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LETTERS TO THE EDITOR

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What's Behind the Mask? A Look at Blood Flow Changes With Prolonged Facial Pressure and Expression Using Laser Doppler Imaging

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Clinically, the initial blanching in burn scar seen on transparent plastic face mask application seems to diminish with time and movement requiring mask alteration. To date, studies quantifying perfusion with prolonged mask use do not exist. This study used laser Doppler imaging (LDI) to assess perfusion through the transparent face mask and movement in subjects with and without burn over time. Five subjects fitted with transparent face masks were scanned with the LDI on four occasions. The four subjects without burn were scanned in the following manner: 1) no mask, 2) mask on while at rest, 3) mask on with alternating intervals of sustained facial expression and rest, and 4) after mask removal. Images were acquired every 3 minutes throughout the 85-minute study period. The subject with burn underwent a shortened scanning protocol to increase comfort. Each face was divided into five regions of interest for analysis. Compared with baseline, mask application decreased perfusion significantly in all subjects ($P < .0001$). Perfusion did not change during the rest period. There were no significant differences with changing facial expression in any of the regions of interest. On mask removal, all regions of the face demonstrated a hyperemic effect with the chin ($P = .05$) and each cheek ($P < .0001$) reaching statistical significance. Perfusion levels did not return to baseline in the chin and cheeks after 30 minutes of mask removal. Perfusions remain constantly low while wearing the face mask, despite changing facial expressions. Changing facial expressions with the mask on did not alter perfusion. Hyperemic response occurs on removal of the mask. This study exposed methodology and statistical issues worth considering when conducting future research with the face, pressure therapy, and with LDI technology. (J Burn Care Res 2010;31:441–447)

Hypertrophic scar is a common problem of burn survivors who have delayed healing or grafted areas. An immature, hypertrophic scar tends to be erythematous with increased microcirculation.[1,2] Pressure therapy to control hypertrophic scar continues to be a clinically accepted practice, despite the mechanism of hypertrophic scar development not being well understood. Although there are studies that debate the efficacy or lack of efficacy of pressure garments on hypertophic scars, none of these have specifically examined pressure on facial scars.[3,4] Scar development on the face is particularly concerning, because it is difficult to conceal and has psychological, functional, and social implications. Since the 1970s, a commonly accepted method of controlling facial burn scar formation has been the use of a custom-made, transparent plastic face mask.[5,6] Recommended schedules for pressure therapy such as the face mask are 20 to 23 hours daily starting at epithelialization until burn scar maturation, typically ranging over 6 months to 2 years.[7,8]

The mask serves as a window for therapists to examine the effects of pressure. A blanched appearance to the raised scar is desirable as it indicates a flattening effect and decreased perfusion. Over time, a lesser

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degree of blanching through the mask may signify a change in the pressure or scar, requiring therapist to alter the mask or mold. Therapists can sculpt the positive mold and apply heat over the mask for facial contouring and added pressure. Tightening the elastic mask straps can also produce additional blanching to the scar. Masks are discontinued once the scar is considered mature.

The transparency of the face mask provides a better cosmetic option than fabric face masks in managing scars. However, as patients move their face (ie, in expression) the rigidity of the plastic mask loses conformity to the facial structures and less blanching is observed. Clinically, patients have also reported reduced compliance due to discomfort from heat or sweat. The effect of mask removal on scar perfusion has not been studied.

Although blanching of the scar has been used traditionally as the way to determine the adequacy of pressure, laser Doppler imaging (LDI) may be useful in illustrating perfusion patterns as it can scan through the face mask while on the patient.[9] LDI is a scanning technique that provides real-time colored images of blood perfusion and flow. Red cell velocity is averaged in the small volume of tissue illuminated by the laser beam. The Doppler shift of the reflected laser light is then used to mathematically arrive at an averaged red cell velocity, synonymous with red cell flow. In a recent review article of laser Doppler technology, Jaskille et al[10] found that although limitations of laser Doppler technology exist, LDI is a powerful research tool advantageous in that it is simple to use, noninvasive, and provides objective measurement.

To date, few studies exist examining the effectiveness of the transparent face mask and other pressure garments. Understanding these patterns in individuals with and without burn may provide us with a better understanding of blood perfusion and its correlation with the scar development and prolonged pressure therapy. The purpose of this study was to use the LDI to document the influence of prolonged face mask use and facial expression on perfusion. There are three hypotheses to this experiment; first, applying the face mask will produce an initial decrease in perfusion. With time, perfusion will increase, although not returning back to baseline. This belief is based on the observation that while there is an initial blanching of the scar on face mask placement, the scar becomes pink again with time. The second hypothesis is that varying sustained facial expressions will affect the amount of pressure on the skin and thus the perfusion. The final hypothesis is that upon removing the face mask, the return to baseline perfusion will be gradual.

PATIENTS AND METHOD

This study was approved by the Institutional Review Board of the Medstar Research Institute. Written informed consent was obtained from each subject before inclusion in the study.

Subjects

Five female subjects without burn and with no significant medical history (age range, 26–43 years) and one male subject with recently healed burns (age, 35 years) were enrolled. The subject with burn was 7 months postburn injury (80% TBSA of deep partial and full-thickness burns) and required use of a partial transparent face mask to control hypertrophic scar on his nose, chin, and cheeks.

All subjects were fitted with transparent face masks made from Silon-STS® (Bio Med Sciences, Inc., Allentown, PA), a copolymer thermoplastic material with an adhered silicone liner. Elastic straps were tightened to the subject's comfort and marked for consistent placement.

Scanning Protocol for Subjects Without Burn

Before scanning, the subjects rested for 5 minutes to acclimatize to the environment. Room temperatures were kept between 25 and 27°C and facial temperatures were documented before scanning. Laser Doppler images of blood perfusion were obtained with the LDI2 (Moor Instruments, Wilmington, DE) high-frequency infrared laser beam. The continuous scan mode and the larger square scan area were selected to capture the entire face and to allow for quicker scanning. Laser eye protection was used throughout all scans. Moor Instruments software version 5.2 was used to select the regions of interest and to calculate the mean perfusion units (PU) in each.

With the subject sitting, the LDI beam was centered on the tip of the nose. The distance between the subject and the incident beam was kept constant at 40 cm. Blood flow images were acquired every 3 minutes throughout the 85-minute study period (see Table 1). Subjects were first scanned three times without the face masks to obtain the baseline perfusion. Next, the transparent face mask was applied and the subject was scanned 10 times (30 minutes) while keeping still. After this was a 15-minute period at which the subject alternated a fixed facial expression (three total expressions) with intervals of rest. The three facial expressions sustained during the scans were 1) smiling, 2) maintaining an opened mouth position, and 3) puckering of the lips. The subject then removed the face mask and scanning proceeded for another 30

Table 1. Prolonged facial pressure and expression protocol

	No. LDI Scans Obtained	Scanning Time (min)	Total Time into Study (min)
Free face scan (baseline)	3	10	10
Face mask application	10*	30*	40*
Face mask application with:			
Smiling	1	3	43
Rest	1	3	46
Mouth opened	1	3	49
Rest	1	3	52
Lips puckering	1	3	55
Face mask removal	10	30	85

* Changes made to burn subject protocol. Time of face mask application was shortened by 15 min (5 scans obtained). Total time in study was 70 min.
LDI, laser Doppler imaging.

minutes. Each subject participated in four trials on different days.

Scanning Protocol for Subject With Burn

The subject with burn underwent the same scanning measures as the subjects without burn with one exception. In subjects without burn, preliminary data analysis revealed no significant changes during the initial 30-minute scanning period at which the mask was applied without facial movement. Subjects without burn also commented on the difficulty with prolonged static sitting. As a result, scanning during that period was shortened by 15 minutes to increase the comfort of the subject with burn. Although the burn patient's entire face was scanned, his face mask only covered his forehead partially, and so it was not included in the data analysis.

Data Analysis

Each subject's face was divided into five regions of interest: forehead, nose, chin, right cheek, and left cheek. Perfusion was assessed for each region individually.

Normal values for perfusion units in the face have not been defined previously. Three scans were obtained at the beginning of each trial to establish the baseline perfusion in each region of interest for that day. The mean of the three baseline measurements in each trial was calculated and used as the reference point. All further perfusion units in that trial were compared with this baseline and expressed as a percent of change.

Statistical Analysis

Statistical analysis was carried out using SPSS v11.5 (SPSS, Chicago, IL). Independent samples t tests were used to compare the facial temperatures between subjects and across trials. Two-way analysis of variance was used followed by post hoc comparisons using the Dunnett T3 and Tukey B test to compare perfusion units in each of the experimental conditions (before face mask application, after face mask application, during the three facial expressions, and after face mask removal). This allowed multiple comparisons between the means through pair-wise comparisons between groups, setting the experiment-wise error rate to the error rate for the collection for all pair-wise comparisons. Values of $P < .05$ are considered significant.

RESULTS

A total 544 images (448 from four subjects without burn and 96 from the subject with burn) were captured by LDI for data analysis. One subject without burn was excluded from the study when images from all trials revealed noise interference due to frequent head movements. Figure 1 illustrates a typical series of LDI images acquired from the subjects. The red color indicated levels of highest perfusion areas while dark blue areas signified the lowest.

Subjects Without Burn

Perfusion decreased significantly from baseline in all subjects, in each region of the face when the transparent face mask was applied ($P < .0001$ in each region; see Table 2). From the initial moment of mask application to the final scan at the end of the 30 minutes, there were no significant differences in any area of the face. Perfusion levels remained at a constant level. When subjects introduced a change in expression through smiling, puckering, and opening of the mouth, there were no significant differences in any of the regions of interest (see Figure 2).

After face mask removal, several things were noted. First, as expected, there was an increase in perfusion compared with face mask values. Second, and most importantly, the chin and cheeks had a statistically significant increase in perfusion above baseline values. The chin had a 4.4% increase in perfusion units above baseline ($P = .05$), whereas the right and left cheeks increased by 17.8% ($P < .0001$) and 20.7% ($P < .0001$), respectively. Although the forehead and the nose also showed some of the same rebound hyperemia, the difference did not reach statistical significance. After keeping the face mask off for 30 minutes, perfusion had not returned to baseline in the chin and the cheeks (see Figure 2).

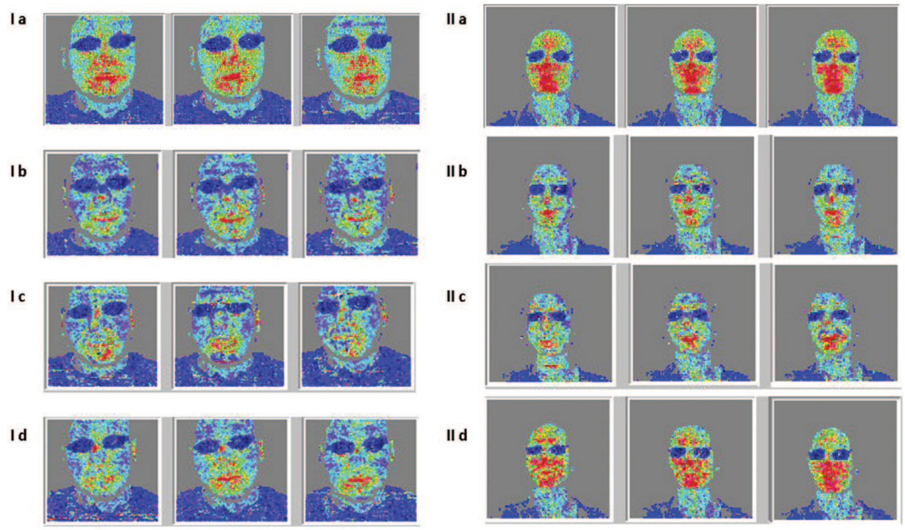

Figure 1. Sequential LDI scans on subject with burn (panel set I on left) and one subject without burn (panel set II on right). The red and orange colors represent areas with higher perfusion and the blue tone represents areas with lower perfusion. Panels Ia and IIa show the baseline premask perfusion; panels Ib and IIb show the first three scans after the face mask was applied; panels Ic and IIc represent the scans during the sustained facial expressions; and panels Id and IId represent the first three scans after face mask removal. Notice a marked decrease in perfusion after face mask removal (Id) when compared with the baseline scans (Ia) on the subject with burn; the subject without burn showed the opposite pattern with an increase in perfusion after face mask removal (IId) compared with the premask baseline (IIa).

Subject With Burn

Similar to the case was with the subjects without burn, perfusion in every region of interest decreased from baseline after the face mask placed ($P < .0001$). Perfusion remained constantly low while the mask was on. In the nose and chin, perfusion increased significantly from having the face mask on to maintaining a smile (the first of the three facial expressions). There were no changes in these areas during the other two facial expressions. The right and left cheek did not show changes with facial expressions (see Figure 2).

On face mask removal, the perfusion of the subject with burn was different from that of those without burn (see Figure 1). The nose, chin, and right cheek had a statistically significant increase in perfusion compared with face mask values ($P < .0001$). However, the left cheek did not show an increase in perfusion (face mask on, PU = 79.06, to face mask removal, PU = 79.4). Another difference is that while a hyperemic response was noted in the subjects without burn, perfusion after 30 minutes without the face mask never reached the pre-face mask baseline in any region of the face ($P < .0001$; see Table 3).

Table 2. Perfusion unit in the face of subjects without burn

	Region of Interest				
Experimental Condition	**Forehead**	**Nose**	**Chin**	**Right Cheek**	**Left Cheek**
Baseline	100	100	100	100	100
Face mask on	70.3	67.7	70.8	76.7	77.5
Smiling	73	72.2	89.5	74.5	72.5
Rest	69.9	65.8	79.2	78.5	79.8
Open mouth	78	67.3	86.3	77.9	83.7
Rest	72.5	71.8	80.7	80.6	85
Puckered lips	74.8	74.8	87.2	82	85.9
Face mask removal	100	101	104.4	117.8	120.7

Perfusion decreased significantly in all areas after face mask application. This decrease was sustained and was not affected by any changes in facial expression. On removal of the face mask, there was a significant increase in perfusion in all areas. The forehead and nose returned to baseline. The chin, right, and left cheeks had a hyperemic response at which perfusion increased above baseline for at least 30 min after removing the mask.

DISCUSSION

The effect of pressure garments on scar maturation remains controversial. Some studies show that the use of pressure garments are effective in the 1- to 3-month period after re-epithelialization and may accelerate the scar maturation process,[4] whereas others claim that there are no effects.[3] Despite this controversy, pressure garment protocols are reported by many burn centers as essential to optimize scar con-

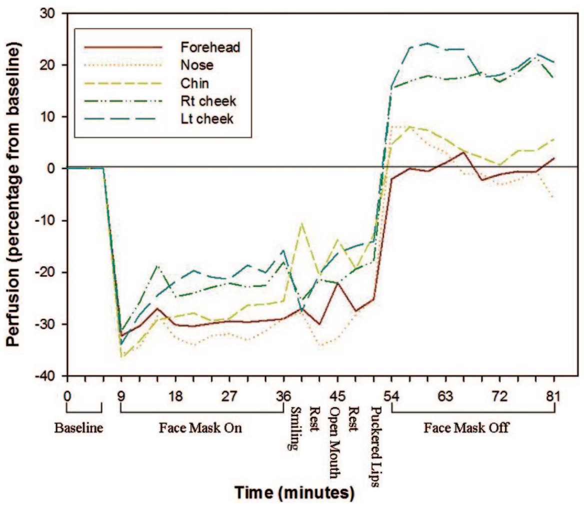

Figure 2. Perfusion patterns in the five regions of interest in all subjects without burn for four trials. Zero percent denotes the baseline value. All areas of the face had a decrease in perfusion on application of the face mask. Performing several facial expressions and maintaining them for 3 minutes did not alter perfusion. On face mask removal, the chin and the right and left cheeks had a statistically significant increase in perfusion above baseline, which persisted for the 30 minutes of measurements.

Table 3. Perfusion units in the face of the subject with burn

Experimental Condition	Region of interest			
	Nose	Chin	Right Cheek	Left Cheek
Baseline	100	100	100	100
Face mask on	54.3	70.6	69.4	79.1
Smiling	69.6	109.5	66.3	78.9
Rest	51.6	75.4	67.3	74.8
Open mouth	53.1	73.4	64.8	71.4
Rest	47.2	67	65.9	72
Puckered lips	61.8	67.7	65.2	74.2
Face mask removal	70.3	84.1	85.6	79.4

Perfusion decreased significantly in all areas after face mask application. In the nose and chin, there was a significant increase in perfusion with smiling. The cheeks did not show this difference. On face mask removal, perfusion increased significantly in the nose, chin, and right cheek, although it remained lower than baseline.

trol; yet, the extreme demands on patients affect compliance. One study reported compliance for head and neck pressure garments only at 44%,[11] whereas another revealed that patients reported daily wearing schedules of no more than 10 to 14 hours of the prescribed 23 hours a day.[12]

Studies showed that hypertrophic scars have increased microcirculation.[1,2] One of the speculated ways that pressure garments may affect scar is by decreasing blood flow. This study set out to illustrate the perfusion patterns caused by face mask application and expression with LDI. LDI has shown potential for predicting hypertrophic scar development in burns by characterizing blood flow changes in patients over time.[13] The feasibility of using LDI to scan through transparent face masks to obtain an objective measure of perfusion has also been proven in healthy subjects.[9]

This study showed decreased perfusion on mask application in all subjects. This was not surprising and is the effect of a couple of forces. First, simply shining the laser through the plastic mask will decrease the measured perfusion units.[9] Second, the pressure provided by the mask will also decrease perfusion. An unexpected finding was that perfusion remained decreased during a 30-minute period with the mask in place, despite the clinical observation that the initial blanching gives way to a more pink appearance after having the face mask on for a few minutes. This suggests that the difference in perfusion between a slightly pink area and a completely blanched out one is small. The clinical significance of this remains to be seen. A second unanticipated finding was that perfusion remained unchanged, despite sustained facial expressions in all regions in the subjects without burn and in the right and left cheeks in the subject with burn. The expectation was to see a detectable change in blood perfusion from mask shifting during facial movements. Subjects were asked to sustain each facial expression for the 3-minute scanning period because Laser Doppler images could not be captured during continuous live active movement. The amount of change in facial range of motion or skin flexibility beneath the mask were not quantified, but may have varied due to subject fatigue.

The more important finding was that removal of the mask elicited a different response in the subjects with and without burn (see Figure 1). A rebound hyperemic response was noted in subjects without burn in the chin and cheeks. The increased perfusion level did not return to baseline level even after keeping the mask off for 30 minutes. The hyperemic response is likely due to rebound vasodilatation in response to the period of blood flow interruption (ischemia) from the mask. It is possible that the chin and cheeks had the most contouring or pressure from the full face mask and thereby had accumulating vasodilatation before pressure relief.

The subject with burn did not show this significant hyperemic response. Although perfusion did increase after removal of the face mask in some areas, it never reached the pre-face mask values, remaining significantly decreased. This study was not conducted to explore a mechanistic explanation to this observation although several possible explanations can be advanced. First, with only one subject with burn, a type I error is possible; that is, observing a difference when there is none, because of lack of power. If this finding was to be confirmed by an adequately powered study, one possible explanation is that burn injury changes the normal vascular hyperemic response. A more adequately powered study on subjects with burn is needed.

Examining the face with LDI posed several problems in this study. First, subjects expressed difficulty with static sitting for 85 minutes. Subjects were asked to be upright during scanning to simulate the position of daily activities. During scanning, head motion created images that could not be used for data pixilation. As a result, one subject who fell asleep at multiple points during the study period had to be eliminated from the analysis. Scanning time and subject positioning with a chin or head rest for comfort need to be considered for future face studies.

A second difficulty encountered was in the variability in the baseline LDI readings. Baseline values have not been defined, particularly for subjects without burn. Even though subjects were given acclimatization time, factors known to affect LDI measurements such as emotional response and temperature response from mask use could not be controlled.[14] For the one subject with burn, those factors in addition to facial hair length mask compliance, and scar maturation between trials could have contributed to the variation in perfusion levels. Heterogeneity of skin blood flow and microvasculature can also contribute to individual variance.[10]

The third difficulty encountered is that the face is a complex scanning and pixelation surface for LDI. Five regions of interest were selected to look at the face in totality. Pixelation templates varied between scans and trials because of individual facial structures and with slight changes in head positioning. Natural facial contours could reflect from scanning directions and artificially change recorded flux range. Despite the inherent intricacy in examining the face, it was selected for this study because of the transparent nature of the mask, which is not an available pressure garment option for any other area. It had also been previously determined that LDI for blood perfusion was feasible through silicone-lined face mask material.[9] The amount of pressure from the mask was not determined because of the technical difficulty and expense in doing so, but the elastic straps securing the mask were marked for consistency.

A major limitation of this study was its sample size. The majority of our subjects were without burn. At the time of study enrollment, only two burn patients in our center required transparent face mask use. One declined participation due to travel distance. In the past 5 years, our burn center has treated an average of three patients per year who required transparent face mask use. Scanning other body regions as well as scanning patients at set intervals throughout the wound healing and scar maturation process may provide us with more useful data.

One issue that may arise in future burn studies investigating the effects of pressure therapy on scar is compliance. The subject with burn enrolled in this study reported wearing his mask 6 to 8 hours throughout the day. Patients have low compliance with pressure garments in more visible areas such as the hand, head, and neck.[11,12] Having the means of objectively measuring the patient's time in pressure garments is critical in determining their effect on hypertrophic scar.

This study exposed key issues worth considering when conducting future research with the face, pressure therapy, and with LDI technology. Researchers need to consider ways of measuring pressure through transparent face masks and tracking patient compliance to better understand the degree of effectiveness with pressure therapy. LDI used in combination with skin biopsies, physiological data collection, and scar evaluations such as the Vancouver Scar Scale may provide us with an overall better understanding of hypertrophic scar.

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