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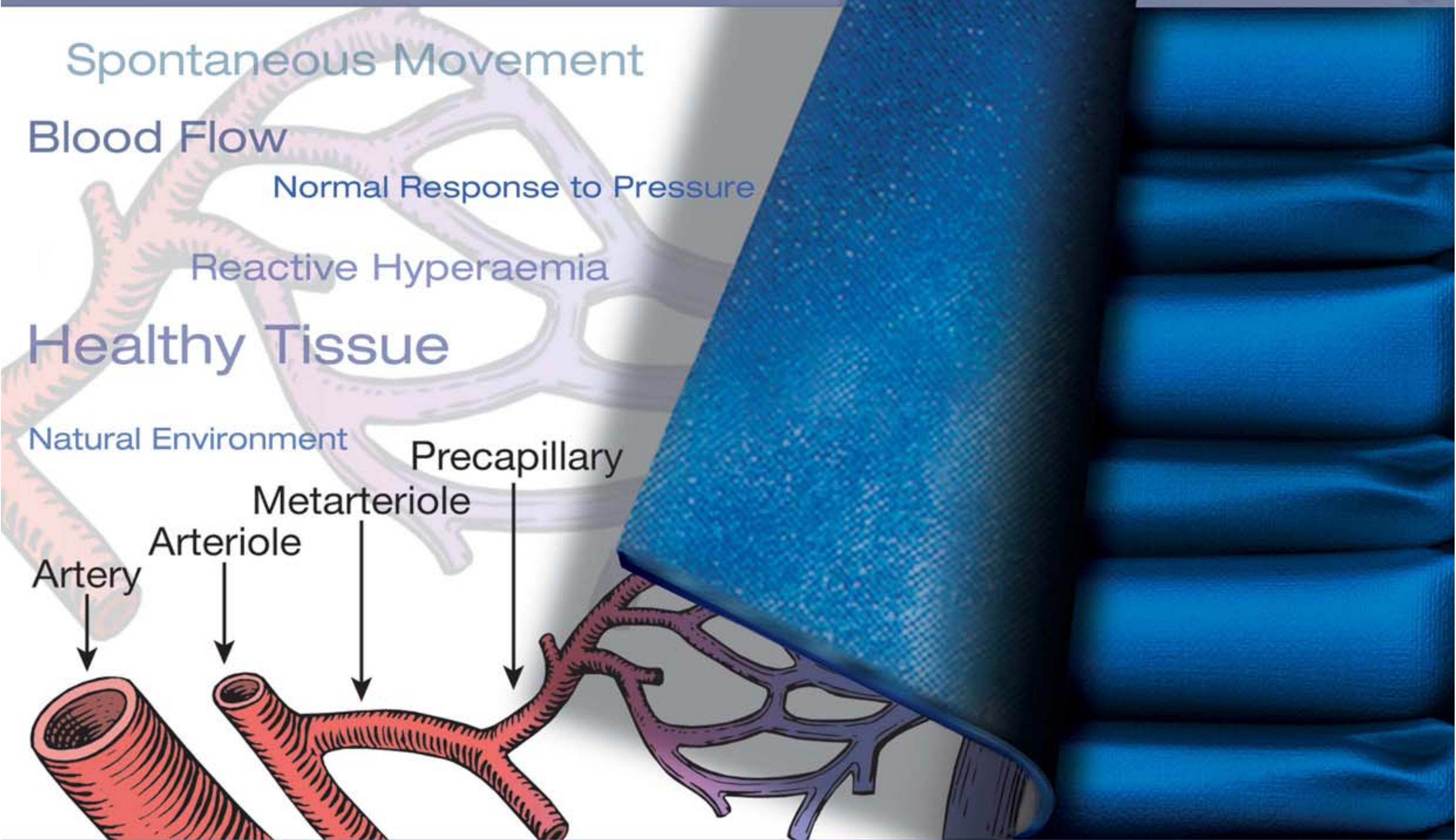

Principles of Alternating Pressure

THE LOGICAL METHOD OF PRESSURE ULCER AVOIDANCE

Introduction

Alternating Pressure Air Mattresses

Pressure ulcers, defined as localised damage to the skin and the underlying tissue caused by a combination of pressure, shear, and friction (Allman 1997), continue to present a major health problem.

The formation of pressure ulcers is complex and not fully understood, yet the availability and use of high-technology pressure-relieving support surfaces has escalated in the past decade, with an extensive range of equipment now available. However, product selection remains complex, as it cannot be assumed that the key principles of pressure relief have been incorporated into all the devices available and not all features have clinical relevance.

This brochure is designed to provide both the technical and clinical attributes of pressure-relieving mattresses. It will explain the physiological basis for using alternating pressure as the modality of choice in the prevention and management of pressure ulcers. It will also explain the optimum performance characteristics of pressure relieving support surfaces and how these can be objectively measured.

Evolution gave us spontaneous movement as the best method for pressure ulcer avoidance.

Huntleigh Healthcare offers alternating pressure to assist nature at times of increased vulnerability.

Contents

Critical Factors in Pressure Ulcer Development

Anatomy of the Skin

The skin is the largest organ in the body and accounts for 15% of the total body weight. It receives a third of the body's circulating blood volume[1]. Blood vessels supply nutrients and oxygen to the skin cells and lymph vessels assist the removal of metabolites and maintain correct fluid balance.

Structures such as muscle and fat have similar basic elements; however the physical structure differs depending on the exact tissue type.

Formation of Pressure Ulcers

A pressure ulcer can be described as an area of localised damage resulting from the combined effects of unrelieved **PRESSURE, SHEAR AND FRICTION**[2]. Subcutaneous tissue and muscle can be more easily damaged by pressure than the overlaying skin[3].

Figure 1 – Pressure ulcer

The formation of pressure ulcers is complex and not fully understood, however the basic process involves the constriction of small blood vessels as a result of compression and/or distortion of the soft tissues. This causes an insufficient supply of essential nutrients and oxygen, together with a build up of waste products from cell metabolism.

Over time, tissue viability decreases and irreversible tissue breakdown and necrosis occur[1].

How Pressure Affects Tissue

Critical determinants of pressure ulcer development, have been described as; the intensity and duration of pressure which together, affect the health of soft tissue and it's supporting structures[4]. Pressure typically means contact pressure measured between the skin and the surface and not the air pressure in an air mattress cell.

Pressure ulcers may result from short periods of high contact pressure or long periods of comparatively low contact pressure[5].

SOME WORK SUGGESTS THAT THE TIME FACTOR IS ACTUALLY MORE IMPORTANT THAN THE PRESSURE INTENSITY[6].

The intensity of contact pressure required to occlude a vessel is related to the pressure of fluid (blood or lymph) flowing within: this is measured in mmHg.

The 32 mmHg Myth

32 mmHg (contact pressure) has previously been viewed as a universal threshold of effective therapy, however, studies show otherwise.

Pressures measured at skin level in healthy volunteers revealed a wide range/pressures across the capillary bed, with very low pressures found in the venous vessels[7] (fig 2).

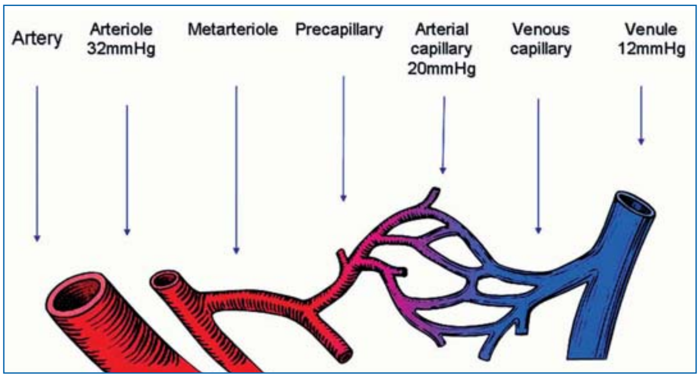

Figure 2 – Blood vessel network

Recent work suggests that the average functional operating pressure is 17 mmHg for the entire capillary bed[8] while clinical evidence suggests that surface pressures less than 20-30 mmHg allow continuous capillary perfusion and avert ischemia, cell death and necrosis[9]. However, these figures will still vary depending on the general condition of the patient and in many cases will be considerably lower.

For example, in debilitated, hypotensive patients blood flow regulation is only partially effective, which may result in pressure damage occurring at relatively low external pressures[1]. It is apparent that there are wide variations in an individuals ability to resist pressure, so 32 mmHg should not be viewed as a universal threshold of effective therapy and in many cases will be considerably lower, particularly when those pressures are unrelieved (constant low pressure).

Contributing Factors to Tissue Damage

As outlined previously, the time factor is a major contributing factor to tissue damage.

Pressure is the combination of the weight of the body pushing down on the mattress or chair resisting it. The way in which our body weight is transmitted through the skeleton will determine how much pressure is being exerted, i.e. duration and positioning is a factor which could result in higher pressures being exerted on soft tissues near bony prominences. This creates high pressure gradients causing significant damage deep within the tissues[10,11] (fig 3).

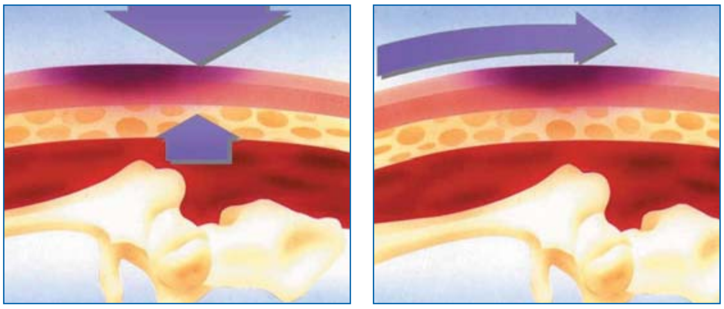

Figure 3 – Pressure and friction effects on the tissue

Friction is the result of the movement of our skin against another surface. This causes scuffing or grazing to the top layer of the skin.

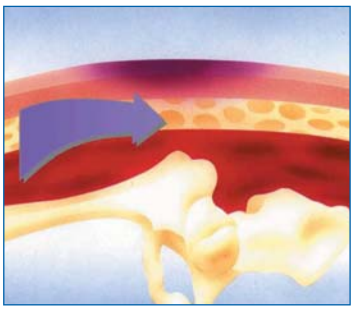

Figure 4 – Effects of shear on the tissue

In addition to direct pressure, endothelial damage of the microvasculature can result from shear forces.

Shearing is a result of gravity pulling the body down onto a surface, especially with inclined supports and excessive skin friction (fig 4).

These forces can cause a significant reduction in blood flow as vessels stretch, kink or tear[12], resulting in reduced blood flow and ischemia. Distortion of blood vessels can also disrupt the endothelium and activate the intrinsic clotting mechanism, leading to platelet aggregation (clotting), which can occlude the affected vessel leading to ischemic necrosis of dependent tissue.

The Natural Method of Relieving Pressure

A healthy person avoids tissue trauma by means of frequent spontaneous movement even during sleep.

Patient groups, such as the elderly[13] and paraplegics[14] move less frequently predisposing them to pressure ulcers. Patients under the influence of sedatives also tend to move less frequently, increasing the risk level. The ideal movement pattern is one which resembles that of healthy individuals – approximately one movement every five minutes[15,16].

Alternating support surfaces mimic natural sleep movement patterns and avoid long term pressurisation of tissue (present in static surfaces), affording protection against ischemia. An additional benefit is that the theoretical flow-rate of blood is significantly greater in vessels which fully recover their round shape than those which remain permanently semi-occluded[17] (fig 5). Figure 5 illustrates this phenomenon, with blood flow through the same vessel held partially closed (purple line).

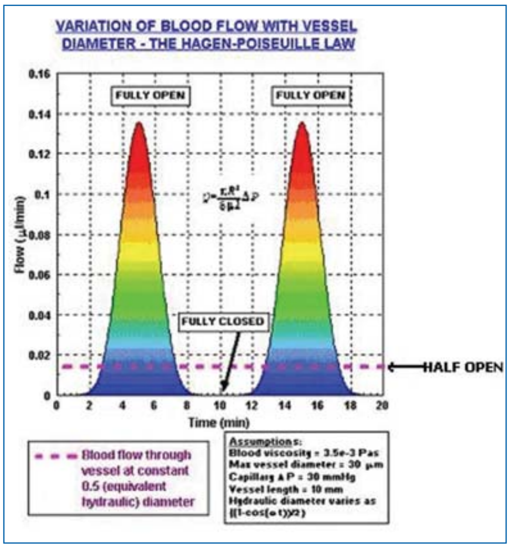

Figure 5 – Variation of blood flow with vessel diameter

Summary

The external factors which affect the blood supply to tissues are paramount in the aetiology of pressure ulcers. The most crucial external factors are recognised as;

- Pressure
- Time
- Shear and friction

Prevention and therapy support systems must therefore be designed to deliver sufficient relief from pressure and shear which is effective over time. **The time varying support characteristics of systems must be analysed and optimised for maximum clinical effectiveness.**

Types of Support Systems

Physiologically, the body requires an environment which provides adequate nutritional supply to and metabolite removal from various tissues. There are two main groups of support surfaces which are used for pressure ulcer prevention and therapy. All surfaces are designed to 'redistribute pressure'.

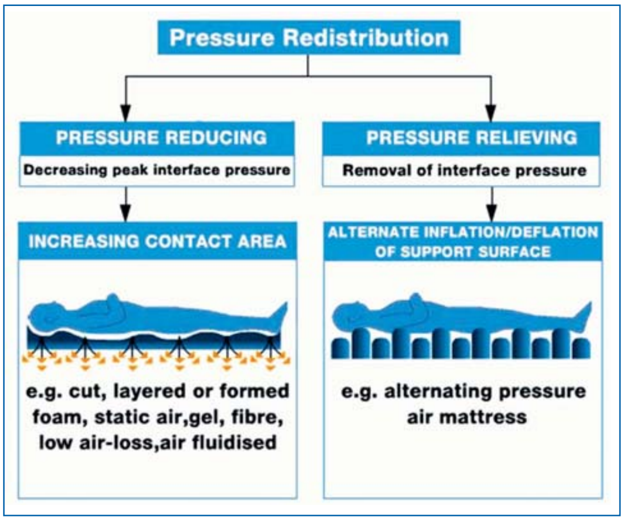

Figure 6 – Difference between pressure reducing and pressure relieving systems

Pressure Reducing Support Surfaces

"The reduction of interface pressure, not necessarily below capillary-closing pressure" [18]

Pressure reduction products (i.e. static powered or non-powered support surfaces such as low air loss, foam or gel devices) attempt to address areas of high contact pressure such as those over bony prominences, by redistributing the body mass over a greater surface area. This is generally achieved by a process of immersion. As the support surface is softened, more of the body comes in contact, mass is more evenly distributed and contact pressures fall.

However, contact pressures, even if low, are constant which is not a normal physiological state and in many cases the pressures are still sufficient to occlude or partially occlude the vessels.

Pressure Relieving Support Surfaces

"Pressure relief is the achievement of pressures below capillary-closing pressure" [18]

Periodic removal of pressure is achieved when we naturally change position or posture and is relieved to the extent that blood is virtually guaranteed to flow.

However, pressure must be relieved for long enough to make a clinical difference[19]. If this can happen regardless of body topology – that is not dependent on the build of a patient etc., then an advantage is gained in terms of consistency of treatment. The practice of regular 2-hourly turning is a laudable, if somewhat limited method of mimicking this natural process because of patient condition, nursing time and resources etc. As early as 1948, the automation of systematic pressure relief, led to a decrease in the incidence of pressure ulcers in an understaffed spinal unit[20]. Today, the use of alternating therapy is routine, in even the most vulnerable patient population, because of consistently beneficial clinical outcomes.

Cycle Amplitude

The loading cycle needs to be of sufficient amplitude and duration to 'lift' the body clear of the deflating cell for long enough to allow reperfusion.

Systems with high amplitude that achieve a low pressure but only for a short duration are unlikely to allow sufficient reperfusion; especially in people with compromised neuro-vascular function (fig 7).

Systems with low amplitude perform similarly to constant low pressure devices and may not elicit a normal hyperaemic response (Fig 8).

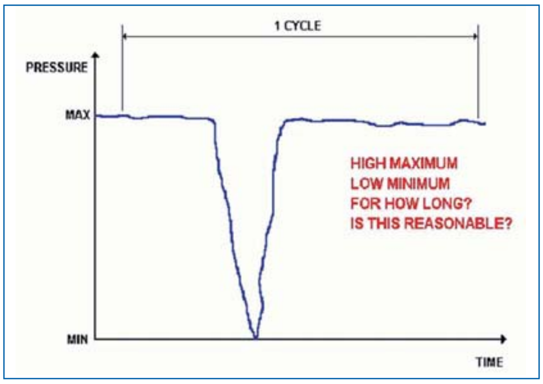

Figure 7 – Maximum and minimum interface pressures

Maximum and Minimum Interface Pressures

In the past, alternating pressure air mattress systems (APAM) have been assessed by a number of techniques. One method looked at maximum and minimum pressures achieved. This is an inaccurate method because although a very low pressure may be achieved, it still does not provide an accurate idea of actual performance (fig 7). For instance, an APAM which reaches zero pressure for just 1 second, can be rated as high as a system relieving pressure for 5 minutes. This cannot be correct, and scientists have indicated that:

"***Alternating pressure.... in which the skin is relieved of all pressure for 5 minute intervals.... does not result in ulceration***"[21]

Average Interface Pressure

Average Interface Pressures have also been used to analyse APAM performance.

Figure 8 shows the response of a true alternating system compared to a 'modulating' or static system. Although the averages may be identical, the pressure relief achieved is totally different. This is because no account is taken of the minimum interface pressure achieved or for how long it remained there during the cycle. It is for this reason that average pressures cannot be used to compare these systems with true APAMs[22].

The variation of pressure with time MUST be analysed when assessing an alternating system.

"Ideally, one should consider multiple thresholds, with each level determined by the patient's peripheral circulation" [23]

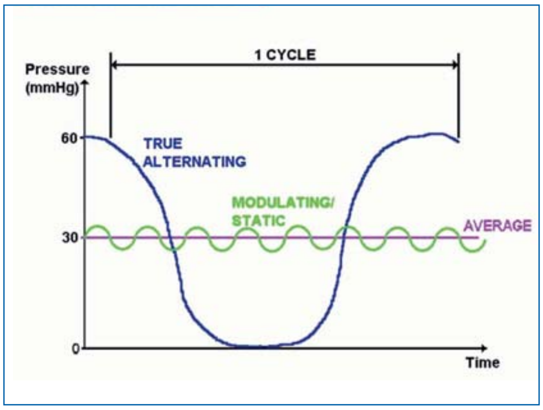

Figure 8 – Response of a true alternating system compared to a modulating/static system

Therefore, choosing thresholds close to arteriolar, capillary and venule operating pressures (30, 20 and 10 mmHg), will help to indicate an APAM's effectiveness. Clearly, the greater the time spent under each threshold... the better! In particular, the 20 and 10 mmHg thresholds[24,25] which are clinically more important.

Pressure Relief Index

The ability of an APAM to relieve pressure below clinically relevant thresholds is measured by calculating the **Pressure Relief Index** (PRI) over a set time.

Figure 9 illustrates the PRI technique with a typical interface (contact) pressure/time tracing for a correctly inflated APAM.

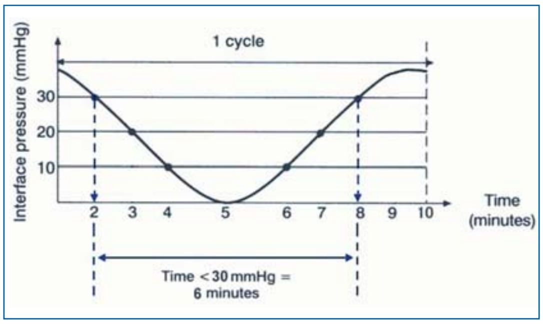

Figure 9 – PRI technique with a typical interface pressure/time tracing for a correctly inflated APAM

Figure 9 shows that interface pressure remained below 20 mmHg for 4 out of 10 minutes, giving a PRI of 40%, below 10 mmHg, the PRI was 20%, and so on.

An easy to understand figure to identify a system's PRI could be measured in minutes per hour below a certain threshold. For example, 40% PRI <20 mmHg means for 24 minutes out of every hour (40% of 60 minutes) the interface pressure was below 20 mmHg. Using this technique, comparisons may be highlighted between systems which use different alternating cycles.

High PRI Performance

By sustaining a high PRI performance, APAM systems will ensure blood vessel diameters remain as large as possible for as long as possible. This is important since flow can increase significantly (up to 16 times in theory)[26] in a vessel when fully opened, compared to when half closed, shown here in simplified form (fig 10).

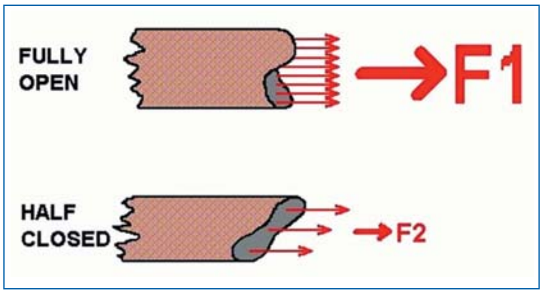

Figure 10 – Blood flow in a fully open and a half closed vessel

This is the most widely used rationale for the use of alternating systems versus static systems. External pressure on the skin compresses tissues and can therefore impede the flow of blood, reducing the delivery of oxygen and nutrients to the surrounding tissues. The pressures near the venous end of the capillary beds in incapacitated patients, has been calculated at 10 mmHg and pressures above this figure are thought to occlude flow in this area. Due to lack of nutrients and oxygen, the surrounding tissue becomes anoxic; and if this persists, tissue necrosis occurs. This can occur within relatively short periods of time.

It is the function of an effective APAM to exploit this phenomenon by holding **contact** pressures as **low** as possible for as **long** as possible. The potential advantage of sustained pressure relief (high PRI) has already been reported in early work[27], more recent studies have demonstrated increased flow rates at low pressures for both healthy subjects[28, 29] and those with impaired neuro-vascular response[30]. Figure 11 shows how the blood flow was affected by contact pressure.

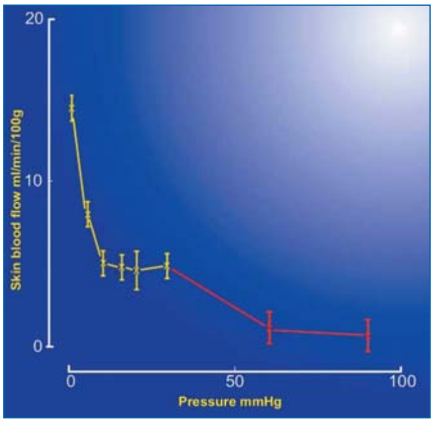

Figure 11 – The effect of contact pressure on blood flow in a human forearm

The use of alternating surfaces has also been shown to be important in the promotion of reactive hyperaemia and is often cited as a key benefit of the surfaces. Reactive hyperaemia is a normal physiological response to pressure relief and is the process by which the body increases blood flow to tissues that have temporarily been deprived of oxygen, so as to restore the natural balance[6], this should not be confused with non-reactive hyperaemia which is a grade 1 ulcer.

The clinical implications of using alternating surfaces are measurable. A comparison of alternating systems with "equivalent" static (pressure reducing) systems in an Intensive Care Unit, showed a significant reduction in the development of pressure ulcers on patients nursed on alternating surfaces[31].

How PRI is Measured

The Pressure Relief Index can be used as an assessment tool to measure the performance of alternating surfaces such as mattresses and cushions. Interface pressure (the pressure existing between the support surface and the test subject) is recorded using a single sensor (e.g. an Oxford Pressure Monitor) which is attached to a computer.

As shown in Fig 12, the sensor is secured over a bony prominence; typically, the heel, sacrum, ischial tuberosities and trochanter. Tests can then be performed in the supine, side lying or sitting positions.

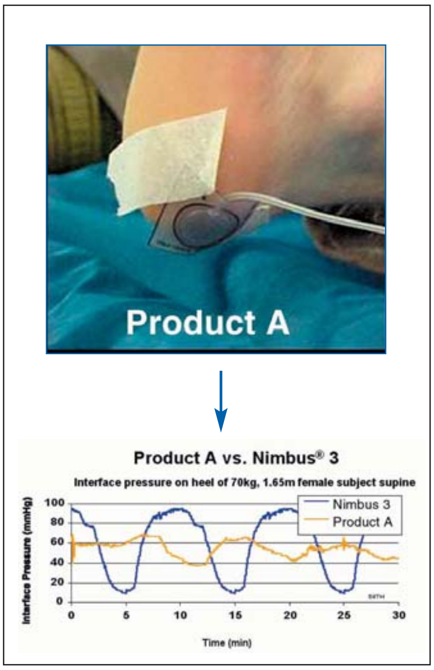

Figure 12 – The pressure sensor attached to the heel and a graph of the results

PRI refers to the percentage of time (threshold) for one complete cycle of an alternating surface, that the interface pressure is below a predefined pressure. The predefined pressures used in mattress assessments are:

30 mmHg – relating to the average blood pressure at the arteriolar end of the microcirculation.

20 mmHg – relating to the average blood pressure in the capillary loops.

10 mmHg – relating to the average blood pressure in the venules.

These pressures relate approximately to the closing pressures of blood vessels at heart level as measured by E.M Landis (1930)[7]. The interface pressures exerted by a seating surface are higher due to the smaller contact area, and blood pressure is also higher since a column of blood exists between the heart and the buttocks. So the defined pressures used for PRI measurement are set higher; 60 mmHg, 40 mmHg and 20 mmHg.

Support Systems – Designing an Optimum Solution

Performance measurements such as PRI are extremely useful tools, but only to measure pressure relief. In an extreme case, a high PRI value could be achieved by steel girders alternately moving under a patient (fig 13).

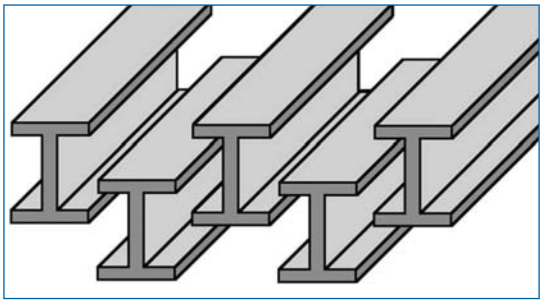

Figure 13 – High PRI value could be achieved by steel girders moving alternatively

Therefore, without knowledge of patient compliance, accurate judgements cannot be made. A system needs to provide sufficient COMFORT to satisfy psychological and sensory requirements, as well as provide effective pressure relief.

A support surface consensus group[32] concluded that there were three main clinical purposes of a support system:

- POSTURAL CONTROL (via appropriate positioning aids)
- COMFORT (via the support surface)
- PRESSURE MANAGEMENT (via the support surface)

In combination with appropriate bed frames, APAMs should meet all three requirements.

Comfort and Inflation Pressure

In air systems, comfort is related primarily to cell inflation pressure and the rate of change of pressure during the cycle. A high inflation pressure prevents 'bottoming out', but leads to discomfort and high peak contact pressures. A low inflation pressure can increase comfort, but limits weight carrying capacity to support the patient, therefore increasing the likelihood of 'bottoming out'. This situation is shown in simplified form (fig 14).

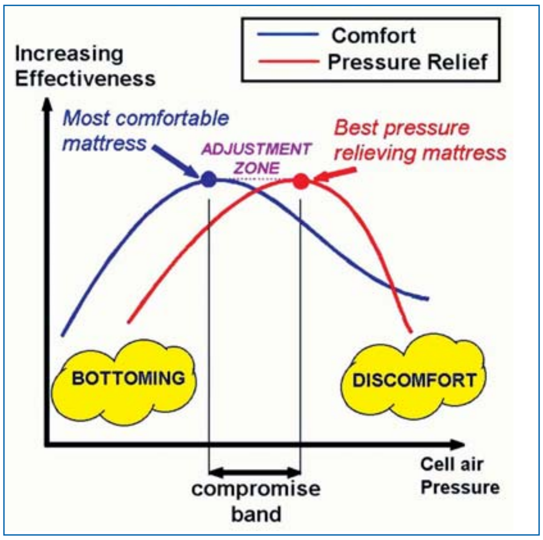

Figure 14 – Optimum inflation pressure and comfort

The shape of patient response curves change with posture and body mass distribution. However, it is generally true that the optimal support pressure for comfort may not be equivalent to that required for maximum pressure relief. An effective APAM must ensure that a careful balance is struck between pressure relief and comfort and must be able to be 'tuned' to the patient's individual characteristics and requirements[33].

Adjustment to Individual Patients

'Tuning' an APAM is possible in two ways: manual and automatic.

Manual Adjustment

This approach is most appropriate for patients who can tolerate some degree of risk should they be placed upon a system which may be under or over inflated i.e. those who are able to make independent postural changes. However, the presence of experienced staff is needed in order to set the appropriate pressure levels. If these two factors are present, then manual adjustment represents value for money and clinically effective therapy[34].

Automatic Adjustment

If staff are not available to optimise system settings or patients cannot tolerate over or under inflation, i.e. highly vulnerable patients, then an automatic device is recommended. Automatic adjustment is achieved by periodic adjustment of the pump's pressure control once the patient has been placed on to the support surface. This is repeated until sufficient clearance is achieved and the patient is well supported. These systems also have more sophisticated alarm and monitoring functions which offer advanced warning of potential dangers to higher risk patients if a failure occurs.

Automatic systems maintain high levels of comfort and pressure relief (PRI) REGARDLESS of patient weight or posture, by adjusting internal cell pressures in response to individual body mass distribution; they have also been shown to be clinically effective[35].

In the more sophisticated mattresses, tuning to individual patient characteristics can be demonstrated using laboratory techniques such as PRI and laser doppler studies[36]. These techniques can demonstrate systems such as the AUTO logic™ system[29] and more so the NIMBUS logic™ system[37] produce idealised physiological responses in a range of individuals.

Does Automatic MEAN Automatic?

It can be said that by optimising inflation pressures, the benefit of high pressure relief is achieved simultaneously with enhanced comfort.

Many manufacturers claim their systems are either automatic or have automatic adjustment. Rithalia and Heath[38] evaluated the ability of four different APAM systems to adapt automatically to changes in posture and weight in healthy volunteers, by monitoring inflation pressure inside the air cells as subjects move through supine, lateral and semi-recumbent positions. It was evident that only the Nimbus® 3 system changed pressures to suit the new positions of the subjects.

When subject mass was considered, it was shown that with an increase in weight there was a corresponding increase in inflation pressure for the **Nimbus 3** system, whereas subject mass appeared to have no effect on inflation pressure for the other APAMs.

The automatic adjustment of **Nimbus 3** systems have shown to respond to all changes in patients position and weight, thereby helping to achieve optimum comfort and pressure relief. This is supported by both clinical outcome and qualitative studies.

In a randomised controlled study, results indicated that not only did the **Nimbus 3** system provide excellent outcomes in sacral ulcers, it was also significantly more effective than the comparator in healing heel ulcers[39]. Studies have also shown the **Nimbus 3** system to be perceived as more comfortable over the other APAMs by the patient population[40].

Automatic adjustment implies continuous monitoring and adaptation of inflation pressure to individual patient requirements and not simply the maintenance of a constant single pressure.

Huntleigh Healthcare's Design Criteria

Achieving high pressure relief (i.e. high PRI) while optimising comfort for each individual patient is a difficult but achievable goal. All Huntleigh APAM's (mattresses and overlays) are based on design concepts geared to physiological requirements, which include:

1. CONSISTENT PRESSURE RELIEF

It has been reported that:
"Pressure relief, below 20-30 mmHg is the cornerstone of the therapy of pressure ulcers" [41].

Huntleigh Healthcare views this as a MINIMUM STANDARD, where the lowest level is often exceeded by achieving substantial PRIs below even 10 mmHg. Independent tests have shown that Huntleigh Healthcare's support systems, achieve a high degree of pressure relief compared with other products available in the market place[42,43,44].

2. 1-IN-2 CELL CYCLE

This is important primarily because it provides a balanced regime of vessel occlusion followed by the pressure relief and re-establishment of flow. In other cycles such as 1-in-3 or 1-in-4 (fig 15), pressure is applied for longer, which could lead to increased heat build-up, sweating and greater metabolic demand[45]. Research has already shown that longer periods of pressure are associated with longer tissue oxygen recovery times[46]. In elderly patients, recovery can take up to two and a half times as long as in healthy people[47].

A balanced cycle, therefore aims, to MATCH loading time with recovery time.

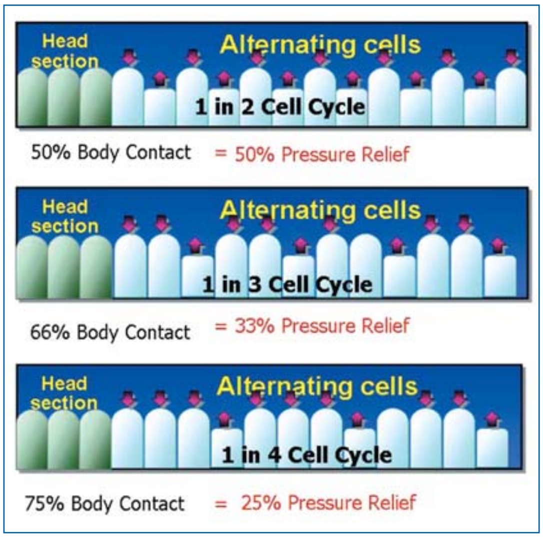

Figure 15 – Differences between different alternating cycles

Rithalia and Gonsalkorale[48, 49], measured mean pressure, mean maximum and mean minimum interface pressure, in which a 2 in 1 cell design APAM (**Nimbus 3** system) was compared to a 1 in 3 cell design surface. A continuous recording technique was used to ascertain the number of minutes/hours that the interface pressure at a given anatomical site was below 10, 20 and 30 mmHg. Considerable differences were seen between sites (sacrum, ischial tuberosities, trochanter and heels).

The 1 in 2 cycle produces a sufficiently long period of pressure relief to allow TISSUE OXYGEN to recover to the 'normal' level (that recorded prior to the subject resting on the mattress). The automatic 2 cell system (**Nimbus 3** system) recovered transcutaneous (tissue) oxygen and carbon dioxide levels close to normal levels, at regular intervals. This reinforces the advantage of a high PRI and shows that the pattern of pressure relief matches the maintenance of tissue perfusion at contact sites.

The results suggest that the method of reporting pressures as a percentage of time below 10, 20 and 30 mmHg is meaningful to allow tissue perfusion to be maintained.

3. CLINICALLY RELEVANT ALTERNATING FREQUENCY

Research has shown that healthy individuals move at approximately 5 minute intervals during sleep[16]. Past work involving at-risk patients has shown that those moving more than 54 times in 7 hours (i.e. once every 7-8 minutes) are less likely to develop pressure ulcers[50]. A MINIMUM MOVEMENT requirement for patients of once every 11.6 minutes has also been recommended[51]. Thus, a cycle time of 10 minutes (5 minutes on, 5 minutes off) provides a movement pattern similar to that chosen by nature and in excess of that recommended by clinical studies. On this basis, all Huntleigh Healthcare Pressure Area Management™ surfaces offer no compromise.

4. ADJUSTABILITY

Support pressures need to be adjusted to accommodate individual patient weight, position and sensitivity. Low inflation pressures increase the risk of 'bottoming out' with heavier patients and cause difficulties with patient handling. High pressures condemn lightweight patients to discomfort and do not guarantee high pressure relief (PRI). Adjustment, either manual or automatic, MUST be a choice open to the care giver in order to provide pressure area management unique to each patient.

Summary

Although many devices exist, their effectiveness is not uniform even when they appear to be of similar construction. The key principle of pressure relief is not always understood and design may be driven by manufacturing and pricing considerations rather than by clinical relevance. By employing scientific methods, the design of Huntleigh Healthcare alternating pressure systems is being continually refined to increase efficacy. The effectiveness of such systems needs to be recognised, and this can be achieved by measuring the pressure relief imparted to the body over time.

Almost any patient can be cared for on any surface without developing pressure ulcers, as long as other interventions are available, such as nursing care and frequent repositioning. If this is not possible it will be necessary to offer a suitable mattress system that offers lowered overall pressure (foam, static, low-air-loss) or an alternating system which periodically changes the pressure through a series of inflated/deflated air filled cells.

As the sophistication of the device increases (automatic pressure adjustment, sacral deflate, alarms etc), the level of dependence on nursing intervention decreases and the dependence on the nurse/caregiver correctly setting and using the equipment also decreases.

In summary, Huntleigh Healthcare products are designed for optimum technical performance. Scientific methodology using surrogate physiological and clinical outcomes measure their performance and these results are then used to refine the product design. Outcomes are further supported by strong field based evidence in situations where the products are faced with all patient groups, including the highly vulnerable, obese and the terminally ill. The best product provides an optimum outcome while ensuring a minimal risk of either setting the product up incorrectly, or choosing the wrong device for the patient's level of risk.

The more sophisticated the product, the greater the peace of mind.

For more information about the support surfaces available from Huntleigh Healthcare and the clinical evidence supporting the product range, please contact your local representative or visit **www.huntleigh-healthcare.com**.

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