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Laser Doppler Imaging of Cutaneous Blood Flow Through Transparent Face Masks: A Necessary Preamble to Computer-Controlled Rapid Prototyping Fabrication With Submillimeter Precision

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A paradigm shift in management of postburn facial scarring is lurking "just beneath the waves" with the widespread availability of two recent technologies: precise three-dimensional scanning/digitizing of complex surfaces and computer-controlled rapid prototyping three-dimensional "printers". Laser Doppler imaging may be the sensible method to track the scar hyperemia that should form the basis of assessing progress and directing incremental changes in the digitized topographical face mask "prescription". The purpose of this study was to establish feasibility of detecting perfusion through transparent face masks using the Laser Doppler Imaging scanner. Laser Doppler images of perfusion were obtained at multiple facial regions on five uninjured staff members. Images were obtained without a mask, followed by images with a loose fitting mask with and without a silicone liner, and then with a tight fitting mask with and without a silicone liner. Right and left oblique images, in addition to the frontal images, were used to overcome unobtainable measurements at the extremes of face mask curvature. General linear model, mixed model, and *t* tests were used for data analysis. Three hundred seventy-five measurements were used for analysis, with a mean perfusion unit of 299 and pixel validity of 97%. The effect of face mask pressure with and without the silicone liner was readily quantified with significant changes in mean cutaneous blood flow ($P < .5$). High valid pixel rate laser Doppler imager flow data can be obtained through transparent face masks. Perfusion decreases with the application of pressure and with silicone. Every participant measured differently in perfusion units; however, consistent perfusion patterns in the face were observed. (J Burn Care Res 2008; 29:42–48)

Managing burn facial scars has long been a challenge in burn rehabilitation as therapists strive to provide their patients with the best cosmetic and functional outcomes. Pressure application for controlling hypertrophic scar in the burn face is a widely accepted practice. While therapists may select from a variety of materials to provide pressure therapy to the burn face, most therapists opt to use a transparent plastic face mask.[1,2] Using the transparent face mask has several advantages. Transparent face masks can have a positive psychological effect on the burn individual when compared with fabric face masks.[3] Patients also show improved compliance with the transparent face mask.[4] The use of transparent face masks allows for more accuracy in determining mask fit,[5] because therapists can directly observe the blanching of burn scars.

A precise fitting transparent face mask is dependent on an accurate cast or face mold and the skills of an experienced therapist. In 1979, Rivers et al[5] first described the transparent face mask fabrication process. First, a negative impression of the face is taken with

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alginate dental impression material. Plaster strips are used to reinforce the alginate. Next, a positive plaster cast is formed by pouring plaster into the negative impression. Once set, heated transparent plastic material is applied over the plaster mold and conformed by hand or vacuum. Finally, the mask is modified to ensure that pressure is applied evenly to the scar. In a survey describing transparent face mask practices, therapists reported this last step to be the most difficult aspect of making a transparent face mask.[2] Therapists also reported that reasons other than growth factored into the need to recast the patient. The results of this survey suggest the need for the development of techniques that provide a better fit of transparent face masks.[2]

Beginning in the mid 1990s, studies have emerged describing new transparent face mask fabrication techniques using computer-aided design and computer-aided manufacturing (CAD/CAM)[6–9] as an alternative to the traditional method. These new surface scanning technologies in the fabrication process are noncontact, which decreases patient discomfort, are less labor-intensive for the therapist, and allow for the possibility of earlier mask fabrication. In addition, CAD/CAM face molds can produce a better fitting face mask than the traditional method of mask fabrication.[9]

Despite the mask fabrication technique used, adequate scar control is considered acceptable when enough pressure is applied to blanch hypertrophic scar without causing ischemia. These blanching areas observed through the mask can change over time and will require further modifications. If Laser Doppler imaging (LDI) can show measured perfusion through a transparent plastic material and can be used in combination with CAD/CAM face mask fabrication technologies, our ability to track scar hyperemia and direct incremental changes in the digitized topographical face mask prescription would become a realistic possibility.

Laser Doppler flowmetry studies have examined microvascular changes in burn wounds[10–13] and the early detection of hypertrophic burn scars.[11–14] LDI has equipped burn surgeons with a noninvasive method to assess burn depth and provide prognosis of burn injuries with better precision.[11–12] With the capacity to monitor microvascular changes in living tissue while providing color coded maps and pixel by pixel perfusion, the LDI has the potential to become a useful tool in predicting scar development if measured perfusion and scar severity can be correlated.[12]

Studies investigating the microvascular perfusion changes with the application of a transparent face mask currently do not exist. Therefore, the purpose of this study was to establish feasibility of detecting perfusion through transparent face mask (with and without pressure) using the LDI scanner on the unburned face.

METHODS

In the interest of feasibility, five uninjured staff members were selected to participate. They included 1) two Caucasian women, 2) one Hispanic woman, 3) one African-American man, and 4) one African-American woman. The ages ranged from 28 to 55 years and all were nonsmokers.

A practitioner from Hanger Prosthetics and Orthotics, Inc. (Bethesda, MD) used a three-dimensional motion tracking laser scanner, Insignia™ (Bethesda, MD), to capture each participant's facial image and to allow for production of customized plaster vermiculite molds. Therapists used Vivak® (Sheffield Plastics, Sheffield, MA), a high temperature transparent copolymer thermoplastic material, and Silon-STS® (Biomed Sciences, Inc., Allentown, PA) (Vivak with an adhered silicone contact liner) to fabricate two face masks for each participant with a vacuum forming apparatus. Therapists fitted and modified the masks to allow for oral, nostril, and ocular openings.

Laser Doppler images of blood perfusion were attained from the faces of five participants with the laser Doppler imager LDI2 (Moor Instruments, Wilmington, DE), using a high frequency, infrared laser beam. The fast continuous scan mode and the larger square scan area were consistently set to capture the entire facial area and to allow for quicker scanning. Skin surface temperatures from the forehead, cheek, chin, and nose were acquired before each scan. To take the environmental temperature changes into consideration, participants were scanned on 3 days under five different arms: 1) without a mask; 2) with a Vivak face mask, no pressure; 3) with a Silon-STS face mask, no pressure; 4) with a Vivak face mask, with pressure; and 5) with a Silon-STS face mask, with pressure. Eighteen 8 ounce weights were applied to nine points surrounding each face mask to provide consistency among the participants (Figure 1).

On the day of scanning, participants were given a minimum 5 minutes of rest time to acclimate to the room temperature. Participants were positioned in supine and remained in this position in between all scans. Eye protection approved by representatives from Moor Instruments was in place.

In an effort to capture data from the extremes of face mask curvature, two participants were selected for right and left oblique scanning trials. Lateral neck rotation measurements were obtained for consistency

Figure 1. Weights applied to face mask, totaling 9 lbs. Eye covers were in place for every scan.

during the scans. Markers were placed to assure that a complete scan was achieved.

Data Analysis

Regions of interest for analysis were defined as the forehead, nose, chin, and right and left cheeks of each participant. The Moor software provided the data in perfusion units and percent pixel validity. Statistical power and sample size were calculated with nQuery Advisor 6.01, by Statistical Solutions (Cork, Ireland). SAS 9.1 software (SAS Institute, Cary, NC) was used to perform the statistical procedures of general linear model, mixed model, and *t* test. Significance was accepted at $P < .05$.

RESULTS

In total, 375 measurements were used, with a mean perfusion unit of 299 and pixel validity of 97%. The highest mean perfusion unit was shown with the free face scan. When a mask without pressure was applied, the mean perfusion unit decreases. However, when a mask with pressure was applied, there was an even greater decrease in the mean perfusion units. A downward trend in mean perfusion units was noted when comparing the Vivak mask without and with pressure with the Silon-STS mask without and with pressure, with the exception of the right cheek. In all the scans, the forehead demonstrated the least amount of blood perfusion and the nose showed the most. Figure 2 illustrates this relationship between perfusion units, facial region, and pressure.

The mean perfusion unit and percent pixel validity of a free face scan (Figure 3B) was compared with masks without pressure (Figure 3C, E). Statistically significant differences were found in perfusion units ($P < .0001$),but not found in percent pixel validity ($P = .12$) (Table 1). When comparing the mean perfusion unit and percent pixel validity of Vivak and Silon-STS masks without pressure (Figure 3C, E)

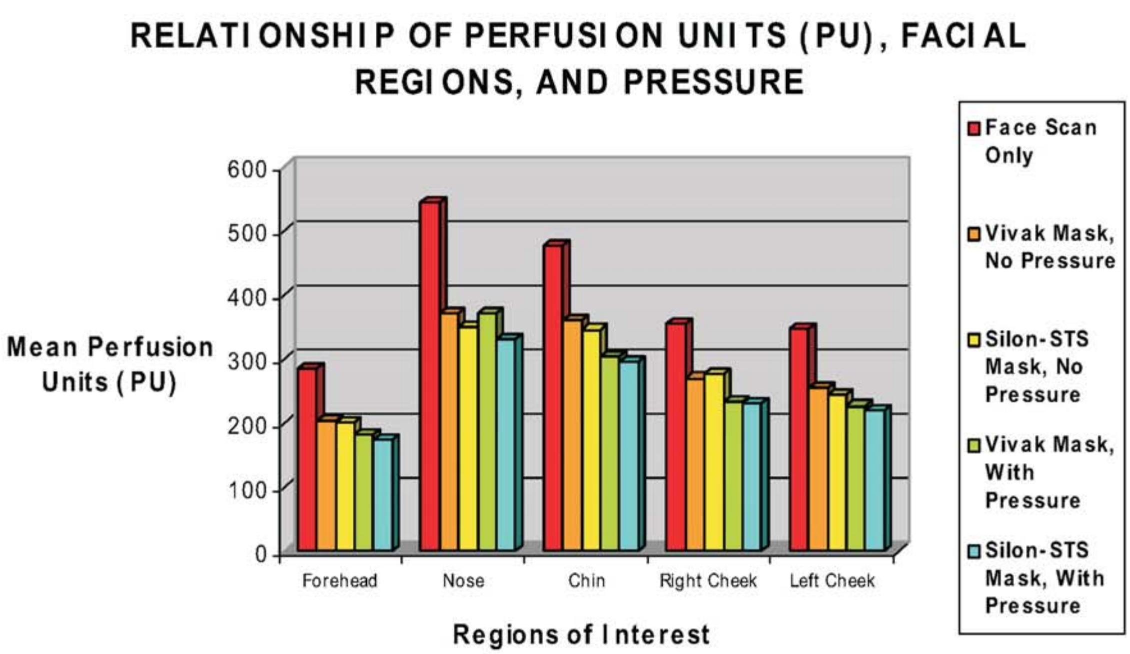

Figure 2. The mean perfusion units in relation to the facial regions and the five different arms.

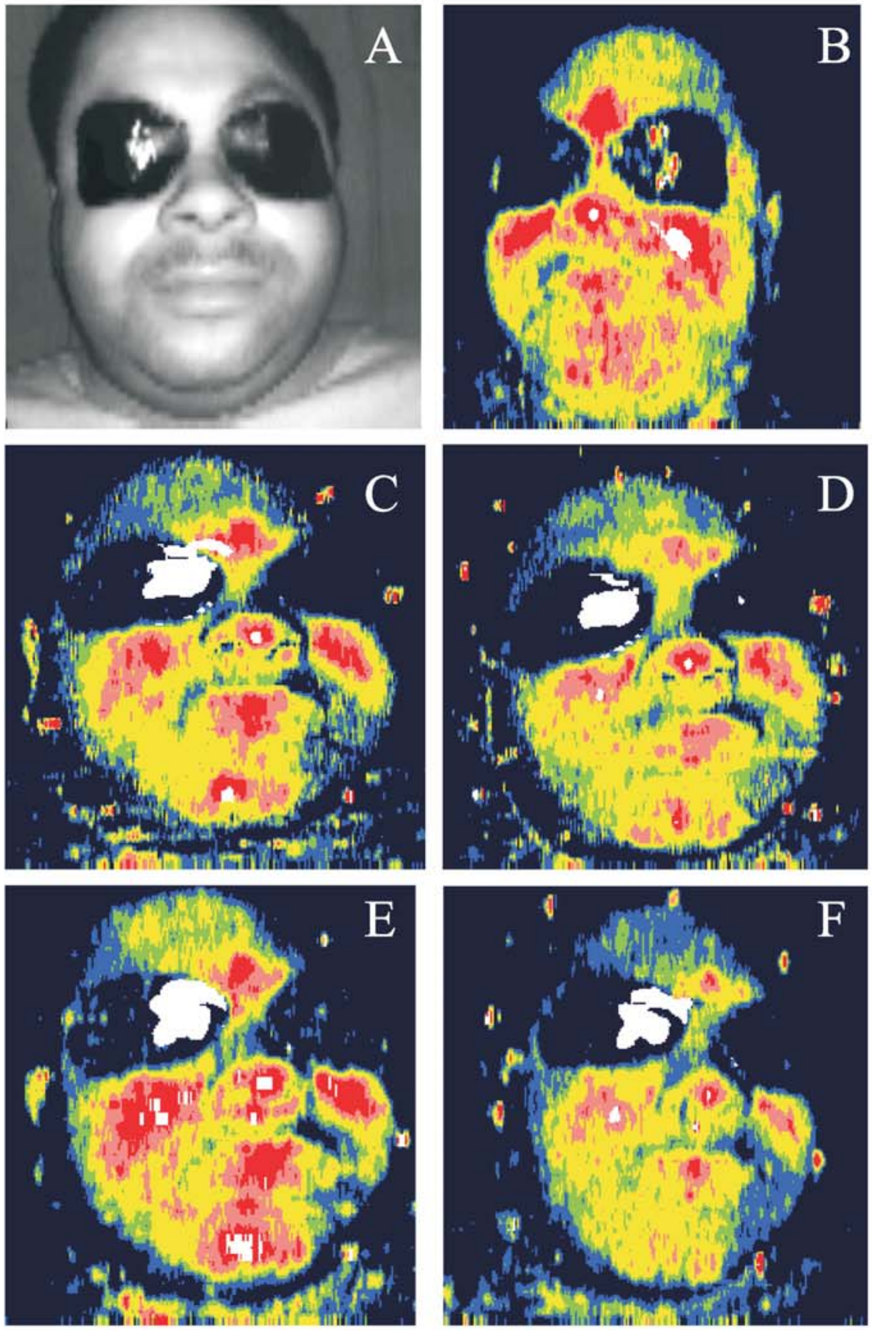

Figure 3. Starting from top left. LDI images of (A) live video image; (B) Face scan only; (C) Vivak® face mask, no pressure; (D) Vivak face mask, with pressure; (E) Silon-STS® face mask, no pressure; (F) Silon-STS face mask, with pressure.

with Vivak and Silon-STS masks with pressure (Figure 3D, F), statistically significant differences were found for both mean perfusion units and percent pixel validity ($P < .0035$; $P < .002$) (Table 2). Nonsignificant differences were found in mean perfusion ($P = .57$) and in percent pixel validity ($P = .07$) (Table 3) when the Vivak face mask was compared with the Silon-STS face mask without pressure (Figure 3C, E). The Vivak mask was also compared with the Silon-STS mask with pressure (Figure 3D, F). Difference in mean perfusion unit value was 13.5 with a nonsignificant P-value of .29.

The extreme curvature and laser deflection could be overcome by two oblique views. The extreme edges of face masks had nonvalid pixels (Figure 4). Overall, statistically significant differences were found in mean per-

Table 1. Free face vs masks without pressure

	Free Face Mean (SD)	Mask Without Pressure Mean (SD)	*P*
Mean perfusion units	368 (152)	273 (96)	<.0001
Percent pixel validity	95.3 (10)	94.5 (6.7)	.12

fusion unit values of the five participants at each facial region ($P < .0001$) (Figure 5).

DISCUSSION

The standard treatment for scar control in healed facial burns is the application of pressure by means of an elastic fabric mask, an elastic fabric mask with silicone insert, or a transparent plastic face mask. Although pressure application for controlling hypertrophic scar in the burn face is a widely accepted practice, much remains to be understood regarding its efficacy. This study showed that with use of the LDI, perfusion measurements were attainable at high percent pixel validity through the mask (with and without pressure application) in five nonburn individuals. These findings implied that the LDI can serve as a useful tool in evaluating perfusion in hypertrophic scar through transparent face masks and in objectively determining the efficacy of pressure.

Clinically, in nonburn or burn patients, we know that as we see blanching of skin or scar from pressure, it correlates with decreased blood flow. This study was able to show that with pressure application, measured perfusion units decreased. As expected, the sole presence of the thermoplastic mask material also demonstrated an effect on the face scan as evident by the decreased mean perfusion units with application of the masks without pressure compared with the free face scans. Masks without pressure did not come in full contact to the participants' faces. Clearly, blood flow had not been affected and as a result, this could

Table 2. Masks with no pressure vs masks with pressure

	Masks Without Pressure Mean (SD)	Masks With Pressure Mean (SD)	*P*
Mean perfusion units	272 (96)	243 (90)	.0035
Percent pixel validity	95 (6.7)	97 (4.0)	.002

Table 3. Vivak® face mask vs Silon-STSÒ face mask (without pressure)

	Vivak Face Mask Mean (SD)	Silon-STS Face Mask Mean (SD)	*P*
Mean perfusion units	270 (96)	261 (95)	.57
Percent pixel validity	93 (7.6)	96 (5.4)	.07

not explain the change in measured perfusion. The scans of the masks without pressure and the corresponding images therefore served as a baseline to look at the effect of pressure.

Previous studies indicate that increased levels of blood flow exist in hypertrophic scars.[13–15] It is not documented whether increased areas of blood flow are potential areas of hypertrophic scar development. In the present study, characteristic perfusion patterns were noted, despite the presence of the face mask or pressure application. The central face, particularly the nose and chin, consistently had higher perfusion when compared with the forehead, which always measured with the least amount of perfusion. Monitoring blood flow changes in

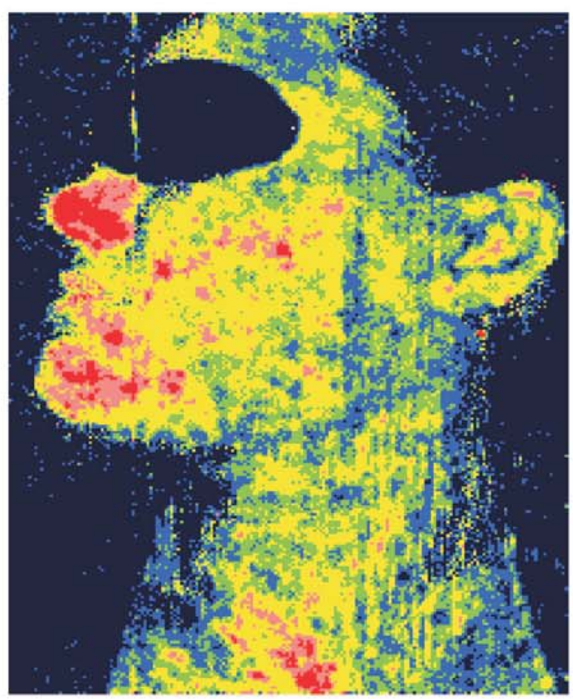

Figure 4. Oblique imaging view capturing a complete scan of the face.

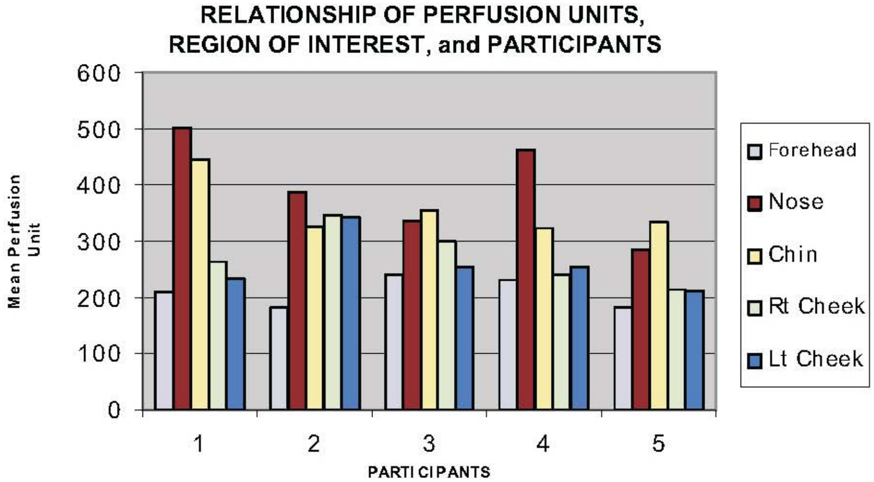

Figure 5. Differences in perfusion units among the five participants across the facial regions.

wounds with the LDI could identify areas of potential hypertrophic scar development.[15]

The results also showed that perfusion measurements significantly differed between participants. Naturally, faces are inherently different by many factors. Further research is needed to determine how factors such as the variance in facial contours or in pigmentation affect perfusion.

We found only one study in our literature review that looked at the consistency and amount of pressure provided by a transparent face mask and compared it with a Jobst hood (elastic fabric) and a Jobst hood with silicone face pad, using the Tek-scan and Mat-scan pressure measurement systems.[1] Straps of the transparent face mask were tightened to the patient's comfort and marked for consistent placement. No significant differences in pressure were observed between the Jobst hood with the silicone and the transparent face mask for the selected facial regions, which included the forehead, left and right cheeks, and chin. Interesting to note, the amount of pressure measured for the tightened transparent face mask across all regions varied between 10 and 25 mm Hg. In our clinical observation, we note that blanching areas of hypertrophic scar achieved on application of the transparent face mask are not usually sustained over time, possibly due to facial movements while talking, changing facial expression, etc. Using the LDI to scan patients while also having a means of measuring pressure (in millimeters of mercury) application to the mask may enable therapists to quantify the amount of pressure necessary to control hypertrophic scar formation.

In this study, masks with silicone consistently diminish perfusion. Although this was not statistically significant when comparing the Vivak mask with the Silon-STS mask, an apparent trend of overall decreased perfusion was noted. In 2002, Musgrave et al[16] used a laser Doppler to measure perfusion of hypertrophic scar and adjacent normal skin with and without application of silicone gel sheeting. Application of the silicone gel sheeting did not significantly alter perfusion in either the hypertrophic scar or normal tissue from baseline measurements, nor was there alteration in flow or rebound phenomenon when the silicone gel sheeting was removed, although surface temperature was found to have significantly increased. In our methods, we did not examine the effects of silicone, but our study, along with Musgrave et al's study, demonstrate the need to further explore the mechanism of silicone gel sheeting on scar and normal tissue.

Several limitations exist in this study. First, our findings were based on a small sample size and the nonburn population. Studies on nonburned faces are essential in helping us better understand the potential uses of the LDI before subjecting a burn patient to the rigors of research trials. In future studies, scanning burn patients with the LDI may verify whether factors such as sex, race, facial contours, or mask fit contributed to individual perfusion differences. Second, inherent calibration issues may exist between individual LDI scanners. In our study, we used consistent settings during the scans, but if multicenter study trials use the LDI in the future, this issue needs to be examined more closely. Third, we clearly see that temperature would have an effect on LDI perfusion measurements. We chose to alleviate that problem by grouping our data by regions of interest in our analysis methods, for example, combining all right cheek temperatures together. Overall, this study serves as a first step in establishing the potential use of the LDI to examine the perfusion patterns in burn individuals and to determine efficacy of burn rehabilitation techniques.

Despite the technological advances made with face mask fabrication techniques, facial burn scar management continues to present a challenge because little is known about individual differences in hypertrophic scar formation and the effects of pressure application over increments in blood perfusion from pressure through a transparent face mask. Perfusion measurements were attainable through the masks at high pixel validity. In the future, three-dimensional digital scanning of facial contours with use of the LDI perfusion scan may prove to be valuable in the development of computer-controlled rapid prototyping of face masks. This new technology would allow for more exact precision and efficiency in the face mask fabrication process.

CONCLUSIONS

- LDI is feasible through transparent face masks at high pixel validity.
- Skin perfusion decreases with the application of pressure.
- Measured perfusion decreases with the addition of silicone to transparent face masks.
- Characteristic perfusion patterns are noted particular to the facial regions.
- Faces are inherently different, resulting in varying individual perfusion measurements.

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