, and BMI.

RESULTS

Gender and Pressure

No significant difference was found in average pressure or maximum pressure between male and female participants (table 2).

BMI and Pressure

No significant correlation was found between height or weight and average pressure. However, a significant correlation ($r=.381$, $P<.01$) between BMI and average pressure was identified. No significant correlation was found between height, weight, or BMI and maximum pressure.

Recline and Pressure

No significant differences in maximum pressure were found between a 0° recline (neutral position) and a 10°, 20°, or 30° recline of the chair back (table 3). No significant difference in average pressure was found between conditions of a 0° recline

Table 2: Average and Maximum Pressure in Relation to Gender

	% Difference Between Men and Women	Significance (<i>t</i> Test)
Average pressure	3.399	.302
Maximum pressure	2.073	.641

Table 3: Maximum Pressure in Relation to Recline of Chair Back

Recline of Chair Back	% Change in Mean Maximum Pressure vs 0° Recline	Significance (t Test)
10°	0.000	1.000
20°	0.463	0.822
30°	1.111	0.649

and both a 10° and 20° recline of chair back. However, a significant reduction in average pressure ($P < .01$ level) was identified between conditions of a 0° and 30° recline of chair back (table 4).

Foot Support and Pressure

A significant increase in average pressure was found by supporting participants' feet at a 0°, 10°, 20°, and 30° recline of seat back (table 5). A significant increase in maximum pressure was found by supporting participants' feet at a 0°, 10° ($P < .01$ level), and 30° recline ($P < .05$ level). No significant difference in maximum pressure was found between not supporting and supporting participants' feet at a 20° back recline, although pressure still increased (table 6).

Feet Elevation and Pressure

No significant difference in average pressure was found between not elevating and elevating the participants' feet on a 30cm footstool, although the statistical value obtained ($P = .052$) approached significance (table 7). No significant difference in maximum pressure was found between conditions of elevating and not elevating the participants' feet on a footstool.

DISCUSSION

The development of pressure ulcers has been linked to multiple risk factors, including reduced mobility,³ impaired sensation,⁵ age,⁷ malnutrition,⁹ incontinence,¹⁰ shear, friction,¹⁸ and pressure.¹⁷ However, the predominant cause of pressure ulcer development is thought to be high interface pressure.¹⁶

Results showed that both average and maximum pressures were independent of gender. The latter supported earlier findings by Garber and Krouskop,³¹ although these investigators did not concurrently examine the relationship between average pressure and gender. On the contrary, although some previous studies^{11,33} have described male gender as a risk factor for pressure development, our study provided no link between male gender and increased interface pressure.

A positive correlation was identified between average pressure and BMI, whereas no correlation was evident between average pressure and height or weight. Similar findings, in terms of average pressure increasing as BMI increases, have been outlined by Scott et al¹ who, although they also used the Force Sensing Array system, used mattresses rather than chairs as a support surface. Unfortunately, with the data obtained in our study, it was not possible to explore the correlation be-

Table 4: Average Pressure in Relation to Recline of Chair Back

Recline of Chair Back	% Change in Mean Average Pressure vs 0° Recline	Significance (t Test)
10°	-0.296	.764
20°	-2.086	.057
30°	-5.628	.000

Table 5: Average Pressure Changes Between Supporting and Not Supporting Participants' Feet

Recline of Chair Back	% Difference in Average Pressure Between Not Supporting and Supporting Feet	Significance (t Test)
0°	13.913	.000
10°	6.324	.000
20°	4.903	.000
30°	2.793	.009

tween pressure and specific BMI categories as previously performed by Scott,¹ because sample sizes were very small when subdivided. This may warrant further investigation.

Reclining the back of the chair from the neutral position did not significantly alter mean average pressure or maximum pressure at either 10° or 20°. Shields and Cook³⁴ had previously found no significant difference in interface pressure between upright and 20° reclined positions. Recline by 30° in our study also showed no significant effect on maximum pressure but significantly reduced average pressure ($P < .01$). The latter may be an important consideration for positioning during seating because intervention to reduce interface pressure will help prevent pressure ulcers. Measurement of sacral interface pressures when assuming a position of a 30° recline would be necessary to ensure that the potential shift of pressure from the ischial tuberosities does not contribute to sacral pressure ulcer development.

Raising participants' feet on a footstool did not significantly affect average or maximum pressures, although the former approached statistical significance ($P = .052$), with elevation of the feet resulting in reduced average pressure. Combined with other medical benefits of foot elevation, such as reduction of edema, this position may be advantageous in terms of reducing interface pressure and thus the risk of pressure ulcer development.

Controversy surrounds average and maximum pressures regarding which is the best outcome measure, which should be reported, and which is the best descriptor of interface pressure. As stated, average pressure is the mean of all the sensor values, whereas maximum pressure is the highest individual sensor value. Some studies have focused on reporting maximum pressure and not average pressure^{17,27,35,36}; however, these researchers did not include reasons for their choice. Although not specified, this may have been because of the constraints of the technology being used. In a rigorous study by a renowned international researcher, Sprigle et al³⁷ reported only average pressure, referring to it as "a very stable measure." Peak (or maximum) pressure was not analyzed in that study because of "the instability of the measure."³⁷ We concur with Sprigle³⁷ that average pressure is a more stable measure and gives a

Table 6: Maximum Pressure Changes Between Supporting and Not Supporting Participants' Feet

Recline of Chair Back	% Difference in Mean Maximum Pressure Between Not Supporting and Supporting Feet	Significance (t Test)
0°	21.657	.000
10°	6.348	.005
20°	3.803	.100
30°	4.192	.028

Table 7: Pressure Changes With Elevation of Participants' Feet

	% Difference Between Nonelevation and Elevation of Feet	Significance (<i>t</i> Test)
Average pressure	-3.093	.052
Maximum pressure	-0.640	.809

better overall picture of interface pressure in disabled people than maximum pressure, which is a single sensor value.

Investigations comparing pressure changes between supporting and not supporting participants' feet (when these did not naturally extend to the floor when seated on the given armchair) produced unexpected results. Supporting participants' feet to achieve 90° of flexion at hips, knees, and ankles significantly increased average pressure at the 0°, 10°, 20°, and 30° recline positions ($P < .01$). Maximum pressure was also significantly increased by supporting the participants' feet at the 0°, 10° ($P < .01$), and 30° recline ($P < .05$) positions, with the increase occurring at the 20° recline not being statistically significant. The increase in pressure found in this study when feet were supported (although not elevated) appears contradictory to recent clinical guidelines that advise feet support during seating.³⁸ Our findings are also inconsistent with ergonomic guidelines given by Dreyfuss,³⁹ who recommended supporting the feet to relieve pressure under the thigh.

CONCLUSION

Although based on a small sample of healthy subjects, this study has shown some interesting results, namely, that reclining the seat by 30° and elevating subjects' feet on a footstool reduced average interface pressure. These findings would add to the other advantages facilitated by these positions as mentioned earlier, including the reduction or prevention in edema. It should be noted, however, that such maneuvers may supplement, but should not replace, pressure-relief techniques for people at high risk of developing pressure ulcers.

Laboratory-based studies using healthy populations, such as those described herein, are considered by us to be essential before application with a disabled cohort.⁴⁰ These first-stage investigations require subjects to adopt a number of seating positions, some of which may be shown later to provide less than optimal pressure relief. As opposed to a disabled cohort, healthy subjects can easily adopt the positions required, sustaining little or no discomfort in doing so. Studies such as these provide a focus of direction for second-stage studies with disabled populations and can potentially minimize pain or discomfort by restricting the range of positions under investigation.

The limitations of this pilot study should be considered. These include the use of small samples and able-bodied participants adopting a "perfect" seated position. Caution must be taken before applying the findings of our study to clinical practice, given the differences between able-bodied and disabled populations, because higher interface pressures have been demonstrated with elderly and disabled populations when compared with young healthy subjects.^{32,41}

In terms of future research, our pilot study should initially be replicated with a larger group of able-bodied subjects. Areas to be included for further investigation include the correlation between interface pressure and specific BMI categories, the effect of tilt beyond 30° on interface pressures, and the change in pressure on the sacrum as the subject is reclined. Results

from these studies should then be verified within a disabled population before their application in clinical practice.

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