Journal of Tissue Viability xxx (2017) 1–9

Contents lists available at ScienceDirect

Journal of Tissue Viability

journal homepage: www.elsevier.com/locate/jtv

Pressure signatures can influence tissue response for individuals supported on an alternating pressure mattress

C.Y. Chai [a], O. Sadou [a, b], P.R. Worsley [c], D.L. Bader [a, c, *]

[a] School of Engineering and Materials Science, Queen Mary University of London, London E1 4NS, UK
[b] Tesla Motors, San Francisco, USA
[c] Faculty of Health Sciences, University of Southampton, Southampton SO16 6YD, UK

ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form
3 May 2017
Accepted 9 May 2017

Keywords:
Pressure ulcers
Tissue viability
Alternating pressure signatures
Supine lying
Microclimate

ABSTRACT

Prolonged mechanical loading can lead to the breakdown of skin and underlying tissues which can, in turn, develop into a pressure ulcer. The benefits of pressure relief and/or redistribution to minimise risk have been well documented. Manufacturers have developed alternating air pressure mattresses (APAMs) to provide periodic relief for individuals on prolonged bed-rest. The present study describes the development of a control system, termed Pneumatic Manager which can vary the signature of an APAM, namely its pressure amplitude, cell profile and cycle period. An experimental array was designed to investigate the effects of varying these parameters, particularly with respect to its ability to maintain skin viability in a group of five healthy volunteers lying in a supine position. Transcutaneous gas (T_cPO_2/T_cPCO_2) tensions at the sacrum were monitored. In addition, pressures and microclimate parameters at the loaded support interface were also measured.

In the majority of test conditions the alternating support produced sacral T_cPO_2 values, which either remained relatively high or fluctuated in concert with cycle period providing adequate viability. However, in 46% of cases at the extreme pressure amplitude of 100/0 mmHg, there was compromise to the skin viability at the sacrum, as reflected in depressed T_cPO_2 levels associated with an elevation of T_cPCO_2 levels above the normal range. In all cases, both the humidity and temperature levels increased during the test period. It is interesting to note that interface pressures at the sacrum rarely exceeded 60 mmHg. Although such studies need to be extended to involve bed-bound individuals, the results provide a design template for the optimum pressure signatures of APAM systems to ensure maintenance of skin viability during pronged loading.

1. Introduction

Prolonged mechanical loading of skin and underlying tissues can lead to a reduction in perfusion and subsequent delivery of vital nutrients to local cells, which affects tissue remodelling and can result in the development of pressure ulcers (PUs) [1]. In addition to local ischaemia, research has revealed other mechanisms associated with pressure ulcer formation namely, impaired lymphatic drainage, reperfusion injury and direct cell damage resulting from high deformations [2]. This disabling condition, which has been implicated as a key indicator of Patient Safety and Quality of Care, particularly affects immobile and insensate individuals who spend much of the day bed or chair-bound. The benefits of pressure relief and/or redistribution have been documented in international guidelines for the prevention and treatment of pressure ulcers for many sub-groups of patients deemed to be at high risk of developing PUs [3]. Thus a number of management strategies are available ranging from regular turning of the patient, which is labour intensive and not always strictly adhered to [4], to active support surfaces including a number of commercial alternating pressure air mattresses (APAMs). These systems tend to be prescribed to high risk individuals to reduce the effects of prolonged load-induced ischaemia on vulnerable soft tissues overlying bony prominences, typically at the sacrum and heels. The main evidence for their effectiveness derives from a large cohort study in which their use reduced the number of PUs at the heels when compared to a control group supported on a viscoelastic foam mattress [5]. In

* Corresponding author. Faculty of Health Sciences, University of Southampton, Southampton General Hospital, Southampton SO16 6YD, UK.
E-mail address: D.L.Bader@soton.ac.uk (D.L. Bader).

http://dx.doi.org/10.1016/j.jtv.2017.05.001
0965-206X/

order to provide sequential offloading of vulnerable tissues manufacturers of APAM systems utilise pressure profiles, whereby the cells within the device inflate and deflate to a prescribed internal pressure along different zones of the support surface. However, there is considerable variation in the pressure profiles or signatures adopted in commercial APAM systems, the characteristics of which have been discussed in a consensus document [6]. These are often determined by practical issues, such as the characteristics of the incorporated pumps, as opposed to considerations related to maintaining tissue viability or status of the supported individual.

Only a few studies have evaluated the features which determine the pressure signature associated with APAM systems. In one such study, the effects of different pressure relief profiles (pressure range of 0–20 and 10–20 mmHg for cycle times of 5, 10 and 20 min) were evaluated by monitoring skin blood perfusion in the heel supported by a single air cell of an experimental mattress [7]. Their findings revealed that the average skin perfusion could be maintained with the pressure relief profiles for healthy subjects. Using a similar approach, Goossens and Rithalia [8] examined the performance of three APAMs (peak internal pressures ranging from 28 to 49 mmHg for cycle time of 10 min) and indicated differences in physiological responses, as assessed by gas tension recovery and tissue perfusion, at the heel of an able-bodied cohort. However, no statistical differences in maximum interface pressures between the three APAMs were observed. In a recent study the present authors evaluated the performance of a prototype APAM with an in-built pressure sensor, where the internal pressures of the sacral section could be adjusted to subject morphology and BMI [9]. Internal mattress pressures and transcutaneous gas tensions ($TcPO_2$ and $TcPO_2$) at the sacrum and a control site, the scapula, were monitored. The skin response to alternating support pressures in a cohort of healthy volunteers were divided conveniently into three distinct categories (1–3), as defined in Table 1.

In the majority of test conditions the internal support produced sacral T_cPO_2 values which provided adequate viability, either remaining similar to those at the control site (Category 1) or fluctuating in concert with the cycles of alternating support pressures (Category 2). In both cases, the associated T_cPCO_2 levels remained within the normal range of 35–45 mmHg [9,10]. However, in a few cases when the head of bed (HOB) was raised ($\geq$45°), there was compromise to the skin viability at the sacrum, as reflected in depressed T_cPO_2 levels associated with an elevation of T_cPCO_2 levels above the normal range (Category 3). In all cases, interface pressures at the sacrum rarely exceeded 8 kPa (60 mmHg). The transcutaneous categorisation was also adopted in a recent publication examining the differences between lateral rotation provided by an active mattress system and the manual repositioning performed by a clinician [4]. Recent studies evaluating support surface performance have also incorporated temperature and humidity sensing [11], motivated by the increasing evidence that thermodynamic conditions within and around skin tissue strongly influence the susceptibility of skin to pressure ulcers [12]. As an example, elevated interface temperatures increase the metabolic demands of the tissue and excessive moisture can lead to skin maceration.

Table 1
Characterization response of transcutaneous oxygen and carbon dioxide tensions in human skin exposed to mechanical loading (Based on [9]).

Category	Changes in transcutaneous oxygen ($TcPO_2$) and carbon dioxide ($TcPO_2$) tensions
1	Minimal changes in both $TcPO_2$ and $TcPCO_2$ from basal unloaded values.
2	>25% Decrease in $TcPO_2$ with minimal change in $TcPCO_2$
3	>25% Decrease in $TcPO_2$ associated with a >25% increase in $TcPCO_2$

The relative paucity of literature provides motivation for the present study, which examines whether there is an optimal internal mattress pressure signature, which maintains tissue viability of individuals supported on an APAM system. This is achieved with the following objectives, namely to,

i) Design and develop a versatile controller for a commercial APAM system.
ii) Design an experimental test matrix, which enables a comparison of pressure signatures imposed on a small cohort of young healthy volunteers.
iii) Evaluate a range of test conditions on the physiological responses, interface pressure and microenvironment at the subject support interface

2. Material and methods

2.1. Control of support mattress

The alternating pressure air mattress used in this study was a commercial system, Model Duo 2, which was loaned by the Research and Development Department of an international support surface manufacturer (HillRom, France). The system has a default operation in which the two distinct sets of cells along the long axis of the mattress are alternatively inflated and deflated (Table 2). The pressure signature associated with the APAM support systems can be defined by a number of variables, as discussed in a consensus document [5]. Their combination will determine the nature of the support afforded to the lying individual. The present study examined the influence of three of the critical parameters, namely pressure amplitude, cell profile and cycle period (Table 1).

The various configurations were achieved with a custom-made control system, termed Pneumatic Manager. To control the inflation phase, three-way pneumatic solenoid valves (Type 141, Hycontrol, Redditch, UK) were used to control air into the cells from a compressed air source. In the deflated state the cells were exhausted to atmosphere (Fig. 1). To control the pressure difference between inflated and deflated cells, the pressures of the air source and the exhaust manifold were each manipulated via means of a variable pressure regulator (Type 700 high flow, Control Air, US). The time-based functions and multiple outputs of a logic control unit (Millennium II Plus, Crouzet, France) were employed to inflate and deflate the individual cells in different configurations, at specified cycle periods. The cyclic timer prescribes the period at which a particular cam stage was maintained. The cam prescribed the cell profile arrangement (1:2 or 1:4) for each stage for the solenoid valves.

Values for the three variables were selected based on a number of factors, including compatibility with existing commercial APAM systems, as well as practical time considerations for individuals involved in the testing. Accordingly, values were assigned to each variable, as summarized in Table 2.

2.2. Subject group

The study was approved by the local Ethics committee of Queen Mary University of London (QMUL) (Ref no. QMREC 2009/43) and informed consent was obtained from each subject prior to testing. Exclusion criteria included any history of skin-related conditions. The study recruited five healthy participants (4 male, 1 female) from the local University student population. Participants were aged between 20 and 26 years of age with a mean height of 1.73 m (range 1.64–1.81 m), a mean mass of 68.6 kg (range 55–80 kg) and a corresponding mean BMI of 22.9 kgm^2 (range 18.9–27.0 kgm^{-2}).

Please cite this article in press as: Chai CY, et al., Pressure signatures can influence tissue response for individuals supported on an alternating pressure mattress, Journal of Tissue Viability (2017), http://dx.doi.org/10.1016/j.jtv.2017.05.001