Interface pressure measurement: Appropriate interpretation of this simple laboratory technique used in the design and assessment of pressure ulcer management devices

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Summary

Pressure redistributing support surfaces, designed to prevent and treat pressure ulceration, are generally based on one of two modalities; constant low pressure (foam, gel, low air loss etc) or alternating pressure. Despite appearing similar, these systems work in very different ways and require different techniques for measuring interface pressure. While such measurements are a useful and increasingly accessible adjunct to the design and evaluation of pressure redistributing support surfaces, when used alone they should not be considered a surrogate for clinical outcome studies. This review discusses why interface pressure measurements are undertaken, the methodologies, the factors that affect data reliability, and whether by making use of innovative Doppler techniques, interface pressure will be superseded by contemporary and perhaps more relevant performance indices such as tissue perfusion. The clinician who can critically appraise interface pressure data will be able to make informed decisions relevant to individual clinical practice.

Introduction

Over the years, interest in the simple act of measuring the pressure exerted at the 'interface' between the human body and a support surface, eg mattress, shoe or prosthesis, has ebbed and flowed. Whereas in the past *interface pressure* (IP) may have been used overtly to predict clinical outcome, particularly with regard to pressure ulceration, today we see it used more frequently to simply describe the performance and off-loading characteristics of a support surface. As such, it is widely used both in the technical development of medical devices and in the customisation and prescription of specialist equipment such as wheelchair seating, artificial limbs and footwear. Without doubt, the ability to measure *IP* has revolutionised these complex areas of clinical practice and in skilled hands has greatly assisted with the avoidance of tissue damage in vulnerable individuals.

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However, the main area of debate amongst groups like the National and European Pressure Ulcer Advisory Panels (NPUAP, EPUAP) and independent researchers concentrates on the methodology and interpretation of *IP* in relation to pressure redistributing mattresses and mattress overlays. Despite the work of these multidisciplinary consensus groups, there is still no one methodology that is accepted by all. This means that clinicians are frequently faced with laboratory data that can be confusing and/or misleading and difficult to translate into clinical practice. The discussion that follows will cover some of the myths and misconceptions, while providing a simple introduction to a range of contemporary measurement techniques that may be encountered in the literature.

32mmHg: exploding the myth

Although a great deal more is known about the strengths and weaknesses of *IP* measurement, there are still remnants of past practice which, with hindsight, should be actively discouraged – making direct assumptions about pressure ulcer outcome being perhaps the most risky. In the 1930s pioneering research by Eugene Landis [1] was perhaps

mistakenly integrated into the pressure ulcer ethos and gave birth to the commonly held belief that an IP of <32mmHg was nominally 'safe'. This belief survived for more than sixty years, despite there being no supporting evidence [2], and has been intrinsically linked to *IP* measurement; a notion perpetuated not least by support surface manufacturers striven to meet expectations and develop the product that simply achieved the lowest pressure. Such belief overlooked simple yet critical factors, such as the *duration* of pressure off-loading [3], the pressure occurring in the deep tissue [4] and the general pathophysiology of pressure ulcers; the nail bed of a healthy volunteer is not representative of load bearing tissue and the normal variance of individual pressures was so wide as to make '32' relatively meaningless [5] (Figure 1).

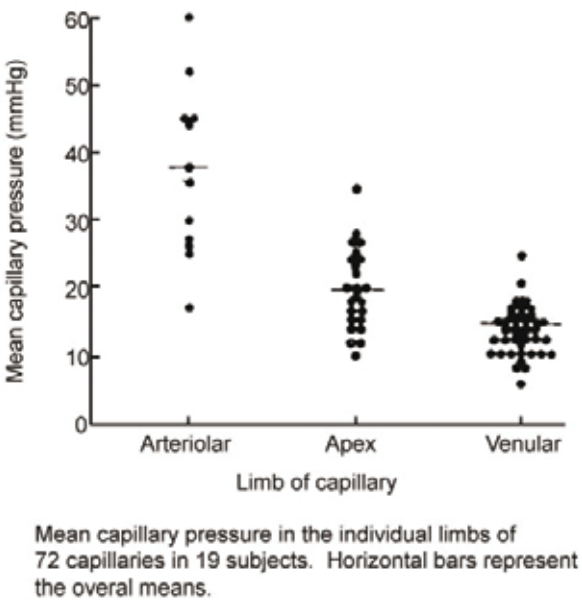

Figure 1 [5]

This aside, when in context *IP* remains an important measurement for both the development and selection of support surfaces. An informed clinician who can critically judge the inherent strengths and weaknesses of the technique, is best placed to use the information appropriately.

Exploring the technique

Support surfaces can be categorised as two distinct modalities (Figure 2) each with its own measurement protocol:

1. ***Constant low pressure*** **(**CLP) devices *(also know as static, reactive, pressure reducing)* do not change pressure beneath the body unless an external force or load is applied. These reduce the applied pressure by increasing contact area through a process of 'immersion' that includes foams, gel, water, air and fluidised bead technology. CLP is best suited to whole body pressure mapping techniques.

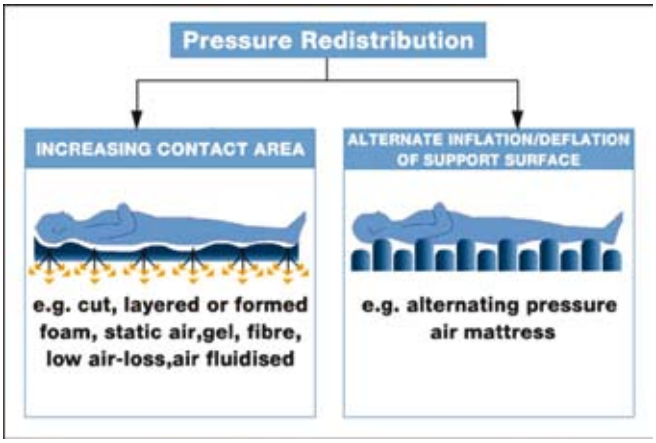

Figure 2

2. ***Alternating pressure redistribution mattress (APRM) devices*** *(also know as dynamic, active, pressure relieving)* are externally powered devices that systematically load and off-load pressure by inflating and deflating cells or segments beneath the body whilst closely matching the intervals to normal spontaneous movement [6]. APRM is best suited to a time based pressure threshold technique [7].

Although some support surfaces may be considered 'hybrid' by design (ie those surfaces that either can be switched between active and reactive or have different segments within one mattress) each modality should be measured independently using either of the techniques described below, as there is not any one technique that does both simultaneously without compromising reliability.

Pressure area index

For CLP systems, the measurement technique of choice is full body mapping using soft flexible mats comprising an extensive matrix of sensors held in a flexible fabric. These mapping systems give two- or three-dimensional images and have the added advantage of quickly distinguishing areas of particularly high pressure, eg under the head or heels (Figure 3). When interest is focused on specific areas of vulnerability, such as in seat cushion evaluation, a smaller array of sensors may be used over a discrete anatomical area.

There are many pressure mapping systems available. Most are easy to use and are popular, but they can be expensive

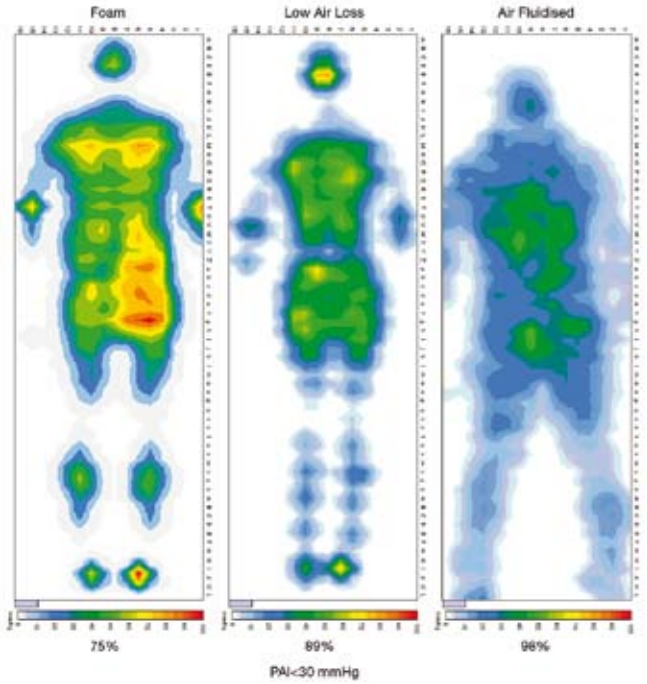

Figure 3

and have performance limitations to a greater or lesser extent. Limitations like the tendency for readings to drift over time or the effect of the 'stiffness' of the mapping framework itself on the support surface beneath are beyond the scope of this discussion, but are well described in the literature [7,8,9,10].

By design a CLP support surface, eg a low air loss mattress, aims to allow the body to 'immerse' into the supporting media. This increases the surface area over which pressure is loaded and thereby reduces the skin-mattress (interface) pressure. Despite the simplicity of this concept, there is no consensus on how the *IP* tests should be conducted and how the results should be reported. In the absence of formal test protocols, individual researchers have developed their own techniques.

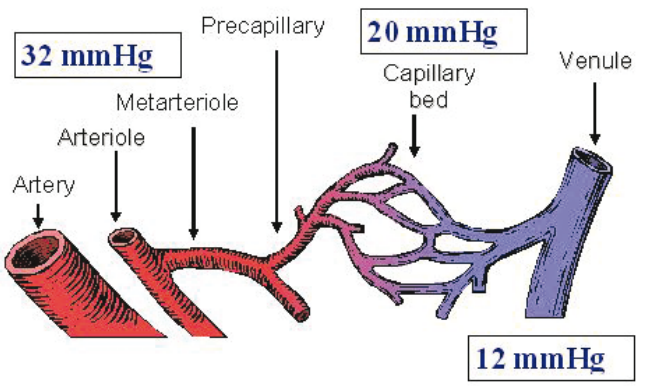

Figure 4

One such approach describes pressure redistribution in CLP devices by using the Pressure Area Index (PAI) – a published technique that provides a 'common language' that can be used between multidisciplinary groups [11].

The PAI is constructed upon nominal thresholds of 30, 20 and 10 mmHg. These figures are based on nothing but a simple approximation to the circulatory pressure in the capillary bed [1,5] (Figure 4) and are merely descriptors. To describe PAI, the number of sensors reading below a given threshold is reported as a percentage of all the sensors bearing weight, with a higher percentage equating to better immersion and enhanced pressure redistribution.

Figure 4 also shows how the PAI can be used to visually compare the way in which different support surfaces redistribute the pressure provided (the testing was done with the same subjects, test equipment etc). However, it could be misleading to make clinical inferences from these maps alone as capillary closing pressure will be different for each individual, particularly those patients who are haemodynamically unstable or suffering from peripheral vascular disease. PAI also shows that pressures are constant over time and that some areas of the body are clearly under greater load (yellow-red areas), serving to illustrate why individualised patient repositioning programs continue to be important, even on sophisticated low pressure support surfaces.

Pressure relief index

Unlike CLP support surfaces whereby immersion is the modality of pressure management, APRMs are designed to work in a more naturalistic way by periodically loading and off-loading the tissue. For these devices applied pressure values (maximum, minimum and average), like those recorded by mapping devices, are perhaps less important than how frequently and efficiently pressure is off-loaded. Given this different perspective, APRMs require a different technique to capture the many different characteristics of the individual cycles, not least of which is time.

Measuring the *IP* characteristics of an APRM is slightly more complex, though valid in skilled hands because reliable and repeatable data can be captured. As for PAI, despite the best efforts of international groups, there is currently no consensus protocol. Figure 5 illustrates the topics discussed by the EPUAP consensus group, with the ranking from top to bottom highlighting the relative time spent in debate – the consensus group ran for two years without conclusion.

However, this lack of consensus does not mean that studies should be of questionable quality; the key is the rigour by which the measurements are taken. If the methods are robust and clearly described, and the strengths and weaknesses understood, data can be meaningful to both clinicians and researchers.

EPUAP Working Group Topics

- Mannequin v Human characteristics
- Relative v absolute measurements
- Accuracy of equipment
- Repeatability
- Specific sites of interest
- Postural variations
- Calibration of equipment
- Resolution of equipment
- Environmental factors (e.g. temperature)
- Analysis of pressure measurements
- Reporting structure - minimum requirements

Top four debating points in blue

Figure 5

Unlike PAI measurement, APRMs are best suited to a single point sensor positioned carefully between one point on the body, such as a bony prominence, and the apex of a mattress or cushion cell (Figure 6). This positioning is critical, as effective pressure relief can only be measured when the supporting cell has deflated. However, although easier to use, multi-sensor full body mapping systems are generally unsuitable for alternating support surfaces as they tend to hold low

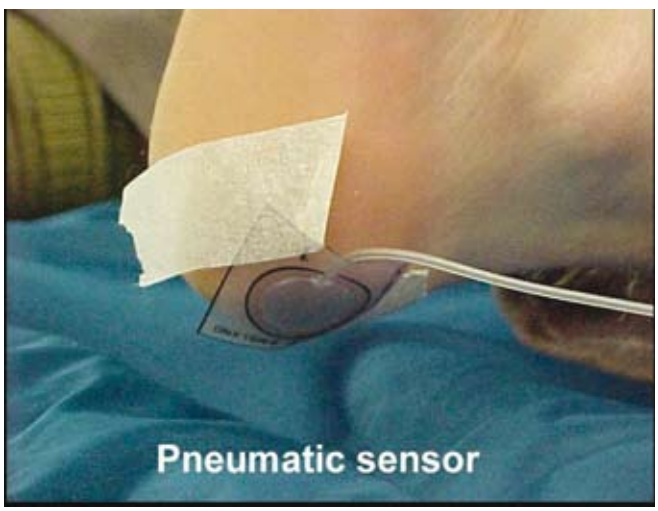

Figure 6

pressures artificially high by creating a 'hammock' over the deflated cell (Figure 7). It is also very difficult to accurately describe an APRMs loading/off-loading profile using a full body mapping system unless a single sensor is isolated within the sensor mat and tracked over time. These limiting factors make the use of mapping systems for describing dynamic mattresses and cushions questionable, although they can be used to illustrate the 'wave form' characteristics of dynamic devices (eg 1:2, 1:3 or 1:4 cell cycles).

Accurate sensor positioning (eg heel, trochanter or sacrum) is critical yet difficult and so it is good practice to repeat the test several times. Once the sensor is positioned correctly,

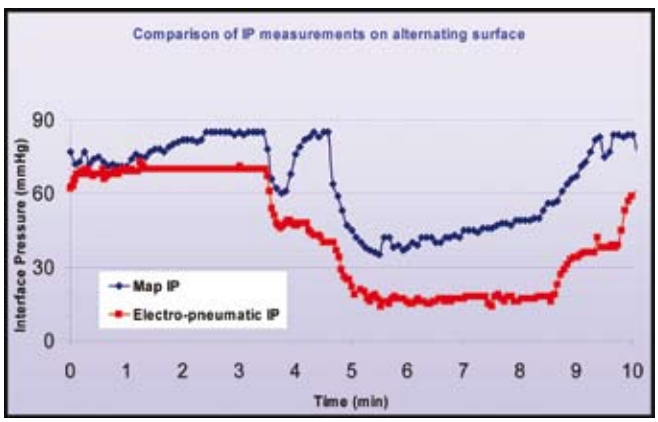

Figure 7. The 'hammocking' effect of pressure mapping systems.

the pressure applied at the interface can be tracked across several cycles. This is an important yet often overlooked step, as devices that automatically adjust to individual body mass distribution require a short equilibration period, typically one or two cycles, to provide optimised pressure relief. PRI will also prove more difficult in those individuals with a higher body mass index, as it becomes increasingly difficult to palpate the bony prominence. There will also be an increasing degree of tissue distortion and there may be a 'contouring' effect whereby tissue 'flows' into the space provided by the deflating cell. These limitations make for difficult test repeatability in the larger individual.

In terms of describing a dynamic support surface it is important to express the performance characteristics as a measure of '**pressure *and* time**' (eg time below thresholds of 30, 20 and 10 mmHg [7]. It is also important to describe the *amplitude* of the cycle, that is the differential between high and low pressures (Figure 8). These three measures are inherently linked and physiologically important, as keeping pressure

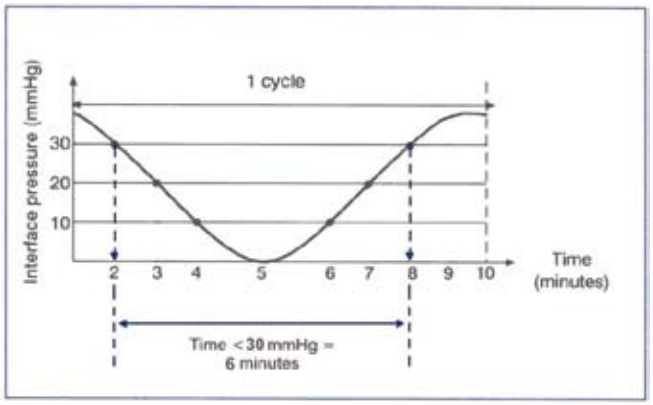

Figure 8

as low as possible for as long as possible has been shown to give the greatest opportunity for tissue perfusion both in healthy volunteers and in people with conditions known to affect blood flow [12,13].

The cycle amplitude is particularly important because to achieve a 'favourable' low pressure perfusion condition, the body must be lifted clear of the deflated segments by resting upon the fully inflated cells. This is characterised by the pressure profile and can be described using PRI. Not all mattress systems described as having an 'alternating mode' may achieve sufficient amplitude to provide a clear difference between loaded and off-loaded states (modulating). Others add a layer of padding between the active cells and the patient that may dampen the effect at the patient-surface interface (Figure 9). In the absence of a standard consensus definition for each modality, the clinician may depend on laboratory data when considering the performance characteristics of a new device. Such laboratory data can be strengthened by combining perfusion studies with IP profiles in order to compare the performance differences between systems that appear deceptively similar. Two such studies clearly demonstrate the positive relationship between higher amplitude cycles that hold pressure lower for longer, and significantly greater perfusion [13,14].

Other considerations

Comfort vs performance

The most comfortable system may not be the most therapeutic and vice versa. However, comfort may clearly be linked to concordance [15] and so even in the absence of a reliable measure, the link between the two makes it an important consideration when describing support surface performance. While the difference between maximum and minimum

pressure (amplitude) is important for perfusion, it does not mean that air pressures within the mattress need to be unduly high – inflation pressure needs only to be 'high enough' to lift the body clear of the deflated cell. This can be demonstrated by comparing how different devices respond to individual variances in subject morphology (eg body mass distribution). Some devices operate by applying set cell pressures that do not vary according to body mass distribution, so require higher inflation pressures to cater for the full range of patient weights. Others depend on manual selection of cell pressure, which can result in marked differences in PRI depending on how it is set up. By contrast, sophisticated devices 'read' changes in the patient weight or body mass distribution and change cell pressures accordingly, thereby offering a comfortable yet optimised support surface.

Semi-recumbent position

Historically, and for practical reasons, much of the *IP* data is collected in the supine position, but this may not be clinically relevant. For example, systems that are designed to achieve complete pressure off-loading when the subject is supine may be unable to do so when the back rest is raised into common nursing positions, even at low angles of elevation[16]. As patients are rarely nursed flat, it is helpful to appreciate both the effect of body posture and of the bed frame when interpreting data for clinical practice.

The importance of the bed frame has been suspected since field outcome studies began to report a reduction in pressure ulceration associated with the use of profiling beds[17]. However, the design of the studies and the generally small sample size precludes any firm conclusion as to whether the mattress or the bed frame has the most influence on outcome. Perhaps

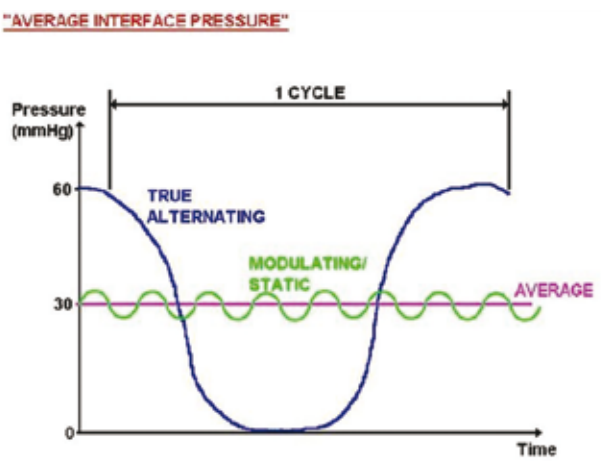

Figure 9

recent laboratory investigations can provide a clue. IP tests comparing bed frames with different mattress platforms showed a clear relationship between IP and how the back rest and knee break articulated. Multisectional frames were best able to reduce the impact of the head up position when compared to simple back lift devices [18], perhaps for the first time shedding some light on the role the bed frame plays in overall pressure ulcer prevention.

There are many other factors relating to both PRI and PAI techniques that can affect the reliability of the data and so the relevance of the report. A non-exhaustive list includes subject body mass distribution and demographics, subject clothing, type of bed frame, calibration and type of test rig, and accurate positioning and repositioning of the sensors. These are important and often overlooked criteria to consider when conducting and reviewing performance data.

Given all the possible confounding factors, a well-designed study will endeavour to control all possible variables and will clearly describe the methodology in sufficient detail to enable replication and critical review. This level of control is particularly important when two competing technologies are being compared. Comparisons should take place in identical test conditions and the direct comparison of data from different origins should be actively discouraged as it can be highly misleading. Essentially, this means that data derived from individual studies should be used with caution and not for the purposes of direct comparison with other devices, nor should it be used to construct 'league tables' (ie performance ranking).

Linking IP with clinical outcome

Although *IP* is not a direct indicator of clinical outcome it can be used to construct a physiological profile when coupled with measurement of tissue perfusion. This is a relatively new technique that has gained credibility following the development of very thin, flexible sensors. These sensors enable contemporaneous mapping of both tissue perfusion and *IP*, providing a clear picture of how different pressure profiles affect blood flow. Although still not a direct marker of clinical outcome, it may be logical to favour the device that optimises the duration of off-loading to deliver the greatest tissue perfusion.

Conclusion

In terms of pressure redistribution, CLP support surfaces reduce IP in much the same way as each other. The key difference between the modalities is the degree of immersion, which is directly related to the degree of pressure reduction and can be simply measured using the PAI. On the other hand, Alternating Pressure Mattress Systems work in very different ways. Even to an experienced eye, mattresses (like cars) may look similar, but beneath the covers (or the bonnets) the differences may be vast! For example, the pressure profiles will almost certainly be different, ie rate of cell inflation and deflation, the pressures within the cells, the amplitude of the cycle, duration of the cycle, ratio of cells deflated at any one time etc. Each of these measures will have an effect on pressure redistribution and subsequent perfusion; this can only be fully explored by means of clinical outcome studies. However, the use of well designed IP and perfusion studies can help to differentiate between the systems in terms of technical performance and can provide useful data by which dynamic support surfaces can be evaluated.

Whether to use a mannequin or human volunteer is yet to be agreed and beyond the scope of this discussion. However, two points are illustrated to give an indication of some key issues in the debate:

1. Human volunteers are difficult to standardise and may not be representative of a patient population, making study replication almost impossible.
2. For accurate PRI measurement, a mannequin would require the same flexibility or joints as a human body to fully respond to the dynamic curvature of a moving surface such as an APRM.

Suffice to say, this topic has possibly provoked the greatest contention in any consensus debate as both approaches have advantages and drawbacks.

While providing useful descriptive data, *IP* and perfusion studies have limitations and do not take into account other important factors, such as moisture and temperature at the patient interface. The best measure of performance of a support surface will remain in the field, that is in following the experiences of vulnerable individuals in their normal care environment using a variety of research designs. Such is the value of clinical data that, when it is added to the body of laboratory evidence, trends emerge and the information 'bundle' can be used holistically to both guide the design of the next generation of medical support surfaces and guide the clinician in selecting appropriate therapies.

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