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Laser-Doppler Imaging Assessment of Skin Hyperemia as an Indicator of Trauma after Adhesive Strip Removal

Harvey N. Mayrovitz and Susan G. Carta

Abstract

The effect of adhesive tape and dressing removal on skin integrity is particularly important for patients who have increased risk for skin damage or impaired physiological responses to skin trauma. Visual observation of skin erythema does not always provide an adequate assessment of acute injury; detection of trauma is limited by the naturally occurring wide range of skin color and tones.

This study had two purposes: (1) to assess the sensitivity and objectivity of laser-Doppler perfusion imaging (LDI) in measuring skin blood perfusion in forearm skin before and after removal of adhesive strips and (2) to determine the relationship between skin perfusion levels after adhesive-strip removal and the peel force required to remove the strips.

Variations in peel-force levels were obtained in two ways: first, from naturally occurring skin differences; and second, by using an adhesive remover product (ARP) developed to reduce skin trauma.

In 10 subjects, acrylic adhesive strips (13 × 70 mm) were placed in pairs on standardized sites on both volar forearms and peeled off 24 hours later at a constant velocity of 5 mm/sec while the peel force was recorded. During peeling, an ARP was used with one strip; nothing was used on the adjacent paired strip (CONTROL). Skin blood perfusion was measured at 5 and 20 minutes after strip removal by non-contact LDI under the ARP and CONTROL conditions simultaneously.

Results show that (1) hyperemia after strip removal is linearly related to peel force ($r^2 = 0.55$, $p < .01$); (2) use of an ARP, as indexed by the hyperemic response, significantly reduces skin trauma (1.02 [SD = 0.11] versus 1.47 [SD = 0.11], $p < .01$) with a mean CONTROL/ARP ratio of 1.56; and (3) the peel force required is reduced by using an ARP. These findings indicate that LDI is a useful, sensitive tool for assessment of skin trauma and that reducing peel forces has a positive effect.

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The effect of removing adhesive tape and dressing on skin integrity is an important issue in all patients and is particularly important in patients who have increased risk for skin damage or impaired physiologic responses to skin trauma.[1-4] Patients at increased risk include those who are immunocompromised and those with fragile skin (such as the elderly), impaired circulation, or a neurologic disorder.[5-7] Part of the adverse effect occurs because adhesives strip away surface scales of the stratum corneum, damaging the surface barrier that helps to regulate fluid balance and to protect the skin from chemical, mechanical, and microbial effects.[5,8,9] Repeated application and removal of adhesive tapes strips the skin, putting it at risk for further damage from physical and chemical trauma; impedes the skin's ability to regulate water and electrolyte loss; and, in wound healing, interferes with re-epithelialization from peri-wound tissue.[9,10]

Although currently used medical adhesive tapes and dressings

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are usually acrylate-based and are less likely to irritate the skin than traditional rubber- and colophony-based adhesives, epidermal damage still can occur. Hyperemia is a warning sign of possible skin damage. It occurs when the body attempts to increase local circulation by flushing the traumatized tissue with oxygen and nutrients[7] as part of an inflammatory-like response.

In many cases, acute injuries are assessed by observing the resultant skin erythema; however, this method cannot always provide the required sensitivity or adequate resolution. In addition, it is not always applicable to dark-skinned patients.

Adhesive removers have been developed to dissolve the adhesive. These products are designed to decrease the amount of force required to separate adhesives from the skin and to help reduce the associated skin trauma. However, there is little objective and/or quantitative research to characterize the relationship between purported force reductions and subsequent skin trauma.

The two-fold purpose of this study was to (1) use laser-Doppler imaging (LDI) to examine skin blood perfusion in forearm skin before and after removal of acrylic adhesive strips and (2) determine the relationship between the resultant post-trauma skin perfusion levels and the peel force required to remove the strips.

Methods

Subjects

Subjects were screened for health status by use of a medical questionnaire and were excluded from participation for any of the following reasons: evidence of poor health; presence of scars, sunburn, tattoos, or excessive hair on the arms; use of topical medications on the skin of the arms; history of skin disease or allergy; use of anti-inflammatory, immunosuppressive, or antihistamine medications. Before the study began, all subjects who participated (n = 10) read and signed an informed consent that had been approved by the institution's investigational review board.

Procedures

Transparent acrylic adhesive strips (13 × 70 mm) were placed in pairs on both volar forearms of 10 subjects (five men, five women) who ranged from 30 to 53 years of age. The strips were placed parallel to one another and were separated by a width of uncovered skin approximately equal to the width of the adhesive strips. Twenty-four hours after the strips were applied, the subjects returned to the laboratory for a two-part assessment. The first part was designed to determine the variability in red blood cell perfusion in unperturbed forearm skin using LDI. Laser-Doppler imaging uses principles similar to those of laser-Doppler flowmetry (LDF),[11,12] which has been shown to be useful in a variety of applications.[13-17] It differs from LDF in that data are acquired via laser scanning of the target areas without direct contact with the skin. The correlation between LDI-measured perfusion and a mechanical flow simulator was reported to be 0.99,[18] and comparisons of LDI with LDF and with thermographic imaging indicate LDI's usefulness for skin measurements.[19,20]

The use of LDI in imaging forearm skin has been helpful in assessing normal spatial variability under both resting and thermal provocations.[21] The validity and reliability of LDI in registering changes in skin blood perfusion has been shown under various conditions, including skin perfusion increases secondary to electrical stimulation,[22] forearm skin hyperemia,[23] iontophoretic deposition of vasodilator substances,[24] skin trauma induced by needle insertion,[25] and inflammatory responses.[26] The method also has shown potential for perfusion studies associated with skin pathology,[27] treatments,[28] and wound healing studies.[29,30]

In the present protocol, the targets were the skin forearm areas covered by the strips and the uncovered area between the strips. With the subject seated comfortably and the arm resting on a padded surface, the target areas were scanned after the adhesive strips were applied. During the study, a total of 60 target areas (each measuring 13 × 70 mm) were scanned (30 on left arms and 30 on right arms). Forty of the areas were covered by adhesive strips (two on each arm of each subject) and 20 were uncovered. Each scan acquired data roughly equivalent to 1,200 LDF samples per area, corre-

FIGURE 1
Hyperemia measured at 5 and 20 minutes after strip removal

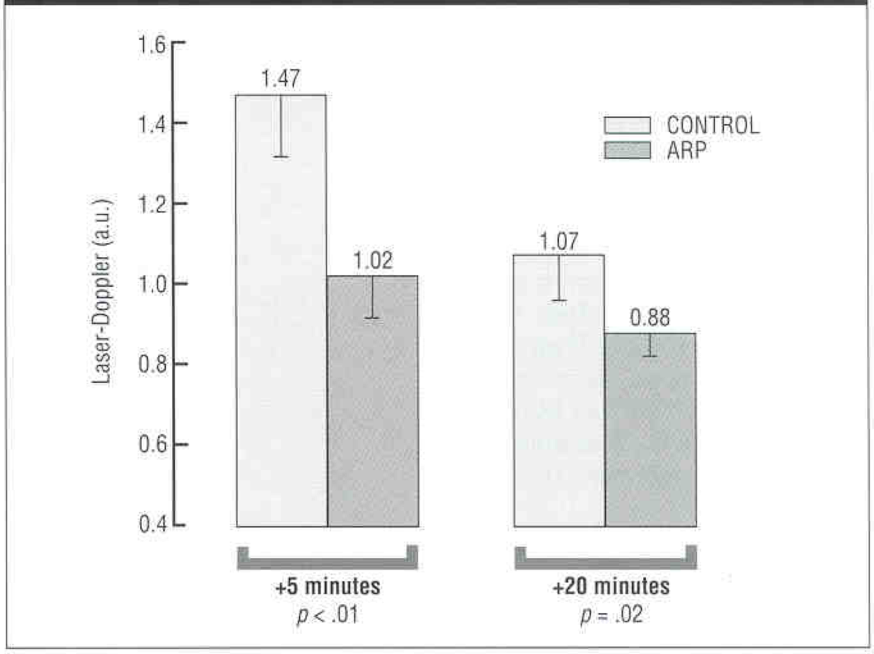
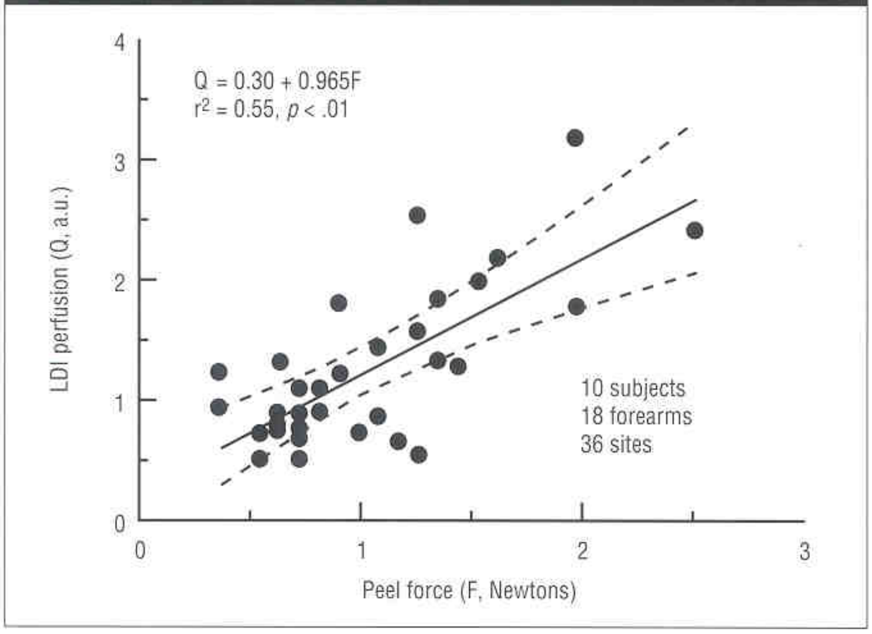


FIGURE 2
Spatial mean perfusion 5 minutes after strip removal



sponding to 1,200 image pixels captured by the computer software. Later, the stored perfusion images were analyzed to determine the spatial average perfusion within each of target areas.

The second part of the study was designed to determine the effect of different adhesive strip removal forces on blood perfusion in skin underlying the strips. One strip of each pair was removed using an adhesive remover product (ARP) (Remove, Smith & Nephew United) and one strip was removed without using a removal aid. The strips were removed at a constant velocity (5 mm/sec) using a calibrated tensile testing device (Instron Ltd., model 4301). During stripping, the force required to remove the strips (peel force) over time was recorded on an x-y plotter. The skin areas that had been stripped were then simultaneously imaged at 5 and 20 minutes after strip removal. The procedure was then repeated on the other arm. The data (perfusion images) were stored in a computer and analyzed after the experiment to determine the spatial average perfusion levels within the stripped skin areas. The mean force required to remove each strip was determined from the continuous time plot of force versus time.

Analyses

The average blood perfusion over the scanned area (Q) was computed and the corresponding average peel force (F) was determined for each strip. Force is expressed in Newtons. Perfusion is expressed in arbitrary units (a.u.) because calibration factors directly associating LDI with blood flow have not yet been established.[12] Overall relationships of perfusion and peel force were tested with bivariate regression of paired Q-F values. The effects of reducing force were tested by comparing perfusion levels at 5 and 20 minutes after peeling with paired nonparametric (Wilcoxon) analyses of differences between ARP versus CONTROL. The level of significance was set at $p < .05$.

Results

Baseline LDI values showed no significant differences between covered and uncovered skin, between left and right arms, or between men and women. The overall perfusion values for the 60 measured sites had a mean of 0.66 a.u. ($SD = 0.15$).

Figure 1 summarizes the LDI perfusion values at 5 and 20 minutes after strip removal. At 5 minutes, both the ARP and CONTROL sites showed a significant increase in perfusion, but the degree of hyperemia was significantly lower at the sites where the ARP was applied during the peeling process. By 20 minutes, the perfusion level had decreased, but the ARP sites remained significantly lower than the CONTROL sites.

Force and perfusion relationships

Figure 2 shows the relationship between the perfusion measured at 5 minutes after strip removal and the corresponding average peel force. Data from two arms had to be excluded from this part of the analysis because of technical problems during the force recordings. The bivariate regression of Q-F reveals a linear relationship, with the regression equation: $Q = 0.30 + 0.965F$ ($r^2 = 0.55$, $p < .01$). In this relationship, Q is expressed in a.u. and F in Newtons (N).

Figure 3 summarizes the overall differences in ARP and CONTROL in absolute force values and in CONTROL/ARP ratios. The peel force required to remove adhesive strips with the ARP was significantly less than that required to remove the CONTROL strip (0.77 [$SD = 0.07$] compared with 1.21 N [$SD = 0.13$], $p < .01$), with an overall CONTROL/ARP force ratio of 1.56 ($SD = 0.09$). This force ratio is similar to the CONTROL/ARP 5-minute blood perfusion ratio of 1.50 ($SD = 0.14$).

Discussion

Laser-Doppler imaging is a relatively new tool for the assessment of skin blood perfusion but it already has been used for various purposes.[17,18,21,28,30-32] The major advantages of LDI over LDF[12] include the following: The probe does not come in contact with the skin; a larger area can be scanned; and a visual image of spatial perfusion variations can be produced. Generation of the spatial information requires sequential sampling of contiguous skin targets: The area of each skin target is approximately the same as the area scanned by LDF.

In the present study, approximately 1,200 individual perfusion values were obtained (expressed as individual pixels) for each target area of 13 × 70 mm, which corresponds to an equivalent pixel area of about 0.75 mm^2. The sampling duration at each site is restricted to make the time for sampling the entire area practical. In this study, the overall scan time per area was about 90 seconds, with an average pixel-sampling duration of approximately 75 msec. The area scan-time of 90 seconds means that values reported at 5 and 20 minutes are actually the mean values within the target area at the specified times ± 45 seconds because the scan began 45 seconds before the specified target times.

One finding of this study that has not been reported previously is the observation and characterization of a relative uniformity of baseline skin blood perfusion levels. The baseline values measured in the present study show that the average blood perfusion values did not differ with respect to presence or absence of skin covering, left or right arm, gender, or site. This finding differs from that usually obtained with LDF, which usually shows considerable spatial variability in resting levels of skin blood perfusion.[13-15] The present finding is thought to be a reflection of the larger skin area measured with LDI together with the averaging process used. These features tend to better reflect the overall skin blood perfusion. This method is less sensitive to the precise placement of LDF probes on the skin, and normal physiological and spatial variations are averaged.

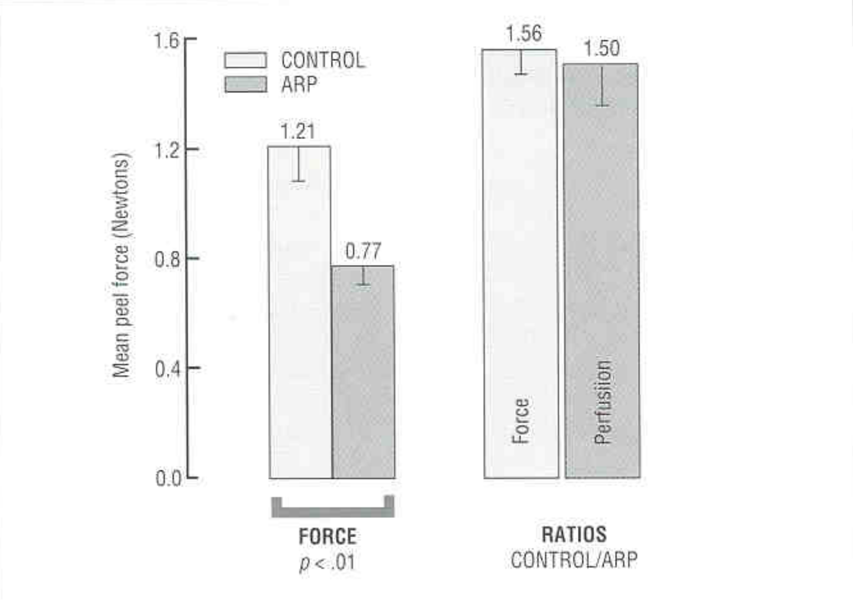
Another new finding was that the amount of LDI-detected hyperemia after stripping correlated highly with the average force required to remove the adhesive strips. Although it may seem logical that the use of greater force during removal would be associated with greater trauma-like effects on the underlying skin, this study provides the first quantitative evidence of this effect and a functional relationship linking force to hyperperfusion levels. This finding, however, should not be interpreted to indicate that measuring force alone is necessarily an adequate assessment of skin trauma. The present results indicate that approximately 55% of the hyperperfusion variation can be explained on the basis of the force-perfusion relationship, but the remaining 45% cannot. This implies that responses to the same removal force vary and that post-trauma hyperemia measured with LDI may prove to be a better indicator.

A clinically relevant finding was that the use of an ARP significantly reduced both peel force and the amount of post-trauma hyperemia. The reduced levels associated with the ARP remained significant at 20 minutes after adhesive removal, which is when data acquisition was terminated under the present protocol. Thus it is unknown how long this differential would remain. However, the initial trauma level, especially in patients who have increased risk for skin damage, may be the most significant factor with regard to skin breakdown and loss of skin integrity. As this study shows, the trauma level can be detected with LDI.

The effect of repeated application and removal of adhesive tape was not evaluated in this study, but on the basis of the direct relationship that was found between force and hyperemia, it can be reasonably speculated that reducing the peel force would be beneficial. Further research is needed to evaluate the effect of repeated adhesive strip removal.

The study findings also raise the possibility that LDI may benefit patients whose hyperemic response is difficult or impossible to detect visually. Additional research is needed to establish the relationship between visually detectable erythema and the LDI-quantifiable hyperemic level. This type of information may aid in the development of criteria to determine under which conditions visual observations are and are not suitable as a means of identifying skin trauma. ■

FIGURE 3
Force and perfusion ratios



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