Clinical and experimental wound closure using a skin stretching device
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Chapter 9

Long-term Results after Closure of Large Skin Defects with the Use of a Skin-Stretching Device

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Submitted for publication.
INTRODUCTION

Plastic and reconstructive surgeons are often faced with skin defects that cannot be closed primarily. Various techniques for closure of such large wounds are developed, including wide undermining, tissue expanders, split skin grafts, and local, distant or free revascularized flaps. However, functional and aesthetic outcome would be improved when primary approximation of skin in these large defects were possible. A relatively simple technique that is based on the use of a skin-stretching device (Sure-Closure™, Life Medical Sciences, Inc., Princeton, N.J.) was introduced by Hirshowitz et al. in 1993. The skin-stretching device decreases the wound-closing tension, allowing primary closure of large defects in a short time span. As a result of stretching forces, the dermal collagen fibers realign rapidly in the direction of the stretching force, perpendicular to the wound margin as was demonstrated in an experimental study using piglet skin. These dynamic changes in collagen fibers explain the significantly decreased wound closing tension resulting from skin stretching and explain how skin stretches beyond its inherent extensibility. Experimental studies on piglets have shown that intraoperative use of this device does not impair the immediate or long-term viability of skin provided that the stretched skin is not undermined.

So far, little is known about long-term outcome with respect to functional and aesthetic aspects of wound closure with the skin-stretching device. Therefore, we present here our clinical experience with the skin-stretching device.

PATIENTS AND METHODS

In a prospective non-randomized study, 30 patients were operated using the skin-stretching device between January 1995 and September 1997. Primary closure of wounds was not possible and other techniques would be required for closure of these wounds. Of the 30 patients, 15 had a malignancy excised, 6 a large hairy nevus, 5 a disfiguring split skin graft, 3 needed a revision of scar tissue, and 1 a free fibula flap donor site, at different locations on the body. Two patients suffered from psoriasis and needed corticosteroid treatment. One patient, with a malignancy, had preoperative local radiotherapy treatment. The mean patients age at the time of surgery was 40 years (range, 1 to 87 years), with a similar sex distribution. Patients were selected for skin stretching when the defect that would occur after
excision was too large for primary closure without skin stretching and enough surrounding skin was present for skin stretching. We have used the device under general, regional and local anesthesia. The operation procedure was well tolerated under local anesthesia. Wounds were closed when possible with a running subcuticular absorbable monofilament suture and otherwise with percutaneous nylon sutures that were removed after 3 weeks.

Patients were seen preoperatively, postoperatively after 3 weeks, 3, 6, and 12 months and at a long-term follow-up for at least 5 years (median, 7 years) for wound control and evaluation of residual scar and function of the particular region. Scars were photographed and maximal width of wound before excision and residual scar was measured. The difference in stretch back (retraction of skin or stretched scar) in various locations were calculated using an unpaired (two-way) independent t-test. Elevation of the scar and consistency were noted as evidence of hypertrophy of the scar. The patients graded the resulting scar on a numerical rating scale from 0 to 10, with 0 being the worst imaginable scar whereas 10 stood for a scar not different from normal skin.

In 24 cases, a complete follow up was possible. Besides 2 cases where a skin graft was needed to close the defect, 3 patients died because of cancer within the follow up period, and 1 patient was lost in the follow-up period. Follow up ranged from 5 to 8 years with a median of 7 years. The functional and aesthetic outcome of wound closure with the skin-stretching device was evaluated in all cases. Patients that were treated with the skin stretching device are listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>Location of skin defects in 30 patients that were treated for wound closure with the skin-stretching device.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part of the body</td>
<td>Wound location</td>
</tr>
<tr>
<td>Head</td>
<td>Face</td>
</tr>
<tr>
<td></td>
<td>Scalp</td>
</tr>
<tr>
<td>Trunk</td>
<td>Back</td>
</tr>
<tr>
<td></td>
<td>Breast</td>
</tr>
<tr>
<td>Upper extremities</td>
<td>Shoulder</td>
</tr>
<tr>
<td></td>
<td>Lower arm</td>
</tr>
<tr>
<td></td>
<td>Wrist</td>
</tr>
<tr>
<td>Lower extremities</td>
<td>Groin</td>
</tr>
<tr>
<td></td>
<td>Upper leg</td>
</tr>
<tr>
<td></td>
<td>Thigh</td>
</tr>
<tr>
<td></td>
<td>Lower leg</td>
</tr>
<tr>
<td></td>
<td>Ankle</td>
</tr>
</tbody>
</table>
OPERATION TECHNIQUE

After the tumor or skin was excised, 2 straight needles (length, 8 cm) were inserted through the dermis opposite each other along the wound margin. The 2 U-shaped arms with 4 curved tissue hooks attached were placed perpendicularly to the intradermal needles in such a way that the hooks punctured the skin and were placed behind the 2 needles. This was performed in such a way that the 2 U-shaped arms, when engaged, pulled the intradermal needles towards each other. After appropriate tension was applied, the device was locked. Approximation of the skin edges was executed by turning the tension knob of the skin-stretching device. As the skin was stretched, tension of the skin decreased because of stress relaxation. This was indicated by the tension gauge moving backwards and tension was reapplied. This procedure was repeated until the wound margins were approximated and the wound could be sutured. The skin-stretching device is designed in such a way that when the force that is applied to the wound becomes excessive (>2.5 kg), the tension knob disengages to prevent mechanical damage of the skin.

RESULTS

Short-term results
In 28 cases (93%), the large defect could be closed primarily with the skin-stretching device. In 2 cases, skin stretching was insufficient due to either preoperative local radiotherapeutic treatment or the large size of the defect (6½ x 11½ cm) at the distal lower leg where the skin was too adherent. Both wounds were covered by a split skin graft. The average size of the defects was 9.6 x 5.6 cm (range, 5.5 x 3.0 cm - 23.0 x 9.5 cm). The 28 wounds were closed intraoperatively after a mean stretching period of 30 minutes (range, 10 - 90 minutes). None of the defects were undermined. Three patients (10.7%) suffered from dehiscence of the wound: 1 patient after skin stretching of a defect of the scalp and 2 patients with psoriasis. All 3 wounds healed satisfactory after secondary intention. One patient (3.6%) had temporarily superficial necrosis of the wound margins. In 2 patients (7.1%), hypertrophic scarring occurred, in both cases on the shoulder. None of the patients developed wound infection. Twenty-two of the 28 wounds (79%) that were closed with the skin-stretching device healed uneventfully without any complications at follow up.
Long-term results
Residual scar and stretch back at 5 years or more postoperatively are summarized in Table II. A wide variation in the amount of scar formation was found. Stretch back after a mean of 7 years was mainly observed on the scalp (average, 56%), back (average, 52%) and shoulder (average, 53%). The average stretch back in these 3 areas was 53% ± 21%. This percentage was significantly less on the

Table II.
Size of residual scar (mm) at minimally 5 years after skin stretching on scalp, back and shoulder (top) and on the extremities, including groin and thigh (bottom) as compared with that of the original lesion (mm). The right columns represent the percentage of stretch back.

<table>
<thead>
<tr>
<th>Size of original lesion (mm)</th>
<th>Size of residual scar (mm)</th>
<th>Location</th>
<th>Percentage stretch back</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>20</td>
<td>Scalp</td>
<td>50%</td>
</tr>
<tr>
<td>45</td>
<td>28</td>
<td>Scalp</td>
<td>62%</td>
</tr>
<tr>
<td>40</td>
<td>25</td>
<td>Shoulder</td>
<td>63%</td>
</tr>
<tr>
<td>65</td>
<td>40</td>
<td>Shoulder</td>
<td>62%</td>
</tr>
<tr>
<td>70</td>
<td>25</td>
<td>Shoulder</td>
<td>36%</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>Back</td>
<td>100%</td>
</tr>
<tr>
<td>50</td>
<td>21</td>
<td>Back</td>
<td>42%</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
<td>Back</td>
<td>20%</td>
</tr>
<tr>
<td>95</td>
<td>42</td>
<td>Back</td>
<td>44%</td>
</tr>
</tbody>
</table>

Mean: 53%, SD: 21%

<table>
<thead>
<tr>
<th>Size of original lesion (mm)</th>
<th>Size of residual scar (mm)</th>
<th>Location</th>
<th>Percentage stretch back</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>4</td>
<td>Thigh</td>
<td>4%</td>
</tr>
<tr>
<td>80</td>
<td>4</td>
<td>Groin</td>
<td>5%</td>
</tr>
<tr>
<td>60</td>
<td>4</td>
<td>Groin</td>
<td>7%</td>
</tr>
<tr>
<td>55</td>
<td>9</td>
<td>Upper leg</td>
<td>16%</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
<td>Arm</td>
<td>12%</td>
</tr>
<tr>
<td>45</td>
<td>5</td>
<td>Wrist</td>
<td>11%</td>
</tr>
<tr>
<td>53</td>
<td>4</td>
<td>Lower leg</td>
<td>8%</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>Lower leg</td>
<td>12%</td>
</tr>
<tr>
<td>50</td>
<td>8</td>
<td>Lower leg</td>
<td>16%</td>
</tr>
<tr>
<td>50</td>
<td>5</td>
<td>Lower leg</td>
<td>10%</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>Ankle</td>
<td>8%</td>
</tr>
<tr>
<td>35</td>
<td>7</td>
<td>Ankle</td>
<td>20%</td>
</tr>
<tr>
<td>70</td>
<td>5</td>
<td>Ankle</td>
<td>7%</td>
</tr>
<tr>
<td>40</td>
<td>4</td>
<td>Ankle</td>
<td>10%</td>
</tr>
</tbody>
</table>

Mean: 11%, SD: 4%
extremities, groin and thigh (average, 11% ± 4%; p=0.0004). In Figure 1, correlations between wound size and scar width are shown in both situations.

At 3 weeks after operation, 23% of the total stretch back had occurred, whereas 57% of the total stretch back had occurred at 3 months postoperatively and 83% at 6 months postoperatively. The rate of retraction of the skin (stretch back) after skin closure of a large defect using the skin-stretching device is shown in Figure 2 for different locations on the body.

Figure 1.
Wound size versus width of scar. Pearson correlation of scalp/back/shoulder, r = 0.118 (p = 0.762); Pearson correlation of extremities, r = -0.039 (p = 0.895).

Mean patients’ impression of the scar as scored on a scale of 0–10, after a mean of 7 years was 7.6 (range, 2 - 9.5 years).
Long-term functional outcome revealed that functional problems did not occur, besides temporary tight feelings on extremities and physical therapy for 2 patients with wounds on the shoulder.
Figure 2.
The rate of stretching of scars in 24 cases in different locations of the wound at 3 weeks, 3, 6, and 12 months and 7 years postoperatively.

CASE REPORTS

Case 1
A 68-year-old woman with a melanoma on the dorsum of the right distal forearm (Fig. 3) was referred for re-excision. An excision of 2 x 5 cm was performed one month before. Under plexus anaesthesia, re-excision with margins of at least 2 cm was made, leaving a skin defect of 5 x 10 cm with the superficial radial nerve and extensor tendons visible. After 30 minutes of skin stretching, the wound was closed primarily. Postoperative follow up showed no wound complications and the functional and aesthetic outcome was excellent. Due to the malignancy, long-term follow-up was not possible.
Figure 3.
Case 1.  A. A 5 x 10 cm defect of the distal forearm after re-excision of a melanoma. Superficial radial nerve and extensors are partially visible.  B. Over a period of 30 minutes, the skin was stretched with the Sure-Closure skin-stretching device.  C. Approximation of the wound before skin stretching using the Gillies hooks with a fair amount of tension was impossible.  D. The skin edges were brought together after 30 minutes of skin stretching with the same amount of tension.  E. One week later, the sutured wound appears to be healing satisfactorily.  Flexion of the wrist by the patient was possible without functional impairment.
Case 2
A 3½-year-old child with a congenital naevus on the left shoulder (Fig. 4) was referred for excision. The skin was stretched for a period of 20 minutes to close the 7 x 10 cm wound. The first 3 months of wound healing were satisfactory. In the following postoperative period, the patient was treated with a silicone occlusive sheeting (Cica-care, Smith & Nephew BV, The Netherlands) because of hypertrophic scar formation. Unfortunately this treatment did not prevent formation of a hypertrophic scar.
Case 3

A 34-year-old female with a congenital naevus on the left scapula (Fig. 5) was referred for excision. A defect of 11 x 14 cm was the result of excision of the lesion. Forty minutes of skin stretching under general anesthesia was necessary to approximate the wound edges. The patient had a long course of physical therapy. The functional and aesthetic outcome was satisfactory.

Figure 5.
Case 3. A. A large irregular congenital naevus on the left shoulder. B. A 11 x 14 cm defect was impossible to close primarily. C. At the end of the operation, after the surrounding skin was stretched for a period of 40 minutes, the wound-edges were sutured. D. At 7 years postoperatively.

Figure 4.
Case 2. A. A congenital naevus on the left shoulder. B. Insertion of the straight needles through the dermis opposite each other along the wound margin after tumor excision. C. As the skin stretched, tension was reduced because of stress relaxation. This was indicated by the tension gauge moving backwards. D. Skin was sutured intracutaneously with a monofilamentous absorbable suture Monocryl. E. Wound healing at 3 months postoperatively. F. Hypertrophic scar formation at 7½ years postoperatively.
Case 4
A 46-year-old man with a melanoma on the right lower leg (Fig. 6) was referred for re-excision. Two months after primary excision, a selective lymphadenectomy of the right groin and re-excision with a margin of a minimum of 2 cm was performed under general anesthesia. A defect of 5.5 x 10 cm was the result of the re-excision. The skin was stretched for 20 minutes and primary closure was accomplished. Rest tumor was not found. Healing occurred without complications and the final scar was barely visible.

Figure 6.
Case 4. A. Re-excision of a malignant tumor resulted in a defect of 5.5 x 10 cm. B. At 6 months post-operatively. C. At 6 years postoperatively.
Case 5
A 76-year-old woman was referred to our department with an eccrine carcinoma on the right hip (Fig. 7) which had been treated unsuccessfully for 3 times already. Medical history showed an extensive form of psoriasis, locally and systemically treated for many years. The tumor was radically excised with a 1 cm margin under general anesthesia. Skin stretching was employed over a period of 25 minutes to close a 9 x 10 cm large defect up to the muscular fascia. Primary closure was accomplished. Wound healing was delayed due to a small dehiscence of 1 cm in diameter. Further healing occurred without complications, and the final scar was inconspicuous.

Figure 7.
Case 5. A. A 9 x 10 cm wound on the right hip. B. Wound healing at 1 month after operation. A slight dehiscence was present and typical irregularity of the surrounding skin was caused by psoriasis. C. At 2 years postoperatively.
DISCUSSION

On the basis of our findings in the present study, it can be concluded that the skin-stretching device provides a simple but effective solution in complex situations of skin shortage. Donor site defects and associated morbidity can be avoided and the approach enables sensate reconstructions with good aesthetic appearance of the skin. The mean stretching time of 28 wounds (93.3%) that were successfully closed was 30 minutes (range, 10 - 90 minutes). Duration of stretching when using the device to approximate large defects appeared to depend on multiple factors such as location of the wound, skin properties and size of the defect. Therefore, it is difficult if not impossible to estimate the duration of skin stretching necessary to close a defect. After a certain period of skin stretching, a point is reached that biomechanical (elastic) properties of the skin, known as mechanical creep and stress relaxation, limit increase in length of the skin and gain in surface area of the skin stagnates. This “end-point” is reached earlier in skin of the scalp, foot, ankle and lower leg as compared with skin elsewhere on the body as a result of adherence of the skin to underlying tissues.

Adverse effects of skin stretching occurred relatively rarely in the present study. Wound dehiscence (10.7%), scar hypertrophy (7.1%), incomplete closure (6.7%), and skin necrosis (3.6%) were the only complications that we were confronted with. Therefore, in our opinion benefits of primary closure of large wounds outweigh the risk of side effects.

The skin-stretching device has been used intraoperatively in the present study and the procedure was performed without undermining of skin edges and the concomitant risk of vascular insufficiency. Experimental studies on piglets\textsuperscript{2,8} have shown that undermining of stretched skin reduces the viability of skin margins in comparison with not undermined skin. Therefore, success of closure of large defects is diminished when skin is undermined. The extremities and the groin region are the parts of the body where skin stretching is most successful whereas the shoulder is the region of the body that is most susceptible for hypertrophic scar formation. The exact mechanisms of the differences in success remain unknown.\textsuperscript{9}

The device is contra-indicated by the manufacturer when skin is irradiated, infected or when skin quality is questionable in cases of presence of atrophic or nonviable tissue near the wound edges. In our study, skin stretching was unsuccessful in 1 patient as a result of reduced elastic properties of irradiated
tissue. However, in 2 psoriasis patients with atrophic skin, skin could be stretched to close a large defect. Although partial dehiscence of the wound occurred in both patients, the final outcome was good. Infected skin has not been stretched with the device in the present study.

After the first application of the skin-stretching device\textsuperscript{1}, a number of clinical studies provided insight in the possibilities of this approach.\textsuperscript{10-23} However, long-term follow up of defects closed using a skin-stretching device are still lacking. In the present study, patients were very satisfied with the end result (mean patient's impression after 7 years was 7.6 on a scale of 0 - 10). To assess the result in terms of residual scars, we compared the width of the scars with the width of the preoperative lesions. Postoperative widening of the scar is expressed as a stretch back percentage. When skin is stretched with a stretching device, one may assume that the skin retracts eventually to its former condition. Our long-term follow-up study of skin stretching reveals that this is not the case. Apparently, dermal elastic fibers cannot bring the dermis back to its original condition after skin stretching. Furthermore, collagen fibers that make up approximately 90% of the dermis are not involved in retraction either.\textsuperscript{24,25} In the present study, a wide variation in stretch back occurred. Substantial stretch back (approximately 50%) was observed in the scalp, back and shoulder region. In the extremities, groin and thigh region stretch back of only 11% was found. In these regions, the width of the definitive scars remained small even when the preoperative lesions were wide (Fig. 1). In a long-term study with skin expanders (more comparable well-documented studies could not be find),\textsuperscript{26} the best cosmetic results were obtained on the forehead and limbs, when taking the original lesions into account. The scars on the trunk remained substantial. After scalp excisions, stretch back is known to be considerable.\textsuperscript{27} In the present study, there seems to be a relation between wound size and scar stretch in the scalp, back and shoulder region. The width of the scar is approximately 50% of the wound size, whereas the width of the scar on the extremities (including groin and thigh) was independent of wound size (Fig. 1).

Furthermore, previous studies have mentioned that scars stretch with a constant rate and most of the stretching occurs within the first 6 months.\textsuperscript{28-30} The rate of scar stretching in the present study was consistent with these reports because 83% of the total scar stretching occurred in the first 6 months postoperatively (Fig. 2).

To our knowledge, this is the first time that a long-term follow-up study, of the effects of skin stretching has been performed. Because the group of patients is
relatively small and heterogeneous, caution has to be taken with conclusions. Nevertheless, the skin-stretching device provides a method to close large wounds in a relatively fast and simple way because the extra skin that becomes available enables primary wound closure. The long-term functional and aesthetic results are good and the frequency of complications is low. The amount of stretch back appeared to be more determined by viscoelastic properties of the skin in situ and less as a result of skin stretching. The width of the scars as compared with the preoperative lesions (stretch back) on the extremities, groin, and thigh appeared to be significantly less than on the scalp, back or shoulder.

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