Measuring Interface Pressure: A Laboratory-Based Investigation Into the Effects of Repositioning and Sitting

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Key Words
- force sensing array
- pressure mapping
- seating

Measurement of interface (or contact) pressure is important in assessing tissue viability in relation to pressure sore prevention and may be achieved through pressure mapping techniques. This article reports on two pilot studies using the Force Sensing Array pressure mapping system in a laboratory setting. The purpose of Study 1 was to examine the consistency of readings from the system across 1-min trials of repositioning, and Study 2 aimed to investigate changes in interface readings over a 20-min sitting period. Analyses on measurements of average pressure (mean of all sensor values) and maximum pressure (highest individual sensor value) were performed using the t-test and repeated-measures analysis of variance. The results demonstrated that the use of average and maximum pressure measurements reflected only low reliability and that 6 min was likely to be the optimal sitting time required before stable pressure measurement. However, because of the limitations of using small convenience samples of healthy participants (n = 44 for Study 1, n = 20 for Study 2), these studies should be replicated with larger samples of healthy participants and then verified with disabled populations before adoption into clinical practice.


High interface pressure maintained over prolonged periods can lead to the development of pressure sores in at-risk persons (Medical Devices Agency, 1997). Pressure sores can result in immense cost both to the health system (Scott, Baker, Stoddard, & Leaper, 1999) and to the person experiencing them. Measurement of interface pressure, therefore, is important in the evaluation of tissue viability and in the prevention of pressure sores (Bader & Hawken, 1986). Neander and Birkenfeld (1991) supported the validity of the use of interface pressure measurement as a means of assessing probable effectiveness of support surfaces. Pressure measurements from mapping systems, such as the Force Sensing Array (FSA)1 used in the studies reported here, potentially can provide valuable data to occupational therapists involved in pressure sore prevention, thus helping to guide clinical decision-making.

Because of the technical nature of pressure mapping systems, issues regarding the accuracy and reliability of measurement can exist; however, the FSA system has been favorably described by several authors in terms of easy calibration, operation and data management, and reliable measurement (Ferguson-Pell & Cardi, 1992, 1993; Ranalli & Moynahan, 1997; Scott et al., 1999). The FSA system has an estimated accuracy of 95% (Parent, Lacoste, & Dansereau, 1999) and has shown high repeatability of measurements on trials using foam cushions (Ferguson-Pell & Cardi, 1993). As with most other pressure measurement systems, the FSA has been shown to demonstrate a creep effect, that is, an intrinsic tendency for pressure readings to increase over time (Taylor, 2000). Creep within this system has been cal-

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Previous studies have shown that interface pressure measurements vary with different seating postures (Henderson, Price, Brandstater, & Mandac, 1994; Hobson, 1992; Koo, Mak, & Lee, 1996) and on repositioning (Bader & Hawken, 1986). Recently, Al-Eisa, Fenety, Egan, and Crouse (2000) demonstrated with the FSA high reliability of measurements on repositioning healthy participants over three seating trials. Repositioning was achieved through the use of a standardized position on the testing chair. Their study used healthy participants and the pressures within the rectangular region under the ischial tuberosities as a criterion measure. These findings contrasted with earlier results from Bader and Hawken (1986), who demonstrated that repositioning healthy participants produced significant differences between positions in the parameters tested (average pressure and maximum pressure). According to Al-Eisa et al., this discrepancy between results may be explained by the use of different protocols and test parameters.

The issue of consistency of pressure measurement related to positioning is further accentuated in a clinical situation with a disabled population, especially for clients with postural problems resulting from altered tone. The likely variability of seating postures within a group of persons with disabilities would confound consistency when conducting preliminary tests to investigate the accuracy of pressure mapping systems. For this reason, the current study was performed in the laboratory setting, using participants without disabilities to provide a benchmark of accuracy before application with a disabled population.

A further general problem with research using pressure mapping systems is that comparison between the results of different studies is restricted by the lack of an agreed protocol for the measurement of interface pressures (Clark, 1994). No clinical protocol has been developed for the use of the FSA that incorporates details such as waiting time before pressure measurement. It is commonly accepted that interface pressure increases with sitting time because of the combined effects of creep and changes within the individual and the seating surface. Because pressure changes over time, it is important to investigate whether it “levels out” after a given period and, if possible, to identify subsequently the duration of optimal sitting times before taking pressure measurements. Minimizing the length of sitting time during evaluation aims to address practical issues such as patient comfort and tolerance.

In an attempt to address the issues described here, the purpose of Study 1 was to examine the consistency of the FSA pressure readings with repositioning in healthy participants before application with a disabled population. Study 2 aimed to investigate changes in interface pressure over a 20-min sitting period to identify an optimal sitting time before pressure measurement.

Method

Design

Both studies used a laboratory-based group study design. FSA pressure mapping measured interface pressures for healthy participants.

Participants

Study 1 was carried out with a convenience sample of 44 student volunteers (1 man, 43 women) ranging in age from 18 to 37 years. Study 2 was carried out with a convenience sample of 20 student and staff volunteers (6 men, 14 women) ranging in age from 24 to 53 years. The sample sizes were considerably larger than those used in previous pressure mapping studies of healthy persons (Al-Eisa et al., 2000; Allen, Ryan, & Murray, 1993; Bader & Hawken, 1986). All participants gave written informed consent before taking part in the study.

Instrument

The FSA is a clinical tool used to assess pressure distribution at an interface, such as that between a person’s buttocks and thighs and a seating surface. The tool comprises a pressure sensing mat (48 cm x 48 cm) containing 225 sensors that is connected through an interface module to a computer (see Figure 1). Data computed from the sensors are presented in various forms, including a color-coded contour map and numerical pressure values. The contour map displays visually the pressure distribution at the interface, and each map is accompanied by corresponding numerical values, including average pressure (the mean of the sensor values) and maximum pressure (the highest individual sensor value). The FSA system was used in both Studies 1 and 2, and only the numerical pressure values of average and maximum pressure were analyzed.

Procedure

The FSA pressure mapping system was calibrated according to the manufacturer’s recommendations, as given in the product manual, using the specially designed calibration frame supplied with the system. The designated software was used to calibrate the system in 20 mmHg intervals to a maximum of 200 mmHg. To maximize consistency, the same calibration was used for both studies. Both studies ran consecutively over 10 weeks, with Study 1 being conducted during the first 7 weeks and Study 2 over the following 3 weeks.
Study 1. All pressure measurements in Study 1 were recorded with the FSA. Methodology and participant positioning were similar to those in Al-Eisa et al.‘s (2000) study. Participants were seated on the pressure sensing mat, which was placed on a nonadjustable armchair with seat height of 51 cm (see Figure 1). The chair surface was made from upholstered foam (Grade R650F foam on seat, Grade R400H on back). Participants were asked to sit with their arms placed on the armrests and were positioned to allow 90° flexion at hips, knees, and ankles. Feet were supported if necessary. Interface pressure in the form of average and maximum pressure were recorded with the FSA system for a 1-min measurement period (Minute 1). Participants then were asked to walk for a distance of 100 m and return and sit in the same posture as before for a second 1-min measurement period (Minute 2). They again were asked to walk for a distance of 100 m and return and sit as before for a third and final 1-min measurement period (Minute 3). The FSA system was set to record pressure at the 1st and 60th sec of each of the three 1-min sitting trials.

The numerical values of average and maximum pressure were statistically analyzed. This analysis was performed with the Statistical Package for the Social Sciences (SPSS) version 9.0 (SPSS, 1998), comparing pressure on repeat positioning and over the three 1-min periods. Statistical tests were the paired samples t test and repeated-measures analysis of variance (ANOVA) (Kinnear & Gray, 1994), both frequently used in pressure mapping studies (Al-Eisa et al., 2000; Defloor & Grypdonck, 2000; Henderson, Price, Brandstater, & Mandac, 1994; Sprigle, Faisant, & Chung, 1990). All statistical analyses were performed at the .05 level of significance.

Study 2. Interface pressure measurements in Study 2 were recorded with the participants seated on the same nonadjustable armchair as previously described. Participants were instructed to adopt a comfortable position and maintain the same seating position for 20-min. During this time, pressure measurements were recorded at 2-min intervals using the FSA system. Statistical analysis was performed with SPSS version 9.0. A repeated-measures ANOVA was used to compare average and maximum pressures recorded at each 2-min interval for the 20-min period.

All pressure measurements were recorded by a single rater, thus eliminating rater variability. The rater was trained in the use of the FSA system by its designers at Vista Medical headquarters in Winnipeg, Manitoba, Canada.

Results

Study 1

A significant increase in both average and maximum pressures was found between the 1st and 60th sec of each 1-min measurement period (i.e., Minute 1, Minute 2, Minute 3; see Table 1). No significant difference was found when comparing average pressure within the 1st sec of Minute 1 with the 1st sec of Minute 2 and the 1st sec of Minute 3 (see Table 2). By contrast, a significant difference was identified when comparing average pressure recorded at the 60th sec of Minute 1 with the 60th sec of Minute 2 and the 60th sec of Minute 3 (p < .01; see Table 2).

A significant difference in maximum pressure was found at the 1st sec among the three 1-min trials (p < .05), with similar results for maximum pressure compared at the 60th sec of Minutes 1, 2, and 3 (see Table 2). Overall, where significant differences occurred (average pressure at 60th sec and maximum pressure at both the 1st sec and the 60th sec), a trend of increasing pressure was found across trials.

Table 1. Changes in Average and Maximum Pressures Within Each 1-Minute Measurement Period: Study 1

<table>
<thead>
<tr>
<th>Interface Pressure</th>
<th>Percent Change Between 1st and 60th Sec per 1-Min Measurement Period</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minute 1</td>
<td>6.618</td>
<td>11.211</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Minute 2</td>
<td>8.798</td>
<td>13.677</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Minute 3</td>
<td>8.999</td>
<td>15.604</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minute 1</td>
<td>8.763</td>
<td>9.242</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Minute 2</td>
<td>7.403</td>
<td>6.085</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Minute 3</td>
<td>8.193</td>
<td>7.129</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>
Study 2

Average pressure was shown to generally increase over the 20-min measurement period (see Figure 2). When the Bonferroni correction (Bland & Altman, 1995) was applied to account for the use of multiple significance tests in the repeated-measures ANOVA, this increase was significant at intervals 0 to 2 min, 2 to 4 min, and 4 to 6 min ($p < .001$; see Table 3).

Maximum pressure also was shown to increase over the 20-min measurement period (see Figure 3). Application of the Bonferroni correction to original results identified significant increases in maximum pressure at intervals 2 to 4 min and 4 to 6 min (see Table 4).

Discussion

Although these pilot studies have shown some interesting results, it is important to note at the outset that their application is limited by the use of small samples of healthy persons without disabilities. Interpretation is further restricted by the use of different groups of participants for the two studies.

Although a lack of agreement exists about which participants form the most appropriate test population for pressure mapping studies (Clark, 1994), Kemp et al. (1993) warned against generalizing from young, healthy persons to elderly patients. Indeed, several authors have demonstrated higher interface pressures in studies with elderly and disabled populations when compared with young, healthy populations (Clark & Rowland, 1988; Hobson, 1992).

Results from Study 1 show a significant increase in both average and maximum pressures over each of the three 1-min measurement periods after being positioned on the pressure mat, that was placed on the chair. Several factors may have contributed to this increase, including creep and changing characteristics in both the foam of the chair and the participants’ buttocks.

Average pressure did not differ significantly between the first seconds of each 1-min measurement period, suggesting that comparable average pressures were achieved on repositioning during seating. Caution must be taken, however, in inferring that comparable average pressure indicates that reliability of measurement in repositioning had been achieved because the same average pressure may be the result of many different seating positions.

In contrast to average pressure, values of maximum pressure on repeat positioning at the 1st second of each 1-min measurement period differed significantly from each other. Because maximum pressure refers to the pressure in a single sensor, it is generally considered to be an unstable measure (Sprigle et al., 1990), and for this reason, it is frequently omitted from statistical analyses in pressure mapping studies. Such fluctuations in maximum pressure...
suggest questions about its usefulness as a reliable measure in pressure measurements during repositioning.

In summary, results from Study 1 suggest that measurements of average and maximum pressure cannot be relied on as a reliable measure across trials using repositioning. Perhaps a better method of estimating reliability of pressure measurement in repositioning is the one recently adopted by Al-Eisa et al. (2000), who examined spatial measurement of the mean pressures within a 3 in. x 3 in. sensor block under the ischium. Participants were positioned in a posture similar to that used in the current study, and results using this sensor block method showed high measurement reliability in repositioning participants. However, these results disagreed with those from a previous study by Bader and Hawken (1986). Using a similar apparatus and average and maximum pressures as outcome measures, Bader and Hawken found significant changes in interface pressure on repositioning. The Al-Eisa et al. study explained these differences between findings in terms of differing protocols and testing parameters. We suggest that further investigations to establish testing protocols and parameters are necessary if direct comparisons between pressure measurement studies are to be made.

Furthermore, Study 1 was carried out using a single rater, thus removing the variable of interrater error. No studies on interrater reliability in the use of the FSA system have been identified. Such studies, however, should be carried out because they have important implications for clinical practice and several therapists may be using the system within one clinical setting.

Analysis of the changes in average pressure over a 20-min sitting period in Study 2 revealed that pressure generally increased over time (see Figure 2), with a highly significant increase over the first 6 min of measurement time ($p < .01$; see Table 2). Similar increases in maximum pressure were found over the 20-min testing period (see Figure 3). Application of the Bonferroni correction showed highly significant increases in maximum pressure between 2 and 6 min ($p < .001$; see Table 4). These findings were similar to the changes observed in average pressure over this period. No significant increase in maximum pressure was found after a 6-min sitting time (see Table 4). These results suggest that the optimal waiting time before pressure measurement is 6 min because increases in average pressure and maximum pressure were significant up to this measurement time.

## Conclusion

The results from these studies have yielded some interesting findings about the application of pressure mapping techniques by the occupational therapist conducting pressure care evaluation. Findings from Study 2 suggest an optimal waiting time before pressure measurement, and Study 1 highlights issues regarding the reliability of average and maximum pressures on repositioning.

Laboratory-based studies, such as those described herein, are essential to investigating various aspects of evaluation before formulating clinical pressure mapping protocols for disabled populations. However, given the limitations of both pilot studies, especially the use of small samples and healthy participants, the studies should be repeated in the laboratory setting with larger samples of healthy participants. These results should then be verified with a disabled population before adoption into clinical practice given that high interface pressures have been demonstrated by this and elderly populations. ▲

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