Clinical and experimental wound closure using a skin stretching device

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Summary and conclusions
CHAPTER 1

Many techniques have been developed for closure of large defects varying from split skin grafts to free revascularised flaps. Tissue expanders turned out to be an important help to create optimal matching and to avoid unacceptable donor sites. However, the use of tissue expanders also had disadvantages. In 1993, a new technique was introduced based on the use of the Sure-Closure skin-stretching system. This skin-stretching device was designed to harness the viscoelastic properties of skin allowing skin to stretch beyond its inherent extensibility in a short period of time. Many clinical studies have been performed that have provided insights in the potentials of the system. However, solid experimental studies on the application of the system and prospective clinical studies with long-term results are still lacking. Therefore, the studies described in this thesis were performed to provide experimental and long-term clinical data on the usefulness of the skin-stretching device.

CHAPTER 2

The different methodologies of wound closure by means of skin stretching are reviewed. Historical features including non-physiological skin stretching of earlobes and lips by women in French Equatorial Africa are discussed. Clinical skin stretching for wound closure was already described in the 1920s. The literature on skin stretching using skin-stretching devices is reviewed. In 1993, Hirshowitz et al. introduced the Sure-closure skin stretching system. The device can be used intraoperatively and many clinical studies have provided insights in the possibilities of this approach and these are discussed in this chapter.

CHAPTER 3

This chapter describes the design of the Sure-Closure skin-stretching system and its use. Two straight needles are inserted in the dermis of opposite wound margins. The skin-stretching device is placed in such a way that its U-shaped arms are inserted through the skin and are anchored behind the intradermal needles. In this
way, the hooks on the surface towards the skin of the U-shaped arms of the device abut against the intradermal needles, which in turn distribute the stretching force equally along the length of the wound margins. When appropriate tension is applied, the device is locked. By rotating the tension screw of the device, skin and subcutaneous tissue approximate. When the wound margins are brought into approximation the wound can be sutured. The amount of skin gain in millimeters to centimeters is difficult to predict and is dependent on various factors. It is a matter of experience, to whether skin that is available on either side of the wound is sufficient for closure and whether mobility of the skin will allow the skin edges to be brought together. Indications and contra-indications and potential adverse effects are discussed.

Chapter 4

In a controlled study on 15 piglets, the efficacy of skin stretching with a skin-stretching device was tested by quantifying the tension decrease during skin stretching in undermined and not undermined wounds. The viability of the skin margins was examined in both situations. We created 30 standardized wounds. In 15 of the wounds on one flank, the surrounding skin was undermined and in 15 wounds on the opposite flank surrounding skin was not undermined. The force required to close the defects with a size of 9 x 9 cm were measured at the beginning, after undermining and after 30 minutes of skin stretching. Wound healing was examined after 1 day and 1 week as well. A tension decrease of 3.02 N (13.6 % reduction of the total force that is required to close the wound) was found in undermining skin before stretching. Skin stretching for 30 minutes resulted in a tension decrease of 6.10 N (26.5%). The tension decrease due to skin stretching is thus twice as high in not undermined skin as in undermined skin. When undermined skin of the wound was stretched for 30 minutes, a tension decrease of 7.60 N (34.1%) was measured. This difference between not undermined and undermined skin was small but significant. However, undermining surrounding skin involved sectioning of musculocutaneous perforating blood and lymph vessels. As a consequence 7 wounds in the undermined group and none in the not undermined group, showed skin necrosis after 1 week. Excessive seroma formation was found in all wounds of which the skin was undermined. In the not undermined wounds,
problems did not occur with wound healing. We conclude that skin stretching for only 30 minutes using a skin-stretching device significantly reduces wound closing tension. The advantage of skin stretching versus undermining alone is clearly shown. Undermining the wound margins before skin stretching gives a small additional tension decrease but has well-known complications, such as skin edge necrosis and seroma formation.

**Chapter 5**

A quantitative microscopical method has been developed to determine changes in the orientation of collagen fibers in the dermis due to mechanical stress. The method is based on the use of picrosirius red-stained cryostat sections of piglet skin in which collagen fibers reflect light strongly when epi-polarisation microscopy is used. Digital images of sections were analyzed quantitatively on the basis of the length of the collagen fibers in the plane of the section as measure for the orientation of the fibers. The length of the fibers was expressed in pixels and the mean length of the 10 longest fibers in the image was taken as parameter for the orientation of the fibers. To test the procedure in an experimental setting, we used skin after 0 and 30 minutes of skin stretching. The orientation of the fibers in sections of control skin differed significantly from the orientation of fibers in sections of skin that was stretched mechanically during 30 minutes \[76 \pm 15 \text{ (n=5)} \] versus \[132 \pm 36 \text{ (n=5)}\]. The method described here is a relatively simple way to determine (changes in) the orientation of individual collagen fibers in connective tissue.

**Chapter 6**

A controlled quantitative histochemical study was performed in 5 piglets in order to establish changes in undermined and not undermined stretched skin. The skin was stretched with a stretching device for 30 min to close a large skin defect. On each flank of the piglet, at a standard position, 9 x 9 cm wounds were created under general anesthesia. On one flank the surrounding skin was undermined cranially and caudally over a 10 cm area. Sections of skin biopsies, obtained during stretching, were stained with picrosirius red and studied with routine light
microscopy and polarized light microscopy in combination with image analysis. The length of collagen fibers was analyzed as a parameter of changes in the dermis resulting from skin stretching. This newly developed quantitative method appeared to be valid, specific and reproducible. It allowed objective determination of changes in length of the fibers in the plain of the sections and therefore changes in orientation of collagen fibers in dermis as a result of skin stretching. Epidermal thickness did not change significantly under the influence of stretching forces in both undermined and not undermined skin. However, the orientation of the collagen fibers changed significantly as a result of skin stretching. In undermined wounds parallel alignment and elongation of the fibers in the plane of the sections was already observed after 15 min of stretching. The fibers became aligned in the direction of the stretching force, perpendicularly to the wound margin. After 30 min of stretching, the mean major axes of the collagen fibers were longest in the plane of the sections ($p<0.001$). This meant that elongation and parallel alignment of the collagen fibers had occurred. Stretching of not undermined skin for 15 min resulted in significantly stronger parallel alignment in the plane of the sections as compared with undermined skin. This was less well defined after 30 min of stretching in not undermined skin.

We conclude that skin stretching for 30 min, using a skin-stretching device, results in significant histomorphological changes of collagen fibers in the dermis of both undermined and not undermined skin. The fibers reorientate rapidly as a result of stretching forces and become aligned in the direction of the stretching force, perpendicularly to the wound margin. These dynamic changes in collagen fibers explain the significant decreased wound closing tension resulting from skin stretching and thereby enable skin to stretch beyond its inherent extensibility.

**Chapter 7**

The aim of this experimental study was to assess skin microcirculation of undermined and not undermined wound edges that were closed by means of a skin-stretching device. In 8 piglets, under general anesthesia, a 9 x 9 cm wound was created on both flanks by excising skin and the subcutaneous layer down to the muscle fascia. At one flank the surrounding skin was completely undermined. During a period of 30 minutes, wound closure was carried out using a stretching device and the principle of load cycling, which stretch the skin and subsequently
moves the opposite wound edges toward each other. During this period laser Doppler flowmetry (LDF) and transcutaneous oximetry (tcpO₂) were simultaneously applied to monitor microcirculation and oxygenation in the stretched skin of both flanks. Undermining the surrounding skin revealed a 12 percent decrease of the laser Doppler signal and a 21 percent decrease of the tcpO₂ value. Skin stretching resulted in a drop of the LDF signal as well the tcpO₂ values whether or not the skin was undermined. Releasing the stretching device resulted in a rapid normalization of the LDF value in undermined and not undermined skin and a slow return of the tcpO₂ values in not undermined skin close to baseline levels. The tcpO₂ values in undermined skin did not return to baseline levels. Each period of skin stretching resulted in a further drop of the tcpO₂ values. Stretching of undermined skin for 30 minutes induced a significant (p<0.0001) decrease in skin oxygenation. As a result, 50 percent of the undermined stretched skin showed skin necrosis of the wound edges which was still present after one week. Wound healing in the not undermined stretched skin was without problems. It is concluded from these experiments that viability of undermined skin becomes compromised as a result of significantly decreased oxygen availability in the skin during and after stretching. Consequently, it is advised to perform skin stretching on not undermined skin rather than undermined skin. In addition, when skin is stretched to close a large defect it makes sense to employ cyclic loading so that recuperation of skin circulation can take place. Furthermore, LDF appeared to produce an atypical signal in monitoring skin viability of wound edges closed with a skin-stretching device.

Chapter 8

A case of primary closing of a large skin defect is described. A 44-years-old male was treated for penile cancer. After left inguinal lymphadenectomy, a large skin defect in the groin remained, that could not be closed primarily. The skin was allowed to stretch beyond its inherent extensibility with the Sure-Closure™ skin-stretching system and the wound edges were closed without tension. Primary closure of a large skin defect was made possible after cyclic stretching and relaxation of the skin. Large skin defects can be closed primarily using a skin-stretching device. Main advantage is the simplicity of the procedure, lacking the need of more complicated reconstructive surgery.
Long-term results of closure of large skin defects using a skin-stretching device are presented. The principle of the skin-stretching device is based on biomechanical properties of the skin (mechanical creep, stress relaxation) and allows skin to stretch rapidly beyond its inherent extensibility. The device is designed to approximate skin edges of large wounds using a controlled amount of tension to prevent damage to the skin. In a prospective non-randomized study, 30 patients with various wound histories, who’s initial wound could not be closed primarily, were operated using the skin-stretching device. Patients were observed preoperatively, postoperatively and at a long-term follow-up (median, 7 years) for wound control and evaluation of the residual scar and function. In 28 cases (93%), successful closure of the large defect was achieved during operation after a mean stretching period of 30 minutes (range, 10-90 minutes). In the other 2 cases, a split skin graft was used for wound closure. Twenty-two (79%) of the 28 wounds that were successfully closed with the skin-stretching device healed uneventfully without any complications during follow up. With respect to long-term scar formation after 7 years, retraction of the skin (stretch back) was mainly observed on the scalp (average, 56%), back (average, 52%) and shoulder (average, 53%). On the extremities, including thigh and groin, stretch back was significantly less ($p=0.0004$, average, 11%). At 3 weeks after operation, 23% of total scar formation (stretch back) had occurred already, whereas 57% had occurred at 3 months postoperatively and 83% at 6 months postoperatively. Mean patient’s impression of the scar, on a scale of 0 - 10, after 7 years was 7.6. In conclusion, the skin-stretching device provides a relatively fast and simple method for closure of large wounds where extra skin length enables primary wound closure. The long-term functional and aesthetic results were good and the frequency of complications was low. Widening of scars was mainly determined by viscoelastic properties of the skin in situ. Stretch back of the skin on the extremities was significantly less than on the scalp, back or shoulder.