Measurement system for the evaluation of alternating pressure redistribution mattresses using pressure relief index and tissue perfusion – a preliminary study

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Abstract

Clinicians who are selecting dynamic support surfaces such as alternating pressure redistribution mattresses (APRMs) for the prevention and treatment of pressure ulcers are faced with commercial literature that predominantly reports on magnitudes of interface pressures, rather than on additional parameters. The aim of this preliminary study was to generate a pressure relief index (PRI) to evaluate dynamic support surfaces using the magnitude of interface pressures as well as their duration. Data for generating a PRI were captured from 11 subjects on two different dynamic support surfaces using three different, arbitrarily selected, interface pressure thresholds. Tissue perfusion measurements were used to evaluate the reliability of the calculated PRI. The results demonstrate a good relationship (r=0.7) between PRI and tissue perfusion values. The generated PRI appears to be a reliable indicator of the recovery time allowed below a given interface pressure and is therefore a useful parameter for selecting appropriate dynamic support surfaces.

Introduction

Despite advances in healthcare and technology, pressure ulcers remain a significant problem. Patients with impaired blood circulation in lower extremities are at particularly high risk of developing pressure ulcers due to substantially high tissue interface pressures while resting on a mattress. Pressure ulcers tend to form in certain areas such as bony prominences, where a given interface pressure will produce higher tissue compression than in areas of only soft tissue [1]. Recently, several researchers have shown by mathematical modelling and animal studies that it is not the superficial tissues, but the deep tissues, that are most commonly affected by external pressures [2, 3]. Whatever the pathophysiological explanations are for the development of pressure ulcers, deep tissue damage is caused by gravitational forces (stress and strain) concentrated at various posture-dependent, weight-bearing bony prominences, such as the sacrum, trochanter and heel [4].

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The literature on pressure ulcer management consistently sites the heel as one of the most common anatomical locations for pressure ulcers to develop. The prevention of heel ulcers is particularly important because they are often difficult to treat in individuals with poor lower limb perfusion that is triggered by diseases such as peripheral vascular disease or diabetes. In this group of individuals, heel pressure ulcers can develop rapidly, with limb- and life-threatening consequences. Also, it has been shown that, with an incidence rate of up to 30% of all ulcers being at the heel, this landmark is the second most common site where facility-acquired ulcers can develop [5, 6].

Given the implication for delayed rehabilitation and morbidity, some alternating pressure redistribution mattresses (APRMs) incorporate technologically advanced heel 'zones'. The strategies of these mattresses and their different zones

depend on the development of hyperaemia in response to pressure relief in the tissues during deflation phase of the support surfaces' alternating cycle to adequately compensate for intervals with blood flow deficits. In essence, to produce re-perfusion after loading, an appropriate course of action is to provide periodic, complete or near complete off-loading. How these mattresses affect clinical outcomes is largely unknown, particularly in patients with poor lower limb perfusion. However, well defined laboratory techniques can illustrate the often marked differences between apparently similar devices.

The aim of this preliminary study was to generate a pressure relief index (PRI) using the magnitude of interface pressures as well as their duration, and to confirm the validity of this index using tissue perfusion measurements. For this purpose, a computerised monitoring system was developed to measure interface pressures using an Oxford Pressure Monitor, model MkII [Talley Group, UK]. This monitor operates by pumping a constant flow of air into an air bubble transducer, in which the pressure is electronically monitored via a strain gauge diaphragm pressure transducer to produce an interface pressure-time trace and any chosen interface pressure thresholds. This system provides repeatable results and has a stated accuracy of ±3% within its range of 0-250mmHg [7]. APRM air cell pressures were measured using standard pressure transducers [RS Components Ltd, UK], and skin tissue perfusion was measured using laser Doppler flowmetry [Vasamedics Inc, USA] [6].

The described computerised monitoring system (Figure 1) was located in a laboratory setting where it calculated the time that the interface pressure remained below pressures that were reported to be in human tissue capillary beds [8, 9]. A graphical programming language [Lab View, National Instruments Inc, USA] was used by the described computerised monitoring

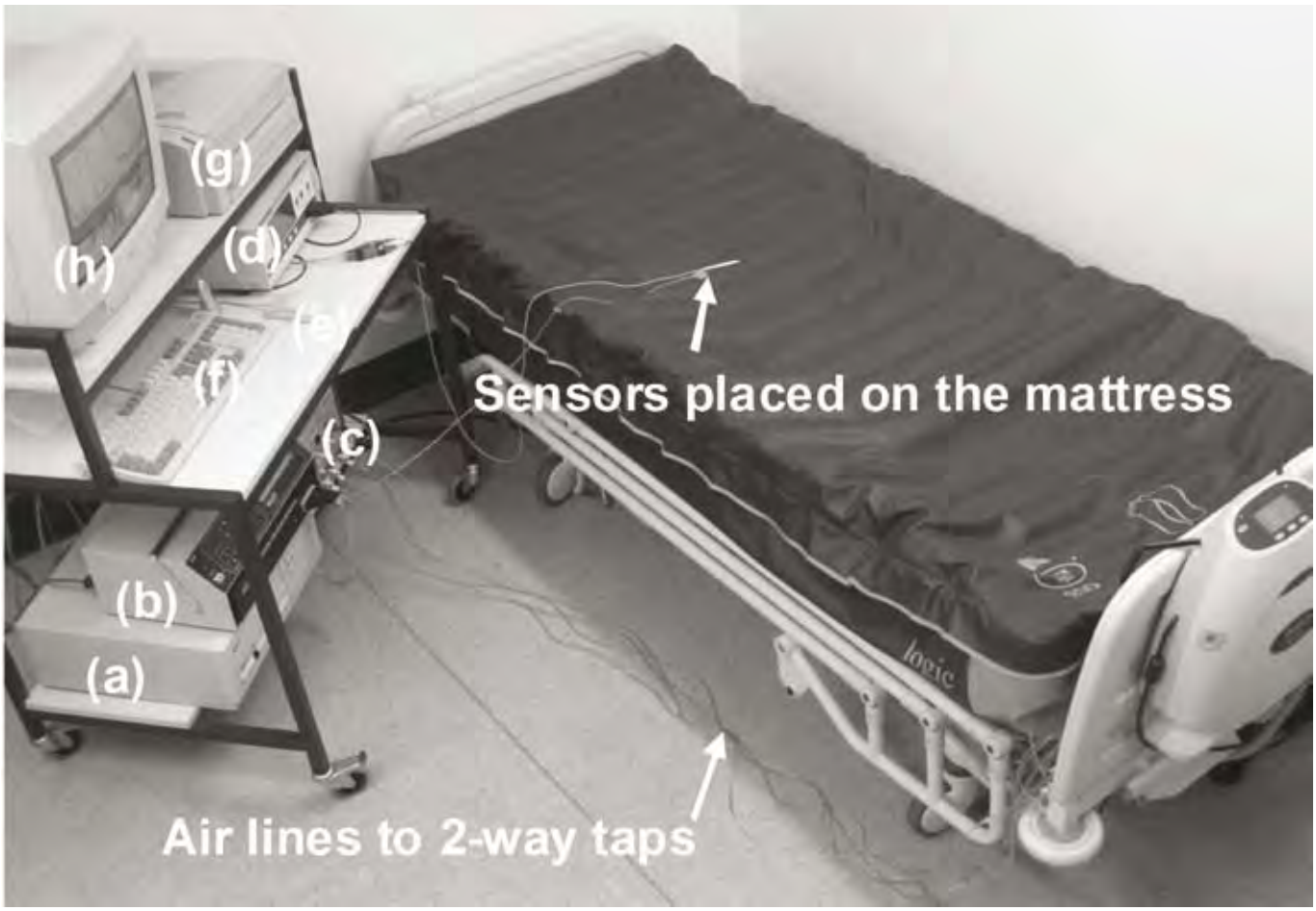

Figure 1. PRI monitoring equipment used for measurements on a mattress: (a) computer, (b) interface pressure monitor, (c) box containing air cell pressure transducers, (d) laser Doppler monitor flowmetry, (e) mouse, (f) keyboard, (g) printer, (h) computer screen.

system to analyse and finally graphically display the captured data. To obtain the necessary data, two different dynamic support surfaces were tested for evaluation with 11 participants.

Methods

PRI measurement

In order to evaluate the described computerised monitoring system, it is important to choose clinically relevant thresholds below which the interface pressure should remain, as these thresholds are considered to influence the re-perfusion of the area previously under compression. Examples of such thresholds are mean arteriolar (approximately 30mmHg), capillary (approximately 20mmHg) and venule (approximately 10mmHg) operating pressures[9], or some other set of clinically relevant pressures for selecting an appropriate support surface. Essentially, a horizontal line is drawn at the interface pressure threshold of interest, and the time is measured that the APRM-interface pressure trace spends below this threshold/line. The PRI is then calculated as the ratio of the time during which the APRM-interface pressure trace spends below the interface pressure threshold and the total time of one inflation/deflection cycle. Therefore, the PRI can be used for any APRM-interface pressure trace and cell inflation sequence, and is therefore a relevant indicator of the recovery time allowed below a given interface pressure threshold for any dynamic support surface.

An example of a PRI calculation is shown below:

Time for 1 complete alternating cycle: *10min*

Time below threshold (e.g. 20mmHg): *4min*

Hence PRI below 20mmHg: *4min ÷ 10min × 100% = 40%*

It is also possible to base all PRI calculations on a 1 hour operation, thus:

Number of complete cycles in 60min: *6*

Total time below threshold (e.g. 20mmHg): *6×4min = 24min*

Hence PRI below 20mmHg: *24min ÷ 60min × 100% = 40%*

Therefore, in 1 hour, there are 36 minutes of pressurisation (i.e. above 20mmHg) and 24 minutes of recovery time. Taking into consideration that patients with poor lower limb perfusion require as long a recovery time as possible, a mattress with a greater PRI would therefore be more beneficial to the patients than a mattress with a lower PRI.

Laboratory tests were carried out to illustrate the applicability of the PRI using two arbitrarily chosen APRMs, one with a low air cell pressure [Duo, Hill-Rom Ltd, UK] and another with a high air cell pressure [Nimbus3, Huntleigh Healthcare Ltd, UK]. For each mattress, the features evaluated were: mean maximum and minimum interface pressures; mean maximum air cell pressure; IP durations below 30, 20 and 10mmHg over a 60 minute period; mean maximum laser Doppler flowmetry; and mean laser Doppler flowmetry per cycle.

Subjects

Eleven subjects (male n=8 and female n=3) participated in the laboratory trials. They were recruited from postgraduate students and staff of the University of Salford, UK. Subjects were chosen to provide a spread of males and females with a reasonable range of ages, weights and heights – range 22-61 years of age (mean±SD, 37.1±11.6), 56-83kg (71.1±7.6) and 1.61-1.81m (1.72±0.06). Ethical approval was obtained prior to subject recruitment. All subjects were able-bodied, had the procedure for the laboratory trials fully explained to them, and their written consent was obtained prior to the commencement of the trials.

Procedure

In order to fully inflate the mattresses prior to any testing, each mattress was allowed to operate over at least two cycles, which is a duration that exceeds the minimum time to reach the optimum operational pressure as recommended by the manufacturers. To enable the subjects to fully relax at a regulated temperature between 23-26ºC, the same quiet room was used to carry out all measurements. It was ensured that the room temperature suited the subjects, so that they were neither too hot nor too cold, and hence comfortable. A standard hospital cotton sheet was draped over each APRM 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. An interface pressure transducer was placed under the right heel and a laser Doppler flowmetry probe under the left heel. In addition to this, care was taken to place both the left and right heel on the same mattress air cell, and particularly in the centre of that cell, so that neither of the heels fell into a gap between inflating and deflating cells. It was decided that this was best done by initially placing the transducer on an inflated cell to minimise the possibility of it moving, and that it could be certain that it was centred over the mattress air cell. All measurements were taken simultaneously over at least two alternating cycles.

A statistical analysis was performed using the Analyse-It software [Analyse-It, UK]. A linear regression analysis was undertaken to compare air cell pressure with subject mass.

Differences between various values were analysed using Student's t-test or the Mann Whitney U-test, depending on whether or not data were normally distributed. A difference was considered significant when $p<0.05$.

Results

The initial results obtained were in the form of pressure-time graph outputs and perfusion time-integral data (Figure 2). The first table from the left just below the graphs shows the legend of the graphs. The second table from the left shows the minimum and maximum air cell pressure (top two rows, in mmHg), as well as minimum and maximum laser Doppler flowmetry (bottom row, in arbitrary units – AU). The third table from the left shows the percentage of time that the interface pressure was below the three arbitrary thresholds of 30, 20 and 10mmHg (top three rows), as well as the mean, minimum and maximum interface pressure and the cycle time (bottom four rows).

Compared to the Duo mattress, the Nimbus3 mattress provided consistently lower interface pressures during the deflation phase of the cycle – Nimbus3: (mean±SD), 20.2±8.9mmHg; Duo: 68.5±13.0mmHg; $p<0.001$. The time intervals calculated over 60 minutes, during which the interface pressure remained below the arbitrarily chosen thresholds of 30, 20 and 10mmHg, were 10, 3 and 0 minutes, respectively for the Nimbus3 mattress. This can be shown as:

$$PRI = \frac{6\ (\text{no. complete cycles in 60min}) \times 10min\ (\text{total time below threshold of 30mmHg})}{60min \times 100\%} = 100\%$$

The Duo mattress achieved 0 minutes below either threshold. This can be shown as:

$$PRI = \frac{6\ (\text{no. complete cycles in 60min}) \times 0min\ (\text{total time below threshold of 30mmHg})}{60min \times 100\%} = 0\%$$

An inverse relationship was found between the minimum and maximum interface pressure and the minimum and

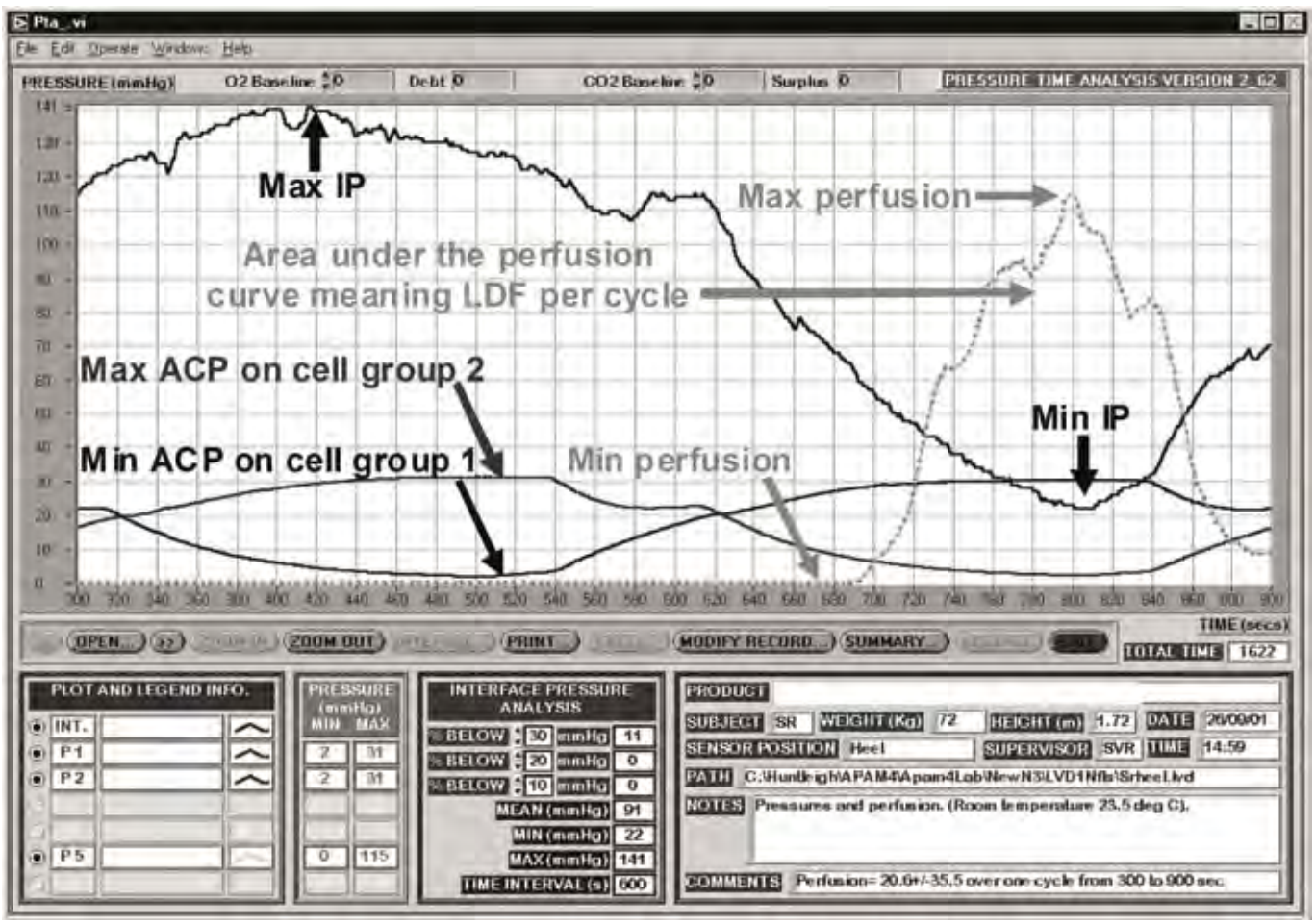

Figure 2. A typical graph showing interface pressure (IP), air cell pressure (ACP) and laser Doppler flowmetry (LDF) trace of a subject's heel on an APRM.

maximum laser Doppler flowmetry measurements, but it was not statistically significant. However, there was a good relationship (r=0.7) between PRI and blood perfusion values. There was no significant difference in the maximum interface pressure under the heel despite the Duo mattress offering significantly lower ($p<0.001$) air cell pressures in the heel region. Skin laser Doppler flowmetry levels, when averaged over each test cycle interval of pressurisation and relief, were significantly greater ($p<0.001$) for the Nimbus mattress (10,171.3±6,721.5 AU) compared to those for the Duo mattress (3,915.6±1,588.2 AU).

Discussion

The most commonly quoted method for the evaluation of support surfaces, both by researchers and commercial vendors of support surfaces, has been the measurement of interface pressures. This is usually done by placing a pressure transducer between the body and the support surface. The discrete measurements of maximum, minimum and mean interface pressure at specific bony prominences, such as the sacrum, trochanter and the heel, have been the most commonly used parameters [10, 11]. However, these measurements give no indication of the time during which a low interface pressure is experienced. APRMs aim to increase perfusion in soft tissues, which are under gravitational compression due to body weight, by cyclically relieving contact pressure from the skin. Both the interface pressure and cycle time have a bearing on the efficacy of such devices [12-14]. It is therefore more useful to be able to measure PRI.

For optimum comfort and pressure redistribution, an APRM must be correctly inflated. The air cell pressure in the mattress should be proportional to the patient's weight and be adjustable depending on the patient's posture on the mattress. If the air cell pressure is too high, then the mattress becomes too hard, giving high interface pressures, and if it is too low then it will bottom out. However, from the patient's perception point of view, although histological evidence has shown that high intermittent interface pressures, as in APRMs, may be more tolerable to tissues [15, 16] than high constant interface pressures [17, 18], high intermittent interface pressures are considered less comfortable by patients [19, 20].

Apart from better pressure relief characteristics and skin tissue perfusion, there are many other parameters, such

as comfort, cost, ease of use, maintenance, and long-term reliability, which should be considered before making a choice of a dynamic support surface for a patient [21, 22]. The results here appear to indicate that the high air cell pressure mattress has, in theory, an advantage over the low air cell pressure mattress in protecting the skin at the heel from the deleterious effects of prolonged recumbency, but with two important reservations.

Firstly, it is recognised that the degree and duration of pressure required to cause tissue damage is reduced in illness or disability, and it is not possible to be certain whether or not the differences in periods of reduction in interface pressures are likely to be of significance in patients as opposed to able-bodied subjects.

Secondly, there needs to be demonstrable clinical evidence that these surrogate physiological measurements correlate significantly with the risk of pressure ulcer formation [23]. This clinical evidence should really be made available and, once this has been achieved, then the technique shown here of using a PRI for the evaluation of dynamic support surfaces will be an invaluable method in assessing the efficacy of these surfaces.

In summary, this is a preliminary study to illustrate a technique of evaluating dynamic support surfaces using a PRI that was calculated from the magnitude of interface pressures, as well as their duration. It was found that a high PRI provides better re-perfusion after loading compared to a low PRI. Also, considering that the present study used the heel as the anatomical landmark for evaluating the applicability of the PRI, it is therefore important to note from the results that low air cell pressures [i.e. Duo, Hill-Rom Ltd, UK] do not necessarily produce sufficient off-loading and hence lower interface pressures under the heel, contrary to the intuitive classical notion. Therefore, based on the presented, combined results of interface pressure and blood perfusion in healthy subjects, it appears that, to produce re-perfusion after loading, an appropriate course of action is to provide periodic, complete or near complete off-loading.

Further studies with a greater number of subjects, including actual patients of different weights and some who are at risk of developing pressure ulcers, should be conducted on a range of dynamic support surfaces to confirm the validity of the presented technique and make it more clinically applicable. The results could then also be used by manufacturers to guide clinicians and purchasing officers in choosing the correct mattresses for their patients.

References

1. Bliss MR. Aetiology of pressure sores. Rev Clin Gerontol 1993; **3**:379-97.
2. Le KM, Madsen BL, Barth PW, Ksander GA, Angell JB & Vistnes LM. An in-depth look at pressure sores using monolithic silicon pressure sensors. Plast Reconst Surg 1984; **74**:745-54.
3. Whittemore R. Pressure-reduction support surfaces: a review of the literature. JWOCN 1998; **25**:6-25.
4. Berlowitz DR & Brienza DM. Are all pressure ulcers the result of deep tissue injury? A review of the literature. Ostomy Wound Manage 2007; **53**:34-8.
5. Young T. Nimbus 3 alternating-pressure replacement mattress. Brit J Nurs 1998; **7**:409-12.
6. Mayrovitz HN & Sims N. Effects of support surface relief pressure on heel skin blood flow in persons with and without diabetes mellitus. Adv Skin Wound Care 2004; **17**:197-201.
7. Wych R, Neil G & Kalisse C. Skin-orthosis interface pressure transducers – a review. Care Sci Pract 1989; **7**:100-4.
8. Landis EM. Micro-injection studies of capillary blood pressure in human skin. Heart 1930; **15**:209-28.
9. Guyton AC. Textbook of Medical Physiology (8th ed). Philadelphia: WB Saunders Company, 1991:170.
10. Medical Devices Agency. Wheelchair Cushions Static and Dynamic: A Comparative Evaluation. London: HMSO, 1997.
11. Berjian RA, Douglass HO, Holyoke ED, Goodwin PM & Priore RL. Skin pressure measurements on various mattress surfaces in cancer patients. Am J Phys Med 1983; **62**:217-26.
12. Rithalia SVS. Evaluation of alternating pressure mattresses: one laboratory-based strategy. J Tissue Viability 2004; **14**:51-8.
13. Mayrovitz HN & Sims N. Effects of different cyclic pressurization and relief patterns on heel skin blood perfusion. Adv Skin Wound Care 2002; **15**:158-64.
14. McLeod AG. Principles of alternating pressure surfaces. Adv Wound Care. 1997; **10**:30-6.
15. Rithalia SVS & Gonsalkorale M. Pressure relieving characteristics of four different commercially available alternating pressure air mattresses. J Rehabil Res Dev 1998; **35**:225-30.
16. Hussain T. Experimental study of some pressure effects on tissue, with reference to bed-sore problem. J Pathol Bacteriol 1953; **66**:347-58.
17. Barton AA. The pathogenesis of skin wounds due to pressure. J Tissue Viability 2006; **16**:12-5.
18. Salcido R, Donofrio JC, Fisher SB *et al*. Histopathology of pressure ulcers as a result of sequential computer-controlled pressure sessions in a fuzzy rat model. Adv Wound Care 1994; **7**:23-8.
19. Grindley A & Acres J. Alternating pressure mattresses: comfort and quality of sleep. Br J Nurs 1996; **5**:1303-10.
20. Rithalia SVS. Comparison of performance characteristics of the Nimbus and Airwave mattresses. Int J Rehabil Res 1995; **18**:182-5.
21. Lockyer-Stevens N. A developing information base for purchasing decisions: a review of pressure-relieving beds for at-risk patients. Prof Nurse 1994; **9**:534-42.
22. Cavicchioli A & Carella G. Clinical effectiveness of a low-tech versus high-tech pressure-redistributing mattress. J Wound Care 2007; **16**:285-9.
23. Price P, Bale S, Newcombe R & Harding K. Challenging the pressure sore paradigm. J Wound Care 1999; **8**:187-9.