Clinical and experimental wound closure using a skin stretching device
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Chapter 4

Tension Decrease during Skin Stretching in Undermined versus Not Undermined Skin: An Experimental Study in Piglets

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INTRODUCTION

Skin defects that can not be closed primarily present a common situation for a plastic and reconstructive surgeon. All kinds of techniques are developed for closure of large defects, varying from split skin grafts to free revascularised flaps.

In 1993, a new technique using the Sure-Closure™ skin stretching system (Life Medical Sciences, Inc., Princeton, N.J.) was introduced. This skin stretching device is designed to harness the viscoelastic properties of the skin by applying a controlled amount of tension evenly along the wound margins using incremental traction. The biomechanical properties of skin, known as mechanical creep and stress relaxation, allow skin to stretch intraoperatively beyond its inherent extensibility in a time span of 30 minutes. The technique eliminates a donor defect and its associated morbidity and achieves sensate reconstructions with good cosmetic appearance of the skin. A lot of important questions remain about the benefits and consequences of undermining of the stretched skin and the viability of the skin margins after skin stretching.

In this controlled study using piglets, we quantify the tension decrease as a result of undermining the skin and during skin stretching in the undermined and not undermined situation and compare the results. The viability of the skin margins up to 1 week after skin stretching was examined in both situations.

MATERIALS AND METHODS

Fifteen Yorkshire piglets, each weighing between 20 and 25 kg, were used in this study. The animals were anaesthetized with a mixture of sufenta forte and ketamine in a dose of 50µg/25mg/kg. After intubation, anesthesia was maintained by spontaneous inhalation of a mixture of halothane (0.8%), air, and oxygen (FiO₂, 47 percent). During the operation the piglets were positioned on their sides. Their skin was shaved and the hair removed. On each flank at a standard position, a 9 x 9 cm square was marked surrounded by a 10-cm area to indicate the area of possible undermining (Fig. 1). Wounds were created by excising the skin and subcutaneous tissue of the indicated square down to the muscular fascia. All the wounds were created at exactly the same location on each animal. This approach was essential because the tension required to close a wound is greater high on the piglet’s back than near the belly and likewise near the shoulder as opposed to the hip.
Two straight needles of the skin stretching device were placed through the dermis opposite each other and 0.5 cm along the wound margin in such a way that the skin would be stretched in a longitudinal direction. Then a no.1 nylon suture was passed through the skin in the center of the wound around the pins and tied in a loop on opposite sides of the wound. A Hounsfield tensiometer was used to measure the tension required to close the wound (Fig. 2). Each measurement was done three times. On one flank, of each animal the surrounding area previously outlined was undermined over the muscular fascia. Once again, the tension required to approximate the wound margins was measured. On the opposite flank, the surrounding skin was not undermined. Which flank was operated on first and whether this flank was undermined or not, were both determined randomly.

When undermining the surrounding skin, we came across multiple musculocutaneous perforators. Some of them had to be coagulated and cut to move the undermined skin freely.

On each wound, the skin stretching system was placed in a way that the U-shaped arms were inserted through the skin and anchored behind the intradermal needles (Fig. 3, above). In this way, the hooks on the undersurface of the U-arms of the device abut against the intradermal needles, which in turn distribute the stretching force along most of the length of the wound margin. After appropriate
The force required to approximate the wound margins being measured with a Hounsfield tensiometer. All measurements were done by pulling on a suture through the skin edge around the needles in the center of the standardized 9 X 9 cm wound.

Tension was applied, the device was locked. By turning the tension screw of the device, approximation of the skin and subcutaneous tissue occurred (Fig. 3, below). The device incorporates in its design a safety clutch, which disengages the tension gauge should the tension on the wound margins increases beyond 2.5 kg. The wounds were closed using the principle of cycle loading. This involves 4 minutes stretching of the skin followed by 1 minute of relaxation by unlocking the system. This was repeated six times over a total period of 30 minutes. As the skin stretched over time, the tension reduced because of stress relaxation. After 30 minutes of skin stretching a final tension measurement was done in the manner described earlier using the same no.1 nylon suture which was placed through the skin in the center of the wound around the pins. The device was removed and the wound was then sutured.

The animals were kept alive for 1 week to evaluate wound healing. The data was analyzed with paired t tests. All experiments were approved by the Medical and Ethical Research Committee for animal experiments.
Figure 3.

(above) The Sure-Closure skin-stretching system was placed in a way that the U-shaped arms were inserted through the skin and anchored behind the two intradermal needles. The pressure gauge reading is zero. (below) Approximation of the skin edges has occurred by stretching the skin. By turning the tension screw of the device, the U-arms abut against the needles, which in turn distribute the stretching force along most of the length of the wound margin. The pressure gauge is rotated almost maximally.
RESULTS

Tension measurements
In this study on 15 piglets, we created 30 standardized defects. In 15 of the defects, the surrounding skin was undermined, and for the other 15 it was not. The results of the experimental study are represented graphically in Figure 4.

![Figure 4](image_url)

These graphics clearly illustrate the additional advantage of skin stretching over that of undermining alone and the relatively smaller difference in tension decrease after skin stretching in undermined versus not undermined wounds.

The mean tension that was required to close all 30 wounds initially was 22.66 N. After undermining the surrounding skin of 15 wounds, a tension decrease of 3.02 N (13.6 percent reduction of the total force that is required to close the wound) was seen. When the undermined skin of the wound was stretched for 30 minutes, we saw an additional tension decrease of 4.58 N. This indicates a total tension decrease of 7.60 N (34.1 percent) as a result of the combination of skin stretching and undermining. Skin stretching for 30 minutes without undermining the surrounding skin showed a tension decrease of 6.10 N (26.5 percent). Skin stretching without undermining showed a tension decrease twice as high in comparison with the procedure for which only the surrounding skin was undermined (Table I). Skin stretching without undermining showed less tension decrease in comparison with
Undermine (n=15)  Not undermine (n=15)

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<td>After skin stretching</td>
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<td>Total tension decrease</td>
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<td>6.10</td>
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On 15 paired flanks, the mean force required to close the wound is listed. Initially, after undermining (only on one flank of each piglet) and after 30 minutes of skin stretching in undermined and not undermined wounds (both flanks). The tension measurements are listed as means in Newton’s.

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<td>Undermining</td>
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<td>Skin stretching</td>
<td>4.58</td>
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<td>Total tension decrease</td>
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The mean tension decrease after undermining, after 30 minutes of skin stretching in undermined and not undermined wounds and total tension decrease. The tension decrease is listed as means in Newton’s.

Wound healing

After the operation on both flanks, the wounds were inspected and dressed. At this time, no dehiscence was seen. After 1 day, of the 15 wounds that were undermined, the central skin margin of four of the wounds showed an area of deep necrosis. This resulted in wound dehiscence and skin necrosis when seen after 1 week. In four other wounds, superficial necrosis of the skin edges was seen, of which only one was healed after 1 week (Fig.5). In all undermined wounds, excessive seroma formation was found.

Of the 15 wounds for which the surrounding skin had not been undermined, we saw a small area of superficial necrosis in only one wound. After 1 week, this wound was completely healed. The seroma formation in these wounds was not substantial. In this series, no instance of infection or hematomas occurred.


**DISCUSSION**

There are various solutions to the problem of closing large skin defects that cannot be closed primarily. These techniques, which often require tissue expanders, skin grafts, regional flaps or microsurgical revascularized free flaps, are time consuming, are sometimes technically demanding, and often cause a donor defect.  

Gibson first described a method to gain tissue for wound closure by skin stretching. Using skin hooks, which were placed in the edge of a flap, it was possible to gain tissue without disrupting the skin. According to some authors, the most efficient way to stretch skin using skin hooks was cycle loading, intermittent stretching of skin followed by short periods of relaxation. Liang et al. used a technique by presuturing the skin with several nylon sutures 1 day before wide excision. They found a decrease in force required to close an 8 x 8 cm large standard-size experimental wound without undermining. The Hershey group reported two experimental studies in piglets in which intraoperative expansion and presuturing were used to close the wounds. They concluded that undermining the wound
margins was a more useful strategy in closing large defects. In both studies, the diameter of the skin defect was 4 cm. The force required to close this wound is small, and undermining or stretching is hardly necessary. In our study, a skin defect of 9 x 9 cm diameter was created. Such a large defect can not always be closed primarily even using excessive force. The skin was stretched six times in 4-minute periods using the skin stretching system. With this device, a stretching force of approximately 25 N can be used.

Using this device, we report a tension decrease after skin stretching that is twice as much as that with undermining the skin. Skin stretching for only 30 minutes significantly reduces wound closing tension in both undermined and not undermined wounds. Although the force required to close the undermined wound after skin stretching was smaller, the actual benefit of undermining the skin was subordinate.

We performed our experiments on piglets, whose skin most closely resembles that of humans. There are similarities not only in histomorphology but also in vascular anatomy and wound healing. Previous studies had no regard for skin circulation. Undermining and skin tension affect the viability of the skin flaps, especially in closing large skin defects. The main blood supply to the skin in piglets is through myocutaneous arteries. Cutting these perforating vessels meant compromising vascular blood supply to the skin.

This study clearly shows, when skin is stretched and closed under a certain amount of tension, undermining impairs viability of skin margins in comparison with not undermined skin. In the undermined wounds, we saw excessive seroma formation and a high incidence of skin-edge necrosis, which in some wounds resulted in wound dehiscence. Skin stretching without undermining the surrounding skin avoided these complications.

We conclude that skin stretching for only 30 minutes using a skin stretching device significantly reduces wound closing tension in both undermined and not undermined wounds. Skin stretching is more important and reduces wound closing tension by twice as much in comparison with undermining alone. Undermining the wound margins before skin stretching gives a small extra tension decrease but has well-known associated complications, such as skin-edge necrosis and seromas. We advise not to undermine the surrounding skin when a large defect is closed primarily using the technique of skin stretching. If a large defect still cannot be closed after adequate stretching, a different technique is necessary.
REFERENCES

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DISCUSSION BY BERNARD HIRSHOWITZ, F.R.C.S.

Many years back, I was privileged to see Dr. Paul Tessier use temporary, strong skin sutures to approximate wound margins, and some half-hour later, he would return to close a wound with more relaxed wound margins using conventional means. This indicates that the concept of skin stretching has been known intuitively for a long while.

However, only as a result of the pioneering contribution of Gibson and Kennedy to the biomechanical properties of skin, plastic surgeons are becoming increasingly familiar with the application of engineering principles in their work. When a skin defect is encountered which is too large for primary closure, the exploiting of the two viscoelastic properties of the skin, creep and stress relaxation, is now more likely to be considered as an adjunct for helping with the wound closure. The time-honored method of wide undermining for the mobilizing of the adjacent skin to facilitate wound closure has inherent drawbacks, because of the damage to the feeding vessels of the skin so undermined. The authors of this article need to be commended in bringing scientific evidence, using animal studies, to support this contention. They have shown that by using incremental traction (load cycling) of intact skin over a period of 30 minutes, although a slightly smaller tension decrease of 6.10 N (26.5 percent) is produced than the combined tension decrease of undermined and stretched skin, 7.60 N (34.1 percent), there are no dangers of delayed healing, skin necrosis, and seroma formation. They have, thereby, also demonstrated that the intraoperative use of this device does not impair the immediate or long-term viability of skin.

It should be remembered that the force required to produce blanching in flaps and undermined skin with its attendant damage to the perforating vessels is usually
much less than that required in uncut skin. Blanching occurs when the fibrous network of the dermis is deformed to such an extent that the lumina of the dermal vessels are constricted and blood flow is impaired. If the condition is unrelieved, necrosis follows. No mention was made of blanching by the authors, probably because of the difficulty of making this observation in piglet skin. The authors' findings do have practical application. Although it is so much easier for a surgeon to undermine skin, using no additional operating equipment to that at his or her disposal, having a skin stretching device handy for such an eventuality is cost effective and could offset the possibility of increased patient morbidity and perhaps scar formation. A cost analysis study of the Sure-Closure skin stretching system was made at the Division of Plastic Surgery at the University of Pittsburgh School of Medicine by K. Narayanan and J. W. Futrell. The summary of the results compiled from data obtained from a 10-patient sample confirms and quantifies the assessment that costs associated with mechanically assisted primary closure using the Sure-Closure system are, on average, less than those with traditional secondary closure techniques. Their study did not specifically deal with the consequences of necrosis and delayed healing associated with skin undermining.

Apart from the Sure-Closure system, various other skin stretching devices have been designed and used for stretching of skin. However, to my knowledge, these devices have not as yet been marketed and, therefore, are not available commercially. The surgeon needs to take into consideration the early "learning curve" in the use of the device. Proficiency can be obtained in as few as two or three cases. Time for each procedure is variable, depending on the severity of the wound and the individual surgeon's skill. It should be noted that the maximal distance between the hooks of the device is 7 cm. Should the skin deficit be somewhat larger than this measurement, it is possible, by pulling on the wound margins with skin hooks, to narrow this gap to enable the hooks of the device to engage the two pins that are threaded through the dermis of the wound margins on either side of the defect. When in place, the device can now become operative. It is assumed that, in the 9 x 9 cm wounds created by the authors on the back of the piglets, a similar approach was used to narrow the size of this defect.
REFERENCES

