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Air-fluidized beds and their ability to distribute interface pressures generated between the subject and the bed surface

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Abstract. Pressures were measured under five anatomical sites prone to pressure sores for ten subjects, supine and sitting on two different air-fluidized beds. The beds were the Clinitron (trademark, SSI) and the Fluidair Plus (trademark, KCI Mediscus). Mean supine pressures were less than 4 kPa under four sites. The average supine buttock pressure was 2.65 kPa. This increased to 3.71 kPa upon sitting up, though pressures did not rise above the accepted capillary closing pressure, on either bed. Low interface pressures at these sites were due to good moulding between subject and bed. Heel pressures averaging 7.08 kPa, were a factor of 2.67 times greater than buttock pressure, and were higher than expected considering the depth the heels sunk to in both beds. This exceeded the accepted capillary closing pressure and was attributed to covering sheets preventing true floatation at the heels.

1. Introduction

Pressure sores are a major problem in health care (Dinsdale 1974). Also known as bed sores, they can form on parts of the body subjected to high, unrelieved pressure and do not heal easily. They can be prevented by regularly turning patients at risk, in order to relieve pressure at vulnerable sites. Since moving patients is not always convenient or desirable, special support surfaces have been developed which reduce the pressure between the patient and the support surface (the interface pressure) by moulding more closely to the contours of the patient. Moulding is important since if it is poor, only a few parts of the body support the weight of the patient, producing high interface pressures at those sites. Good moulding leads to the patient's weight being supported over a greater area so that interface pressures are lower.

One such support surface designed to mould well is the air-fluidized bed, also known as the bead bed. This is essentially a large tank filled with silicone coated sodalime microspheres (about 80 μm in diameter). Air is blown up through the bottom of the tank into the microspheres. The air flow agitates and suspends the microspheres causing them to behave like a fluid. The patient floats on the bed, separated from the fluidized microspheres by a loosely fitting filter sheet. Theoretically, the bed should mould perfectly to the shape of the patient, leading to very low interface pressures. Ideally, the pressure at a given point on the body of a patient floating on a fluid depends on the depth of that point below the fluid surface: the greater the depth, the higher the pressure.

Unfortunately, there is little published quantitative data describing pressures under body sites most at risk, or examining the effect on pressure of sitting up on air-fluidized beds. Ryan and Byrne (1989) measured interface pressure under key body sites for five beds,

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one of which was air-fluidized, and Krouskop *et al* (1984) compared the pressure relief characteristics of an air-fluidized bed and a low air-loss bed. Boorman *et al* (1981) evaluated an air-fluidized bed and compared it with a standard foam mattress. Although repeat readings were taken in some of these studies, they were taken in quick succession without repositioning the pressure sensor, leaving the measurements susceptible to possible bias (Bader and Hawken 1986, Allen *et al* 1993b). In addition, the lack of a standardized measurement technique makes these studies difficult to compare.

In this study, a simple but thorough and validated (Allen *et al* 1993a, b) technique was used to measure interface pressures at vulnerable body sites. This technique is described in brief in the next section. Two air-fluidized beds were evaluated and compared. The aim of this study was to provide repeatable, quantitative data on interface pressures at key body sites on these beds.

2. Methods

2.1. Subjects and equipment

Measurements were made on ten young, healthy volunteers: five females (mean mass 66.8 kg, range 54–78 kg) and five males (mean mass 86.6 kg, range 81–95 kg). Each wore thin cotton theatre pyjamas.

Interface pressures were measured using a Talley SA500 Pressure Evaluator with a 28 mm diameter sensor pad (Talley Medical Group Ltd, Hants, UK). This had been found to be most accurate in a laboratory study of the accuracies of commonly available measuring systems (Allen *et al* 1993a). The Talley instrument could not display pressures below 2.67 kPa (20 mmHg), so a Novatrans electronic strain-gauge pressure transducer (Medex Medical Inc, Lancs, UK) was connected to the system and its output amplified and displayed as a voltage on a digital voltmeter (DVM). For consistency, all readings were read off the DVM, including those above 20 mmHg.

Two air-fluidized beds were evaluated: the Clinitron (SSI, Notts, UK) and the Fluidair Plus (KCI Mediscus, Oxon, UK). For the latter bed, the rate at which air was blown through the microspheres could be controlled. In the absence of an easily standardized recommended setting, this variable 'fluidization' was set to maximum for all subjects. Each bed had its own removable back rest. The Clinitron had a fabric-covered frame with adjustable elevation, whereas the Fluidair Plus was supplied with three shaped foam wedges which together provided a fixed elevation of 40° from the horizontal. A single, untucked cotton sheet was used with each bed, though it is noted that KCI Mediscus prefer their bed to be used with a Goretex (trademark) sheet instead. No pillow was used.

2.2. Technique

For each bed, the measurement protocol was as follows. Each subject lay supine in a standard position, arms by side, feet 25 cm apart, and was given 5 min to relax after the bed had been switched on. Interface pressures were investigated under five key body sites: occiput, scapula (right, R), sacrum, buttock (R), and heel (R). The sensor was placed under each site in turn and a reading of interface pressure taken. This involved inflating the sensor until the electrical contacts within it broke, then slowly deflating it. When the contact was made, the pressure was read. This was repeated once again to guard against a spurious result. When there was a small difference between these two readings, the average was recorded. Subjects moved a minimum amount to allow repositioning of the sensor, and care was taken to smooth out the filter sheet at the site of each reading. On completion of all sites, all interface pressures were measured once more.

The back rest was then placed on the bed so that the subject could sit up at 40° from the horizontal. The subject sat as far up the bed as possible to standardize the procedure. The measurement process was repeated for the sitting position, though readings were not taken for the occiput or scapula.

The whole process was repeated on four separate days. Thus, each of ten subjects had eight readings taken at each site, supine and sitting, on a given bed. These eight readings were averaged giving 10 mean pressures (and 10 standard deviations SD) at each site for a given bed. The average of these 10 means was plotted (± average of 10 SD) to show average pressure (± best estimate of repeatability) at each site for each bed.

Average interface pressures at each site were compared with the accepted capillary closing pressure (4.0–4.7 kPa), above which blood flow is reduced (Landis 1930, Kosiak *et al* 1958, Dinsdale 1974, Fronek and Zweifach 1975, Reswick and Rogers 1976). Capillary closing pressure is perhaps not ideal as an upper limit for safe interface pressures since interface pressures can differ from pressures within tissue. However, an alternative has yet to be agreed on in the literature. Capillary closing pressure is therefore the most commonly used threshold for safe interface pressures.

2.3. Data analysis

So as not to assume a Gaussian distribution, the non-parametric Wilcoxon's signed rank sum test was used to test for significant differences between both beds at each site. The same test was used to check for significant changes in interface pressure between supine and sitting positions for the sacrum, buttock and heel on both beds.

3. Results

3.1. Average supine pressures at each body site

Figure 1 shows interface pressures, supine and sitting, at each side for both beds. Pressure was low at most sites. On average it was 1.57 kPa and 2.04 kPa at the scapula and sacrum, respectively, and 2.65 kPa at the buttocks. Even pressure under the occiput was low, averaging 3.05 kPa, a factor of 1.15 times higher than buttock pressure. For both beds, only heel pressures exceeded accepted capillary closing pressure, averaging 7.08 kPa, which is 2.67 times greater than buttock pressure.

3.2. Average effect on pressure of sitting up

Interface pressure at the sacrum rose slightly for each bed upon sitting up by 0.55 kPa to 2.59 kPa on average (NS Clinitron, $p < 0.001$ Fluidair Plus). Buttock pressure rose significantly for both beds by 1.06 kPa to 3.71 kPa on average ($p < 0.001$ each bed). Thus, buttock pressure in the sitting position was 1.4 times greater than in the supine position. Mean buttock pressures did not, however, rise above accepted capillary closing pressure upon sitting up for either bed.

3.3. Differences between beds

Heel pressures on the Fluidair Plus were lower than those on the Clinitron by 0.67 kPa (supine) and 1.09 kPa (sitting). Though these differences are statistically significant ($p < 0.01$ supine, $p < 0.001$ sitting), they are small in comparison with the average heel pressure of 7.08 kPa. There were no significant differences in interface pressure between beds at any other site.

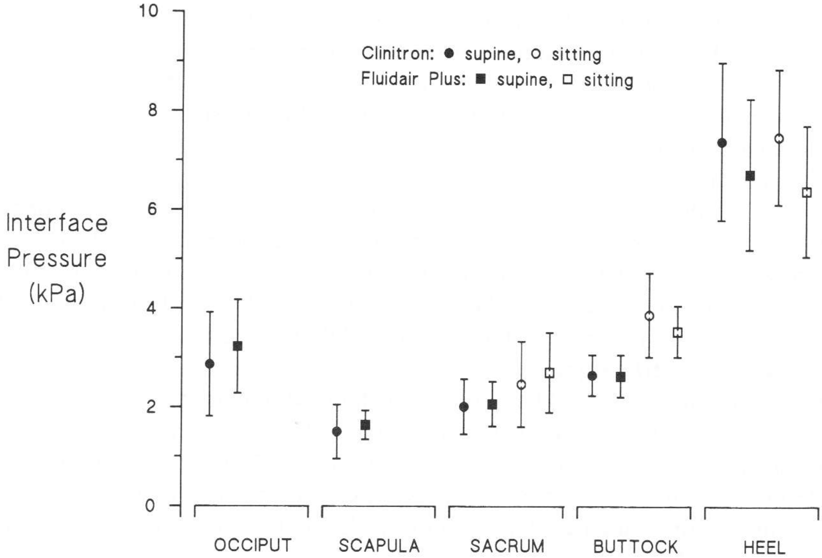

Figure 1. Mean interface pressures at each site, supine and sitting, for the two air-fluidized beds. Each point is the mean of 10 subjects. Error bars indicate average repeatability (± SD).

4. Discussion

The fact that the results were able to show up small differences re-confirms the good repeatability and efficacy of this technique for measuring interface pressures between subjects and support surfaces (Allen *et al* 1993b).

There is disagreement between the results of previous studies, especially at the heels. Ryan and Byrne (1989), Boorman *et al* (1981) and Krouskop *et al* (1984) measured the pressure to be 1.60 kPa, 1.47 kPa and 2.40 kPa, respectively, at the scapula, and 2.27 kPa, 2.00 kPa and 2.53 kPa, respectively, at the sacrum. This compares with average pressures of 1.57 kPa (scapula) and 2.04 kPa (sacrum) in the present study. Occipal pressure was found to be 4.00 kPa by Boorman *et al* (1981) whereas Ryan and Byrne found it to be 2.00 kPa. The present study measured occipal pressures of 3.05 kPa on average. The lower occipal pressure measured by Ryan and Byrne (1989) may have been due to the use of a pillow. Differences in interface pressure were large at the heel, where Ryan and Byrne (1989) and Krouskop *et al* (1984) both measured heel pressures of 3.33 kPa, yet Boorman *et al* (1981) found them to be 9.33 kPa. The 6 kPa disagreement may be due to differences in measurement technique. The heel pressures measured in the present study lie between the previous values (7.08 kPa on average). Buttock pressure was measured by neither Ryan and Byrne (1989) nor Krouskop *et al* (1984), though Boorman *et al* (1981) did measure it, finding it to be 3.20 kPa. They measured heel and occiput pressures that were respectively 2.92 and 1.25 times greater than buttock pressure, agreeing well with the present study. None of the previous studies measured sitting pressures.

A comparison can be made with an initial assessment of a replacement mattress (Allen *et al* 1993b) using the same technique. That study employed six subjects, the average body weight of which was similar to the present study. Over the five sites investigated in the present study, interface pressures on the air-fluidized beds ranged from 0.5 to 0.8 times what they were on the replacement mattress. Pressures under the occiput, which were much greater than the accepted capillary closing pressure on the replacement mattress, were well below this pressure on the air-fluidized beds. Heel pressures were also less on the air-fluidized beds than on the replacement mattress, with pressures reduced on average by 1.92 kPa. It should be noted that no sheet was used in the replacement mattress study. Sheets tend to reduce the moulding effect, and will therefore tend to increase the difference between the two types of bed.

Low interface pressures were obtained at most sites on the air-fluidized beds. This indicates that the beds mould well to the shape of the subject, thus supporting the weight of the subject over a larger area. However, moulding is not ideal. Heel pressures were still high, in fact higher than expected, considering the depth the heels sunk to. In theory, pressure on a body part depends on the depth it reaches. In none of the subjects did the heels sink to a depth greater than the buttocks, so it might be expected that heel pressures would be less than buttock pressures. The fact that this is not the case is most likely due to the filter sheet and overlying cotton sheet preventing true flotation and perfect moulding.

Interface pressures at the sacrum and buttocks were higher in the sitting position than in the supine position. This is because in the sitting position more of the body weight is supported by the buttocks. Consequently, they sink deeper. The sacrum and buttocks are now at a greater depth than when supine, so because of the good moulding of the beds to the body surface the pressure on both sites is greater.

The high relative cost of air-fluidized beds, which has been criticized by Bliss and Thomas (1992), makes the scientific study and comparison of beds particularly important. Without scientific data, clinical staff will not be able to begin considering how to balance costs and clinical pressure reduction.

5. Conclusion

Both air-fluidized beds performed similarly, giving interface pressures that were lower than the accepted capillary closing pressure at all sites except the heel. Heel pressures were higher than expected, and can be attributed to the covering sheets preventing true flotation.

Even though heel pressures were greater than accepted capillary closing pressure, they were a substantial improvement over the interface pressures reported for a less expensive replacement mattress.

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