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Assessment of alternating air mattresses using a time-based interface pressure threshold technique

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Abstract—Laboratory evaluation techniques for support surfaces have centered largely around interface pressure (IP) measurement, typically analyzing discrete maximum and minimum levels, or calculating the average pressure. Nowadays, alternating pressure air mattresses (APAMs) are used increasingly for the prevention and treatment of pressure sores. Pressure relief (PR) provided by an APAM is time-varying. A computerized system that measures IP, air pressure, and pressure-time characteristics of dynamic support surfaces has been developed for performance assessment. Using this system, IP was recorded continuously and the durations of pressures below three thresholds (30, 20, and 10 mmHg) were calculated automatically. Fifteen sound volunteers were used to evaluate the pressure-relieving characteristics of four APAMs, including one overlay. Results indicated significant differences ($p<0.001$) between products when durations below 20 and 10 mmHg thresholds were analyzed, showing some devices were only capable of momentarily relieving pressure. Maximum contact pressures on the sacrum were significantly lower ($p<0.0001$) on devices where inflation pressure was adjusted according to the body mass of the subject. With further clinical validation, this tool could assist in the selection of alternating surfaces of any description.

Key words: *alternating pressure air mattresses, equipment design, interface pressure, pressure relief, pressure sores.*

INTRODUCTION

Round-the-clock turning of patients every 2 hrs is a time-honored and proven method of pressure sore prevention (1,2). However, manual turning is labor intensive and may also induce pain in some persons (3). Increasingly, devices that cyclically change the area of exposure to pressure (alternating surfaces), without involving postural change of the subject, are becoming more popular for the prevention and treatment of pressure sores (4,5). Performance comparisons between alternating pressure air mattresses (APAMs) have been based largely on interface pressure (IP) measurements. In most cases, discrete measurements of maximum, minimum, and mean IP at specific bony prominences, such as the sacrum, have been used for analysis (6–8).

Since both time and pressure are important factors in the formation of decubitus ulcers (9,10), it would be useful to know the magnitude and duration of low pressures in the assessment of alternating surfaces. As pressures within human capillary beds range from approximately 10 to 30 mmHg (11,12), the application of external pressures within and beyond these limits may cause reduced blood flow and accumulation of metabolites via lymphatic occlusion (8). The premise is therefore made that the pressure relief (PR) imparted by an APAM is related to the time IP remains below this range of pressures. We have developed a computerized system that measures IP, air pressure, and pressure-time characteristics of dynamic support surfaces (13). This system was used in the present study to compare the pressure relieving performance of four different commercially available APAMs, including one overlay.

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METHODS

Monitoring System

Interface pressure was measured continuously using the Oxford Pressure Monitor 2 (OPM2: Talley Group Ltd, Hants, UK), and the air pressure inside mattress cells was recorded simultaneously. Measurement accuracy of the OPM2 was ±4 mmHg (14,15). The computerized monitoring system (**Figure 1**) used a graphical programming language (LabView®, National Instruments, Austin, TX, USA). The method employed a minimal amount of hardware to yield maximum flexibility by turning the computer into a data acquisition tool and its screen into a control panel.

The computer interface read the pressure sensor outputs, analyzed them, and represented the results graphically (**Figure 2**). The software was developed to calculate the time IP remained below any three arbitrarily chosen thresholds. We chose 30, 20, and 10 mmHg to indicate IP close to and below microvasculature operating pressures (11,12). IP measurements were acquired over several cycles of the APAM system. PR was expressed as a percentage of the cycle, which allowed like-for-like comparisons to be made by choosing any common multiple of the cycle times. For example, using 1 hr as a basis, the PR of a 10-min cycle APAM is multiplied by 6, and that of a 7.5-minute cycle multiplied by 8.

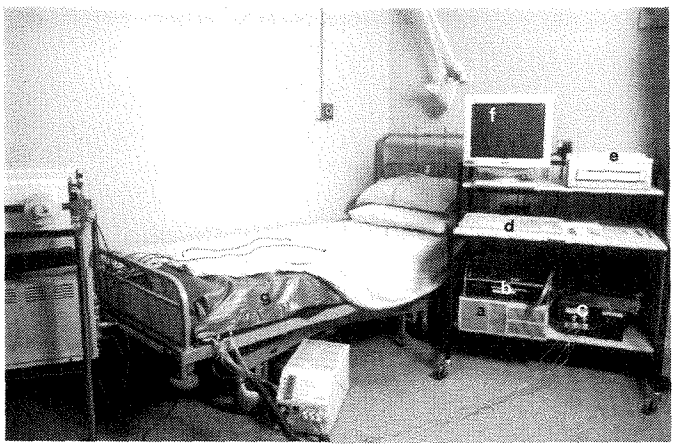

Figure 1.
Computerized system connected to an alternating pressure air mattress (System D) under test: a) Computer; b) Oxford Pressure Monitor; c) Air pressure transducers; d) Key board and mouse; e) Printer; f) VDU; g) Mattress.

Mattress Evaluation

Laboratory tests were carried out on four different APAMs. The four systems assessed were British made. They included a mattress overlay with large cells, an air mattress with sensor, a double layer (longitudinal/transverse cell) mattress, and a single layer three-cell-cycle mattress. For each mattress, the following were evaluated:

- IP durations below 30, 20, and 10 mmHg over a 60-min period
- Mean maximum and minimum IP
- Peak air pressures
- Operational reliability and general ease of use
- Comments regarding perceived comfort level.

Mattresses Tested

System A: Large Cell Overlay

This overlay is placed over a standard bed mattress and consists of 20 transversely arranged individual air cells that are alternately inflated and deflated according to a 10-min cycle (i.e., 5 min inflated, 5 min deflated). The inflation pressure can be adjusted to match the weight of the subject, according to guidance printed on the pump unit. At any given moment, half the cells are inflated and half deflated (1-in-2), thus imparting PR to all areas more frequently than typically achieved by manual turning. The cells are easily removable for replacement.

System B: Air Mattress with a Sensor

The mattress consists of a complex, double-layer, interwoven, single-piece cell structure, with 20 transverse cells operating in a 1-in-2 cycle over 7.5 min. The assembly of the layers is such that the mattress forms a slightly concave surface. A pressure sensor pad covering approximately the top half of the bed can detect and react to changes in weight distribution of the subject, thus minimizing the risk of grounding.

System C: Double Layer (Longitudinal/Transverse Cell) Mattress

In this mattress, the air cells are arranged in two horizontal layers. The base layer has 7 cells running lengthwise and the top has 18 transverse cells in single-piece construction. The longitudinal cells stay permanently inflated at nearly 50 mmHg. The transverse cells are inflated in a 1-in-2 sequence with a cycle time of 12 min. This mattress has a tendency to straighten up suddenly, if not secured properly with straps and fasteners, when used with an inclined backrest.

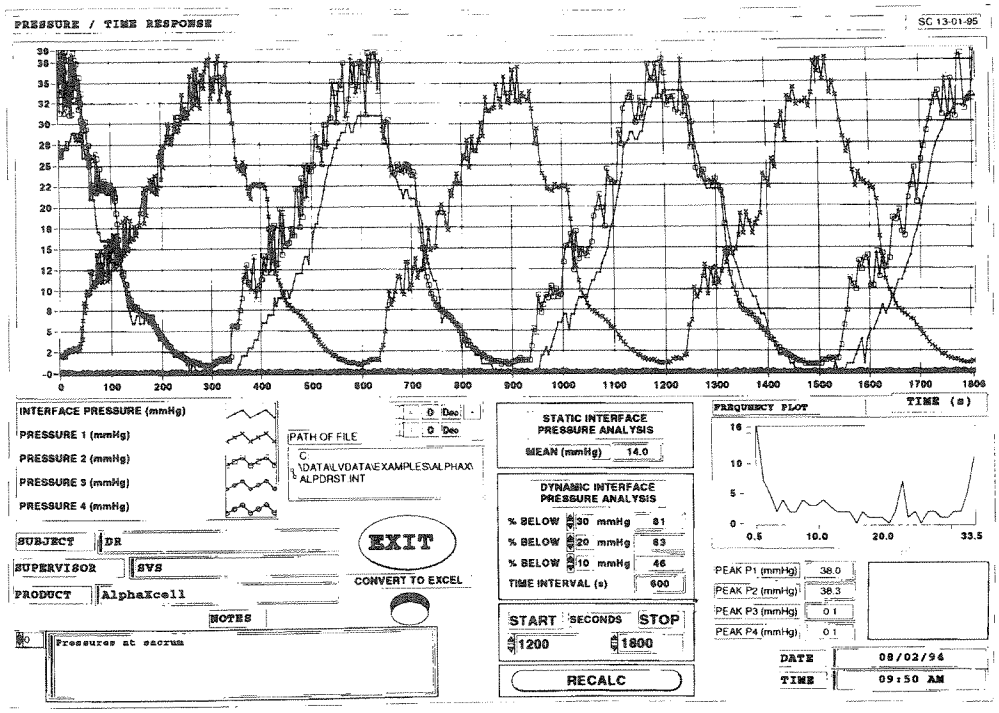

Figure 2.
A typical printout of raw data showing tracings of interface pressure and air pressures (System A). Salford Royal Hospitals NHS Trust, Dept. of Medical Illustration - copyright, reprinted with permission.

System D: Single Layer Three-Cell-Cycle Mattress

This mattress operates on a three-cell-cycle pattern, that is, 1-in-3 cells is (partially) deflated at a time. The subject support surface consists of 20 individual tubes arranged in a transverse configuration across the bed. The system has two modes of operation, namely "short wave" and "long wave," for sitting and supine positions respectively. The cycle time, 13.5 to 13.75 min, is manually changed according to the mode of operation. Although the mattress itself is light, the pump is heavy (11.5 Kg) and floor-based. As air cells are not restrained, they have a tendency to trap under one another, especially when used with an inclined backrest in the sitting position.

Testing Procedure

The pump connected to the mattress was first switched on and allowed to operate for at least 45 min prior to any testing. The same room, at a regulated temperature between 23 and 26 °C, was used to carry out all measurements. A standard hospital cotton sheet was draped over each APAM prior to testing. The subjects were asked to lie on the mattress wearing normal light clothing, with legs uncrossed and arms at sides. Two standard pillows were used to support the head. The anatomical position was determined by palpation and a single pneumatic transducer placed between the site of measurement and the support surface. Measurements of IP were carried out over at least two alternating cycles under the sacrum (supine), heel (supine), left trochanter (side lying), and buttock (bed back rest at 45°) on each subject. Care was taken to avoid creases in clothing or the bed sheet, and to ensure that the transducer did not lie over a seam or belt in any clothing. In addition, the transducer was placed on the crest of a cell so that it did not fall into a gap between inflating and deflating cells. This was done by initially placing the transducer on an inflated cell to act as guidance for final positioning of the subject. Following the measurements, subjects were questioned on the general theme of comfort, and asked which of the four surfaces they found most acceptable. Observations on

the operation of systems were noted, together with any other comments from the volunteers.

Statistical analysis was performed by means of paired Student t-test and Wilcoxon Signed Ranks test, depending on whether the distribution was normal or non-normal. All analysis was performed using the Astute (DDU Software, Leeds, UK) statistics package.

Subjects

Fifteen volunteers, 9 males and 6 females, participated in the evaluation, which was conducted with ethics committee approval. They were recruited from postgraduate students and staff of the University College Salford. Subject age, weight, and height ranged from 21 to 55 (mean±SD, 32.3±9.3) years, 62 to 115 (75.1±14.9) kg and 1.59 to 1.91 (1.70±0.10) m, respectively. All subjects were identified as being sound and had the procedure fully explained to them. Their written consent was obtained prior to the commencement of the measurements.

RESULTS

Results from continuous readings were first analyzed to indicate maximum and minimum contact pressures. These are summarized in **Table 1.** The pressure-relieving characteristics of the mattresses are shown in **Table 2,** expressed in minutes per hour below the three chosen thresholds. All data were analyzed over a period of one complete cycle. Unless otherwise stated, significance implies $p<0.05$.

Performance

System A

Mean maximum IP (30.2±5.3 mmHg) on the sacrum was at the same level as on system B (29.4±4.4 mmHg) and significantly lower ($p<0.0001$) than system C (46.6±6.5 mmHg) and system D (37.8±7.3 mmHg). The large cell overlay also recorded mean minimum IP values (0.6±1.0 mmHg) similar to system B (0.9±1.5 mmHg) and system C (0.1±0.5 mmHg) on the sacrum. In 10 out of 15 cases, minimum pressure readings were at the zero level. On average, IP remained below 10 mmHg for 28.1±6.9 min out of every hour, which was significantly greater than system D ($p<0.0001$). However, using the inflation guidance on the pump did not always result in sufficient pressure to support the weight of the subject when the overlay was used with an inclined backrest.

System B

The mean maximum contact pressure on the sacrum was 29.4±4.4 mmHg, and pressures remained below 10 mmHg for 25.0±5.5 min out of every hour. This was significantly lower than system D (mean maximum IP=37.8±7.3 mmHg and pressures below 10 mmHg for 8.7±6.9 min/hr). This also took the shortest time (9.1±1.6 min) to inflate from a flat condition. Minimum pressure readings recorded zero in nine cases. The main problem with the mattress appeared to be its heavy weight (13 kg) and the position of the sensor pad, which only covers the upper half of the mattress. It was generally perceived as a comfortable support surface.

Table 1.
Mean maximum and minimum recorded interface pressures* at specific locations.

	Sacrum		Trochanter		Buttock		Heel	
Mattress	Max	Min	Max	Min	Max	Min	Max	Min
System A	30.2	0.6	42.3	15.7	63.3	35.6	147.1	39.4
SDs	5.3	1.0	5.3	9.5	15.7	14.9	27.9	16.1
System B	29.4	0.9	45.3	21.7	56.4	35.1	136.7	61.4
SDs	4.4	1.5	7.6	9.7	15.8	13.4	27.1	26.3
System C	46.6	0.1	61.7	18.0	67.5	41.3	183.0	67.5
SDs	6.5	0.5	7.9	6.5	15.1	16.5	37.5	28.0
System D	37.8	6.7	53.6	24.7	59.1	35.0	186.9	100.3
SDs	7.3	3.1	7.6	8.1	14.2	12.3	40.0	30.4

*Pressures in mmHg.

Table 2.
Pressure relief* under the sacrum.

Mattress	min/hr <30 mmHg	min/hr <20 mmHg	min/hr <10 mmHg
System A	54.5 (6.8)	42.4 (5.3)	28.1 (6.9)
System B	55.5 (5.2)	38.3 (8.3)	25.0 (5.5)
System C	34.5 (8.6)	28.9 (5.0)	23.2 (4.3)
System D	33.3 (14.6)	18.9 (4.5)	8.7 (6.9)

*Internal pressures in mmHg; standard deviation in parentheses.

System C

The double layer mattress took the longest time (mean=31.3±4.4 min) to inflate from flat. When it was initially inflated, the pump alarmed after nearly 25 min and had to be switched 'off' and 'on' again to continue inflation. During the trial period, the system broke down once and had to be sent for repair. The mattress also gave the highest maximum IP (mean=46.6±6.5 mmHg, $p<0.002$) at the sacrum. On average, IP remained below 10 mmHg for 23.2±4.3 min/hr, which was significantly greater than system D. In 14 out of 15 cases, the minimum IP readings recorded 0. Six out of 15 subjects reported discomfort due to the dragging action, or up and down motion, of the cells when used with an inclined back-rest.

System D

Of all the APAMs included in this trial, the three-cell-cycle mattress gave the lowest PR measurements. Because the pneumatic cells did not deflate completely (minimum air pressure was approximately 10 mmHg), the mean minimum IP (6.7±3.1 mmHg) on the sacrum was significantly higher ($p<0.0001$) than on all other systems. Contact pressure was relieved below 10 mmHg on sacrum for only 8.7±6.9 min/hr. This was significantly shorter ($p<0.0001$) than the times achieved by the other three systems. Maximum IP readings at the sacrum (37.8±7.3 mmHg) were lower than the longitudinal cell mattress ($p<0.003$) but higher than the overlay ($p<0.003$) and the mattress with a sensor pad ($p<0.003$). Seven out of 15 subjects reported discomfort, especially when the mattress was used with an inclined backrest.

DISCUSSION

APAMs operate by pumping air sequentially into a given group of cells at a preset rate, which then remain inflated for a certain time. Subsequently, a mechanism operates to allow passive deflation of cells. Both the inflation pressure and cycle time have a large influence on the pressure relieving characteristics of the device (16,17). For optimum comfort and PR, an APAM must be correctly inflated (18). To this end, the air pressure in the mattress should take account of the weight and posture of the subject.

Our results suggest that the performance of different APAMs varies considerably according to detailed design. In this study, system B modified the operating pressure automatically, while system A (an overlay) was adjusted manually. Two systems (C and D) did not vary the operating pressure at all. Systems A and B gave greater PR at the sacrum ($p<0.0001$ below 30 mmHg, $p<0.0001$ below 20 mmHg) than mattress systems with fixed air pressure settings. However, there was poor correlation between PR results and physiological parameters, such as weight, height, and body mass index of the subjects. Therefore, it cannot be assumed that the inflation characteristics of the mattresses were ideal for all, or indeed any, of the subjects. Also, caution should be used in drawing any general conclusions from a small number of subjects who may not represent a typical hospital population.

In summary, the continuous measurement of IP and subsequent PR analysis, as described in this study, is, in our view, a sounder way of evaluating APAMs than using other methods, such as pressure impulse (19,20) and discrete transcutaneous oxygen ($tcPO_2$) readings (21). Although all four mattresses here were capable of relieving sacral IPs to below 10 mmHg, durations at these low pressures varied considerably (**Table 1**). This technique overcomes the limitations of simply measuring maximum and minimum IPs, where the timing of relief is not reported (6,22,23). Ultimately, the effectiveness of these devices can only be fully assessed by performing controlled clinical trials (24). We are continuing the investigation to assess other parameters, such as comfort, ease of use, maintenance, and long-term durability in the clinical environment. If clinically substantiated, this may provide a simple but effective way of predicting the efficacy of alternating pressure mattresses and cushions.

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