EDGE LIGHT: A NEW APPROACH TO STUDYING THE MICROVASCULARIZATION OF THE SKIN

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INTRODUCTION

Clinicians have been interested in investigating capillary blood flow and what affects it, ever since Homo sapiens complained of a blister, corn, tight bandage or cast, or a decubitus ulcer—any condition leading to ischemia with the potential of then progressing to tissue necrosis.

One of the problems in investigating capillary blood flow has been the difficulty of reliable measurement. As a method of measuring small-vessel blood flow, plethysmography is the most direct, but unfortunately it is limited in its applicability (Barbenel et al.,

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[Dr. Verhonick died October 1, 1977.]
More indirect methods have been used which infer the capillary blood flow through its relationship with temperature, visual appearance of the skin, absorption rates, or pressure. These indirect methods include the use of thermography, thermistors, direct-pressure and interface-pressure instruments, uptake of radioactive isotopes, use of transparent materials to view changes in areas under pressure, and transillumination.

A new technique of modified transillumination, described in this article, was developed using normal healthy adults as subjects. It is noninvasive and does not require the application of instrumentation to the skin surface.

REVIEW OF TECHNIQUES

Thermography

Thermography produces a visual image indicative of the temperature distribution over the skin surface. Areas of the skin that have a normal blood flow have a normal skin temperature, and present a pattern of infrared radiation emitted by the skin surface (Barnes, 1963, 1968). Changes in the blood flow affect the skin temperature and can be detected by a change from the baseline thermographic pattern. Evans et al. (1976) used thermography to study arterial obstruction in the lower limbs: the investigators found that thermography identified the abnormal skin temperature distributions that were due to arterial occlusions in the lower limbs.

Verhonick, Lewis, and Goller (1972) used thermography in studying decubitus ulcers. They used the thermogram to document the effects of body weight pressure (lying on a stretcher) on the knee and heel. Reactive hyperemia, “flushing”, was documented on sequence thermograms by a high pressure area showing first as a cold area, then “flushing” to show as a higher-temperature region than surrounding areas, and finally equilibrating back to a near-baseline temperature distribution pattern. In the mentioned study, thermography was investigated as means of quantifying the relationships between body-weight pressure and temperature change.

Earlier, Goller (1971) had established the relationship between temperature change and a known amount of pressure. Kosiak (1961) and Lindan (1961) found the pressures to be most intense when they are related to bony or tendinous prominences; they may exceed 100 mm Hg over these areas. The relationship between allowable pressure and time duration, for “safe” pressure-time support, was published by Kosiak in 1961.
Interface Pressures

Various means of pressure measurement have been used to evaluate interface pressure. No available device is without problems: the reader is referred to Ferguson-Pell et al. (1976) for a full discussion of such problems. Most commonly used devices are either pneumatic or are variations of strain-gage application. Pneumatic sensors, consisting of from one to eight inflatable membraneous cells, utilize electrical contacts within the cells that close at the point where internal pressure equals the interface pressure. Strain-gaged diaphragm transducers measure surface strains by electrical strain gages, but they are rigid, and the dimensions need to be small if they are to be used on curved interfaces. A commercial ‘beam’ transducer (monolithic strain-gaged beam encapsulated in rubber) was evaluated at Strathclyde (Ferguson-Pell, 1976): it was found that the ‘beam’ responded to inplane forces as well as to normal forces.

Research into the difficult problem of reliable pressure measurement continues, and includes the use of an elastic disc with which electrical measurements may be made by resistive, inductive, or capacitive techniques.

Other Methods

Other methods of looking at pressure and its effects on the microcirculation involve the use of radioactivity-tagged isotopes. Daly et al. (1976) used Xenon$^{133}$-labeled saline to measure changes in uptake by the microcirculation of the skin in response to pressure. Hickmann et al. (1966), using Na$^{24}$ on the backs of rats and the volar surface of forearms in humans, measured the alteration of skin blood flow caused by pressure. These investigators found that when the pressures approximated mean capillary pressure (25 mm Hg), Na$^{24}$ clearance rates averaged about 80 percent of normal. However, cyclic loading resulted in different effects on capillary blood flow during the loading and unloading phases of the cycle.

Romanus (1976) studied the influence of time, pressure, and temperature on the microvasculature of the hamster’s cheek pouch. Repetitive pressure, even though not damaging on single application, produced alterations in blood flow depriving the tissue of normal oxygen levels. Barbenel et al. (1976) attempted to find a load level which was critical for effecting a sudden decrease in capillary blood flow. These investigators used an abdominal fold and the technique of transillumination. Their findings showed no correlation between load levels and the point where blood content of the skinfold suddenly decreased.
That areas of ischemia can be made visible through transparent materials was demonstrated by Miller and Sachs (1974). It is fairly evident, to an observer looking through the transparent material, that the ischemic area is also the point of greatest pressure. The other contact areas of skin, however, do not show any gradations of skin-color change to indicate degrees of alteration of capillary blood flow due to the pressure of body weight.

**EDGE LIGHT TECHNIQUE**

Verhonick, Lewis, and Kissinger, while working on a protocol to quantify measurement of variables pertinent to the acquisition of decubitus, developed a technique of modified transillumination (edge light) which shows alterations in capillary blood flow in skin-contact areas. With the subject lying supine on a Plexiglas surface and draped with a dark cover, two photolamps (3400 K) were positioned to allow a strong section of light to pass through the edge of the Plexiglas support surface (hence “edge light”). The refraction of the light passing through the half-inch thick Plexiglas illuminated the skin areas that were in contact with it. As viewed from below, this modified transillumination revealed differences in the color densities (presumably due to amount of blood flow) of the otherwise uniformly-colored non-ischemic contact area under body weight.

Figure 1 illustrates the appearance of the torso viewed from below by conventional lighting, through a transparent Plexiglas support surface. This type of photograph is similar to those published by Miller and Sachs (1974). Figure 2 illustrates the same subject, again viewed from below through a rigid Plexiglas sheet, but this time the illumination is “edge light” as described earlier. In Figure 3, a piece of thin flexible cellulose acetate has been attached to the underside of the Plexiglas support surface, and on this the pattern of blanched areas that is visible under edge-lighting has been delineated with a “grease pencil.” (One-foot rules, supported by the cellulose acetate film, provide a reference scale.)

Figures 4, 5, and 6 illustrate the same situations as Figures 1, 2, and 3, respectively, but with a different subject.

**The Attempt to Correlate Visual Contact Patterns with Interface Pressure Data**

The rank-order distribution of pressures, as may be inferred from the observation of skin colors while the subject is resting on the

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*A group of 35-mm color slides, illustrating the edge light phenomenon as described here, is on file at the editorial offices of the Bulletin of Prosthetics Research. Subject to availability, these may be borrowed for study and/or copying.*
FIGURE 1.—Subject A, shown lying supine on a sheet of rigid (half-inch-thick) transparent Plexiglas®. Subject is illuminated from below with conventional direct lighting; black drapes restrict entry of light from above. Photograph was taken looking upwards through the transparent Plexiglas®.
FIGURE 2.—Subject A, arranged and photographed as in Figure 1, except that the illumination is provided by “edge light.”
FIGURE 3.—Subject A. A grease pencil has been used to trace the pattern of blanched area boundaries seen only faintly in Figure 2. (These boundaries and areas, clearly visible to the observer with edge light, are somewhat less clearly visible in a good color photograph. Black-and-white photography, however, records only a suggestion of the phenome-
FIGURE 4.—Subject B, photographed under conditions described in Figure 1.
FIGURE 5.—Subject B, photographed under conditions (edge light) described in Figure 2.
FIGURE 6.—Subject B, with pattern traced as described in Figure 3.
rigid transparent Plexiglas sheet with edge lighting, is considered to be a direct indication of the distribution of pressures as they would be with the subject resting on a non-compliant operating table. Thus, this same distribution is also considered to be a useful guide for an experimenter who wishes to locate pressure gages in areas of greatest interest for tests with other supports.

The presence of any gage (regardless of its thickness or compliance) between the body and a noncompliant support will cause an artifactual increase in apparent pressure. At more rigid body tissue (e.g., a bony prominence with very little covering of soft tissue) or for a thicker gage, this artifactual increase will be greater. Conversely, softer and thicker flesh, or very thin gages, or a softer supporting surface, should each provide a smaller increase of recorded pressure above the true pressure. Nevertheless, it may be hypothesized that the rank order of pressures distributed over the various body surfaces is preserved in the rank order of the gage readings from those areas.

Based on this hypothesis, the subject shown in Figure 7 was used in preliminary tests. The gage was an inflatable pneumatic membrane cell made of two walls, each flexible plastic .003-inch thick. Pressures were measured between the supine body and a thin foam mattress on the metal plate of a wheeled hospital stretcher. Because the pressure gage was thin and flexible, and because of the use of the foam mattress, the artifactual increase in observed pressure beyond that existing without a gage was considered modest, though there was no direct validation of that opinion. The subject appeared to have interface pressures of 58 mm Hg at body midline on the sacral horizontal line and 66 mm Hg at a point one-quarter of an inch above it. Both pressure values are far higher than capillary blood pressure, which is in general agreement with the severe blanching observed through the rigid Plexiglas sheet. In contrast, the pressure between body and foam mattress at midline 1 inch below the horizontal line was only 30 mm Hg, probably slightly lower than capillary pressure. Looking at the pattern seen on the edge-lighted Plexiglas sheet, one could predict from the dark noncontact area between the buttocks that pressures at body midline would decrease rapidly as one moved the gage downward from the sacrum. Likewise, pressures decreased progressively from the sacrum to the outer quadrants of the buttocks, in the same approximate rank order as the trace contact pattern demonstrated by edge light. (Those patterns are much more apparent to the eye than they are in photographs.)

Obviously, there must be careful placement of the body in the same position and with the same muscle tensions, to permit valid
FIGURE 7.—Subject used in preliminary tests with pressure gage, shown here under conditions as described in Figure 3.

comparison between visual observation with edge light on the hard Plexiglas sheet and estimates of pressures from gages at critical locations between the body and the softer mattress.

DISCUSSION

The technique of edge light, and the correlation of the trace contact pattern with interface pressures and thus with alteration of the microvascularization of the skin, has not been studied in a controlled research design with a large number of subjects. However, findings from our study are suggestive that the trace pattern of color gradients revealed by the technique of edge light is inversely related to the pressure gradients, with the lighter-colored contact areas being under greater pressure from body weight than the darker-colored contact areas. It is further suggested that the gradations in color are positively related to amount of blood in the subpapillary venous plexus and capillaries of the skin (Lewis, 1927), with the ischemic pallor indicating cessation of blood flow. Gradations of color ranging from pallor to dark would indicate gradations
of the increasing amounts of blood in the subpapillary venous plexus and capillaries.

Lindan et al. (1965) suggested that the gradient of pressure across contour sites, such as the buttocks, is approximately linear. Newell et al. (1970) suggested that higher gradients exist around bony prominences. The interface pressure measurements and edge light trace patterns as studied by the authors suggest that the pressure gradient across the buttocks contour is not linear, and that the pressure gradient patterns differ depending on individual skeletal and subcutaneous structures.

It is recommended that the technique of edge light be further studied and correlated with interface pressure measurements under controlled conditions. If, on further investigation, edge light continues to disclose subcutaneous irregularities, it is recommended that the technique be explored for use also in detection of breast cancer. From the perspective of the subjects' safety, the technique of edge light has as its assets: noninvasiveness, freedom from instrument attachment, and the lack of exposure to radiation. And, unlike many other investigative techniques in the clinical area, the technique of edge light can be used by non-physician investigators.

REFERENCES


