Clinical and experimental wound closure using a skin stretching device

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Chapter 7

Oxygenation and Microcirculation During Skin Stretching in Undermined and Not Undermined Skin

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INTRODUCTION

The concept of skin stretching using a stretching device as introduced by Hirshowitz et al. in 1993 is now routinely used in plastic surgery. Skin stretching decreases the wound-closing tension allowing primary closure of large defects. This technique eliminates donor defects and related morbidity. Furthermore, it enables sensate reconstructions with good cosmetic appearance of the skin.

The incidence of complications as a result of skin stretching such as skin necrosis is low, but can occur when tension is applied to skin to close large defects. Tissue viability may be compromised especially when the skin around the wound is undermined.

The aim of the present study was a comparative evaluation of the microcirculatory flow and oxygen availability during stretching of undermined and not undermined skin using skin laser Doppler flowmetry (LDF) and transcutaneous oximetry (tcpO₂). LDF has been proven to be efficacious in evaluating effect on blood flow in skin undergoing expansion in rabbit, pig and man. TCPO₂ is a non-invasive, reproducible and objective method that gives information about oxygen availability in the skin.

The piglet is an accepted and suitable model for human skin, because of similarities in vascular anatomy. Both have a segmental pattern of cutaneous blood supply, which includes musculocutaneous perforating vessels. Therefore we have studied the effects of undermining the skin and skin stretching on microcirculation and oxygen availability in a piglet model.

MATERIALS AND METHODS

The ethical committee for animal research of the Academic Medical Center of Amsterdam approved the study. A series of 8 female Yorkshire piglets weighing 20 - 25 kg was used. The animals were anaesthetized with a mixture of sufentanifort and ketamine in a dose of 50 mg and 25 mg per kg body weight, respectively. Following intubation, anesthesia was maintained by spontaneous inhalation of a mixture of halothane (0.8 percent), air and oxygen (FiO₂, 47 percent).

The use of the Sure-Closure™ skin stretching system (Life Medical Sciences, Inc., Princeton, N. J.) has been described in detail in our previous reports. Briefly, on each flank a 9 x 9 cm square wound was created by excising skin and
subcutaneous tissue down to the muscular fascia. On one flank of each animal, surrounding areas of skin previously outlined, were undermined between the subcutaneous layer and muscular fascia. Undermining was not performed on the other flank. Skin was stretched on both flanks in a longitudinal direction with the Sure-Closure skin stretching system (Fig. 1). The wounds were closed using the principle of load cycling over a period of 30 minutes with a 4 minutes interval of stretching the skin and a 1 minute relaxation interval by unlocking the system, thus allowing recuperation of the skin circulation. Continuous monitoring of skin circulation was performed during 30 minutes of skin stretching. After 30 minutes of skin stretching and continuous monitoring of skin circulation, the device was removed and wounds were then sutured. The animals were kept for one more week to evaluate wound healing.

LDF and tcpO₂ were used to assess skin microcirculation as described previously in detail. Previous studies have shown that the methods are highly reproducible and a good correlation has been found between the 2 methods. LDF was carried out with a Periflex PF 3 system (Perimed, Stockholm, Sweden). A tcpO₂ monitor (TCM 3; Radiometer, Copenhagen, Denmark) was used to measure the oxygen tension on the surface of the skin. The probes of the two gauges were affixed to the skin with double-sided adhesive attachment rings at 1 cm from the wound margin of the skin on each side of the defect and also at 1 cm cranially of the skin stretching device (Fig. 1a). A reference electrode was attached to the shoulder away from the stretched skin (Fig. 1b). Any changes in transcutaneous pO₂ values, not caused by stretching or relaxing the skin, was ruled out. The probe temperature of the tcpO₂ sensor was maintained at 44°C. Operations and analyses were performed at a constant temperature of 22°C. Blood pressure and core temperature of the animals were recorded and kept stable during operation. In order to obtain a stable baseline, a period of 20 minutes was allowed for equilibration, prior to LDF and tcpO₂ analyses. All LDF signals in perfusion units (PU) and tcpO₂ values in mm Hg were continuous registered by computer. The data were statistically analyzed using analysis of variance of repeated measures. A p value of 0.05 was taken as level of significance. Mean differences between values obtained during skin stretching and relaxation were assessed by the paired Student t-test.
Figure 1a.
The Sure-Closure skin stretching system, anchored behind the two pins, is in a relaxation period. Simultaneously monitoring by LDF, black probe in close proximity of left wound margin, and tepO₂, white probe in close proximity of right wound margin.

Figure 1b.
Approximation of skin edges during skin stretching. Simultaneously monitoring by LDF and tepO₂. The reference electrode is seen on the shoulder.
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RESULTS

The mean laser Doppler signal before undermining the skin was 13.2 x 10 PU. After undermining this was 11.6 x 10 PU. The mean tepO₂ value before undermining was 67.5 mmHg, after undermining 53.3 mmHg. Therefore undermining the surrounding skin caused a 12 percent decrease of the laser Doppler signal and a 21 percent decrease of tepO₂ values.

Changes in both flow and oxygen availability of undermined and not undermined skin were observed as a result of incremented traction.

Figure 2.
The mean changes, of the I.DF, from baseline value were calculated for each time-point and depicted in a figure (above = undermined and below = not undermined). Baseline value (0 x 10 PU, t = 0 minutes) was at the beginning of skin stretching. The absolute value (t = 0 minutes) after undermining the skin was 11.6 x 10 PU. Bars represent standard error of the means. Skin was cyclic stretched in 30 minutes with a 4 minutes interval of stretching the skin and a 1 minute relaxation period.
TABLE I.
Mean differences in LDF signal and \( \text{tcPO}_2 \) values after 4 minutes of skin stretching and after 1 minute of relaxation in 8 piglets. Statistical analysis using the paired \( t \)-test was performed on data shown in Figs. 2 and 3.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean increase (coefficient)</th>
<th>SD</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDF, undermined</td>
<td>5.4</td>
<td>4.9</td>
<td>0.02</td>
</tr>
<tr>
<td>LDF, not undermined</td>
<td>4.6</td>
<td>4.6</td>
<td>0.03</td>
</tr>
<tr>
<td>( \text{TeO}_2 ), undermined</td>
<td>12.1</td>
<td>13.1</td>
<td>0.03</td>
</tr>
<tr>
<td>( \text{TeO}_2 ), not undermined</td>
<td>13.4</td>
<td>7.9</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Mean changes in the LDF signals are shown in Fig. 2. An instant drop in skin blood flow in both undermined and not undermined skin occurred during skin stretching. Relaxation of the skin resulted in rapid normalization of the LDF signal to baseline levels in not undermined skin to a level just above baseline levels in undermined skin (Fig. 2). Differences between LDF signals after 4 minutes of skin stretching and after 1 minute of relaxation were statistically significant (Table I). Each cycle of 4 minutes stretching and 1 minute relaxation showed a comparable fluctuation of the LDF signal, resulting in a LDF value after 6 cycles of stretching and relaxation close to baseline levels in both undermined and not undermined skin. Zero point of flow or signs of permanent diminished perfusion never occurred during stress relaxation. LDF values were similar in undermined and not undermined skin during 30 minutes cyclic skin stretching (Table II).

TABLE II.
Statistical analysis comparing the means of the repeated measurements obtained at time, 0, 5, 10, 15, 20, 25 and 30 minutes at the end of each period of relaxation. Analysis of variance was performed on data shown in Figs. 2 and 3.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean increase/decrease (coefficient)</th>
<th>SEM</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDF, undermined</td>
<td>-0.02</td>
<td>0.05</td>
<td>0.75</td>
</tr>
<tr>
<td>LDF, not undermined</td>
<td>0.04</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>( \text{TeO}_2 ), undermined</td>
<td>-0.97</td>
<td>0.12</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>( \text{TeO}_2 ), not undermined</td>
<td>0.32</td>
<td>0.11</td>
<td>0.09</td>
</tr>
</tbody>
</table>
The mean changes of the tcpO$_2$, from baseline value were calculated for each time-point and depicted in a figure (above = undermined and below = not undermined). Baseline value (0 mmHg, t = 0 minutes) was at the beginning of skin stretching. The absolute value (t = 0 minutes) after undermining the skin was 53.3 mmHg. Bars represent standard error of the means. Skin was cyclic stretched in 30 minutes with a 4 minutes interval of stretching the skin and a 1 minute relaxation period.

The mean changes of the tcpO$_2$ value during cyclic skin stretching are represented in Figure 3. A drop in skin oxygenation of undermined and not undermined skin was found when skin was stretched. Differences between tcpO$_2$ values after 4 minutes of skin stretching and after 1 minute of relaxation were statistically significant (Table I). Relaxation of the skin resulted in normalization of the tcpO$_2$ values to baseline levels in not undermined skin but in undermined skin tcpO$_2$ values recovered only partially during relaxation (Fig. 3). As a result, in contrast with not undermined skin, stretching of undermined skin for 30 minutes resulted in a highly significant decrease of skin oxygenation (Table II). Again in these measurements, zero point of flow never
occurred in both undermined and not undermined skin. Skin necrosis occurred in 4 wounds, all found in the undermined group, still present after one week. In 2 wounds, necrosis resulted in wound dehiscence. Excessive seroma formation was seen in all wounds of which the skin was undermined. In the not undermined wounds, problems in wound healing did not occur.

DISCUSSION

Cyclic skin stretching with a skin stretching device for 30 minutes results in significant histomorphological changes of collagen fibers in the dermis in both undermined and not undermined skin. The fibers realign rapidly as a result of stretching forces and become aligned in the direction of the stretching force perpendicular to the wound margin. These dynamic changes in collagen fibers explain the significantly decreased wound closing tension resulting from skin stretching. Creep deformation under constant stress and stress reduction under constant strain (i.e., stress relaxation) occurs without interference in the microcirculation and oxygenation in not undermined skin after 30 minutes of skin stretching. As a result of cyclic relaxing, skin circulation recovers. This is in contrast with not undermined skin, where oxygen availability of undermined skin drops continuously as a result of mechanical stress. Wound edge viability is compromised when undermined skin is subsequently stretched causing a high incidence of skin edge necrosis, as has previously been reported. Complications in wound healing do not occur in not undermined wounds. In the present study we show that LDF signals are very similar in undermined and not undermined skin whereas tcpO₂ levels are significantly lower in stretched undermined skin than in not undermined skin. As a result of these lower tcpO₂ levels, viability of skin was compromised resulting in a high incidence of skin edge necrosis which resulted in dehiscence in some wounds although zero values of oxygenation were never observed. Therefore, the assumption that the flap with marginal initial vascularity, either caused by prior surgery, radiation, or else can be safely expanded as long as tcpO₂ levels are maintained above zero' levels does not apply.

An explanation for the discrepancy between LDF and tcpO₂ values as parameters for skin blood flow in undermined and not undermined skin may be that high LDF values are less reliable. Although several authors reported
encouraging results with LDF to detect impaired perfusion of skin under various circumstances$^{25,29,32}$, LDF did not appear to be a valuable monitor (compared to tcpO$_2$) to detect loss of viability in undermined stretched skin in the present study, which is also demonstrated by the correlation coefficient of -0.13 in Figure 4. LDF estimates rather than measures dermal microcirculatory blood flow. The device only provides a gross estimation of tissue oxygenation in a small piece of dermis. Furthermore, LDF measures both nutritional flow and nonnutritional flow in deeper vessels including arteriovenous thermo-regulatory shunts. The arteriovenous shunt flow in normal skin and acute random-pattern skin flaps on flanks of piglets has been reported to be over 60 percent of the total blood flow.$^{33-35}$ This arteriovenous shunt flow may cause the discrepancy in measurements of skin microcirculation by LDF and tcpO$_2$. Moreover, sensitivity of LDF may vary with flow rates, especially at low flow rates.$^{36}$ Severe skin ischemia may be present even when LDF levels are adequate caused by the uneven distribution of the microcirculation, and the important role of arteriovenous anastomoses.$^{37}$

LDF and tcpO$_2$ measurements are often used to ensure safe tissue expansion in cases of breast reconstruction or soft tissue coverage after removal of a variety of skin problems.$^{39,23}$ Over expansion may lead to loss of viability and, therefore,
morbidity because of tissue ischemia. The present study was not performed to evaluate whether the use of LDF and tcpO₂ improves skin stretching in a clinical setting. In fact, these techniques are still too cumbersome for routine clinical employment.723 Clinical assessment of tissue expansion during skin stretching on the basis of skin color and capillary refill should satisfy.38,39 The present study was performed to investigate to what extent stretching affects oxygenation and microcirculation in undermined and not undermined skin. So far, only one study reported on the use of a pulse oximeter probe that was inserted in the wound margin in close proximity of the skin stretching device in a series of patients in order to assess microcirculation in the skin edges.3 At the time of stretching, oxygen tension dropped temporarily, for a few seconds, from normal values to approximately 75 percent. These readings were obtained at a stretching force of 1.6 kg although skin tension was maintained, oxygen saturation of the tissues rapidly returned to its initial value. In the present study on piglets, where a force of approximately 3 kg. was used during cycle loading for 30 minutes, recuperation of the oxygen tension occurred only during the relaxation period when the skin stretching device was unlocked. During the one of relaxation, in not undermined skin, oxygen tension returned to normal values but in the undermined skin, oxygen tension never returned to normal values.

To our knowledge, this is the first time that changes in both oxygenation and blood circulation of undermined and not undermined skin are compared in a study on piglets during stretching using a skin stretching device. Skin stretching results in a drop of skin blood flow as well as skin oxygenation measured with LDF and tcpO₂, respectively. However, release of the device causes the skin circulation to recuperate within one minute. Stretching of undermined skin, but not of not undermined skin, for a period of 30 minutes affects oxygen availability of the skin significantly which compromised the viability of the skin. Consequently, it is advised to perform stretching on not undermined skin rather than undermined skin. Secondly, it makes sense to use the principle of cycle loading so that recuperation of the skin circulation can occur.
ACKNOWLEDGMENTS

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REFERENCES


