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The physiological response of soft tissue to periodic repositioning as a strategy for pressure ulcer prevention

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ABSTRACT

Background: Individuals who have reduced mobility are at risk of developing pressure ulcers if they are subjected to sustained static postures. To reduce this risk clinical guidelines advocate healthcare professionals reposition patients regularly. Automated tilting mechanisms have recently been introduced to provide periodic repositioning. This study compared the performance of such a prototype mattress to conventional manual repositioning.
Methods: Ten healthy participants (7 males and 3 females, aged 23–66 years) were recruited to compare the effects of an automated tilting mattress to standard manual repositioning, using the 30° tilt. Measures during the tilting protocols (supine, right and left tilt) included comfort and safety scores, interface pressures, inclinometer angles and transcutaneous gas tensions (sacrum and shoulder). Data from these outcomes were compared between each protocol.
Findings: Results indicated no significant differences for either interface pressures or transcutaneous gas responses between the two protocols ($P > 0.05$ in both cases). Indeed a small proportion of participants (~30%) exhibited changes in transcutaneous oxygen and carbon dioxide values in the shoulder during a right tilt for both protocols. The tilt angles at the sternum and the pelvis were significantly less in the automated tilt compared to the manual tilt (mean difference = 9.4–11.5°, $P < 0.001$). Participants reported similar comfort scores for both protocols, although perceived safety was reduced on the prototype mattress.
Interpretation: Although further studies are required to assess its performance in maintaining tissue viability, an automated tilting mattress offers the ability to periodically reposition vulnerable individuals, with potential economic savings to health services.

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1. Introduction

Pressure ulcers (PUs) are localised areas of injury to skin and/or underlying tissues, commonly occurring adjacent to bony prominences, which provide a focal point for the compression of soft tissues (EPUAP-NPUAP, 2009). PUs represent a disabling long term condition that has been recognised as both a Patient Safety and Quality of Care indicator for individuals in both hospital and community settings (Department of Health, 2010). Additionally, PUs negatively impact on patients' rehabilitation and quality of life (Spilsbury et al., 2007). Despite the increased attention within health services, their incidence rate remains unacceptably high with associated treatment costs estimated at £4 billion per annum in the UK (National Patient Safety Agency, 2010) with higher costs associated with the more severe grades of PU (Dealey et al., 2012).

International guidelines for pressure ulcer prevention (European Pressure Ulcer Advisory, 2009; National Institute for Health and Clinical Excellence, 2005) recommend frequent repositioning for individuals at risk. This is achieved in practice by periodically redistributing the pressure to enable relief of previously loaded areas. Individuals with reduced mobility often require clinicians or carers to assist in postural changes, which are maintained with the use of pillows and/or cushions. Although there is limited evidence surrounding the required frequency of repositioning on various support surfaces, guidance suggests changes in position every 2–4 h for individuals with reduced mobility (Vanderwee et al., 2007). This process of manual repositioning is time consuming and labour intensive. Indeed, a recent study estimated frequent repositioning to cost between €200 and €250 per patient over a four week period (Moore et al., 2013).

In order to provide repositioning and reduce the burden on healthcare providers, some manufacturers have introduced tilting mechanism in association with support surfaces. These so-called lateral rotation devices are designed to mimic manual repositioning and have been defined by the NPUAP Support Surface Standards Initiative

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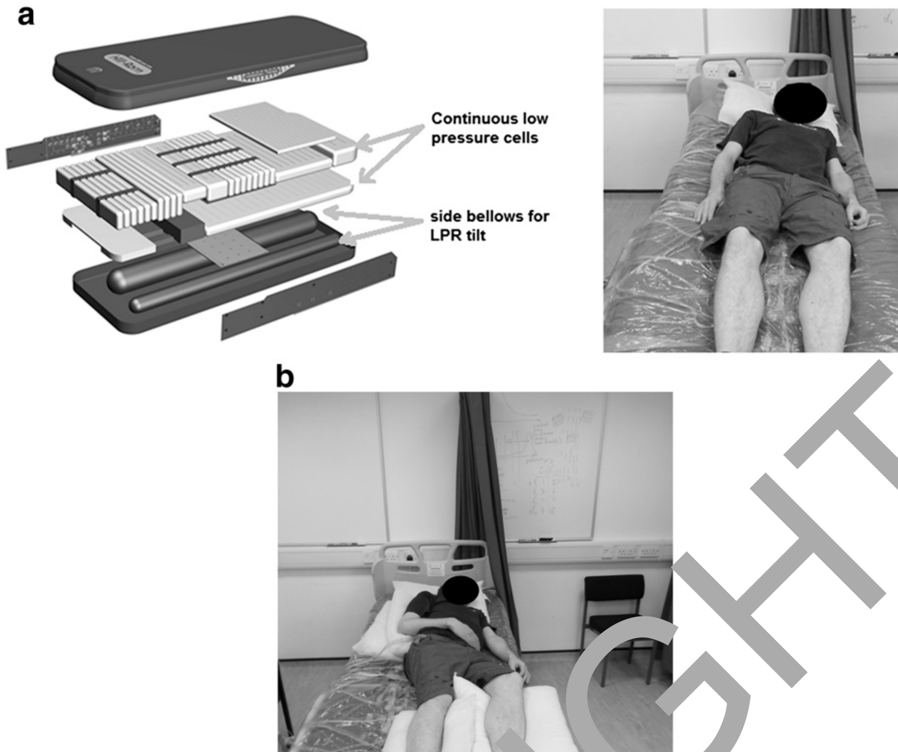

Fig. 1. (a) Schematic of the prototype LPR device with air billows to provide tilt. (b) Example of manual tilt to the left with the individual supported by pillows.

(2007) as "…a support surface that provides rotation about a longitudinal axis as characterized by degree of patient tilt, duration and frequency" (National Pressure Ulcer Advisor Panel, 2007). Despite their intended purpose, evidence regarding the efficacy of lateral rotation devices remains predominantly anecdotal in nature. Of the few published studies, Melland et al. (1999) evaluated the Freedom Bed™ in 24 adults with degenerative disease, residing at home or in a long-term care facility. The authors reported a significant improvement in sleep quality using the tilting bed, although its performance with respect to maintenance of tissue viability was not fully assessed. Yi et al. (2009) investigated the effect of tilting using 3 prototype lateral rotation beds with twenty healthy volunteers using interface pressure as a primary outcome measure. Results indicated a significant reduction in peak interface pressure measures in one bed with two segments rotating about one axis, compared with the supine position.

The performance of support surfaces have been evaluated using several different measurement techniques. One of the most common approaches, adopted in both clinical and research settings, involves measurement of the interface pressure distribution between the surface and a supported individual. However, it is well established that interface pressures alone do not alert the clinician to risk of pressure ulcers and the imprecise relationship between pressure magnitude and duration limits the predictive or prognostic value of the measured parameter (Reenalda et al., 2009). Accordingly, much research has utilised measures of tissue viability, often in the form of transcutaneous gas monitoring, to examine the tissue response to mechanical loads (Chai and Bader, 2013; Kim et al., 2012; Makhsous et al., 2007). These studies have shown distinct changes in tissue oxygen ($TcPO_2$) and carbon dioxide ($TcPCO_2$) tensions when measured at differing skin sites subjected to representative external pressures (Knight et al., 2001). Thus the combination of interface pressures and transcutaneous gas values provides considerable insight into the biomechanical cause and physiological effects of tissue loading as a result of a periodic loading on various support surfaces.

There is only limited evidence in the literature to suggest that lateral rotation might prove an effective alternative to manual repositioning,

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Table 1
Summary of the physiological response from the ten healthy participants as defined by the Chai and Bader (2013) criteria (Section 2.4), for each postural phase of both LPR and Manual protocols.

Shoulder											Sacrum									
Participant	LPR					Manual					LPR					Manual				
	Sup.	Left	Sup.	Right	Sup.	Sup.	Left	Sup.	Right	Sup.	Sup.	Left	Sup.	Right	Sup.	Sup.	Left	Sup.	Right	Sup.
1	1	1	1	3	1	1	1	2	3	2	1	2	2	2	2	1	1	1	1	1
2	2	2	2	3	2	2	1	3	1	3	1	1	1	1	1	2	2	2	2	2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	3	2	2	1	1	3	2	2	1	2	2	3	2	1	1	1	1	1
5	1	2	1	3	1	1	1	1	3	2	1	3	2	3	2	1	2	1	2	2
6	1	1	1	1	1	1	1	1	2	3	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	2	1	1	1	1	2	3	1	1	1	1	1	1	1	1	1	1
10	1	1	2	2	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1

although the specific design of the tilt mechanism will inevitably affect its ability to provide pressure redistribution. More certain is the fact that the characteristics of the individual support surface will influence tissue response. In addition, patient satisfaction and perceived safety are paramount to ensure clinical translation and compliance with pressure redistributing devices. Accordingly, the current study has been designed to combine objective physiological and biomechanical measurements with critical subjective parameters to evaluate a prototype automated lateral rotation system. Its performance was compared to a manual tilt commonly performed in the clinical setting.

2. Methods

2.1. Description of support surface and tilting mechanisms

The prototype tilting mattress designed by Hill-Rom, or Lateral Pressure Redistribution (LPR), utilised an air-cell design, which provided continuous low pressure (CLP) support. The LPR mattress incorporated an automated tilting mechanism through inflatable side bellows under the full length of the LPR mattress (Fig. 1a). In order to tilt the participant, the opposing side bellow of the LPR mattress was inflated to

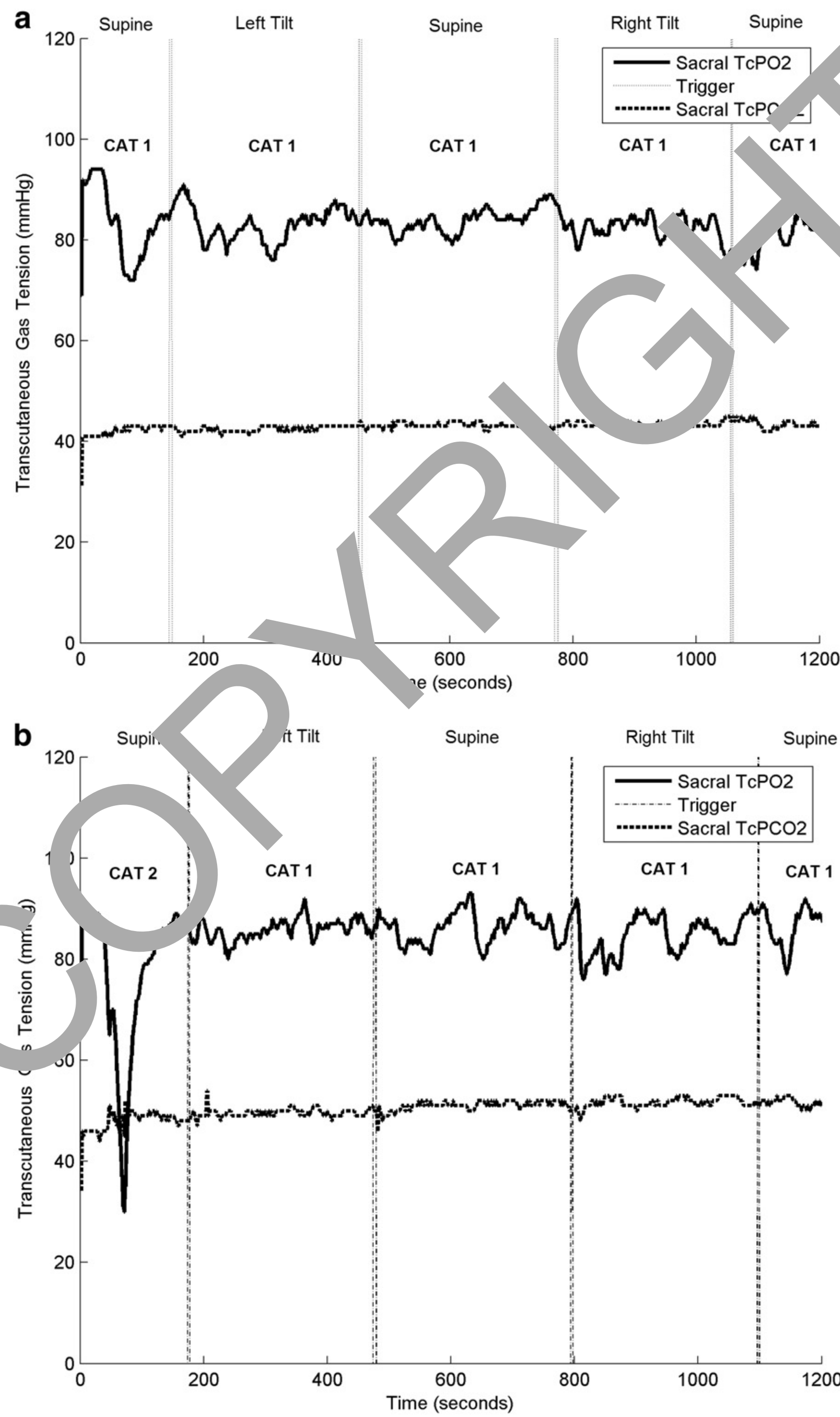

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Fig. 2. Category one response (denoted CAT 1) at the sacrum (participant 4): (a) LPR protocol; (b) Manual protocol.

provide a tilt in the transverse plane, which was maintained throughout the relevant tilt phase of the test session. The inflatable bellows provided an additional 20 cm in lateral height, which translated to the bed being tilted 14°. This tilting mechanism was compared to a manual tilt performed by a registered nurse (MW) on the same LPR mattress (Fig. 1b). During the manual tilt, postures were maintained with pillow support at the back and lengthways under the legs (Fig. 1b). This manual tilt was performed to achieve an approximate 30° elevation angle at the pelvis (Moore, 2012). The CLP setting on the mattress, used for both manual and automated tilting protocols, was optimised with respect to the Body Mass Index (BMI) for the individual participant (Chai and Bader, 2013).

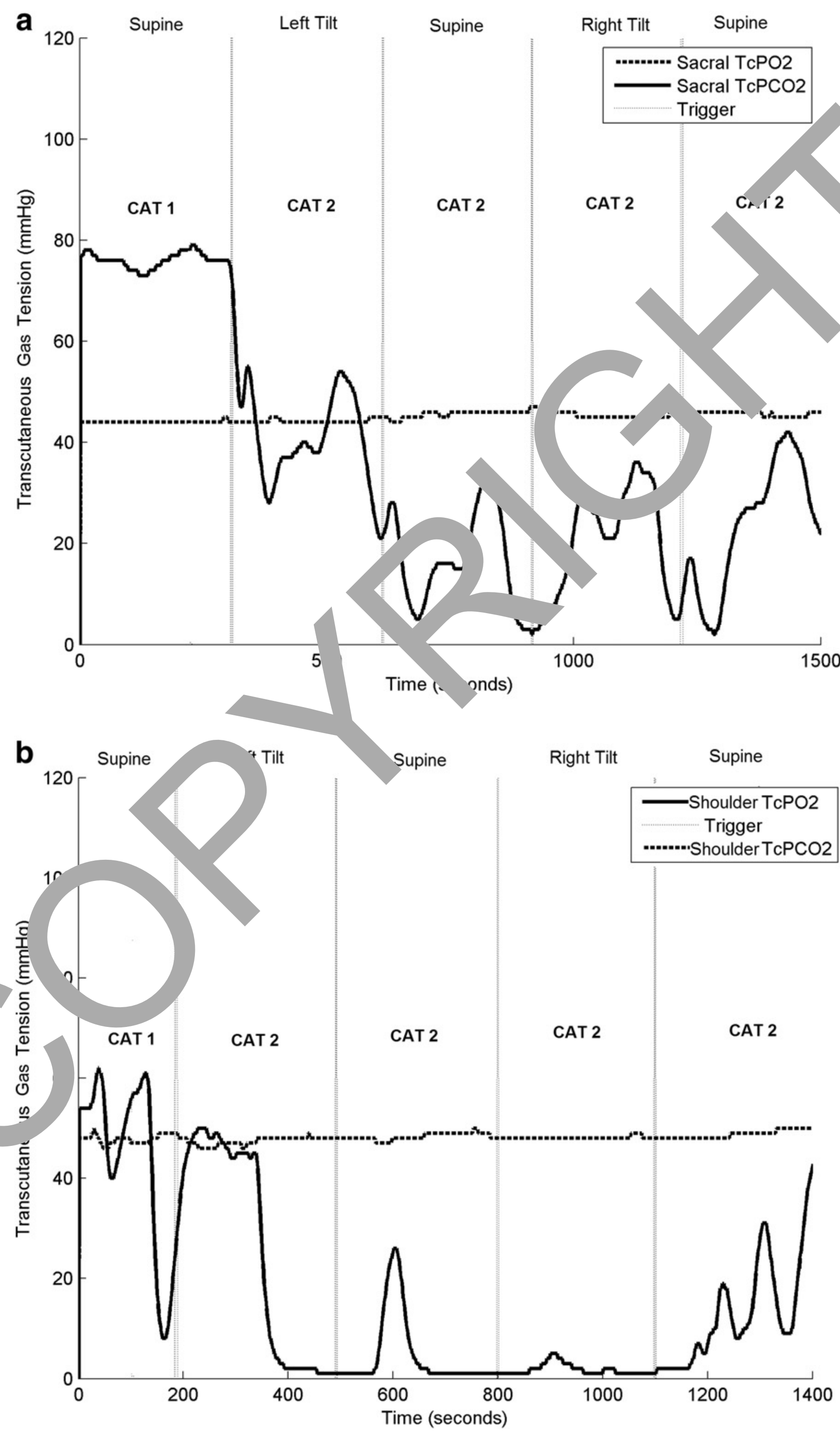

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Fig. 3. (a) Category two response (denoted CAT 2) at the sacrum during the (a) LPR protocol and (b) Manual protocol whilst the individual is tilted to the left and subsequent postures (Participant 1). (c) Category two response (denoted CAT 2) during the LPR protocol at the shoulder whilst the individual is tilted to the right (participant 9) which recovers to category one in the subsequent supine posture. (d) Category two response (denoted CAT 2) during the Manual protocol at the shoulder whilst the individual is tilted to the right (participant 9) which develops into a category three response (denoted CAT 3) in the subsequent supine posture.

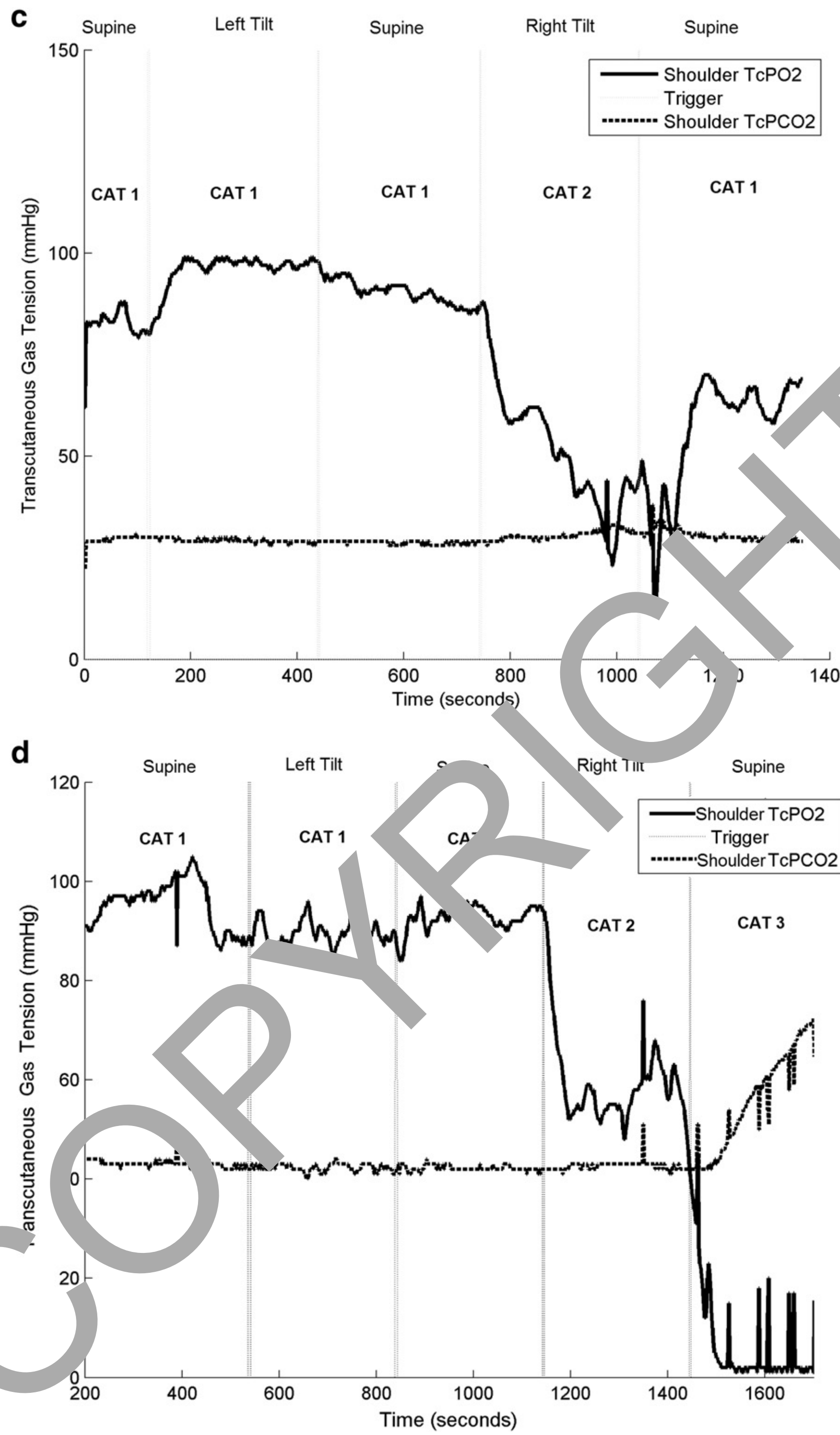

Fig. 3 *(continued)*.

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2.2. Participants

Ten healthy participants (7 male and 3 female) were recruited from the local University population. Participants were aged between 23 and 66 years of age (mean 41 years) with an average height of 1.75 m (std = 0.18 m) and an average weight of 78.5 (std = 11.8 kg). Participants were asked to wear a pair of shorts and loose fitting clothing during data collection. The study was approved by the local ethics committee of the University of Southampton and informed consent was obtained from each participant prior to testing. Exclusion criteria included any participant with a history of skin-related conditions, or who were unable to lie in a supine posture for a period of 2 h.

2.3. Test equipment

Physiological measures of transcutaneous oxygen ($TcPO_2$) and carbon dioxide (T_cPCO_2) tensions were monitored at two body sites, the sacrum and the right shoulder, using combined electrodes (E5280 O2 & CO2 combined, Radiometer, Denmark) attached to separate monitors (TCM4, TCM3, Radiometer, Denmark). Each electrode was heated

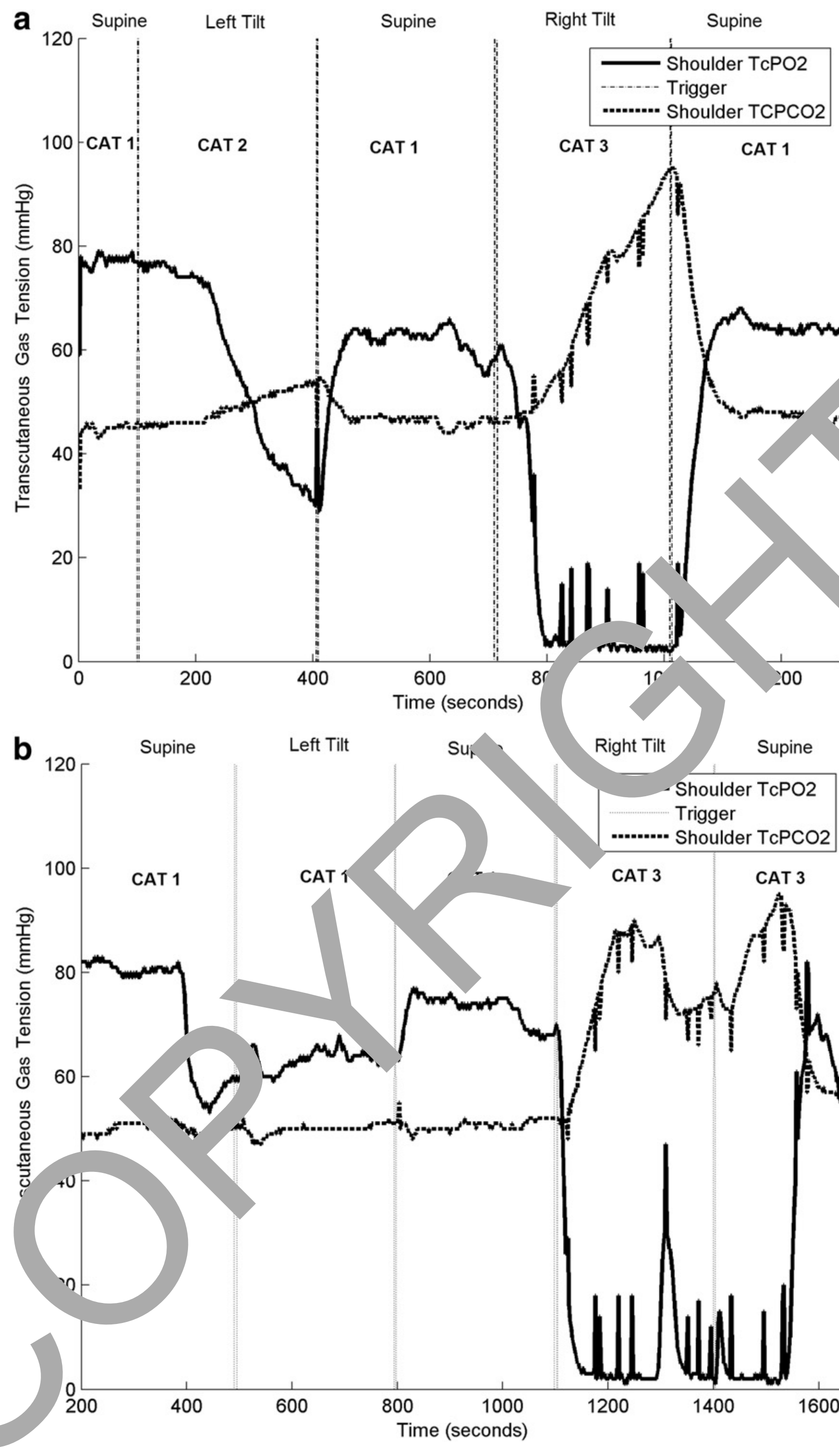

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Fig. 4. Category three response (denoted CAT 3) during the (a) LPR protocol and (b) Manual protocol at the shoulder whilst the individual is tilted to the right, with a subsequent recovery to category one (denoted CAT 1) during the final supine posture (participant 1).

to 43.5 °C to ensure maximum vasodilation (Bogie et al., 1995). Interface pressures were recorded via a thin sheet incorporating 96 sensors placed on the support surface and attached to an interface pressure monitoring system (Talley MkIII Pressure Monitor, Romsey, UK). This pressure mapping array included two 12-sensor arrays, located under the sacral and shoulder areas, at a corresponding spatial resolution of 3 cm in both directions. The remaining 72 sensors were positioned along the body with a spatial resolution of 5 cm across the body width and 12 cm along the body length. The angle at which each participant was tilted was measured by a hand held inclinometer (SOAR, Digital Level metre 1700). These measurements were recorded in the coronal plane at the level of the sternum (chest), pelvis and ankles.

2.4. Test protocol

All test procedures were performed in the Biomechanics Testing Laboratory in the Clinical Academic Facility within Southampton General Hospital, where the room temperature was maintained at 24 °C. Participants were asked to lie in a prone position for a 20 minute period to attain unloaded basal $TcPO_2$ and T_cPCO_2 values.

Table 2
Summary of peak pressure data (mm Hg) for all participants at optimum IP during the LPR and Manual tilt phases (median and interquartile range IQR presented).

		Supine		Left		Right	
Parameter	Mechanism	Median	IQR	Median	IQR	Median	IQR
Peak body[a]	LPR	46	41 → 52	51	44 → 59	49	38 → 72
	Manual	53	49 → 62	48	44 → 61	40	38 → 60
Peak shoulder[b]	LPR	42	34 → 66	48	40 → 87	51	40 → 72
	Manual	42	38 → 74	30	29 → 37	46	37 → 60
Peak sacrum[b]	LPR	46	42 → 48	48	46 → 49	47	41 → 52
	Manual	66	48 → 100	51	48 → 60	52	48 → 60

[a] Estimated over 72 sensors.
[b] Estimated over a 12 sensor array.

After this acclimatisation period each participant was then carefully positioned in a supine posture on the prototype mattress for 5 min, while the first interface pressure was recorded. Participants were then positioned into a further four equal 15-minute postures or 'phases', which followed the order of; right tilt, supine, left tilt and supine. This was standardised for both LPR and manual tilt protocols. Transcutaneous gas tensions were continually monitored throughout all phases of the test. Three separate interface pressure measurements were recorded after 5 min of each distinct postural phase i.e. right and left tilts, and during the final supine phase. In order to measure the tilt angles, inclinometer measures were taken once for each of the three levels of the body in both tilted postures (right and left).Participants were also asked to rate their comfort and safety using a five point Likert scale, during each phase of both the LPR and manual tilting protocols. For both the LPR and the manual tilt protocols the same measures were performed on two different days (maximum of one week apart).

2.5. Data analysis

Data processing of the interface pressures and transcutaneous values were performed using Matlab (Mathworks, USA). Values of peak pressures were estimated from the pressure distributions under the sacrum, shoulder and the remaining body area during each phase. The trends in the transcutaneous gas tensions were categorised according to the criteria recently published by Chai and Bader (2013). To review briefly, changes in $TcPO_2$ and $TcPCO_2$ from baseline unloaded values were divided into three distinct categories, namely:

Category 1. Minimal changes in both $TcPO_2$ and $TcPCO_2$ values.
Category 2. >25% decrease in $TcPO_2$ with minimal change in $TcPCO_2$
Category 3. >25% decrease in $TcPO_2$ associated with a >25% increase in $TcPCO_2$

Normal unloaded values of transcutaneous gases have been reported in the literature, with $TcPO_2$ ranging from 50 to 90 mm Hg and $TcPCO_2$ ranging from 38 to 4[illegible] mm Hg (Knight et al., 2001).

All data were examined for normal distribution prior to analysis using the Shapiro–Wilk test. This test indicated that parametric statistics (mean, standard deviation) were appropriate for use with the inclinometer tilt angles. However, the data for interface pressures were non-normal in distribution and, as a result non-parametric statistics were employed (median, inter-quartile range). Non-parametric inferential statistics were applied to the categorical and interval data, associated with the transcutaneous category responses and the comfort scores. Comparisons of LPR and manual tilt data involved the non-parametric (Wilcoxon signed rank test) tests during the different postures with the significance value set to $P \leq 0.05$.

Table 3
Summary of segmental tilt angles (degrees) during the LPR and Manual tilt cycles mean and (standard deviation).

	Sternum (chest)		Pelvis		Ankles	
	LPR	Manual	LPR	Manual	LPR	Manual
Right	21.4 (4.4)	30.8 (6.5)	17.8 (5.6)	23.6 (5.4)	9.8 (4.1)	4.7 (4.6)
Left	17.5 (5.5)	31.1 (5.9)	12.6 (3.3)	25.6 (6.3)	7.6 (3.2)	3.0 (2.1)
Combined	19.4 (5.0)	31.0 (6.2)	15.2 (4.2)	24.6 (5.9)	8.7 (3.7)	3.8 (3.6)

3. Results

3.1. Monitoring physiological parameters

Physiological tissue responses showed consistency within individuals when tested with both the LPR and Manual protocols, with many participants exhibiting little change in $TcPO_2$ and $TcPCO_2$ during the entire test period (Table 1, Fig. 2). There were, however, some variations in the tissue response between participants particularly during the latter phases of the test protocol. Thus in the initial supine phase, the participants demonstrated minimal changes in $TcPO_2$ and $TcPCO_2$ values (Category 1) for 90% of cases for both tissue sites (Table 1). Whilst the participant was tilted to the left, shoulder and sacral $TcPO_2$ and $TcPCO_2$ levels remained stable in most cases (>80%). Only one participant (10%) exhibited a change in sacral category, which was observed during both test protocols. During the second supine phase, sacral responses remained stable (Category 1–2) for all participants (Table 1). However, one participant on LPR and two participants during manual tilt exhibited a Category 3 response at the shoulder. The right tilt phase revealed an increasing number of Category 2 (Fig. 3a and b) and Category 3 observations at the shoulder. During the final supine phase for LPR session, all participants recovered to a Category 1–2 at the shoulder (Fig. 3c). By contrast, Category 3 was maintained at the shoulder during manual protocol in 30% of cases (Fig. 3d). It is interesting to note that two of these participants demonstrated this Category 3 response for both test protocols (Fig. 4a and b). During the final supine phase, the response at the sacrum had recovered for both LPR and manual protocols with all participants exhibiting Category 1 or 2 responses.

3.2. Biomechanical assessment

Table 2 illustrates the median values of peak interface pressure for both LPR and manual tilts. The results showed no significant differences between values in both test sessions ($P > 0.05$). Furthermore, these mean values did not exceed 66 mm Hg (8.8 kPa) for any of the body sites (shoulder, sacrum, body) and the inter-site differences were not significantly different ($P > 0.05$). There were also no significant differences in the peak interface pressures ($P > 0.05$) between postures (supine, left tilt and right tilt), for both the LPR and Manual tilt protocols.

The results from the inclinometer indicated that the LPR tilt proportionally reduced from the head to the ankles, with a trend of greater angles associated with left tilt compared to right tilt. For both the sternum and pelvis the LPR tilt angles were significantly lower than the corresponding values for the manual tilt protocol (mean difference = 9.4 to 11.5°, $P < 0.001$). By contrast, at the level of the ankles, the LPR device produced greater tilt than for the manual protocol by a mean difference of approximately 5° (Table 3).

3.3. Comfort and safety feedback

The results from the comfort survey suggested that during the supine phase participants reported to be 'comfortable' or 'very comfortable' in the majority of cases (17/20, pooled for both LPR and manual tilt protocols). However, during the tilted phases the comfort scores varied considerably, with feedback ranging from 'very comfortable' to 'uncomfortable'. The effective decrease in comfort levels compared with the supine posture was evident for both LPR and manual protocols. It was also observed that some subjects felt 'unsafe' whilst being tilted during both LPR and manual protocols. This was reported more frequently during the LPR protocol with 5/10 reporting 'unsafe' compared to one individual during the manual tilt protocol, a difference which was shown to be significant ($P < 0.05$).

4. Discussion

This study has combined a range of objective measures in association with subjective feedback to compare a prototype lateral rotation (LPR) mattress to a standard manual tilt. This revealed that the responses were in general similar for both tilting protocols, although some distinct differences were noted between protocols in a small proportion of the healthy cohort. Thus, results of the physiological measures of transcutaneous gas tensions indicate characteristic trends in tissue response associated with equivalent interface pressures for both tilting protocols. In addition, comfort scores were similar between the two protocols. However, the participants reported some safety concerns whilst being tilted, particularly during the LPR protocol, despite the fact that the angle of tilt achieved at the sternum and pelvis was significantly lower using the LPR mattress.

The present study revealed that during supine lying there are relatively low interface pressures across the body and sacral tissue gas tensions remain stable, with the majority of participants exhibiting a Category 1 response. This result was also shown by Kim et al (2012) who reported values for interfaces pressures that are similar in magnitude and distribution to the present study (median = 46, range 27–84 mm Hg). In addition, their evaluation of transcutaneous tissue oxygen values at the sacrum was reported to remain stable during 20 minutes of static supine lying with mean values of TcPO2 between 31 and 37 mm Hg. An interesting finding of the present study was that some individuals exhibited a reduction in $TcPO_2$ values (Category 2 response, Fig. 3a–b) at the shoulder and in a small number of cases when individuals were tilted towards the right, this was associated with an increase in $TcPCO_2$ values (Category 3 response, Fig. 4a–b). These responses were also reported in healthy individuals by Chai and Bader (2013) at the sacrum, when the head of the bed angle was raised in the supine position. The difference in body site response could be associated with the differing methods of bed tilt employed by the two studies, with Chai and Bader (2013) tilting the head up in the sagittal plane and the present study tilting the whole body in the transverse plane. The presence of the transcutaneous gas tension electrode did not influence the soft tissue responses in the shoulder, with corresponding peak interface pressure values matching those at the sacrum and the remaining body sites (Table 2).The Category 2 and 3 responses in tissue gas tensions are indicative of localised tissue ischemia, which is commonly regarded as one of the main mechanisms of pressure ulcer aetiology (Bouten et al., 2003). When the oxygen supply to the cell niche is compromised, the metabolic state of the tissue will change from aerobic to anaerobic respiration. This will result in anaerobic glycolysis and the potential build-up of metabolites associated with this process, namely lactate. Indeed, previous research has correlated lactate concentrations found in sweat in loaded tissues, with a decrease in $TcPO_2$ and an associated increase in T_cPCO_2 (Knight et al., 2001).

The present study indicated similar physiological responses at the shoulder and sacrum despite a significant reduction in the magnitude of tilt angle when comparing the LPR and manual protocols. The reduction in tilt magnitude may have resulted from the mechanism of the prototype mattress involving a single segment, single axis design (Fig. 1a). It is also of note that the degree of tilt the bed produced without an individual lying on it (14°) differed to the angles of tilt measured on the participant at the ankles (3.8°) and sternum (19.4°). However, pelvis tilt angles were similar in magnitude (15.2°). Yi et al (2009) reported higher tilting angles with a two segmented bed rotating about a single axis, with an associated reduction in peak interface pressure from the supine position. However, larger tilt angles (up to 40°) may also increase the risk of PU formation (Russell and Logsdon, 2003), with the potential increase of shear in the skin and soft tissues (Turpin and Pemberton, 2006). Both the present study and that of Yi et al (2009) reported that participant comfort and stability were, in some cases, reduced with an automated tilting protocol. However, neither of the studies incorporated a period of familiarisation on the automated tilting mattress. If participants were conditioned to repositioning by means of lateral rotation devices, perceived comfort and safety may have improved.

The predominant limitation of the current study was the use of a cohort of able-bodied individuals, which limits the ability to generalise the results across differing sub-populations who may demonstrate distinct responses and recovery time (Makhsous et al., 2007). In addition, the present participants were instructed to lay supine in the centre of the mattress, which may not reflect the actual positioning encountered in the clinical setting. Furthermore, the order of the phases was standardised, which may have resulted in tissue responses that are influenced by the state experienced in a previous phase. This is exemplified in a few cases where tissue viability compromised in the tilt phase did not recover in the supine phase (Fig. 4b). It must also be recognised that automatic devices can not completely replace individual patient care. Indeed regular skin checks performed by a trained healthcare professional are still recommended in international guidelines for pressure ulcer prevention (European Pressure Ulcer Advisory, P., 2009).

In the context of current budgetary cuts and staffing constraints within the National Health Service (NHS) there is limited scope to provide conventional repositioning to all those in need of this intervention. Indeed, recent literature has shown the cost of pressure ulcer prevention and management has a major impact on the healthcare system, with manual patient repositioning costing between €200 and 250 per patient over a four week period (Moore et al., 2013). Although providing an automated tilting mattresses may represent a larger initial cost compared to a conventional support surface, the system offers the potential to reduce this financial burden over the long-term, provided it delivers an equivalent performance in terms of pressure relief to compromised soft tissues when compared to standard clinical practice. Such devices may further enable personalised tilt cycle times, and optimised internal air cell pressures within the mattress, thus providing optimal levels of management for vulnerable skin tissues. In order to provide guidance on tilting regimes, movement patterns of healthy individuals lying in bed could be monitored to identify repositioning strategies which could be implemented with the automated device (Linder-Ganz et al., 2007).

5. Conclusions

This study has shown that an automated tilting mattress has comparable performance to a manual tilt in terms of both interface pressures and physiological responses, as measured by transcutaneous gas tensions. However, differences did exist between the two techniques involving the degree of tilt angle achieved and perceived safety. Automated tilting mattresses offer the potential to reduce the burden of manually turning patients and could provide personalised care for individuals who are at risk of developing pressure ulcers.

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Conflict of interest

The prototype mattress was kindly provided by Hill-Rom.

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