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Direct measurement of cutaneous pressures generated by pressure garments

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Pressure garments are the mainstay of burn scar management despite limited scientific evidence. This study demonstrates a simple method of directly measuring the cutaneous pressures generated by a pressure garment. The results show pressure garments generate an increase in subdermal pressures in the range 9–90 mmHg depending on the anatomical site. Garments over soft sites generate pressures ranging from 9 to 33 mmHg. Over bony prominences the pressures range from 47 to 90 mmHg. This method is believed to be more representative of the pressures generated than the interpositional techniques that measure garment–skin interface pressure, as it avoids garment distortion, the interference effect of the measurement device (size, conformation, area) and directly measures subdermal pressures. The method should be useful for larger research projects on pressure therapy and also for clinical management of pressure garments in the treatment of hypertrophic scar.

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Introduction

Pressure garments have been the mainstay of burn scar management since the late 1960s, when pressure was incidentally noted to have a beneficial effect on hypertrophic scars when used for the management of burns contractures[1].

Despite anecdotal and clinical evidence of the beneficial effect of pressure therapy on hypertrophic scars, there is little scientific evidence available. In part this is due to the difficulty in measuring the pressure transmitted to the scar and skin by a pressure garment.

All studies that have attempted to measure the pressure generated by pressure garments have either extrapolated the result from measurements of garment tension[2] or have measured the interface pressure between garment and skin[3–7]. These studies used electronic monitors or balloon pressure transducers interposed between the garment and skin.

The problems noted by these same authors against using these external interface techniques include:

1. Distortion of the garment, hence raising garment tension and increasing the pressure generated.
2. Poor conformity of the device to the skin.
3. Being unaware to what degree external pressure is transmitted to and through the skin.

In addition, no control measurement for comparison is possible. In fact, even the accuracy of the electrical transducer used in the measurement of pressures applied to the skin has been questioned by Patterson and Fisher[8]. They measured a mean magnitude error of over 20 mmHg in a study of five different external pressure transducers.

In an attempt to overcome these problems, this novel technique of cutaneous pressure measurement was used. It directly measures the subdermal cutaneous pressure. The technique is well established for the measurement of compartment pressures by orthopaedic, trauma and plastic surgeons, to assist in the management of compartment syndromes, and is similar to a technique used to investigate the role of pressure in the aetiology of pressure sores[9,10].

Materials and methods

A 19G needle is connected to a continuous low flow pressure transducer as is widely used to monitor arterial or central venous blood pressure by anaesthetists. The transducer is calibrated, zeroed and the needle is inserted subdermally (*Figure 1*). Following a short 10–20 s period of equilibration a reading is obtained in mmHg. This is the resting subdermal pressure. Following the application of a custom-fitted pressure garment the reading is repeated by re-inserting the needle at the same site.

To evaluate this method seven sites on the left leg of one of the authors were needled (*Figure 2*). Each site was needled to measure resting subdermal pressure (control measurement), a pressure garment worn and then each site re-needled to measure

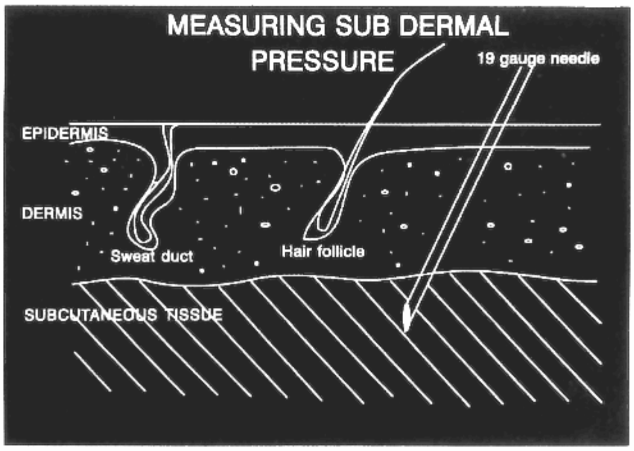

Figure 1. Illustration of subdermal position of measuring needle

subdermal pressures with the garment in situ (*Figure 3*). This process was performed twice at each site to assess reliability and reproducibility of the readings. In addition several needle gauges were assessed ranging from 14G to 25G. There was no significant difference between the results obtained with the different needle gauges, however it was felt that there would be less error using the maximal comfortable needle gauge.

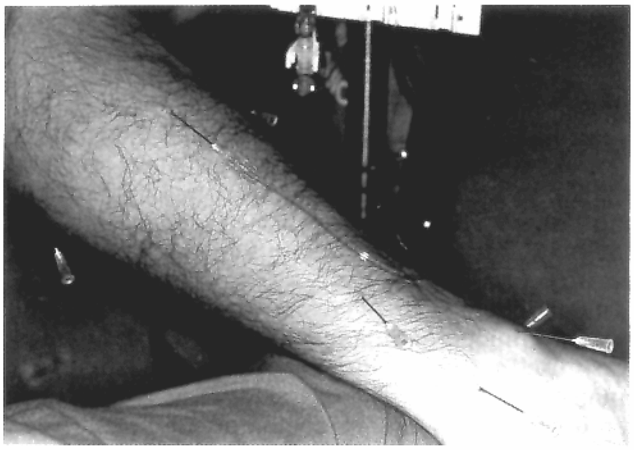

Figure 2. Measurement needles in the leg.

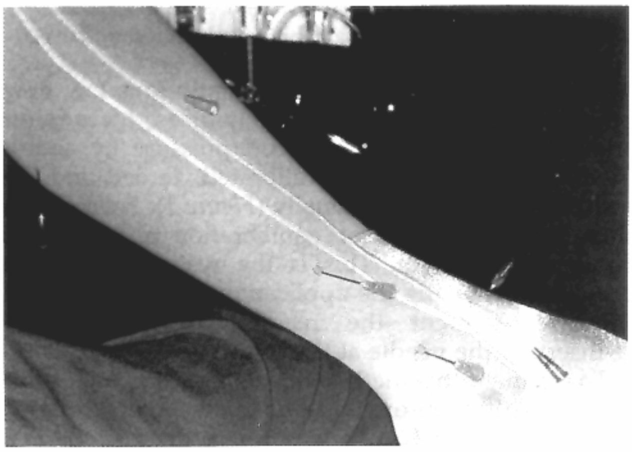

Figure 3. Measurement needles in the leg, following application of a pressure garment.

The interface pressures between garment and skin were also measured at the seven sites by the balloon technique[7], to allow comparison of the direct subdermal pressure measurement with the measurements obtained by the interface techniques previously reported[3,4,7].

Results (Table I)

Subdermal pressures with pressure garment on vs. resting skin tension (control)

The results demonstrate that pressure garments do produce increased pressure subdermally and hence this pressure must be transmitted through and within the skin. The pressure increase is in the range 9–90 mmHg, with a median of 30–38 mmHg. This is a statistically significant increase by the Wilcoxon-Signed Ranks test where $P < 0.05$. Over 'soft' sites (i.e. overlying musculature) the subdermal pressure increase generated by the pressure garment is in the range 9–33 mmHg with a mean of 21 mmHg. Over 'bony' prominences (i.e. when subdermal readings are taken over bony prominences) the subdermal pressure increase ranges from 47 to 90 mmHg.

Direct subdermal pressure readings vs. interface/interposition readings

When direct subdermal measurement pressures under a garment are compared to measurements performed by the interface or interpositional technique, it can be seen that the interposition technique tends to overestimate the pressures generated over soft sites. However, over bony prominences the interposition technique tends to underestimate the pressures generated.

Discussion

For a better understanding of the mechanisms and effect of pressure therapy on hypertrophic scar we need to be able to reliably measure the pressure in the skin or scar, generated by a pressure garment. The insertion of a needle connected to a pressure transducer subdermally, allows reliable and reproducible measurement of subdermal pressures.

This method allows the establishment of a baseline or control pressure against which the subdermal pressure generated by a garment can be compared. This has previously not been possible using the interface or interpositional techniques. In addition, the direct measurement of the subdermal pressures avoids some of the problems raised by other authors of the interpositional technique. These are reported as mainly concerning the distortion of the pressure garment, thus raising garment tension; the size and non-conformity of the interpositional device; and the indirectness of the technique such that it measures external pressure.

Table I. Pressure readings at the seven sites

Site	*At rest control (mmHg)*	*Pressure garment on direct subdermal measurement (mmHg)*	*Pressure garment on interface measurement (mmHg)*
Soft sites			
Medial mid calf	5, 6	21, 22	36, 36
Posterior calf	−2, −3	24, 24	66, 66
Posterior to malleolus	0, −1	12, 18	17, 16
Medial lower calf	0, 1	30, 32	59, 58
Bony sites			
Anterior shin	0, 1	48, 47	46, 51
Anterior ankle	5, 6	84, 78	39, 39
Medial malleolus	−2, −3	92, 90	54, 52

It is reasonably safe to assume that the increase in pressure measured subdermally when a pressure garment is applied externally, reflects pressure that is transmitted through the skin. However, what exactly is pressure and what is being measured? There is considerable confusion in the existing physiological literature with respect to the definition and terminology relating to pressures within tissues. However, there seems to be agreement that the subdermal pressures measured with this technique represent scalar total tissue pressures[10–13], though there are possible sources of error as discussed by Le et al.[10] and Ferguson-Pell[12]. Total tissue pressures are the sum of the interstitial fluid pressures and solid tissue pressures when the cross-sectional area occupied by the two elements remain unchanged. Brace and Guyton are helpful in defining 'The total tissue pressure in the subcutaneous tissue is determined by the sum of: (i) the pressure due to the radial tension of the skin, and (ii) any external pressure'[11]. Hence it seems that the measurement of any change in subdermal pressures represents a change due to the external pressure. How this scalar total tissue pressure translates into local vector forces (tension, compression, and shear) in the skin and influences scar is unknown. At present there is no known in vivo vector force measurement system, but its importance in the understanding of pressure effect on scar can be seen in the work on the effect of uniaxial longitudinal surface forces on skin vasculature[14].

Within the restraints of not knowing exactly what is occurring at the local vector forces level or how pressure influences scar, we have demonstrated the subdermal pressures generated by a pressure garment, from which, further work may evolve to solve some of the above unknowns. This technique may allow us to quantify an effective subdermal pressure whilst not revealing exactly what is occurring intradermally, however this is useful in that it gives us an easy and quantifiable guide to the degree of pressures involved. This may prove useful clinically in assessing if an applied garment is failing to produce the required pressure to influence scar. Unfortunately this *required pressure* is also unknown, though frequently quoted at between 20 and 40 mmHg or greater than the arterial capillary pressure[1,3,4,6,7].

Within the above limitations this study shows that a pressure garment does create an increase in pressure through the skin into the subdermis and not just an increase in interface pressure, as has been previously documented. If we examine the pressures recorded at 'soft' sites, the increase in pressure generated by a garment is between 9 and 33 mmHg with a mean of 21 mmHg. This compares with interface pressures measured at the same sites with a range of 17–69 mmHg and a mean of 48 mmHg. Other authors report interface pressures over soft well-padded sites, such as the forearm, of between 0 and 37 mmHg, with average pressures between 10.6 and 19.4 mmHg[3,4].

Other authors report wide ranges of pressures depending upon different anatomical areas[1,3,15]. This is confirmed when we examine our pressures recorded over bony prominences. Over these sites the subdermal pressures generated by a garment range from 47 to 90 mmHg. The interface pressures under the same garment tend to be lower, ranging from 39 to 52 mmHg. This is probably due to the padding effect of the interposition balloon, which would diffuse the effect of the pressure garment over the bony prominence by padding the prominence.

There are no previous reports of pressures generated by a garment over bony prominences. However, within the results of Robertson et al.[6] an interface pressure range of 37–65 mmHg is recorded over the anterior aspect of the shin. This compares well with our interface pressures of 46–51 mmHg measured at a similar site (subdermal pressures of 47–48 mmHg).

Overall the subdermal pressures measured over the bony prominences when a garment is applied (ranging from 47 to 90 mmHg) do seem rather high and evoke concern about skin ischaemia and breakdown. However, a review of the literature investigating the effect of pressure on tissues, particularly in relation to the aetiology of pressure sores, reveals interesting data[13,16]. High interface pressures in the region of 60–100 mmHg have been measured over ischial tuberosities on sitting and similar pressures underlying other prominences such as the greater trochanter[17,18]. Yet, pressure sores do not result from these high pressures. Experimental studies reviewed, report that continuous pressures of 50–100 mmHg for periods up to 12 h did not result in pressure sores[13,15]. Further studies demonstrate that if surface pressures are 50 mmHg then the underlying deep pressures are 250 mmHg[10]. These studies support the theory that in the aetiology of pressure sores the pressure is generated from within at the site of the bony prominence and the pressure is dissipated laterally as it approaches the skin, much like an inverted triangle with the apex at the bone and the skin at the dissipated base of the triangle. Thus pressure sores start with necrosis of the deep tissues, especially muscle which is sensitive to ischaemia. This is unlike a pressure garment that creates an external pressure with the apex of the triangle at the surface, seen as peaks overlying bony prominences, and the pressure dissipating laterally and deeply[10,19]. It should also be noted that over the bony prominences where we recorded our high pressures there is no muscle, and we know skin is more resistant to pressure and ischaemia. Hence externally applied pressures cannot be compared to those measured in the aetiology of pressure sores. This is supported by evidence of high external pressures existing in other situations apparently without ill-effect. For example, we daily use surgical tourniquet pressures between 250 and 350 mmHg for 1–2 h periods without skin breakdown. Amputation stump bandaging can result in interface pressures as high as 170 mmHg (mean of 67 mmHg) over the tibial tuberosity[5], again without complications (though this degree of pressure is not recommended). Admittedly, pressure garments are worn for continual periods longer than those studied, however we assume that pressure ischaemia and necrosis do not occur under the garment, due to movement and constant shifting of the site of peak pressure. Thus the peak site of pressure is intermittently found at different spots on the underlying skin, much like one avoids pressure sores from developing over ischial tuberosities by continually shifting ones weight. Yamaguchi et al.[20] support this indirectly by showing that it requires circumferential pressures of 50 mmHg to diminish peripheral circulation, and despite higher peak pressures the circumferential pressures recorded were always below this level. Unfortunately, clinically one does occasionally see areas of graft or skin breakdown over bony prominences secondary to excessive pressure and it may be necessary to reduce garment tension over these bony prominences or pad these areas[21].

Over soft sites the interface pressures recorded seem higher than the subdermal pressures. This is likely to be due to distortion of the garment, hence creating a greater elastic force, and possibly due to incomplete transmission of pressure from external interface to the subdermis. This is supported by evidence from Sawada[7] who showed that even a 1-mm-thin plastic plate interposed between garment and skin significantly increased the measured interface pressure.

Due to the large variation in pressures seen between anatomical sites, individuals and even garments, this study is being enlarged to examine a number of different 'patients', a large number of different anatomical sites and different garments to better determine what pressures are generated by pressure garments within the skin.

Conclusion

The modification of a system used to assess compartment pressures to directly measure subdermal pressures and to study the effect of a pressure garment is reported. This method allows a control measurement to be taken and avoids the problems associated with external interface or interpositional measurements.

This preliminary study demonstrates that a pressure garment produces an increase in subdermal pressure in the range 9–33 mmHg over soft sites and 47–90 mmHg over bony prominences. This compares favourably with similar studies using indirect methods of pressure measurement. The results demonstrate that interface techniques tend to overestimate pressures generated over soft sites and underestimate pressures generated over bony prominences, when compared to subdermal pressure measurements. This logically 'fits' the arguments proposed against interface techniques.

Further larger studies are required to document the pressures generated by pressure garments and their anatomical variance. This pressure measurement system will allow a prospective randomized trial of measured pressure therapy in the prevention of scar hypertrophy.

In addition to research, this technique will help clinically in the management of hypertrophic scars that are failing to respond to pressure therapy, by allowing assessment of the adequacy of the pressure being applied by the pressure garment.

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