Adaptive Skin Blood Flow Increases During Hip-Down Lying in Elderly Women

Harvey N Mayrovitz, PhD, and Joshua R Smith, MS

Abstract

OBJECTIVE: Pressure ulcer development due to unrelieved pressure during extended cardiovascular, orthopedic, and other procedures is an important clinical problem. Because blood flow changes within pressure-loaded tissue affect the skin breakdown process, the relative effects of 2 support surface strategies on trochanter skin blood flow were investigated.

DESIGN: Skin blood perfusion was assessed by laser Doppler methods during 1 hour of continuous loading. Blood perfusion was measured before and during hip-down loading on a gel pad (static surface) and a dynamic multi-segmental surface that provided periodic alternating pressure relief. Female volunteers ($N = 20$, age ≥ 60 years) were tested on each surface in random order with sequential tests separated by 5 to 8 days. Effects were assessed by comparing perfusion during the first and last 15 minutes of hip-down loading with a 15-minute baseline.

SETTING: Research center

RESULTS: Pre-load perfusions (dynamic vs static support) were similar (0.57 ± 0.06 vs 0.64 ± 0.08). During loading, however, a significant progressive increase in perfusion was noted only with dynamic support; by the end of the loading interval, this increase in perfusion had significantly exceeded the pre-load baseline (1.22 ± 0.26, $P = 0.001$).

CONCLUSION: These findings reveal a surface-dependent blood flow impact, with the multisegmental dynamic approach being associated with greater flow during loading. The mechanism, though speculative, is consistent with a greater vascular adaptation potential offered by the dynamic surface. Conditions that facilitate such adaptive flow increases would appear to be of considerable benefit in helping to prevent ulcer development.

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PRESSURE ULCER DEVELOPMENT DUE TO unrelieved pressure during extended cardiovascular, orthopedic, and other surgical procedures is an important clinical, humanitarian, and economic problem.[1-7] Many factors contribute to the development of pressure ulcers,[8-10] but in most instances the final common pathway is associated with blood flow changes within pressure-loaded tissue. These detrimental blood flow changes affect the skin breakdown process in several ways,[11-14] and techniques to mediate these blood flow changes would potentially help prevent breakdown. Many reports in the literature have compared various strategies and concepts in this regard,[15] and accumulated knowledge about the vascular physiologic mechanisms responsible for breakdown has led to progress in new support surface concepts and designs targeted to reducing pressure ulcer occurrence. Blood flow is important in this process; therefore, the present report is concerned with the investigation of blood perfusion effects of 2 widely different support surface strategies, 1 based on static support and 1 based on dynamic support in the form of multisegmental small air cells that provide periodic alternating pressure relief. In order to accomplish

Harvey N Mayrovitz, PhD, is a Professor of Physiology at the College of Medical Sciences, Nova Southeastern University, Fort Lauderdale, FL. Joshua R Smith, MS, is Research Associate at the Miami Heart Research Institute, Miami, FL. Submitted July 28, 1998; accepted in revised form October 23, 1998.

this, trochanter skin blood perfusion was assessed in 20 elderly women during 1 hour of continuous hip-down lying on both of the surface types and the resulting blood perfusion patterns were recorded and analyzed.

Methods

Subjects

Postmenopausal women were chosen for this study to eliminate variability that might occur due to hormonal cycles and to have a group that was representative of a population at greater risk for ulcer development simply because of their age. Twenty women of at least 60 years of age volunteered to be participants, then signed an Institutional Review Board–approved informed consent form. Their average age (mean $\pm$ sem) was 70.4 $\pm$1.9 years (range 60 to 85). Ten subjects were Caucasian and 10 were Hispanic. Subjects were of varying body habitus: Their average height was 62.8 $\pm$ 0.7 inches (range 58 to 69) and their average weight was 144.7 $\pm$ 7.9 pounds (range 82 to 208). The subjects' average body surface area was 1.67 $\pm$ 0.45 kg/m^2 (range 1.32 to 2.04). Eleven subjects were classified as hypertensive (systolic pressure >140 mm Hg or diastolic pressure > 90 mm Hg), although no subject exceeded a systolic pressure of 160 mm Hg. No subject had a history of diabetes or vascular disease other than mild hypertension. No subject was taking vasoactive medication, and none had any skin ulcers.

Experimental design

Subjects were tested on 2 different support surfaces, 1 a static surface and 1 a dynamic surface. The static surface was a gel pad (Action Pad, Action Products, Hagerstown, MD) comprised of a dry viscoelastic polymer (Akton). It is similar to other gel pads used in operating rooms. The dynamic surface was an alternating pressure-relief system produced by MicroPulse (Portage, MI). The MicroPulse system is comprised of a control unit (air pump) and a thin MicroCell pad with over 2500 small air cells enclosed in a fluid-proof cover. The air cells are arranged in rows so that at any given time the patient is supported by 50% of the cells (all those that are inflated). Cells are not in contact with the patient when they are deflated. The product cycles approximately every 4 minutes to allow the tissue over the deflated cells to reperfuse at frequent intervals. Both the static

Figure 1

SUBJECT 1, PERFUSION PATTERN DIFFERENCES BETWEEN STATIC (A) AND DYNAMIC (B) SUPPORT
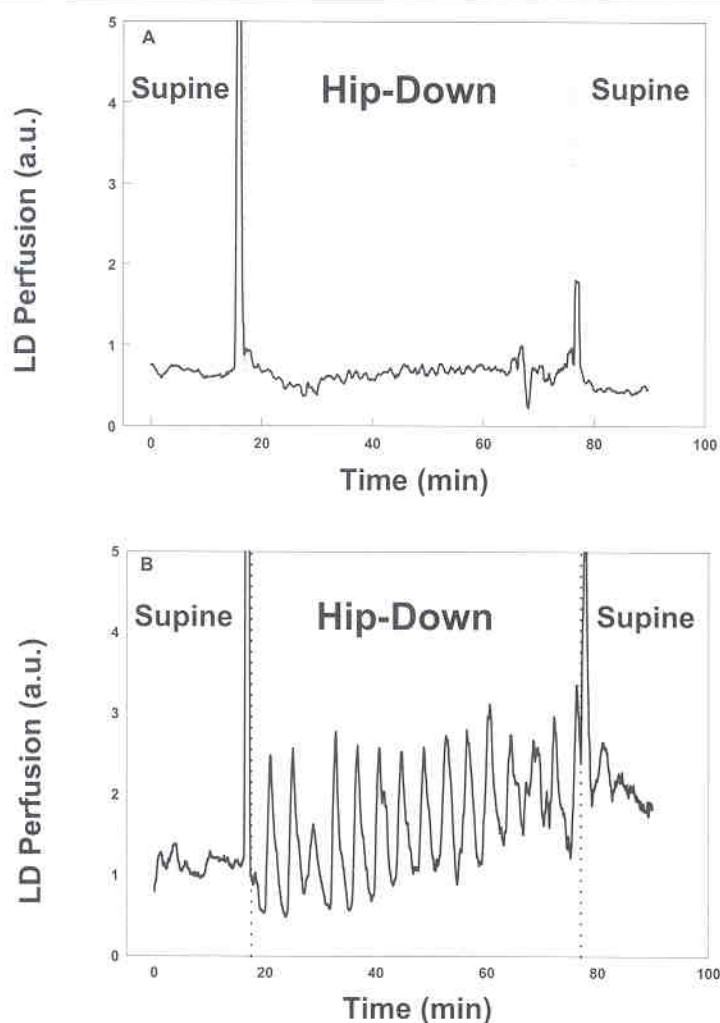
In A, turning to the hip-down position is followed by a gradual decrease in perfusion that reaches a minimum after 15 minutes, followed by a near recovery to baseline levels. In B, hip-down lying is associated with a rhythmic perfusion pattern with a peak amplitude and overall mean perfusion that increases; by the end, the minimum perfusion value of the rhythmic variation exceeds the mean baseline level.

and dynamic surfaces were placed on top of a 2-inch foam pad on a standard examination table located in a temperature-controlled (73° to 75° F) test room.

Protocol

On the first visit, each subject was placed supine on 1 of the 2 support surfaces, the choice of which was determined on a random basis; subjects wore hospital gowns, not their street clothes. A laser Doppler blood perfusion probe (P-440 Softflex, Vasamedics, Inc, St. Paul, MN) was placed on the proximal trochanter prominence. The probe encapsulation, which is a soft flexible silicone elastomer, conforms gently to the skin surface. Its softness and uniform flat surface area reduce pressure concentration effects and minimize potential tissue trauma subsequent to compression. This technique has been applied under a variety of experimental conditions.[16,17] Following standard practice, laser Doppler perfusion is expressed throughout this paper as arbitrary units (au).[18,19] A small thermocouple temperature sensor was then affixed to the subject's skin within 0.4 cm of where the blood perfusion was being measured, and skin temperature was measured at 5-minute intervals throughout the procedure. A light blanket was placed over the subject. Subjects were instructed to lie as still as possible. Blood perfusion was recorded continuously during a 15-minute baseline interval, after which the subject was turned on her side so that the laser Doppler probe was in contact with the support surface and could measure blood perfusion at the site of skin compression. Blood perfusion was measured continuously during 1 hour of hip-down lying.

About 1 week later (5 to 8 days), the subject returned and the procedure was repeated on the same hip using the other support surface. Blood pressures were recorded in all subjects at the start and end of each procedure. Neither systolic nor diastolic blood pressures changed significantly during either procedure or from week to week. Overall mean values of supine systolic/diastolic pressures for this population were 138.4/77.5 mm Hg prior to the start of the procedure and 136.6/75.5 mm Hg at the procedure's end.

Results

Skin temperature changes

During the 60-minute hip-down lying interval, trochanter skin temperature increased on both surface types. The changes, measured as the difference

Figure 2

SUBJECT 2, PERFUSION PATTERN DIFFERENCES BETWEEN STATIC (A) AND DYNAMIC (B) SUPPORT
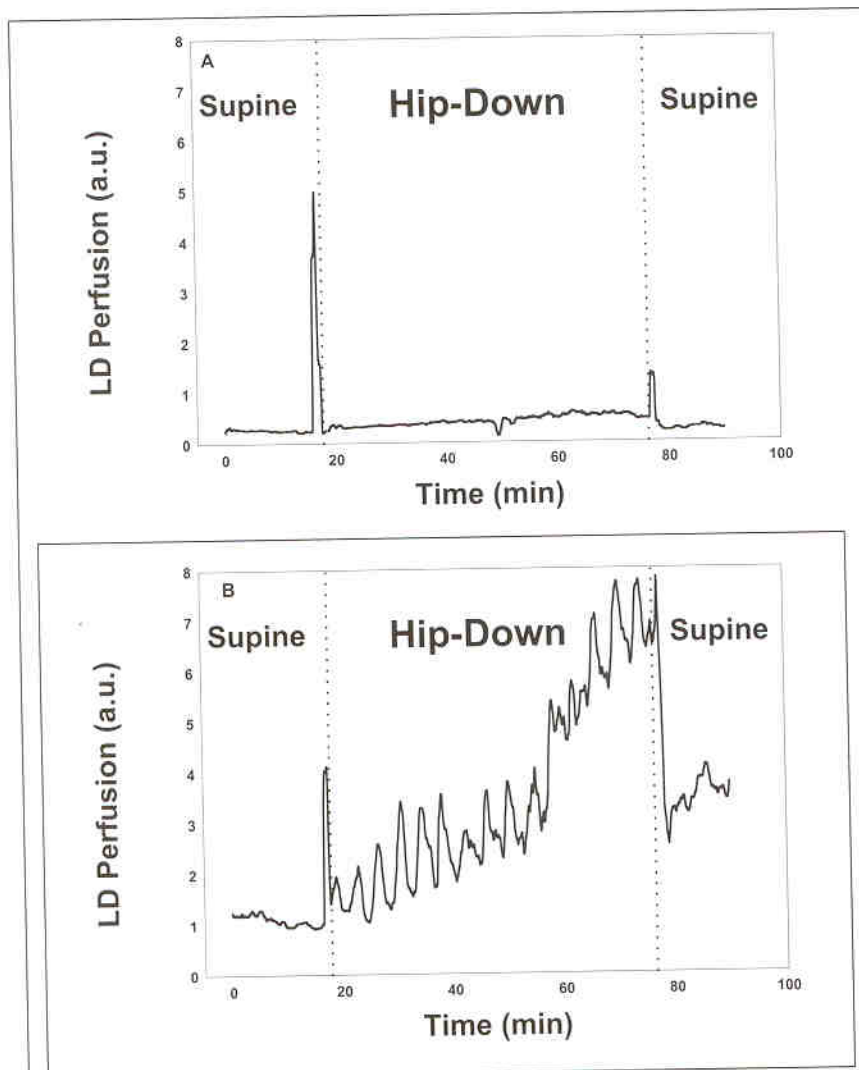
Hip-down lying did not produce a perfusion decrease below baseline on either the static (A) or the dynamic (B) surface. However, the differential perfusion pattern and the dramatic increase in perfusion that resulted from lying on the dynamic surface is clearly seen.

between the average skin temperature during the last and first 15-minute intervals, were insignificantly different between the static and dynamic surfaces ($1.42° \pm 0.10°C$ vs $1.59° \pm 0.13°C$, $P > 0.25$, Mann-Whitney test).

Perfusion response patterns to hip-down lying

Blood perfusion response patterns during hip-down lying were somewhat variable with respect to individual subjects and significantly different with respect to the support surface type. Figure 1 illustrates the patterns for 1 subject (64 years, 5 feet 8 inches, 200 pounds). After turning to the hip-down position on the static surface (A), a gradual decrease in perfusion is noted that falls below the pre-load baseline and reaches a minimum after about 15 minutes of compression. This is followed by a near recovery to baseline levels for the remaining hip-down lying interval, except for a transient change at about 68 minutes. In this figure and those that follow, the large excursions at minutes 15 and 75 are artifacts due to movement as the subject is repositioned. In contrast to the pattern on the static surface, turning to the hip-down lying position on the dynamic surface (B) is associated with a rhythmic perfusion pattern with a peak amplitude and an overall mean perfusion that tends to increase during the interval. By the end of the interval, even the minimum perfusion value of the rhythmic variation exceeds the mean baseline level.
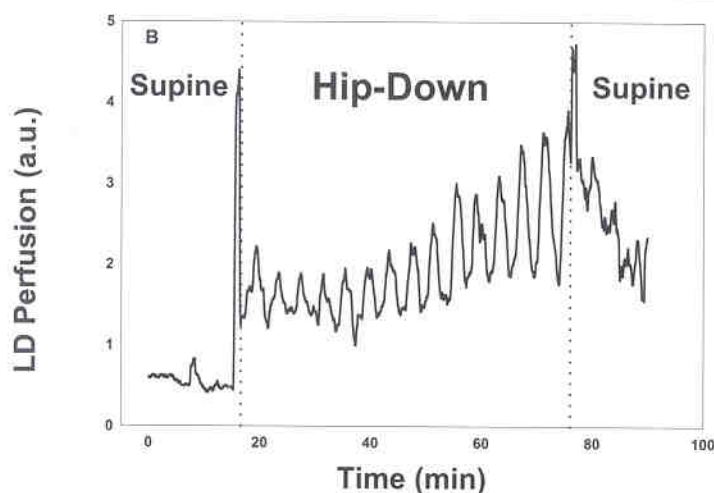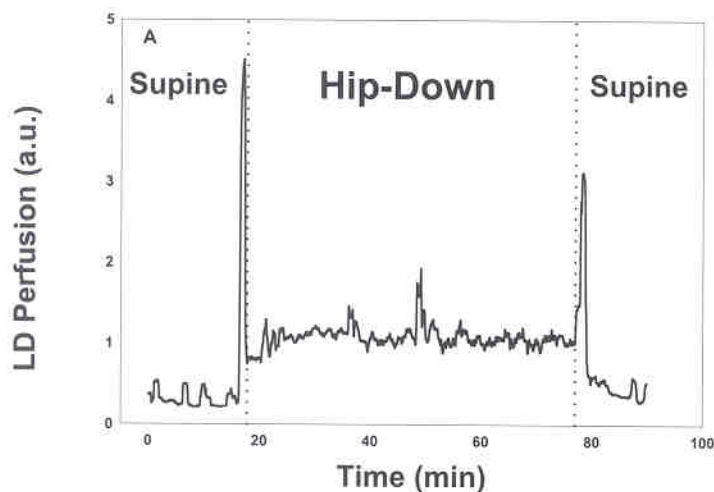
A somewhat different pattern is seen for the subject response shown in Figure 2 (60 years, 5 feet 4 inches, 170 pounds). In this subject, the hip-down lying position did not produce a perfusion decrease to a level below baseline on either the static or the dynamic surface. However, the dramatic increase in perfusion associated with the dynamic surface and the quite different temporal pattern during the interval is clearly seen.

Figure 3 illustrates a pattern for a subject (60 years, 5 feet 7 inches, 190 pounds) in which the perfusion in the early part of hip-down lying was significantly higher than baseline on both surfaces. However, it is noted that after about 30 minutes, the perfusion on the dynamic surface shows an increasing trend, whereas perfusion does not increase on the static surface.

Figure 3

SUBJECT 3, PERFUSION PATTERN DIFFERENCES BETWEEN STATIC (A) AND DYNAMIC (B) SUPPORT

Perfusion in the early part of hip-down lying was significantly higher than baseline on both surfaces. After about 30 minutes, perfusion on the dynamic surface (B) shows an increasing trend, whereas on the static surface (A), perfusion does not increase.

Overall perfusion changes

Overall perfusion responses associated with both surfaces were quantitatively

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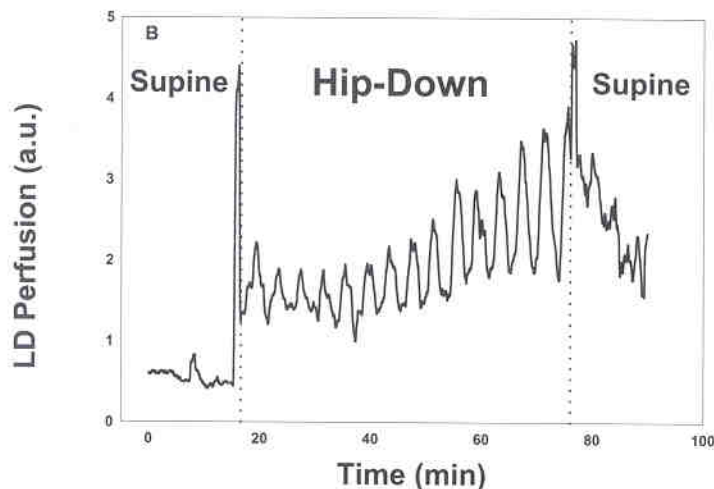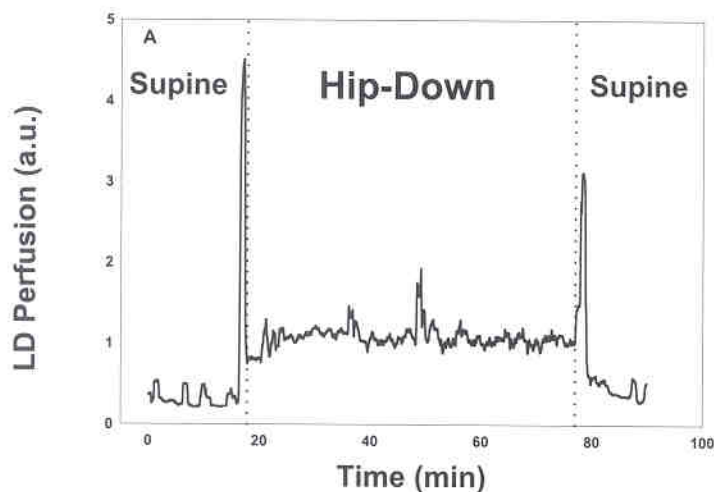
A somewhat different pattern is seen for the subject response shown in Figure 2 (60 years, 5 feet 4 inches, 170 pounds). In this subject, the hip-down lying position did not produce a perfusion decrease to a level below baseline on either the static or the dynamic surface. However, the dramatic increase in perfusion associated with the dynamic surface and the quite different temporal pattern during the interval is clearly seen.

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Overall perfusion changes

Overall perfusion responses associated with both surfaces were quantitatively

assessed by comparing the first and last 15-minute intervals of hip-down lying with the average perfusion during corresponding 15-minute baseline intervals. Analysis was via the Wilcoxon nonparametric test for dependent samples with a P-value of 0.05 taken as significant. These results are summarized in Figure 4. The dynamic support surface was associated with a progressive and significant blood perfusion increase from the first ($P = 0.05$) to the last 15-minute interval during hip-down lying ($P = 0.001$). For the dynamic surface, the pre-load baseline perfusion of 0.57 ± 0.06 increased to 0.76 ± 0.10 during the first 15 minutes and further increased to 1.22 ± 0.26 during the last 15 minutes of hip-down lying. In contrast, no significant perfusion increases occurred with the static surface from the baseline perfusion value of 0.64 ± 0.08. There was no significant correlation between skin temperature changes and blood perfusion on either of the support surfaces.

Discussion

The main experimental findings of this study clearly demonstrate that the different blood perfusion response patterns during hip-down lying were mainly dependent on the support surface used. When a dynamic surface with small air cells was used, there was a rhythmic variation in perfusion that coincided with the rhythm of the alternating inflation and deflation of the cells. Although this type of pattern was not unexpected, the progressive and significant increase in perfusion during the hip-down loading interval was not predicted. This feature was not present when a static support surface was used. The perfusion increase on the dynamic surface was unrelated to the skin temperature change, as these changes were similar for both surfaces, and temperature was not correlated with perfusion changes.

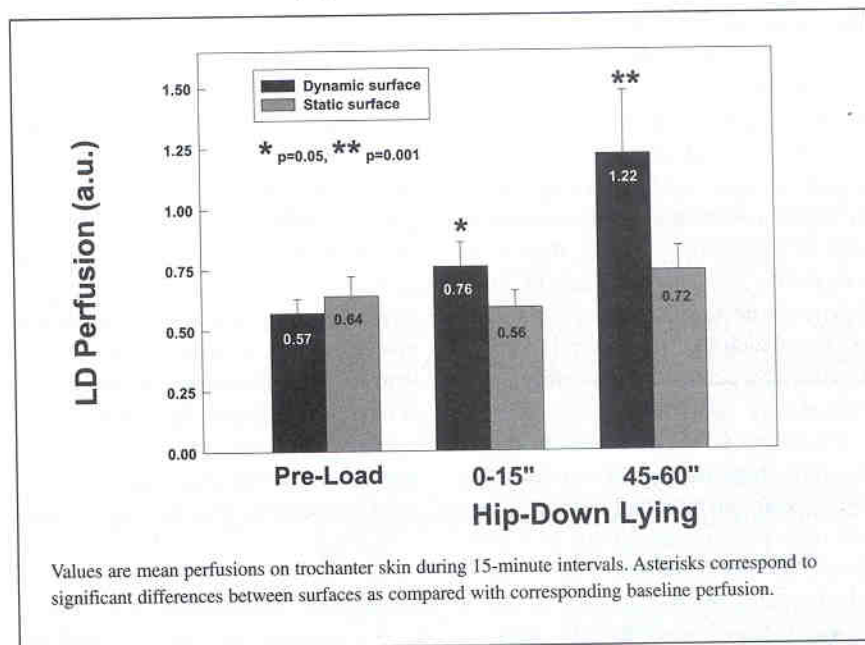From a functional viewpoint, this increase in perfusion, unique to the dynamic surface, would appear to be useful as an aid in helping to prevent the development of pressure ulcers. This follows from the important role of local blood flow as a factor in pressure ulcer development. Pressure-related decreases in tissue blood perfusion occur by compression of tissues and vessels and by alterations in the tissue structure that cause abnormal blood vessel twisting and bending within and near the compressed tissue. Thus, a support surface that tends to ameliorate these detrimental blood flow effects would seem to be of significant potential benefit.

The specific property of the dynamic surface used in this study that facilitates the blood perfusion response as differentiated from a static surface is not fully clarified. In a series of studies of hip-down lying on static low interface pressure surfaces,[20-22] a gradual increase in perfusion in healthy subjects that reached about twice that of the baseline after 60 minutes of loading[20, 21] has been noted. This was not observed with patients deemed at high risk.[22] In these earlier studies, however, the type of laser Doppler probe used (small, steel, and undeformable) did not permit an assessment of the effects of localized pressure concentration, skin irritation, and temperature changes at the probe site as causative or confounding factors. A probe imbedded in foam rubber eliminates some of these issues and was used to assess sacral perfusion in elderly stroke patients.[23] Interestingly, after 30 minutes of lying supine on a foam mattress, perfusion was increased above baseline by about 35% in patients judged at low risk. This may suggest that some degree of perfusion adaptation may occur with an appropriate static support surface but that an appropriate dynamic surface serves to augment this process.

These issues are difficult to resolve

Figure 4

OVERALL BLOOD PERFUSION COMPARISONS BETWEEN STATIC (A) AND DYNAMIC (B) SUPPORT

Values are mean perfusions on trochanter skin during 15-minute intervals. Asterisks correspond to significant differences between surfaces as compared with corresponding baseline perfusion.

because the cited studies were not designed as surface comparison studies. Thus, potential surface-dependent differential responses not attributable to the possible confounding variables noted are unclear. One previous comparative report that used an experimental design similar to that of the present report showed no difference between the dynamic and comparison static surfaces with respect to the progressive blood perfusion feature herein observed.[24] The dynamic surface used in that study, however, did not have the small air cell configuration. Therefore, it would seem reasonable to infer that the blood perfusion adaptation during hip-down lying is related to the specific nature of the support surface design and intrinsic vascular responses to external pressure.

Increases in external pressure[25] (and resultant increases in tissue pressure) cause associated decreases in the pressure that acts across the walls of small arteriolar blood vessels.[26] This reduction in distending transmural pressure normally causes a short-term myogenic vessel response,[27] resulting in blood vessel vasodilation and blood flow increases.[28] Although this active vasodilation helps to restore the diminished blood flow, its capacity to maintain the flow is limited by the amount and duration of the external pressure. A full understanding of how this physiologic mechanism may explain the present observations is not yet available. It is plausible, however, that by interspersing rhythmic intervals of pressure removal on small regions of tissue, as occurs with the small air cell dynamic surface, a cumulative and progressive vasodilatory adaptation occurs that in part accounts for the observed blood perfusion increase during the hip-down lying interval. Such rhythmic activity may not only permit intermittent and summated flow recovery, but, it is speculated, may also provide a stimulus for a flow-dependent vasodilatory adaptive

process. When endothelial cells that line the innermost aspect of blood vessels are exposed to increased shearing stresses, they release increased amounts of vasodilatory substances.[29] Rhythmic external pressure changes would have the effect of producing periodic increases in peak blood velocity,[30] thereby exposing endothelial cells to transient intervals of high-peak shear stress. If the present hypothesis is correct, this would produce increased levels of vasodilator substance

> **A support surface that could promote increased perfusion would appear to be useful as an aid in preventing pressure ulcer development.**

release that would contribute to a progressive flow increase in the off-loading intervals of the hip-down lying position.

The potential implications of these findings to clinical practice go directly to the issue of pressure ulcer prevention. The problem of pressure ulcers is not limited to the elderly or bed-bound nursing home residents; pressure ulcers occur with alarming frequency in other patients as the result of vascular deficits produced during extended surgical procedures and postoperative recovery intervals. In these situations, an otherwise healthy young or middle-aged person who would not normally be considered at risk is put at high risk for ulcer development. A recent report has indicated that 8.5% of all patients undergoing surgical procedures greater than 3 hours will develop pressure ulcers, with a national prevalence of 17.3% during vascular surgery.[31] Independent of the specific mechanism, the present findings

suggest that via its positive impact on blood flow during compression of a bony prominence, the use of a dynamic support surface with a small air cell configuration may potentially help reduce the number of skin breakdowns associated with such surgery-related events. Very recent findings that compared a small air cell dynamic surface and a static support surface with respect to ensuing pressure ulcer development in patients undergoing more than 3 hours of surgery would tend to support this concept.[32,33]

It is important to recognize that the subjects in the present study were elderly women who would not normally be classified as high-risk patients. It is therefore unknown if the blood perfusion responses obtained would be characteristic of patients at high risk for pressure ulcer development. There is some evidence that during extended surgical procedures, patients who demonstrate perfusion increases fare much better than those who do not with respect to subsequent pressure ulcer development.[13] Thus, a natural extension of the present study would be to characterize perfusion responses using a similar but necessarily modified design to study such patients.

Another issue that has not been explicitly considered in the present study is the possible role of interface pressure as it relates to the differential perfusion responses associated with static and dynamic surfaces. The static surface produces a more or less stable pressure, whereas the dynamic surface cycles from a peak pressure to a near-zero pressure during the deflation interval. Although this is the very feature that the authors believe is responsible for the perfusion augmentation, other phenomena, such as a differential average pressure between the 2 types of surfaces, may be operative. A future study to tease out the relative effects of rhythmicity vs pressure effects may shed further light on the underlying mechanisms.

In summary, the preliminary findings of this report suggest a support surface–dependent blood flow impact, with the present multisegmental dynamic support approach yielding a greater flow during loading. Although the mechanism responsible for this increase is not as yet fully clarified, this feature appears to be of potential benefit in aiding ulcer prevention by providing the setting for compensatory vascular adaptation during loading. ▥

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