Perforator-based interposition flaps for sustainable scar contracture release: a versatile, practical, and safe technique

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Abstract

Introduction: Problematic scar contractures are frequently observed following extensive (burn) wounds. In this study we investigated the applicability of islanded and non-islanded perforator-based interposition flaps as a technique for release of scar contracture.

Materials and Methods: Patients requiring surgery for scar contracture release were included. Preoperatively, a suitable perforator was identified by color Doppler sonography. The flap design was tailored according to the localization of this perforator and the anticipated defect. Flap measurements were performed intraoperatively and at follow-up. Supple scar tissue was included in the flap design when necessary, to increase the applicability of this concept in extensively burned patients. Flaps were converted into island flaps on indication to circumvent significant kinking of the flap base and compromised tissue perfusion.

Results: Twenty-two flaps were performed of which four were converted into island flaps. All flaps survived, but in four cases necrosis of the tip was observed. After a mean follow-up of 7.8 months the width and surface area of the flaps had expanded to 123% (40-311%) and 116% (60-246%), respectively. One flap was converted into a full thickness skin graft during the initial operation.

Conclusions: This concept of perforator-based interposition flaps was found to be a reliable and versatile technique for broad scar contractures. Moreover, it allows intraoperative tailoring as the flap base can be islanded when indicated. Nevertheless, additional venous outflow is warranted and operation time is saved if the flap base remains intact.

Introduction

Patients with burn scars are frequently faced with disfigurement and functional impairment because of scar contractures. Linear scar contractures can be released with local random flaps such as Z-plasties. For the release of broad scar contractures, full thickness skin grafts (FTG) or split thickness skin grafts (SSG) frequently remain the treatment of choice. Unfortunately, the effectiveness of skin grafts is limited by scar contraction, which often necessitates additional reconstructions. Recent advances in the field of tissue engineering and dermal substitution may create unique opportunities for burn scar reconstruction in the nearby future but still render a scar with suboptimal functional and cosmetic qualities.

Local flaps of preferably uninjured skin and subcutaneous tissue provide, in theory, a superior and long-lasting effect of contracture release. Many local flaps were developed on trial and error basis, as surgeons were unaware of the underlying vascularization. Random flaps are considered to have a restricted length-to-width ratio that ranges between 1:17 and 2:19 dependent on the body region. They have limited possibilities for transposition, also because they can not be converted into island flaps. When the length-to-width ratio is exceeded, these random flaps could encounter vascular limitations.

To provide sustainable contracture release for broad scar contractures, longer flaps are necessary. Longer flaps can be designed if the fascia is included and if adequate tissue perfusion is ascertained. Similarly, longer flaps such as axial pattern flaps can be created. However, this flap design needs to be made exactly within the territory of these axial arteries. The degrees of freedom for tissue transfer can be considerably increased by islanding the flap, which provides an enormous increase in possibilities for transposition.

The discovery and utilization of perforators was a breakthrough in the battle between blood supply and survival of flaps. This means that a flap could be potentially based at any anatomical site as long as it incorporated a perforator artery with concomitant veins. Previous studies have demonstrated that these perforators can be easily and reliably detected by using (color) Doppler sonography. Taylor et al. performed basic research on these vessels and their role in vascularization of the skin and showed that the body contains a few hundred of such perforating vessels with a diameter larger than 0.5mm.

Nowadays, free flaps and island flaps are the types of perforator flaps that are most commonly used in plastic surgical practice. Wei et al. described “free style” perforator flaps, which are free flaps based on innominate perforator vessels. In addition, Waterston et al. presented a flap design, called the “ad hoc” perforator flap, whereby island flaps were created. However, the most convenient, simplest and safest technique, a perforator-based local flap, is seldom described. Mehrotra et al. presented case studies...
on perforator-based flaps which they named “perforator-plus” flaps\textsuperscript{19,20}. This flap is based on a perforator leaving the skin base intact, providing additional vascular supply and venous outflow. It therefore resembles a random flap but has increased reliability and the potential to create a larger flap. This technique is safe and does not require extra operation time. Drawbacks of leaving the skin base intact are that this may limit flap rotation, leave dog-ears and result in kinking of the flap base and thereby compromising the blood supply.

We have experienced the advantages of islanded as well as non-islanded perforator flaps. This enabled us to come to a versatile flap design for reconstruction of broad scar contractures: the skin base is left intact when possible, while the option remains to convert this flap into an island flap (or even a FTG) if necessary. We applied and evaluated our treatment algorithm for the reconstruction of broad scar contractures by non-islanded and islanded perforator-based interposition flaps. We studied flap survival and complication rates. In addition, a quantitative analysis was performed of changes in the surface area to critically evaluate the sustainability of the contracture release over time. Although sustainability of contracture release is considered an essential component, follow-up measurements of the surface area for perforator flaps have never been performed to date.

**Materials and Methods**

**Patients**

All patients undergoing surgery at the department of Plastic, Reconstructive, and Hand Surgery in the Red Cross Hospital from November 2008 to November 2009, were considered. Patients older than 12 years and suffering from broad scar contractures after burns or necrotizing fasciitis were included. The perforator-based interposition flap was utilized in all patients who required flaps with a length-to-width ratio higher than 2:1. This ratio was chosen based on previously published studies which revealed problems with effective tissue perfusion for random flaps with a length-to-width ratio exceeding 2:1\textsuperscript{7,9,10}. From all patients verbal consent was obtained. The principles outlined in the Declaration of Helsinki were followed. According to the clinical research legislation ethical approval was not necessary.

**Surgical technique (Figure 1)**

The flap was designed on healthy skin in the vicinity of the planned release. When sufficient healthy skin was lacking for the flap design, supple scar tissue, that remained from spontaneously healed epidermal or superficial dermal burns, was included. The concept of including supple scar tissue in flaps was shown to be safe and efficient\textsuperscript{21-23}. Moreover, considering supple scar tissue in the flap design increased the applicability of this concept. “Ad hoc” perforators were identified preoperatively in this area by color Doppler sonography (Figure 2). A more convenient and simpler option, a hand-held unidirectional Doppler, could have been used for preoperative localization\textsuperscript{14}, but has the drawback of providing less detailed information\textsuperscript{15}. Color Doppler sonography provides additional data on the flow, calibre, and course of the perforator\textsuperscript{24}. The flap design was tailored to a local transposition flap and possible islanding of the flap was anticipated. The flap surface area, area of scar tissue, and the angle of rotation were traced on a pliable transparent plastic sheet, which is a reliable and valid planimetry method\textsuperscript{25}. The sheets were scanned and measured using digital image analysis software (NIS-Elements, Nikon,
Amstelveen, the Netherlands). The width, length, and area of the flaps were measured prior to incision. It should be noted that measuring island flaps was performed differently from non-islanded flaps: the width was not measured at the base of the flap, but at the location of the perforator, and the length was measured from the edge of the flap at one side to the edge at the opposite side (Figure 3).

In the first 6 cases the flap design included the perforator, which was located at the base of the flap (Figure 1b). For these cases the perforator was identified during surgery. Subsequently, the flap design was slightly adjusted: the perforator was located outwith the flap base, thus circumventing the need to identify the perforator (Figure 1c). The flap was thinned to the subdermal plexus. Then a release of the contracture was performed. The flap was easily and safely converted into an island flap when an unacceptable mechanical tension or kinking of the flap pedicle occurred due to the transposition. If the flap remained congested after islanding, without other causes that could be anticipated, the flap could be safely turned into a FTG, which will result in a less optimal but still acceptable result. This treatment algorithm is represented in Figure 4. For closure of the donor site and for securing the flap in place, absorbable sutures were used. When the donor site had to be closed under significant mechanical tension transcutaneous non-absorbable polyester fiber sutures were used.

Follow-up
Postoperative complications were registered. Necrosis was subdivided in superficial and full thickness necrosis. Superficial necrosis was defined as epidermiolysis, where re-epithelialisation occurred within two weeks. Full thickness necrosis was defined as necrosis resulting in an unhealed wound after two weeks with possible long-term consequences. Surface area measurements were performed at a minimum follow-up of three months.

This follow-up period was chosen because split and full thickness skin grafts show the most scar contraction during the first three months postoperatively. The percentage of necrosis, if any, was determined retrospectively by planimetry of the pictures. All measurements were performed by the same investigator.

Statistical analysis
Statistical analysis was performed using SPSS for Windows version 17.0 (SPSS Inc., Chicago, USA). Normal distribution was tested by applying the Kolmogorov-Smirnov Test and by calculating the skewness and kurtosis. If the population was not normally distributed, the Mann-Whitney U Test (MWU Test) or, in case of paired data, the Wilcoxon signed ranks test was used. To compare categories the Fisher’s exact test was used when less than five cases were observed in one category and the Chi-Square test was used when more than five cases were observed. The significance criterion was set at 0.05.

Results
Twenty-two flaps were performed on 18 patients (3 male and 15 female), with a mean age of 33 years (14-58 years). Twenty patients had burn scar contractures and 2 patients had contractures after necrotizing fasciitis. None of the patients had a significant medical
history of vascular diseases or wound healing disorders, such as diabetes. Of the 22 flaps, 10 were located in the head-neck region, 6 on the upper extremities, 4 on the lower extremities, and 2 on the trunk. Three patients smoked. In Table 1 the flap characteristics are listed. Seventeen of the 22 flaps were inset into the release with their base left attached (Figure 5). These flaps had a mean rotation angle of 102˚ (57-163˚). Four of the 22 flaps were intra-operatively converted into island flaps (Figure 6). The decision to island a flap was partially based on the rotation angle. However, in all cases this remained a clinical decision which was primarily based on adequate perfusion to the flap. All donor sites could be closed primarily. One case was categorized separately: this flap was converted into a FTG. The reason being that when the flap was raised, prior to rotation, it was acutely congested and cyanosed and therefore a flap was a non-viable option.

All flaps survived, however, 2 flaps showed epidermiolysis and 4 showed full thickness necrosis of the apex (Figure 7). The mean percentage of necrosis for these 21 flaps was 3.8% (0-51.4%). The patient with 51.4% necrosis of the total flap area underwent a release in the head-neck region whereby an unexpected amount of subcutaneous scar tissue complicated a safe conversion to an island flap. This was the only patient in our study group who required a secondary procedure after a perforator-based flap.

Comparing the non-islanded flaps with the perforator within the flap design to the non-islanded flaps with the perforator outwith the flap design, showed no significant difference in the incidence of necrosis (Fisher’s Exact Test, p=0.52) or percentage of necrosis (MWU Test, p=0.18). For the non-islanded perforator flaps, the mean angle of rotation of the flaps without necrosis was 97˚ (57-157˚) and of the flaps with necrosis was 120˚ (73-163˚). This difference was not statistically significant (MWU Test, p=0.21). The case where the flap was converted into a FTG had a complete take rate of the graft seven days postoperatively.

In 11 of the 21 flaps (52.4%) supple scar tissue was included with a mean percentage of 13.1% (n=21, 0-49.4%) of the total flap area. No significant correlation could be demonstrated between the percentage of scar tissue and the percentage of necrosis (n=21, Spearman’s Rho correlation coefficient = -0.26, p= 0.25). Furthermore no significant difference was found between flaps with and without scar tissue concerning the incidence of necrosis (Fisher’s exact test, p= 0.64). The mean width of the flaps was 4.1 cm (2.8-6.0 cm) and the mean surface area, measured before incision, was 36.1 cm² (18.3-62.2 cm²). After a mean follow-up of 7.8 months (3.0-13.8 months) the mean width of the flaps increased to 4.8 cm (2.4-11.8 cm) and the mean area increased to 39.2 cm² (16.3-60.8 cm²). The width of the flaps at follow-up was 123% (40-311%) of the original width and the area of the flaps was 116% (60-246%) of the original area. No significant decrease of the width and area was registered at follow-up compared to the original width and area at the time of surgery (Wilcoxon signed

<table>
<thead>
<tr>
<th></th>
<th>All flaps (n=21)</th>
<th>Non-islanded flaps (n=17)</th>
<th>Islanded flaps (n=4)</th>
<th>Statistical tests (non-islanded versus islanded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean length-to-width ratio (range)</td>
<td>3.0:1 (2.0:1-4.5:1)</td>
<td>2.9:1 (2.0:1-4.5:1)</td>
<td>3.3:1 (2.5:1-3.9:1)</td>
<td>p = 0.32¹</td>
</tr>
<tr>
<td>Mean surface area at time of surgery, cm² (range)</td>
<td>36.1 (18.3-62.2)</td>
<td>35.3 (18.3-62.2)</td>
<td>39.6 (28.1-60.0)</td>
<td>p = 0.53¹</td>
</tr>
<tr>
<td>Mean surface area at follow-up, cm² (range)</td>
<td>39.2 (16.3-60.8)</td>
<td>37.3 (16.3-60.8)</td>
<td>47.1 (30.9-58.6)</td>
<td>p = 0.18¹</td>
</tr>
<tr>
<td>Mean expansion of surface area, % (range)</td>
<td>116 (60-246)</td>
<td>113% (60-246)</td>
<td>129 (86-208)</td>
<td>p = 0.46¹</td>
</tr>
<tr>
<td>Mean width at time of surgery, cm (range)</td>
<td>4.1 (2.8-6.0)</td>
<td>4.1 (2.8-6.0)</td>
<td>4.2 (3.5-5.0)</td>
<td>p = 0.75¹</td>
</tr>
<tr>
<td>Mean width at follow-up, cm (range)</td>
<td>4.8 (2.4-11.8)</td>
<td>4.9 (2.4-11.8)</td>
<td>4.4 (3.6-5.5)</td>
<td>p = 0.79¹</td>
</tr>
<tr>
<td>Mean expansion of width, % (range)</td>
<td>123 (40-311)</td>
<td>126 (40-311)</td>
<td>109 (80-157)</td>
<td>p = 0.90¹</td>
</tr>
<tr>
<td>Incidence of full thickness necrosis, %</td>
<td>19.0 (4/21)</td>
<td>17.6 (3/17)</td>
<td>25.0 (1/4)</td>
<td>p = 1.00¹</td>
</tr>
<tr>
<td>Mean % of full thickness necrosis (range)</td>
<td>3.8 (0-51.4)</td>
<td>4.7 (0-51.4)</td>
<td>1.3 (0-5.2)</td>
<td>p = 0.90¹</td>
</tr>
<tr>
<td>Incidence of scar tissue in flap, %</td>
<td>52.4 (11/21)</td>
<td>47.1 (8/17)</td>
<td>75.0 (3/4)</td>
<td>p = 0.59¹</td>
</tr>
<tr>
<td>Mean % of scar tissue in flap (range)</td>
<td>13.1 (0-49.4)</td>
<td>12.5 (0-49.4)</td>
<td>15.8 (0-32.8)</td>
<td>p = 0.52¹</td>
</tr>
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</table>

Table 1. Overview of the characteristics of all flaps and of the non-islanded and islanded flaps separately. The statistical tests column displays the statistical comparison of outcomes of the islanded versus the non-islanded flaps. ¹ = MWU Test, ² = Fisher’s exact test.
ranks Test, \( p = 0.42 \) and \( p = 0.59 \), respectively. Figure 8 shows an example of an expanded perforator-based flap. The flap that was converted into a FTG measured 48% of the original width and 35% of the original area 2.5 months postoperatively.

Discussion

So far studies on the application of perforator-based interposition flaps for scar contracture release are lacking in breadth and depth. Mehrotra et al. introduced the “perforator-plus flap”\(^{19} \). They presented ten patients, of whom one case concerned a post-burn scar contracture. Even though these perforator-plus flaps were successfully used, no systematic data on flap geometry were collected. Waterston et al. reported on “ad hoc” perforator flaps for burn scar contracture release\(^{18} \). These “ad hoc” perforator flaps all concerned island flaps, although probably in some cases a local transposition perforator flap, without islanding, would have been sufficient. They performed a retrospective study and structural data on the flap geometry and follow-up were lacking.
We merged the principles of perforator-plus flaps and ad hoc perforator flaps into a treatment algorithm (Figure 4). Initially, flaps were raised with their base intact. However, a flap can be safely and easily islanded intraoperatively, if the need arises, and we consider this flexibility a major advantage of our flap design. Our algorithm for perforator-based flaps provides a safe and versatile tool to ensure sustainable scar contracture release. Firstly, the vascularization of these flaps is secured by the presence of a perforator, which can be found practically everywhere. During this study we confirmed that reliable flaps could be raised based on perforators at all anatomical sites. This reliability was confirmed with low flap necrosis of 3.8%. Harvesting a flap adjacent to a scarred area may also have contributed to final flap survival. We propose that following the initial burn injury the subdermal plexus of healthy adjacent skin may have been adapted due to changes in microcirculation. Therefore the vascularization of this adjacent skin is suited to a situation of inferior blood supply. Practically, it may be compared to a “flap delay procedure”, which was shown to promote flap survival.

Secondly, the best tissue is being used: adjacent healthy skin with subcutaneous tissue, which showed no contraction. In our study we evaluated the changes in flaps geometry using reliable, valid and standardized measurement techniques. We objectively showed that these flaps provide sustainable contracture release. This clinically significant finding demonstrates the adaptation (expansion/stretching) of the perforator-based flaps as opposed to contraction that normally occurs for SSGs and FTGs. After a mean follow-up of 7.8 months both the width and surface area of the flaps had expanded with an increase of 123% and 116% of the original size, respectively. This flap expansion could not be contributed to a possible difference between the flap size prior to incision and the size after suturing the flap. This is quantitatively supported by analysis of these flaps at an average of 2.9 months postoperatively: the width and the surface area of these flap when comparing this to flap dimensions before the incision measured 103% and 100% of the original width and flap surface area, respectively (data not shown).

Thirdly, the applied algorithm proved to be versatile and practical. It was shown clinically that supple scar tissue could be included in the flap design, probably because the subdermal plexus appeared to be preserved in this tissue. Supple scar tissue may therefore be considered as a second choice and safe alternative when sufficient healthy skin is lacking, such as in extensively burned patients.

Initially, the flap was designed with the perforator located at the base of the flap. Later, the perforator was placed outwith the local flap design (Figure 1b and 1c). This small but practical modification circumvented the necessity to explore the perforator and therefore reduced the risk of damaging these vessels. This adaptation reduced operation time for the majority of the cases where no kinking of the flap base occurred and no conversion to an island flap was necessary. Consequently, the operation time required for raising these safe perforator-based flaps is comparable to the operation time for random flaps. On the other hand, no significant differences between non-islanded and islanded flaps regarding the incidence and percentage of necrosis could be demonstrated which means that flaps could be safely islanded when indicated.

Lastly, the perforator-based interposition flap results in a cosmetically superior outcome compared to the standard treatment. All donor sites were closed primarily. The scar of the donor site was situated along the present burn scar and is therefore less notable. These perforator-based flaps can be applied to many other reconstructive scenarios, such as coverage of a trauma wound with exposed bone, chronic wounds or coverage of third or fourth degree acute burn wounds.

Conclusions

The algorithm for perforator-based interposition flaps was found to be practical, safe and feasible. We demonstrated that perforator-based flaps provide sustainable contracture release. For the first time surface area measurements of (perforator-based) flaps for contracture release were objectified. Interestingly, our data even indicated an expansion of the width and surface area of these flaps in time. In this study we confirmed that reliable flaps could be raised based on perforators on all evaluated sites. We believe this algorithm and flap method is easily reproducible and can be incorporated into clinical practice of any surgeon routinely performing burn contracture release.

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References


