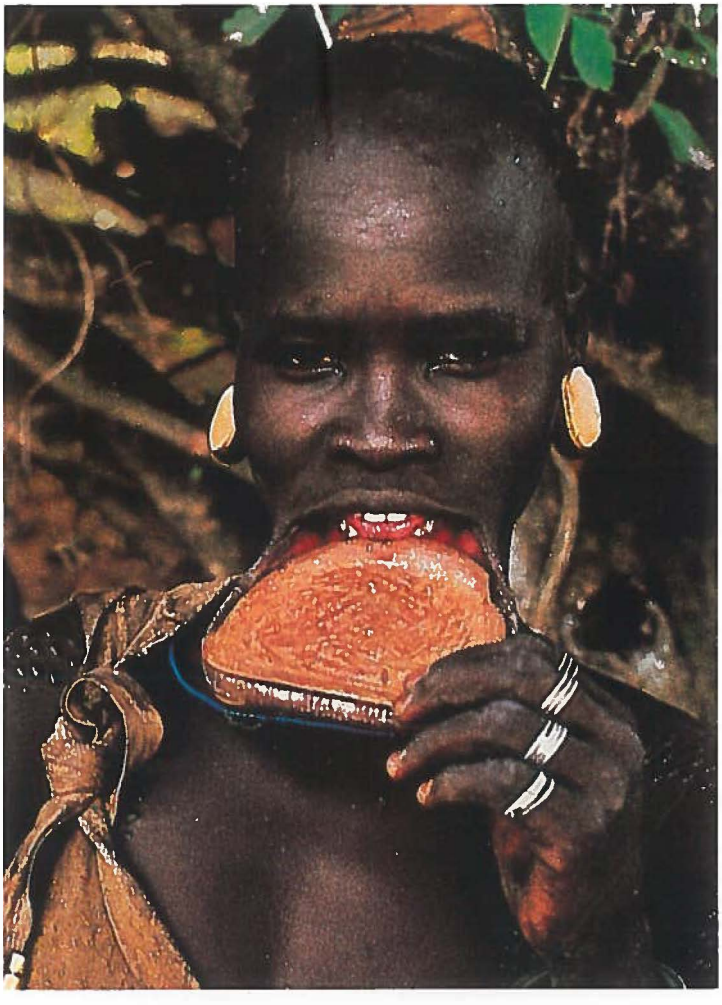
Controlled tissue-expansion in reconstructive surgery

Rappard, Julien Henri Antoine van

CONTROLLED TISSUE-EXPANSION IN RECONSTRUCTIVE SURGERY



Julien H.A. van Rappard

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Cover: Mursi woman of the Omo Valley, Ethiopia (Caputo, 1983).

STELLINGEN

behorende bij het proefschrift

CONTROLLED TISSUE-EXPANSION IN RECONSTRUCTIVE SURGERY

Julien H.A. van Rappard

Groningen, 2 maart 1988

I

Indien indicatiestelling strikt plaatsvindt kan tissue-expansion als een belangrijke bijdrage in de reconstructieve chirurgie worden beschouwd.

(dit proefschrift)

II

Ondanks het feit dat er een verhoogde mitotische activiteit wordt waargenomen in de epidermis betreft tissue-expansion toch meer 'oprekking' dan 'nieuwvorming' van weefsel, dit in tegenstelling tot wat over het algemeen in de literatuur wordt gesuggereerd.

(dit proefschrift)

III

De daadwerkelijke weefseloppervlaktewinst welke onder invloed van een tissue-expander wordt bewerkstelligd is ongeveer een factor 2.5 lager dan op grond van zijn afmeting en volume zou kunnen worden verwacht.

(dit proefschrift)

IV

Er zijn redenen aan te voeren dat kapselvorming in hogere mate plaatsvindt om een geëxpandeerde dan om een niet geëxpandeerde prothese.

(dit proefschrift)

V

Het resultaat van reconstructies middels tissue-expansion is in hogere mate afhankelijk van ervaring dan men met het oog op de eenvoud van de techniek zou denken.

(dit proefschrift)

VI

Een informatienetwerk voor de deelnemende centra van het Interuniversitair Cardiologisch Instituut Nederland (ICIN) zal een positieve impuls leveren aan het hart- en vaatziektenonderzoek in Nederland.

(CADANS, het zenuwstelsel van de cardiologie. Definitiestudie voor een informatienetwerk voor de Nederlandse Universitaire Cardiologie, 1987)

VII

De totale heupprothese is een duurzame en veilige medische voorziening. Na 10 jaar heeft 20% van de hiermee behandelde patiënten een revisie-operatie ondergaan, terwijl ruim 80% van de overgebleven groep tevreden tot zeer tevreden is met hun artificiële heup.

(Van der List, Lange termijn resultaten van de totale heupprothese, 1988)

VIII

In tegenstelling tot het Kocks continente ileostoma dient voor het construeren van het Kocks continente urostoma niet het distale deel van het ileum te worden gebruikt.

(Go, The continent Ileostomy (vervolg), 1988)

IX

Bij patiënten met (cheilognato)palatoschisis verdient het de voorkeur de sluiting van het voorste palatumdeel uit te stellen tot minimaal het derde levensjaar.

X

De door Watson-Jones geponeerde stelling 'It is worse to sprain the ankle than to break it' is onjuist gebleken.

(Van Rappard and Van Houtte et al.; Neth. J. Surg. 39: 65, 1987)

XI

Bij de behandeling van een ossaal defect van langer dan 6 cm in pijpbeenderen heeft het gerevasculariseerde fibula transplantaat de voorkeur boven conventionele behandelingswijzen als spongiosaplastiek of niet gerevasculariseerde botspanen.

XII

Niet alleen infectie maar ook uitdroging leidt tot verdieping van een brandwond. Humane cadaver allografts zijn een goed substituut om eventueel verloren gegane blaarkappen te vervangen.

XIII

Although men and women may be known by their deeds, they are recognized by their faces.

(Charles Gardner Child, III, M.D., 1965)

XIV

Het gebruik van cirkelzaagmachines dient door een ieder na vier uur 's middags vermeden en voor doe het zelvers verboden te worden.

XV

Ter bewerkstelliging van het sluiten van het spreekwoordelijk defect in de hand van mijn vrouw lijkt de Krach van 1987 een betere reconstructieve techniek dan Tissue-Expansion geweest zou zijn.

RIJKSUNIVERSITEIT GRONINGEN

CONTROLLED TISSUE-EXPANSION IN RECONSTRUCTIVE SURGERY

PROEFSCHRIFT

ter verkrijging van het
doctoraat in de geneeskunde
aan de Rijksuniversiteit Groningen
op gezag van de Rector Magnificus
Dr. E. Bleumink
in het openbaar te verdedigen
op woensdag 2 maart 1988
des namiddags te 4.00 uur

door

Julien Henri Antoine ridder van Rappard
geboren te 's Hertogenbosch

1988
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Promotiecommissie:

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UNIVERSITY OF GRONINGEN
THE NETHERLANDS

CONTROLLED TISSUE-EXPANSION IN RECONSTRUCTIVE SURGERY

THESIS

submitted to fulfil the requirements
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on the authority of the Rector Magnificus
Dr. E. Bleumink
to be defended in public
on Wednesday, March 2nd 1988
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by

Julien Henri Antoine ridder van Rappard
born in 's Hertogenbosch

1988
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'I can't understand that while primitive tribes in Africa will expand ears and lips to twelve inches in diameter, we will 'bore' a lower lip to fix the upper.'
Cheidomir Radovan (1932-1984)

To Feikje, our parents,
René, Dominique and Olivier.

CONTENTS

INTRODUCTION

The plastic and reconstructive surgeon is often confronted with tissue defects to be closed. Usually this can be achieved by primary closure, free grafts or pedicled flaps. Free skin grafts often provide an aesthetically unacceptable colour and texture match and can even lead to functional impairment. Flaps can be unreliable and the donor sites can be a problem. To create an optimal 'matching' and to avoid unacceptable donor sites, the use of tissue-expanders turned out to be an important help in plastic and reconstructive surgery. After the first application of a 'prototype' tissue-expander by Neumann in 1957 the greatest part of the development of the technique of tissue-expansion was promoted by the late Chedomir Radovan, Eric Austad and Louis Argenta in the seventies. Many investigations followed, giving more insight in the possibilities of this technique.

At the end of the seventies this new technique was mostly applied to breast reconstruction after amputation for cancer. Since then the list of indications for tissue-expansion has been growing enormously. First, tissue-expansion procedures were used in relatively simple situations as closing defects after excision of naevi, haemangiomas, tattoos or correction of broad scars. Gradually a variety of indications were developed such as burnwounds (Argenta 1983[1], Szalay 1985[1+2], Wyllie 1986, Chang 1986 and Leonard and Small 1986), congenital deformities as syndactily (Morgan and Edgerton 1985) and even craniopagus twins (Shively et al. 1985), ear reconstruction (O'Neal et al. 1984), calf augmentation in polio affected legs (Carlsen 1985), correction of amputation stumps (Rees et al. 1986), expansion before free vascularised tissue transfer (Herndl and Mühlbauer 1986), early (Matthews and Missotten 1986) and late (Leighton et al. 1986) scalp reconstruction and many others. This new technique has proven to be a great acquisition in reconstructive surgery.

Simultaneously with the applications basic research of the (patho)physiology of tissue-expansion was started. Questions have been raised, answers have been controversial. However, as W.C. Grabb said in 1982 discussing a paper about tissue-expansion of Chedomir Radovan: 'The band wagon is rolling'.

This thesis will survey the present-day state of experimental and clinical tissue-expansion and will report on the authors studies of the subject.

Part I

REVIEW OF THE LITERATURE AND AIMS OF STUDY

Chapter 1

REVIEW OF THE LITERATURE

Trying to categorise the literature about tissue-expansion it is possible to divide the relevant information into four parts:
- the history of the phenomenon 'tissue-expansion'
- the clinical aspects of tissue-expansion
- experimental work about tissue-expansion
- questions that remain to be answered

1.1 The history of the phenomenon 'tissue-expansion'

Skin adaptation to growth, obesity and pregnancy are physiologic phenomena. The first application of non physiologic soft tissue-expansion has been an unconscious but very regularly used principle in Africa. Thaw (1938), Burnett (1945), Weeks (1956) and Caputo (1983) describe in several issues of National Geographic Magazine the practice of stretching of lips, earlobes and necks by means of wooden disks or rings. The first clinical application is mentioned by Neumann (1957) who describes skin expansion in the temporo-occipital region for reconstruction of an ear. The technique was later refined by Radovan (1976, 1978, 1979, 1980, 1982[1], 1982[2], 1984), Lapin et al. (1980, 1985), Austad et al. (1982[1], 1982[2], 1983, 1986[1], 1986[2]) and Argenta (1983[1], 1983[2], 1984[1], 1984[2], 1985[1], 1985[2], 1986).

Tissue-expanders of above mentioned pioneers had to be inflated by repeated injection of saline. Austad and Rose (1982) developed so-called self-inflating tissue-expanders. By utilizing an osmotic gradient that draws extracellular water through the wall of the silicone envelope they fill themselves very gradually. Depending on volume and shape the inflation periods of these prostheses are relatively long. Moreover they will contain hypertonic sodiumchloride which in case of rupture can cause necrosis. For this reason they will not be taken into account in this thesis.

1.2 The clinical aspects of tissue-expansion

In the beginning the clinical application was restricted to breast reconstruction (Radovan 1976, Lapin et al. 1980). In time, after more experience was gained the

number of indications increased. Manders et al. (1984[2]) were the first to provide a systematic pattern of indication. Argenta (1984[2]) described his experiences according to the different areas of the body. Scalp, face, neck, breast, trunk, back, buttock and extremities have their own indications. Manders et al. (1984[2]) payed attention to the complications. Their series, containing 35 patients with 41 tissue-expanders, provides a good insight to this problem. The clinical studies are frequently completed by technical experiments e.g. by Argenta et al. (1983[2]), Leonard and Small (1986), Morgan and Edgerton (1985), Shively et al. (1985) and Rees et al. (1986).

1.3 Experimental work about tissue-expansion

After empirical findings in patients, experimental work has been set up. This work can be arranged under the following items:
- cytohistology
- vascularisation
- expansion techniques
- monitoring

Cytohistology:
A clear insight has been given in the cytohistological changes of expanded guinea pig skin by means of light microscopy (Austad et al. 1982[2], Pasyk et al. 1984) and electronmicroscopy (Pasyk et al. 1982, Pasyk 1984). New formation of tissue in the epidermis of expanded skin is assumed but not definitely proven (Austad 1982[2], 1986[2], Mackinnon and Gruss 1985). Unfortunately, the experiments took place in guinea pigs whose skin differs very much from that of human beings.

Vascularisation:
Under the influence of expansion vascularisation of skin is supposed to increase (Cherry et al. 1983, Sasaki and Krizek 1983, Sasaki and Pang 1984). However, when the results of these experiments are reviewed critically, the stated increase in vascularisation is probably similar to the delay phenomenon.* The role of the capsule, which is formed around the tissue-expander has been suggested to interfere with this vascularisation. In various articles there is a controversy about this subject (Cherry et al. 1983, Sasaki and Krizek 1983, Leonard and Small 1986).

Expansion techniques:
The main problems are the selection of proper size, shape and volume of implants. The frequency of inflation also needs full attention. Radovan (1984) and Morgan and Edgerton (1985) advised that the base of the expander should have the same size as the defect to be reconstructed. In that way one would achieve doubling of

* Delaying a flap means partly dissecting and resuturing it, which is supposed to open up the collateral circulation.

the surface-area. Gibney (1984) advised that the base of the expander should have 2.5-3 times the size of the defect to be closed. Manders et al. (1984[2]) advised to place the largest tissue-expander possible. Shively et al. (1985) presented a more mathematical approach but this depends on an extensive and therefore hardly practical computer programme.
Brobmann and Huber (1985) experimented on pigs to determine if it was more advantageous to use one large expander or several small ones. It seemed that one large implant is more efficient than several small ones.

Monitoring:
Lee et al. (1985) experimented monitoring of expanded tissues. They analysed changes in intra-expander pressure under the influence of anticontractile drugs. Measurements of the rate and extent of expansion showed that there was a statistically significant increase in these parameters under the influence of Papaverine or Cytochalasin D.
Hallock and Rice (1986) examined vascularisation of expanded skin by means of percutaneous Po_2 measurements. In this way they determined an optimal inflation time.

1.4 Unanswered questions from the literature

Many questions, which have not been answered satisfactorily, can be encountered in the literature. Chronological listing of authors and their questions are as follows:

- Austad et al., 1982[2].
  Is tissue-expansion simply a 'loan' or truly a 'dividend' of extra tissue?

  What is the clinical implication of atrophy of expanded panniculus muscle?
- Cherry et al., 1983.
  What is the implication of dermal and panniculus carnosus thinning in tissue-expansion on the blood supply of the skin?

  What is the actual mechanism of increased vascularity associated with tissue-expansion?
- Ryan, 1983
  What is the stimulus to new skin growth in tissue-expansion?

  What is the interference of tissue-expansion with lymphatic drainage?
- Sasaki, 1984
  Does skin expansion involve only stretching of existing tissue?

  If new skin is formed, is it not possible to expand the same area of skin repeatedly to maximize the excess skin available for reconstruction?

  What is the best method of achieving a maximal volume of skin pocket for installation of a breast prosthesis?

- Argenta, 1984[2]
  What is the variation in fibroblasts, collagen and myofibroblasts in the capsule around tissue-expanders compared to capsule around non-expanded prostheses?

- Vistnes, 1984
  What happens exactly in tissue-expansion?
  - Do intermolecular bonds rupture or weaken to allow sliding apart of collagen fibrils?
  - Is an enzyme released in response to trauma that weakens the galea?

  Is a 'bathtub' depression observed on muscle after tissue-expansion only temporary muscle compression and not muscle atrophy?

  Does capsule remain after the expansion and in part makes up some of the apparent thickness of the skin?

- Brobmann and Huber, 1985
  What is the reason of a decrease in dermis thickness but no decrease in epidermal thickness when expanded skin is compared with un-expanded skin?

- Shively et al., 1985
  Some system to convert tissue-expanders volume to surface-area is needed so the surgeon can select the proper size expander for specific needs.

- Mackinnon and Gruss, 1985
  Is there a tendency of expanded skin to return to its natural pre-expansion state?

  What is the most expedient time-table to use to obtain maximum expansion over the shortest period of time?

  What is the effect of tissue-expansion on a peripheral nerve?

- Lampe et al., 1985
  Tierexperimenten sollen weiter erklären müssen ob es zu einer wirklichen Hautvermehrung kommt, oder welche andere Ursache den oft verbluffenden Hautgewinn erklären können.

- Gibson, 1986
  The time of tissue-expansion seems too short for much new growth to have occured. Is it then just 'mechanical creep'?

- Dover, 1987
  How does skin expansion work?

1.5 References (See part IV)

Chapter 2

AIMS OF STUDY

Developments in reconstructive surgery usually have an empirical background. The development of the tissue-expansion technique is no exception. However, questions have arisen gradually, which justify animal experiments in order to provide a scientific base to the use of tissue-expanders. In our opinion obscurities are still present on the cell level, the capsule and assessment of skin surface gain. Therefore, the aim of the present study is to analyse the following basic aspects of tissue-expansion:

I What are the cytohistological changes in soft tissues under the influence of tissue-expansion?
II Is tissue-expansion a loan or truly a dividend?
III What is the role of capsule formation in tissue-expansion?
IV Is it possible to be objective about surface-area increase in tissue-expansion?
V Arrangement of the clinical findings in tissue-expansion.
VI Is the success of tissue-expansion dependent on experience?

Part II

EXPERIMENTS IN TISSUE-EXPANSION

Chapter 3

HISTOLOGICAL CHANGES IN EXPANDED SOFT TISSUE

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HISTOLOGICAL CHANGES IN EXPANDED SOFT TISSUE

'The time of tissue-expansion seems too short for much new growth to have occurred. Is it then just "mechanical creep"?'
Gibson, 1986

3.1 Introduction

Plastic and reconstructive surgeons are often confronted with tissue defects requiring closure. Many techniques, varying from split skin grafts to free revascularised flaps, can be used. All have their own advantages, restrictions and 'prices'. In the last few years the tissue-expansion technique is added to these methods. With the help of a silastic balloon, in general implanted under the subcutaneous fat layer and above the deep fascia, the overlying tissue can gradually be stretched. With the so gained extra tissue an adjacent defect can be closed. Advantages are an optimal functional and cosmetic result, no residual donor defect and minimal operative procedures, compared to extensive flap surgery. Disadvantages such as one extra operation, frequent visits to the out-patient department and higher costs in comparison to simple split skin grafting, have to be considered. Nevertheless, tissue-expansion has become a commonly used technique in the past few years.

This newly accepted technique is based on already known physiological phenomena. Tissue-expansion has been observed in nature from the beginning of mankind. The 'pregnant abdomen' is an example of how overlying soft tissue can be extended to accomodate the underlying mass of increasing size. The African lip- and earlobe stretching are other examples of non-clinical tissue-expansion. In 1957 Neumann[1] was the first to apply clinically the concept of tissue-expansion. An implanted rubber balloon was used to create extra tissue for reconstruction of an ear. At the end of the seventies Radovan[2], Argenta[3] and Lapin[4] refined and improved the technique of tissue-expansion. At first it was used mainly for breast reconstruction; later on the most diverse indications were described.[5-14]

Together with its wide acceptance, interest in its underlying physiological mechanisms grew. The most important question that has been posed in the last few years is: 'What happens to the expanded tissue?'.[15-21]

Austad et al.[15] and Pasyk et al.[22] carried out experiments regarding histological changes in expanded soft tissue. Unfortunately, in contrast with what is used clinically, they did their experiments with self-inflating expanders. In this way a very gradual expansion takes place. Moreover, they described the cytohistological changes in guinea pigs. These animals all have a 'scruff', which allows the skin to

move freely on the deeper tissue and to be picked up in large folds.[23] Especially this last quality makes this kind of animals less suitable for experiments on (skin) tissue-expansion. In contrast, the pig'skin is widely accepted to resemble that of man more closely than that of any other laboratory animal; in some ways even more than that of baboons and monkeys.[24] To obtain more information regarding changes at the cytohistological level during expansion of soft tissue, we performed our tissue-expansion experiments in pigs (Göttinger Minischwein).

3.2 Material and methods

A series of four mixed-breed, fully-grown, male, castrated pigs (PI-PIV) was used for the experiments. The average weight was 32 kg (±2 kg), and their mean age was 9 months (±1 month). They were housed in a temperature and light controlled room. Water and food were offered ad libitum. Each animal was kept in an apart stay. General anaesthesia was given during all operations.

Five pre-shaped silicone tissue-expanders (rectangular, 250 cc, 10-6-5 cm, remote fill dome, Cox-Uphoff International) were implanted under standard conditions and in a standard way in each animal on locations A, B, C, D and E (Fig. 3.1). Different protocols of inflation were applied to study the most gentle mechanical stress to the skin.

PI and PII

The expanders situated in locations A, C, D and E were gradually inflated in the manner in which they are usually employed in human practice (initially 50 cc, 50 cc each week). In this way the maximal volume was reached after four weeks. The expander in location B was not inflated at all and acted as a sham operation, while F was the control site.

PIII and PIV

Five tissue-expanders per animal were implanted in the same way as described above on locations A, B, C, D and E (Fig. 3.1). Inflation of the expanders on the

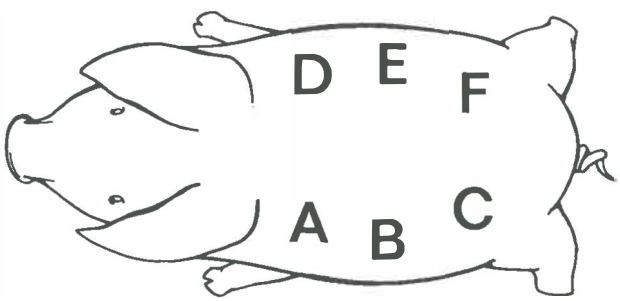

Fig. 3.1: Schematic drawing indicating the locations where expanders are inserted.

different locations took place in the following way and is marked as percentage of the maximal volume (250 cc).
A : 0 cc in total (sham operation)
B : 10% initially, 15% weekly (6 weeks)
C : 25% initially, 25% weekly (3 weeks)
D : 50% initially, 50% after 1 week
E : 100% initially
F : control

Biopsies of all locations in all pigs (I-IV) were taken after different time intervals (in days after the operation): T0, T7, T14, T21, T28, T35, T42, T180.

The biopsies taken for light microscopy were diamond-shaped and measured 1 to 0.5 cm. They were all taken on a comparable location above the expander. The biopsies were 'stretched' immediately after excision to the same surface as they had before excision. After pinning on cork the biopsies were fixed at once in formaldehyde solution (4%, neutral buffered in 33 mM $NaHPO_4$ and 42 mM $NaHPO_4$).

The biopsies taken for electron microscopy measured 1 mm x 1.5 mm,were immersed in ice-cold phosphate buffered glutaraldehyde (1.5%) for 3 hours, subsequently transferred to Na-cacodylate buffer 0.1 M (pH 7.4) and submitted to Epoxy-Resin embedding.

For light microscopy 6 μm thick sections were submitted to 8 different staining procedures (table 3.1). For transmission electron microscopy grey sections of resin embedded specimen were stained with Lead citrate and Uranyl acetate and studied under a Philips EM 300 microscope. A pilot study[25] revealed that there were no cytohistological differences between the samples taken after fixing the total location including the tissue-expander or biopsies taken intraoperatively with subsequent fixation.

Table 3.1: Eight different staining procedures were used for visualisation of the different cytohistological structures.

- Ferrohaematoxylin-staining according to Weigert (Azofloxin z.g. HWA)
- Trichrome-staining according to Goldner (modification according to Jerusalem)
- Methylgreen pyronin-staining according to Kurnick MGP
- PAS-staining
- Orcein-staining according to Pranter
- Orcein-staining according to Gieson
- Van Gieson-staining according to Hanssen
- Azan-staining according to Heidenhain

3.3 Results

The histomorphological changes resulting from tissue-expansion are difficult to

quantify. For this reason the histological changes occurring in the different layers will be described mainly qualitatively and statistical relevance will be given only where possible.

– Epidermis

In comparison to the control and 'sham' group, epidermal thickness did not change under the influence of expansion ($p > 0.05$, ANOVA). Even in the rapidly expanded locations normal thickness was seen after 7 days. Occasionally the poly-

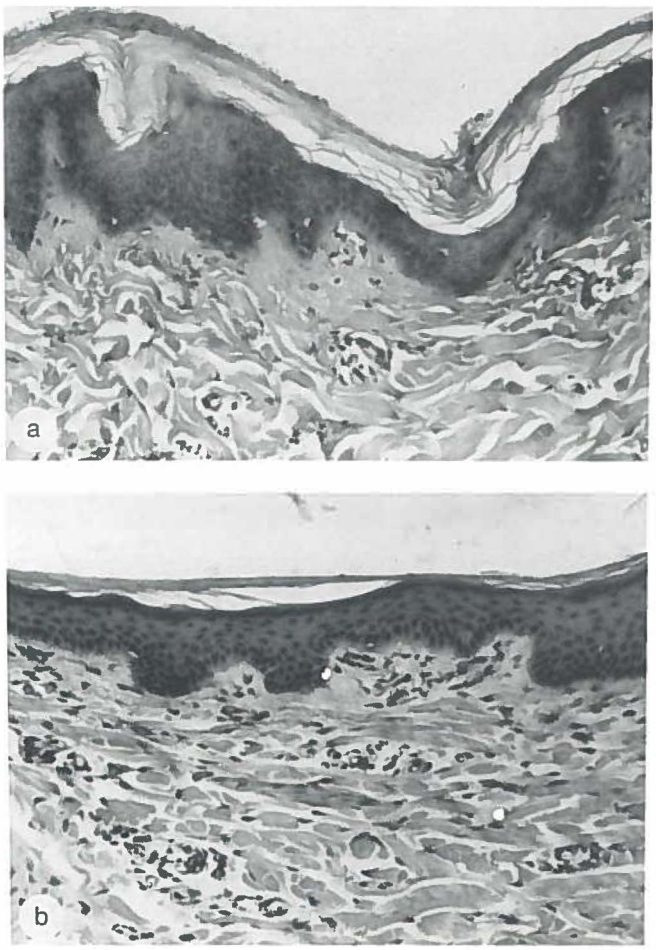

Fig. 3.2: Epidermal-dermal junction in:
a) Control skin. Peaked and dome-shaped high dermal papillae impact to a wave-like appearance of the border line. Several papillae contribute to one ridge (× 200, PAS and hematoxylin).
b) Stretched skin. Loss of ridges and reduction of papillar size, result in a flattened border line and epidermal surface (× 200, PAS and hematoxylin).

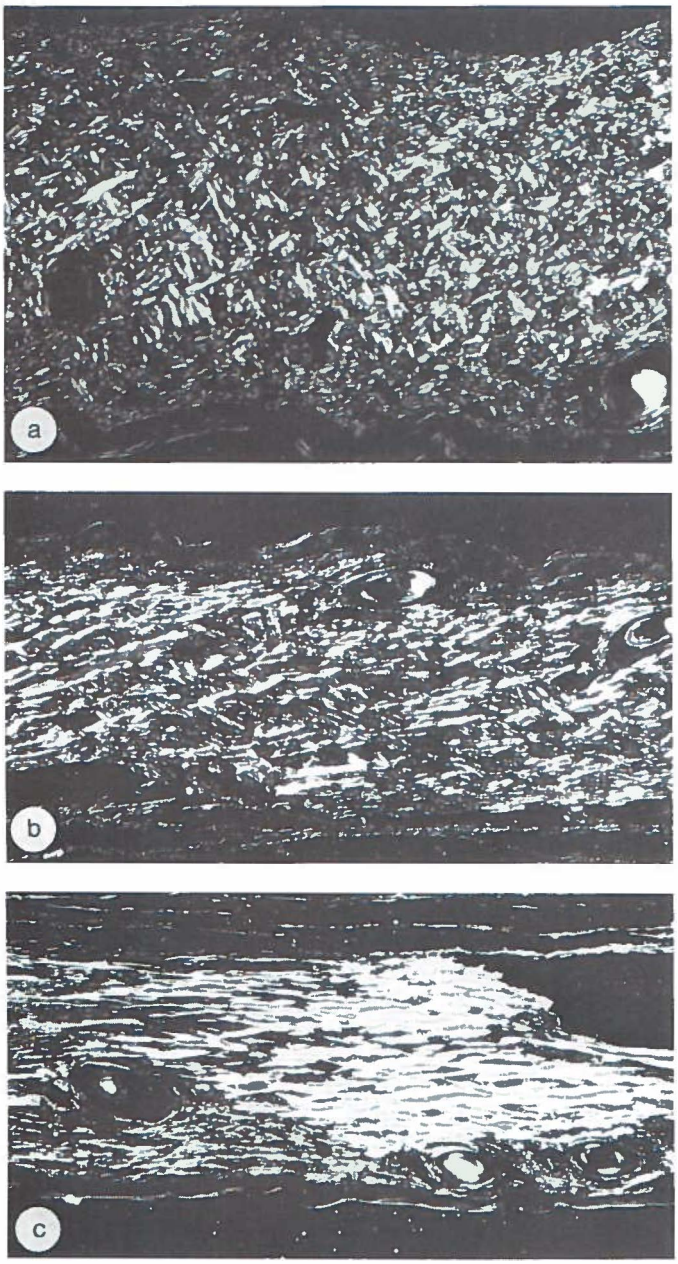

Fig. 3.3: Texture of dermal collagen fibres in:
a) Control skin. Bundles of collagen fibres cross at a mean angle of about 70° (× 30, polarised light).
b) Moderately stretched skin, crossing of collagen fibre bundles in an acute angle (× 30, polarised light).
c) Extremely stretched skin. Collagen fibres run almost parallel to the surface (× 30, polarised light).
Note in b) and c) the reduction of dermal thickness.

hedral cells appeared somewhat flattened. Light microscopically no increase in mitotic activity could be recorded. In the standard expanded locations there was no difference in the four histologically distinguishable layers (stratum lucidum is absent in pigskin) or in the different cells. By contrast, in extremely acute expansion (PIII and IV locations D and E) spontaneous erosion of the epithelium sometimes occurred. The nuclei became pyknotic and on the level of the rete ridge cleavage at the basal membrane was seen. This resulted in some edema and dermal capillary injection. A marked flattening of the rete ridge was observed, which was most pronounced in locations where expansion was fastest. After more than 6 months the undulating complementary pattern did not return (Fig. 3.2).

– Dermis

The dermis appeared less tolerant to expansion than the epidermis. Its thickness diminished in comparison to that of control and 'sham' operated animals and this thinning was dependant on the rate of expansion ($p = 0.0001$, ANOVA). However, neither the distribution nor the density of fibroblasts was significantly different from unexpanded skin. The usual 3-dimensional texture of the collagen fibers is characterised by a cross linkage of collagen bundles by about 70°. The more acute the expansion the more the angle of this cross linking diminished. This phenomenon started in the stratum reticulare while in the later stages the stratum papillare was also involved. Finally all collagen fibers were running almost parallel to the surface. After 6 months the 3-dimensional image still showed angles less than 70°. The collagen fibres showed a tendency to hyalinization (Fig. 3.3).

– Dermal appendages

- *Hair*: The papillar epithelium of the papil of the hair roots, though sensitive to anoxia, showed no change at all in the expanded skin. The distance between the hair follicles in expanded skin became larger, new hair formation was not seen.
- *Sebaceous glands*: These were relatively insensitive to stretching. Incidental signs of blockage, either as a result of inactivity or by compression of the excretory duct, were noticed.
- *Arrectores pilorum*: These hair adnexes appear relatively insensitive to stretching. Only in the situations of extreme expansion (PIII and IV locations D and E) the muscle cells underwent atrophy and even necrosis. In these cases no signs of recuperation were noticed (Fig. 3.4).

– Subcutaneous fat

This layer is very intolerant to expansion. Its thickness diminished in standard expansion, while clear signs of atrophy were found. In faster expansion necrosis of fat cells is frequent, while recuperation was absent even after a period of more than 6 months after expansion.

– Muscle

The muscle layer of the pig'skin is a non-continuous coat called panniculus carnosus. It does not exist in humans with the exception of the platysma muscle in the antero-lateral neck region. This layer is sensitive to stretching and pressure. After exceeding a certain threshold of expansion, atrophy of muscle fibers was a common finding. The striation pattern decreased or was lost, hyalinisation occurred and the cells became necrotic. Formation of giant cells and calcification of the damaged tissue was the final step of the catabolic events (Fig. 3.5).

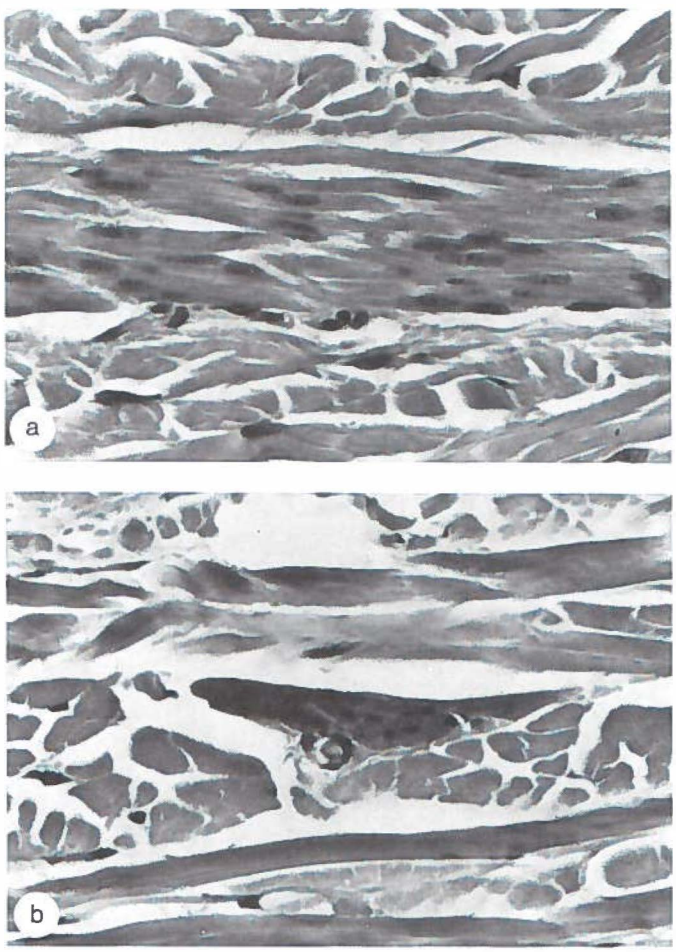

Fig. 3.4: Arrector pili muscles in:
a) Control skin. Nuclear structure and cytoplasmic organization clearly recognizable.
b) Extremely stretched skin. Condensed cytoplasm and nuclei suggest coagulation necrosis.
Note in a) and b) the almost equal fibrocyte density (× 400, hematoxylin and eosin).

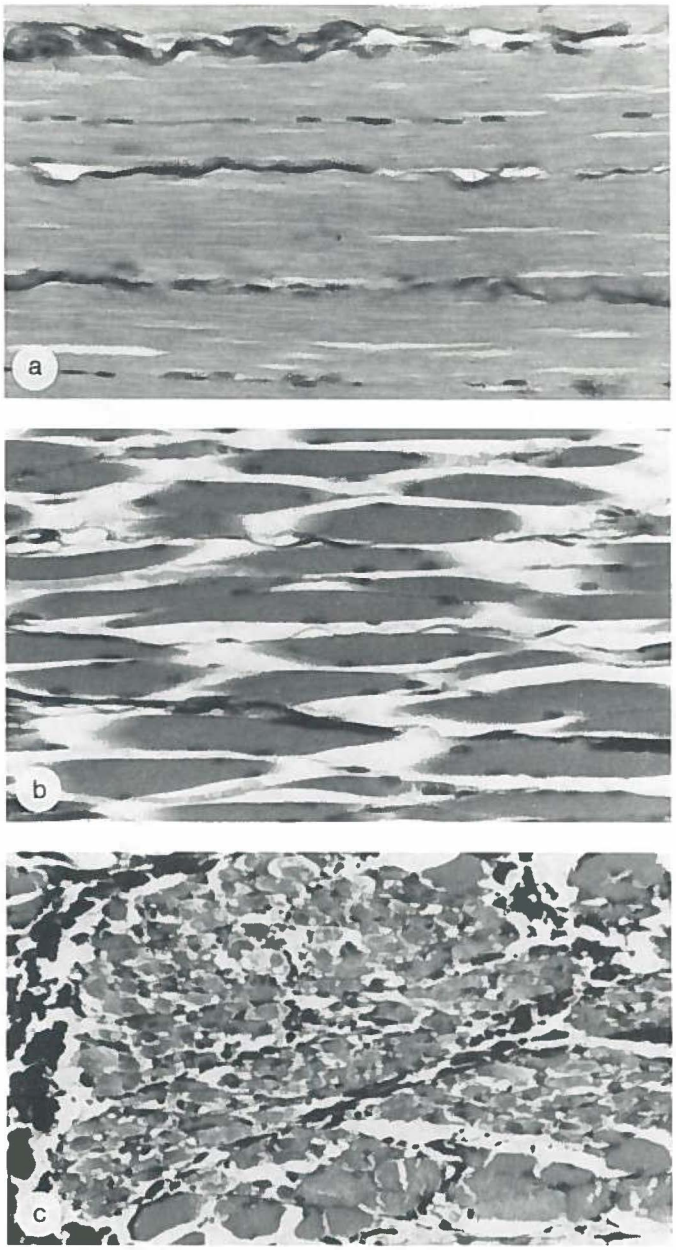

Fig. 3.5: Panniculus carnosus in:
a) Control skin. Close arrangement of striated muscle fibres (longitudinal section, × 300, van Gieson).
b) Moderately stretched skin. Opening of intercellular space due to shrinkage by atrophy of individual muscle cells (oblique section, × 300, van Gieson).
c) Extremely stretched skin. Area of muscle cell necrosis.
Note the thickening by condensation of perimysial connective tissue (cross section, × 300, van Gieson).

– Capsule

Usually a capsule develops around tissue-expanders, like around all foreign bodies. Primarily granulation tissue existing of macrophages, fibroblasts and lymphocytes developed. Within about 7 days a double layered capsule, consisting of a cell-rich inner layer of macrophages and an outer coat of lymphocytes and mainly fibroblasts, was present. During the course of time the outer coat gradually became more rich in collagenous fibres. During the first phase this capsule and the bordering subcutis was abundantly vascularised. The border between capsule and subcutis became clearer secondary to the fading of the sterile inflammatory reaction. Later the capsule close to the tissue-expander was covered by a continuous cellular

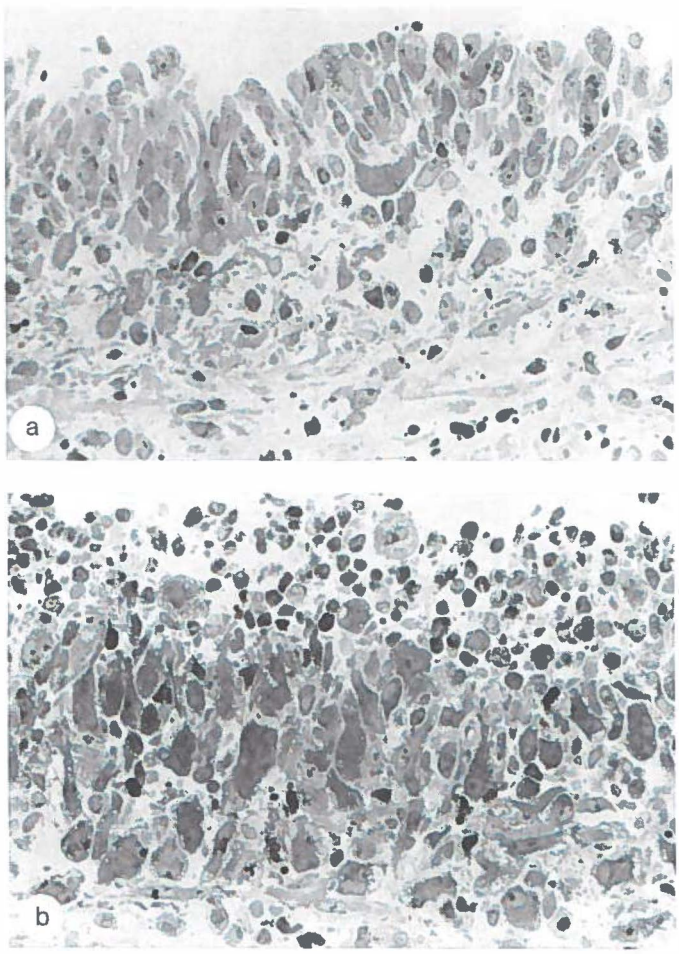

Fig. 3.6: Innermost coat of capsule:
a) Consisting of 3 to 4 layers of macrophages only with underlying granulation tissue.
b) With neutrophils and cellular debris intersperged between macrophages and expander.
a) and b) from the same specimen (semithin sections for TEM, × 400, toluidine blue).

coat consisting of macrophages. Adjacent to the macrophages a capsule of collagen fibers arose, which condensed progressively. However, the histomorphology of the capsule surrounding the same tissue-expander could vary considerably. Differences were also noticed during the course of the experiment ranging from only granulation tissue after three weeks to a chronic progressive inflammatory reaction after 10 weeks. Incidentally an increased number of eosinophilic granulocytes were present. In none of the sections signs of an acute or chronic bacterial infection were seen. Giant cells were occasionally associated with hemorrhages. Now and then these multinuclear cells contained a birefringent material possibly identical with silicon particles derived from the tissue-expander. There was no statistically relevant correlation of the histomorphology of the capsule and the rate of inflation. The reactivity of the capsular granulation tissue is probably more dependant on local factors like hematoma, mechanical factors, possible allergic reactions to for example talcum powder, suture material or gauze, local immunologic disregulation, and necrosis of overlaying fat and muscular tissue (Fig. 3.6 and 3.7).

– Vascularisation

In this morphohistological study an increase in vascularisation of the expanded skin could not be demonstrated. Occasionally the expansion resulted in extravasations. Rupture of small vessels occurred first in the subcutis, especially in the fat layer and following increasing expansion, also in the dermis. This extravasation resulted in a sterile inflammatory reaction characterized by the appearance of

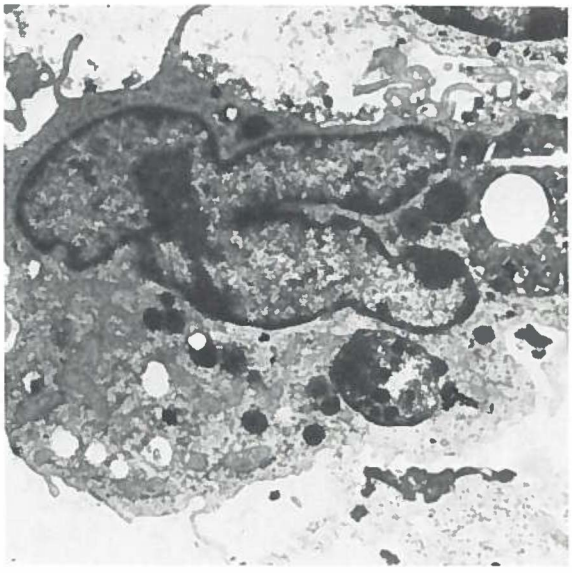

Fig. 3.7: Macrophage from free border of innermost capsule, exhibiting primary lysosomes and phagolysosomes (TEM, × 5400).

macrophages, lymphocytes and fibroblasts. Though bradytrophia can lead to calcification, this reaction was not seen in acute stretching, except in regions of distinct muscular necrosis.

– Nervous tissue

The nervous tissue appeared tolerant to expansion. No clear difference was seen between the control or sham sites and the expanded sites. An occasional condensation of the perineurium in the expanded tissue might indicate a slight atrophy by pressure.

3.4 Discussion

Although soft tissue, when adequately expanded, has an apparently normal appearance from the macroscopical point of view, several changes are noticeable at the microscopical level. The presented findings reveal different tolerances towards expansion in the different layers. All layers with the exception of the epidermal layer seem to suffer under the expansion process. A circumscript increase in fibroblasts in the dermis is probably a reaction on the inflammatory process that results from the expansion. An increase in the number of dermal collagen bundles was not noticed (Fig. 3.8). Fat cells and muscle cells first decreased in number and in size, while fast expansion caused necrosis followed by fibrosis in regions of damaged

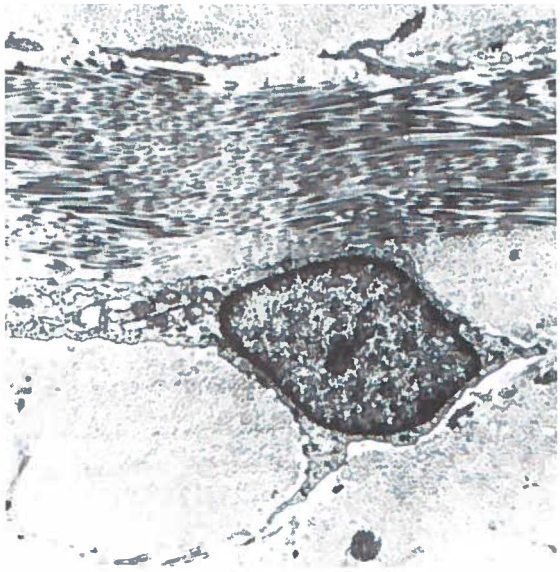

Fig. 3.8: Fibrocyte from stretched skin with normal appearance. No indications of production of secondary collagen (TEM, × 6500).

tissues.In our experiments the sterile inflammation was more pronounced than described by Austad, et al.[15], while, in contrast, the increase in vascularisation was absent. Particularly the harm caused by a relatively fast expansion demonstrates that, with exception of the epidermal layer, tissue-expansion results only in a passive stretching of tissue.

According to Gibson[21,26] there are three possible ways in which skin can be stretched:

1) 'by using its inherent extensibility': this is the phenomenon that provides the possibility to close small skin defects directly.
2) 'mechanical creep': the gradual stretching of skin beyond the limits of its inherent extensibility.
3) 'biological creep': gradual stretching of skin lying over a slowly expanding subcutaneous mass as for example the pregnant uterus. This is not 'stretching' as commonly understood, since the skin is not thinned while it extends. In other words, it is effected by metabolic activity, creating new epithelium, collagen and elastic fibers, bloodvessels, nerves and lymphatics, probably stimulated by hormonal factors.

Since striae in the abdominal skin usually remain after pregnancy, it has been suggested that the expansion of the pregnant uterus occurs too fast to give the skin enough time to 'grow'.[21] Our present data indicate that tissue-expansion is anything but 'biological creep'. The explanation may be found in the fact that the skin as an organ is too specialized to allow regeneration. The same holds true for other highly specialised organ systems, for example the central and peripheral nervous system, the lung and kidney. The reaction to an injury to these organs is only healing of the original structure by fibrosis. Only in very primitive animals (as for example worms and reptiles) full regeneration of parts of the body is seen. In contrast, in the epidermis of higher species a pool of undifferentiated stemcells ensure a constant supply of cells which can undergo specific differentiation (keratinization).[27] This explains the relative tolerance for expansion of the epidermis and the absence of thinning of this layer and suggests the formation of new tissue. Extensive experiments done with flowcytometric techniques in expanded pigskin demonstrated an increase in mitotic activity.[28] Indeed, as demonstrated by Francis and Marks, stretched epidermis always reacts with increase of mitotic activity.[29] The epithelial cells of the epidermis react – also temporarily – to various stresses.[30] For instance exposure to mechanical stress produces horny skin on the hands of mineworkers. When no more mechanical stress is exerted the horny coat exfoliates. U.V. irradiation as after exposure to sunlight not only brings about the tan but also induces an increase in epidermal thickness. Everyone must have experienced that after the holidays the tan fades and skin regains its smoothness. Therefore, secondary to exposure to shear forces the epidermal cells will react immediately until the stress is compensated.

Finally, as mentioned above, it can be concluded that in almost all layers, with exception of the epidermis, our observations suggest that tissue-expansion is really more stretching than formation of new tissue. The frequently experienced widening of scars after clinical application of the tissue-expansion technique, which originates presumably from the process that was termed 'stretch-back' by Nordström[30], confirms these findings. Moreover, the exact role of the barely changing epidermal layer in the total procedure, has to be clarified.

However, we are aware that our material is limited and that the presented data are therefore somewhat preliminary. Furthermore extensive studies will take place to compare our animal results with findings in human tissue. Moreover, the period of time of the experiments (7 months) is too short to rule out the possibility of dysplastic or metaplastic changes on the long term after tissue-expansion.

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Chapter 4

EPIDERMOPOIESIS IN CONTROLLED TISSUE-EXPANSION

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EPIDERMOPOIESIS IN CONTROLLED TISSUE-EXPANSION

4.1 Introduction

The plastic and reconstructive surgeon is often confronted with tissue defects that have to be closed. Usually it is possible to do this by primary closure, using free grafts or pedicled flaps. Several problems can arise in these latter cases. Sometimes the grafts provide an aesthetically unacceptable colour and texture match and can even lead to functional loss. Also the reliability of the flaps can be a problem as well as produce undesirable donor defects. To create an optimal 'matching' and to avoid unacceptable donor sites, the tissue-expansion technique has recently become an important asset in reconstructive surgery. With an inflatable balloon which is placed under the subcutaneous fat above the deep fascia, the skin is gradually stretched. In a second operation which takes place some weeks later, the balloon is taken out and an adjacent defect is then closed without leaving any donor defect.

Developments in reconstructive surgery often have an empirical background, and the development of the tissue-expansion technique is no exception. However, academic questions have arisen which necessity animal experiments. The basic question in this technique is: 'Does tissue-expansion provoke the formation of new tissue or is it just stretching of skin?' (Austad et al., 1982 and Gibson, 1986).

Extensive histomorphological studies, especially of Austad et al. (1982 and 1986) and Pasyk et al. (1982), give insight into changes which take place in soft tissue under the influence of stretching. Unfortunately, in these experiments common laboratory animals such as rats or guinea pigs were used. These animals all have a 'scruff' which allows the skin to move freely over the deeper layers and to be picked up in large folds (Patterson, 1968). Specially this latter quality makes this kind of animal not suitable for experiments on (skin) tissue-expansion.

The skin of the pig is widely accepted to resemble that of man more closely than any other laboratory animal, in some ways even more than that of baboons and monkeys (Ordman & Gillman, 1966). For this reason we performed our experiments on tissue-expansion in fully grown pigs (Göttinger Minischwein) whose skin most closely resembles that of humans (Glodek and Oldings, 1981).

In a previous project we studied the cytohistological changes of expanded soft tissue in pigs in comparison to man (Van Rappard et al., submitted). In this paper we study the changes in the epidermis and investigate whether a proliferative response is evoked by expansion. As a technique we used flowcytometry on epidermal cell suspensions from expanded skin.

4.2 Material and methods

Operation technique

Four mixed breed, male, castrated Göttinger minipigs were used in this experiment. The average weight was 33 kg (± 3 kg), and their mean age was 10 months (± 1 month). They were housed two by two in a temperature and light-controlled room, while water and food were offered ad libitum. They were operated in a standard way (Van Rappard et al., submitted). In three animals (PI-PIII) used for cell kinetic studies five tissue-expanders (rectangular 250 ml, 10-6-5 cm, remote fill dome, Cox-Uphoff International) per animal were implanted under the subcutaneous fat layer but above the deep fascia. They were placed at locations A, B, C, D, E as marked in figure 4.1. The expanders at locations A and B were inflated immediately after the operation until the maximal volume of 250 ml was reached. The expanders situated at locations D and E were initially filled to 25% of the maximal volume, additional filling with 25% of the maximal volume took place at weekly intervals. In this way the maximal volume of 250 ml was reached in three weeks. The expander in location C was not filled at all and functioned as 'sham' operation, while the F location was used as the control. 42 Days after the first operation on all locations, defects, as large as the skin surface gain were created. They were all closed with expanded skin by means of random pattern advancement flaps. In locations C and F only incisions were performed as no tissue had been excised. In one additional pig (PIV), used for quantitative assesment of stretching (see below), one expander was inflated to a volume of 250 ml.

Skin sampling

From all locations A, B, C, D, E and F of each pig (PI-PIII) skin specimens (diameter ± 3 mm, thickness ± 0.4 mm) were taken for cell kinetic studies at regular time intervals. These were taken with a razor blade, without anaesthesia, using a flexible metal guard in which a circular hole was punched (Bauer & De Grood, 1976). For quantitative assessment of epidermal stretching 2 mm punch biopsies were taken before and immediately after implantation of an expander.

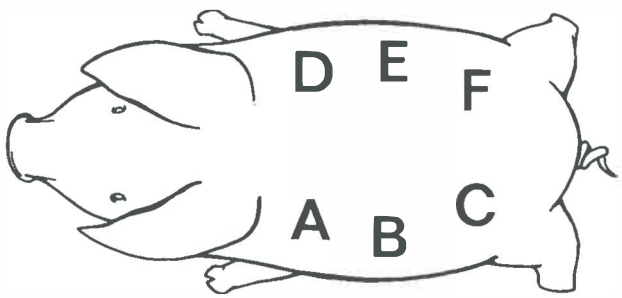

Fig. 4.1: Schematic drawing of a pig in which the locations where the expanders are inserted, are marked.

This was done under anaesthesia. From all specimens single cell suspensions were prepared as described below.

Sample preparation and DNA staining
Single cell suspensions were prepared essentially as described by Bauer et al. (1980). In brief, the procedure was as follows: the biopsies were transferred to 0.2 ml of 0.15 M phosphate buffer containing 1% crude trypsin (Difco 1:250) and 0.3% dithioerythritol (Sigma). The superficial biopsies were incubated for 20 min., the punch biopsies for 30 min. at 37°C. After incubation the pieces of skin were transferred to small test tubes containing 0.5 ml 0.15 M phosphate buffer with propidium iodide (PI, 20 mg/l) and sonicated for 2 seconds (Sonifier B-12, Branson Sonic Power Company) to dissociate the epidermis. Then 0.1 ml foetal calf serum (to inhibit traces of trypsin), 0.05 ml of DMSO and 0.1 ml RNA'se was added. The stratum corneum and the dermis remain intact with this procedure so that no admixture of dermal cells occurs. After filtration through gauze (mesh approximately 50 μm, Phywe, BRD) and a staining period of 15 min., cellular DNA was determined with the flowcytometer. The cell concentration was about $2\text{-}4.10^5$ cells / ml.

Flowcytometry
Flowcytometry means the measuring of 'properties' (such as DNA content) of individual cells in flow. With respect to this study, it means that we measured the DNA content per cell. Cells are forced to pass through a light beam. The fluorochrome is excited and the emission signal (proportional to the DNA content) is measured with a suitable detector. The signals are then sorted as to size and the data presented as a DNA histogram. With the help of flowcytometry very large numbers of cells can be analyzed at high speed, up to 1000 cells/second, allowing an objective and a reliable analysis. We used the 50H Orthosystem (Ortho Instruments, Westwood, MA) equipped with a 5W argon ion laser (164-05, Spectra Physics, Moutain View, CA). The PI fluorochrome was excited with the 488 nm laser line and the fluorescence was measured with a high-pass filter RG630 (Melles Griot, Zevenaar, The Netherlands). At least 10^4 cells were counted at a flow rate of about 100 cells per second. The data were stored and analyzed with a PDP11/34 computer (Digital Equipment, Galway, Ireland). Both area and the peak value of each fluorescence signal were measured. The ratio area : peak is an excellent discriminator between artefacts due to doublets of diploid cells and real single tetraploid cells (Bauer and Boezeman, 1983). Typically the value of clumped cells was 0.5%-1%.

Cell cycle analysis
The DNA histograms were analyzed mathematically using a programme as described earlier (Bauer et al, 1980). This procedure provides us with a percentage of diploid cells (Go, G_1, differentiated cells from the stratum spinosum), cells in the

S-phase (DNA content between 2 c and 4 c) and tetraploid cells (cells in G_2 and mitosis).

Quantitative assessment of stretching
To the epidermal cell suspension in a fixed volume, a known number of chicken erythrocytes were added. These can be distinguished from the keratinocytes because of the difference in DNA content. The ratio of keratinocytes to erythrocytes was then calculated from the histograms and from that the absolute number of epidermal cells in the 2 mm punch biopsies.

4.3 Results

Cell counts
In order to test whether, due to the implantation and subsequent inflation, there was a real stretching of the epidermis, cell counts were made on suspensions from 2 mm biopsies taken immediately before ($n = 5$) and after ($n = 6$) expansion from one pig. We found a value of 94,948 $\pm$ 17,854 cells for normal skin. After implantation and insufflation we found a significantly lower value of 70,653 $\pm$ 12,933 cells ($p < 0.03$, Wilcoxon rank test). Because of the rather large standard deviations and the extra load on the animals we did not investigate the recovery to normal values.

Flowcytometric DNA determinations
In the sham-treated areas (sites C) no response could be observed during the experimental period, the percentages $S + G_2M$ being similar to those of the control sites (F). The data from both locations therefore were pooled and considered as controls (mean percentage $S + G_2M = 4.04 \pm 0.076$, $n = 53$). In each of the other locations A, B, D and E and in each of the pigs there was a more or less similar response. Generally a transient decrease in the percentages of $S + G_2M$ after implantation was followed by an increase reaching peak values at day 7 or 8. After a decrease to control values, one or two subsequent peaks were observed. Although there were inter-individual differences in the response no significant differences in the patterns nor in the heights of the peaks were observed in the different locations A, B, D and E, if we took the mean values for $S + G_2M$ for all three animals. This means that the different inflation procedures (A and B, versus D and E) were not reflected in the responses obtained. Therefore the value for A, B, D and E at a particular day were pooled for the three animals and the mean value plotted against time (Fig. 4.2). The number of biopsies at one particular day are indicated in the figure (total number $n = 188$). The dotted line represents the mean value for the controls. The standard deviation is indicated by the hatched area. A statistical analysis revealed the encircled points as significantly below (days 2 and 51) or above the control values ($p < 0.05$ T-test). The pattern now becomes more clear. A drop in the percentage of $S + G_2M$ was observed at day two followed by a rise,

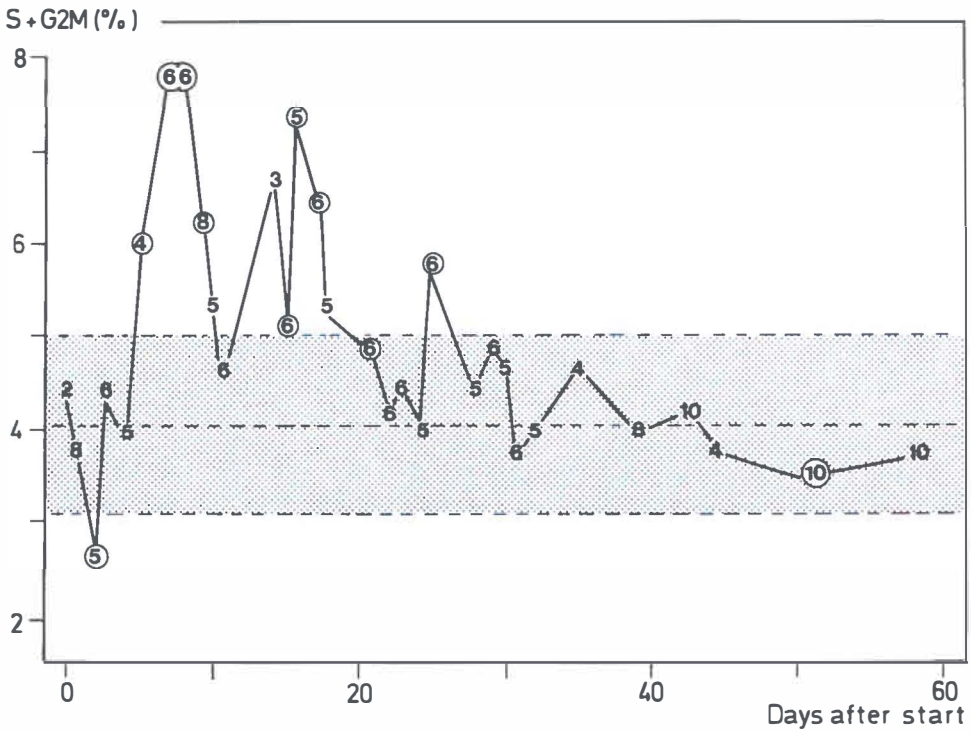

Fig. 4.2: The percentages of cells in S + G_2M as a function of time after expansion and inflation. Each measuring point represents the mean value for all three animals of all the locations A, B, D and E taken at a particular day. The number of biopsies is indicated by an integer. The encircled points are significantly different from the control values.

reaching a top at day seven or eight. Two further peaks were observed around day 14-16 and at 25 days. After 26 days the percentage of S + G_2M returned to normal values. The removal of the expanders at day 42 after implantation resulted in a downward trend as to the percentages S + G_2M, the point at day 51 being significantly lower than normal.

4.4 Discussion

One of the important questions related to the tissue-expansion technique is whether there is new formation of tissue or whether it is just stretching of skin. This paper deals with the effect on the epidermis. Although there are already some studies carried out that indicate a regenerative response (Austad et al., 1982 and 1986), we decided to choose an animal whose epidermis resembles best to the human skin in architecture (Ordman and Gillman, 1966). Furthermore we used a technique that has not been reported up to now in this kind of investigation,

namely flowcytometry. This has certain advantages over the previous studies. First, large numbers of cells can be analysed in a short time with high reproducibility. Secondly, the subjective element present in techniques that are based on autoradiography (cells in S-phase) or mitotic counting (cells in M-phase) is eliminated. Thirdly, more information is obtained regarding the cell cycle since we can measure the percentages of the cells in S and in G_2 and mitosis. In this study we took the cells in S + G_2M (as a percentage of the total cell number) as the parameter for proliferation. In steady state conditions there is a fixed value for this percentage, since the cycling cells are randomly distributed over the cycle. Changes from the steady state, for instance on a stimulus, will be reflected in a change of the percentage of cells in S + G_2M. This is largely independent of the model that underlies growth regulation. Currently two concepts are in favour. The first is that in normal unstimulated skin there is a long cell cycle time of the germinative cells, caused by a very long duration of the G_2-phase and that on stimulation there is a dramatic shortening of the G_1 with the effect that production of cells is enhanced (Weinstein et al., 1984). The second is that the cell cycle duration is more or less constant but that only a minor proportion of the germinative pool consists of cycling cells, the remainders being in a resting state (G_0-cells). At need these cells enter the cell cycle resulting in a higher production (Boezeman & Bauer, 1987). In both models the percentage of S + G_2M will rise after stimulus. It is evident that there really is a regenerative response after the expansion procedure. We could also show that in our experimental set-up the epidermis was stretched after inflation. However, what exactly elicits the response is not clear. Since the sham-treated animal responded in neither way, the operative procedure itself had no effect. If stretching is the only eliciting factor, one might expect differences in response to different insufflation regimens. This was not found. Probably a certain threshold has already been crossed in the experiments using the lower inflation rate. In human skin a regenerative response to tape stripping can be measured by a rise in the percentages of S + G_2M about 40 hours after tape stripping. We have conclusive evidence that this is due to recruitement of G_0 cells. If there is an analogy in pigskin and if the response is due to stretching one would therefore expect the rise in S + G_2M much earlier than after 7-8 days. Thus the possibility that other factors elicit the response cannot be excluded. For instance it is known that after implantation encapsulation of the expander takes place (Pasyk et al, 1984). Diffusion of mitogenic factors from these cells could also elicit the response (Lazarus & Gilgor, 1979). Since however encapsulation is also observed in sham treated animals, this explanation is not likely. Another surprising finding is the periodicity we found in this experiment. Peaks were found at roughly 8 days intervals. We have no biological explanation for this periodicity. It cannot be explained on the basis of a cell cycle time in pigs in the range of 127-161 hours as reported in the literature (Morris & Hopewell, 1985). This, however, is most probably a considerable overestimation since it is based on the assumption that all cells of the germinative pool are cycling. In conclusion, although the exact working mechanism cannot be unravelled in

detail, we have unequivocally shown that tissue-expansion is followed by a regenerative response.

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Chapter 5

CAPSULE FORMATION IN CONTROLLED TISSUE-EXPANSION

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CAPSULE FORMATION IN CONTROLLED TISSUE-EXPANSION

'Appropriate studies have to be done to clarify the role of capsule formation in tissue-expansion'
Pearl, 1984

5.1 Introduction

Capsular contracture around artificial implants is a major challenge in plastic and reconstructive surgery. The interest in this pseudo-capsule formation mainly dates back to 1963 when Cronin and Gerow developed silicone breast prostheses.[1] First, clinical experiences and later on cytohistological research data were described.[2-11]

The formation of a capsule surrounding endoprostheses is influenced by various aetiological factors, including excess prosthesis motion, haematoma and seroma, infection, incipient fibrosis at the level of the surgical dissection and injury. Moreover the so called 'X-factor' in which leakage of silicone, cellular immune antibody reactions and formation of myofibroblasts are frequently mentioned, plays an important role in capsule formation.[12-16] Some people react with more fibrosis to an external influence than others. When a sterile foreign body is inserted, the human body reacts with formation of scar tissue around the implant. In general within eight days of implantation a well-established cellular capsule develops with evidence of fibroblast polarity and an early laying down of collagen. At one month the fibroblasts have polarized, the cellularity decreases and the actual structure will thin out. After two months the capsule becomes less cellular and the collagen content increases. In this period fine capillaries have grown into the sheath. By three months the capsule has become more compact and fatcells migrate into it. In time some thinning will take place but no further changes will occur.[2,16]

In some situations the formation of a capsule can be an advantage as for example in silastic rod procedures, to stimulate tendon sheath formation. In other situations it really can be a burden as for example when breast endoprostheses are implanted and these soft implants become very hard by capsule contraction. A tissue-expander, obviously being an artifical implant, induces capsule formation too. The expansion technique can benefit considerably from this phenomenon because the capsule may have an important role to play in the vascularisation of the flap.[17] On the other hand however, the capsule will set bounds to the inflation volume after some weeks and will therefore decrease the length of the advancement flap at the definitive reconstruction.[18]

Because of the fact that in the literature histological descriptions of foreign-body

reactions in humans and laboratory animals look alike, animal experiments are justified.[4,6,9] In the following experiment an attempt was made to find a deeper understanding of the formation of this capsule. Moreover the influence of inflation rate and time of incorporation on capsule formation around tissue-expanders was studied.

5.2 Material and methods

A series of four mixed breed male castrated pigs (Göttinger Minischwein, PI-PIV) were used for this experiment. The average weight was 35 kilograms ($\pm$2 kg), and their mean age was 9 months ($\pm$1 month), which means full grown. They were housed in a temperature and light controlled room, water and food were offered ad libitum. All animals were kept in seperate sties. General anaesthesia was given during all operations. Six tissue-expanders (rectangular, 250 cc, 10 × 6 × 5 cm, Cox Uphoff International) per animal were inserted in a standard way (Fig. 5.1). Subcutaneous pockets were dissected bluntly above the deep fascia. The implants were inserted with their injection ports placed closely to the midline. Adequate haemostasis was carried out and no drains were used. Initially no antibiotics were administered.

– PI and PII

In PI and PII an attempt was made to study the influence of inflation rate on capsule formation in tissue-expansion. The same procedure was applied to both pigs. Inflation took place weekly, while the percentages of the maximal volume (250 cc) varied in the different locations:

- location A: inflation 0% ('sham' operation)
- location B: inflation 10% each week
- location C: inflation 20% each week
- location D: inflation 25% each week
- location E: inflation 50% each week
- location F: inflation 100% at the initial operation

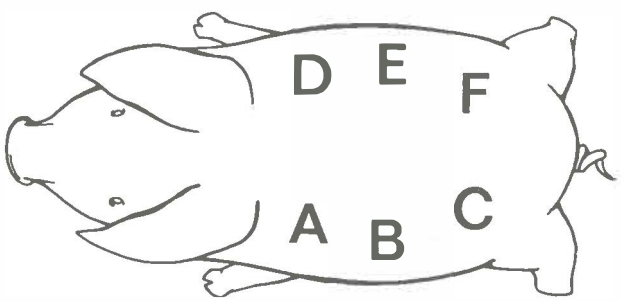

Fig. 5.1: Schematic drawing indicating the locations where expanders are inserted.

In this way the time of expansion in the different locations varied from one day (location F) till 10 weeks (location B), while the expander in location A acted as a 'sham' operation. After different time intervals (2, 4, 6, 8, 10, 14 weeks) excision biopsies were taken from the capsule at each location.

– PIII and PIV

In PIII and PIV an attempt was made to study the influence of the time period of incorporation on capsule formation in tissue-expansion. In both pigs the same procedure was performed. Inflation of the expanders in locations B up to and including F was carried out in the usual way. At the initial operation 25% of the maximal volume was inflated and 25% was added at weekly intervals. In this way the final volume of 250 cc was reached in 3 weeks. The expander at location A was not inflated at all, thus acting as a 'sham'. Excision biopsies were taken from the capsule after the following time intervals:

- location A: after 2, 4, 6, 10, 14 weeks
- location B: after 2, 4, 6, 10, 14 weeks
- location C: after 4, 6, 10, 14 weeks
- location D: after 6, 10, 14 weeks
- location E: after 10, 14 weeks
- location F: after 14 weeks

The excision biopsies measured 0.5-1 cm and were pinned on cork immediately after excision and extended to the same size as before excision. The samples were fixed in formolaldehyde and afterwards stained by different procedures. In all locations each time before biopsies were taken softness and compressibility were tested. This was done by two different examiners and rated subjectively on a scale of I to IV as described by Baker.[19]

5.3 Results

During the experiment many problems arose. The most important drawback was in the sampling. First of all it was difficult to take small samples at the relatively deep level of the capsule. On taking larger samples the defects could not be closed without tension. To avoid artefacts the biopsies had to be taken by scalpel and not by diathermic knife (the diathermic knife cuts easily through scar tissue but does not damage the prosthesis). As a result the expanders were easily damaged by the scalpel. Several expanders were perforated. Moreover dehiscense and infection were frequently encountered after the biopsy. This was probably because of the inevitable tension that resulted after the biopsy or because of scouring of the wounds by the animals themselves. For this reason only a small part of the planned number of samples could be evaluated morphohistologically. When tissue-expanders had been damaged during biopsy and had to be removed, evaluation of the residual capsule was performed on macroscopical as well as microscopical

level.Because of reasons previously described it was not possible to evaluate the 112 planned biopsies. In total only 39 biopsies (17 in PI and PII, 22 in PIII and PIV) could be considered to be adequate for investigation. An ad random distribution over the different locations was not achieved. For this reason it was not possible to draw any statistical conclusions. The aim of the experiment was not reached. Adequate insight in the influence of inflation rate and incorporation period on capsule formation in tissue-expansion could not be obtained.

– Macroscopic evaluation

The differences in consistency between the slowly or fastly inflated tissue-expanders, subjectively judged by hand, was not clear. Nevertheless, a slight tendency to higher capsule formation after four months seemed to excist in the gradually expanded locations (PI and PII, locations B, C and D). During the period of incorporation up to about 10 weeks in the gradually expanded locations firmness increased (PIII and PIV, locations B, C, D, E and F). Macroscopically no increase in firmness was found after a period of more than 12 weeks after the initial operation. A residual capsule was still seen 12 weeks after expanders were taken out (because of perforations during sampling). Although this layer seemed to decrease in thickness in some locations a thick fibrotic layer was still present after 12 weeks.

– Microscopic evaluation

Primarily, granulation tissue excisting of macrophages, fibroblasts and lymphocytes developed. Within about 7 days a double layered capsule, existing of a cell rich inner layer of macrophages and an outer coat of lymphocytes and mainly fibroblasts, was present. After about four to five weeks the outer coat gradually became richer in collagenous fibers. During the first phase this capsule and the bordering subcutis were abundantly vascularised. The zone between capsule and subcutis became more clear secondary to the fading of the sterile inflammatory reaction. Later on the innerside of the capsule consisted of a continuous cellular coat of macrophages. Adjacent to the macrophages a layer of collagen fibres arose, which condensed increasingly. However, the histomorphology of the capsule could vary considerably in time. An increased number of eosinophilic granulocytes was incidentally present. Giant cells were occasionally associated with haemorrhages. Now and then these multinuclear cells contained a double-breaking material, possibly silicone particles derived from the tissue-expander identically as described by Wilflingseder.[3] A tendency to thicker and more active capsules was seen in those cases which were frequently inflated (thicknesses of over 3.5 mm). However, the histomorphological aspects of the capsules of different rates of inflation could not be proven to be statistically relevant for reasons mentioned earlier. A tendency to thicker capsule formation was observed when the incorporation time was longer. This increase seemed to take place in a more or less gradual way.

5.4 Discussion

Scar tissue around an artificial implant produces what we call a pseudo-capsule. The properties of such capsule formation depend on several factors.[15] Since early formation of a capsule during tissue-expansion possibly implies a limiting condition in the expansion procedure, our aim was to investigate factors that could play a role in capsule formation. Therefore we studied the influence of the period of implantation and of inflation rate, the latter being exclusively connected with tissue-expansion technique. However, the study was thwarted by unforeseen problems. First of all the idea that we would easily obtain capsule biopsies without problems of closing the defects, appeared wrong. Moreover, regular intervention in capsule formation, i.e. opening of the capsule many times to take biopsies, gave more problems than considered beforehand. We could not prevent the infections. Antibiotics and special sties without any sharp object did not solve the problems. In spite of all problems and misjudgements a variety of histomorphological changes were seen in different locations. The morphohistological differences between gradually expanded locations on one hand (PIII and PIV, locations B-F) and the 'sham' operated or the rapidly inflated on the other hand (PI-IV, locations A; PI and PII, locations F) are problably related to the repetition of expansion. Every time a tissue-expander is inflated one or more capsule inducing factors will be produced, followed by histological changes. Expansion produces more pressure in the capsule. This can lead to seroma, one of the capsule inducing factors.[15] Every transcutaneous punction introduces a smaller or greater source of contamination into the expander region, contributing in this way to capsule formation. An important factor is that of haematoma formation. Each time the soft tissue around the expander is stretched vascular ruptures may take place. We think in addition to all known factors leading to capsule formation around foreign bodies some extra factors may play a role during tissue-expansion. This explains why there probably is a tendency to more firmness and thicker capsules in gradually expanded prostheses.

The presented results and accompanying remarks are much too preliminary to be of any value or credibility. More extensive experiments have to be done. They have to deal with larger numbers of animals and expanders, to avoid 'using' locations more than once. Moreover in the same experiment locations should be tested with non inflatable implants e.g. breast prostheses, to acquire a more detailed insight in the differences in capsule formation.

In conclusion, the exact role played by inflation rate and incorporation time of tissue-expanders on the formation of capsules, is not yet solved. It is reasonable that some extra factors play a role.

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Chapter 6

THE MODELLING OF SKIN-EXPANDERS

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THE MODELLING OF SKIN-EXPANDERS

6.1 Introduction

The technique of tissue-expansion has become an important and powerful tool in plastic surgery. Nowadays a lot of experience has been gained about the application and selection of appropriate expanders. However, there are still complicating factors, such as the quantity and quality of tissues, undergoing expansion, and the specific location of the donor site. These uncertain aspects have made that in each specific case one usually resorts to a mixture of sound clinical judgement and trial-and-errors methods to select the most appropriate expander. Therefore, there is still an urgent need for a method to convert tissue-expander volume to surface-area. Using tissue-expansion, the surgeon has to adopt the best values of three parameters, namely the shape of the expander, its size, and its inflation volume. The crucial question then is how the final area gain is related to these three parameters. The aim of this paper is to analyze this question from a mathematical point of view. Just in advance, we realize that the insight obtained via mathematical modelling will cover merely part of the real situation, but we are convinced that this approach may serve as an indispensable and useful starting point for further research.

To start with, we will deal with the question which inflation volume should be chosen to obtain a prescribed skin-area gain. We shall answer this question with respect to different expander shapes used in current practice. In this way a scheme is developed by which the surgeon can select the optimal parameter values. We emphasize, however, that such a scheme is only valid under certain assumptions. For example, we have to assume that the volume of inflation can be accurately determined and keeps constant during the treatment. This basic requirement is not always met in the current expanders. Another point of warning is that the formulae presented below yield the area gain of the expander. This is not exactly the same as the area gain of the skin. Furthermore, the maximum stretching of the skin may be quite different from the remaining area gain because of, e.g., elastic properties of the skin and 'stretch-back' phenomena.[1] However, in the discussion we will argue that all these complicating effects can be taken into account by correcting the results of the mathematical models in quite a simple way. In the next section we will propose a general scheme to calculate the relation between volume and surface-area of arbitrarily shaped expanders. In general, this approach will lead to substantial numerical effort, but we also point out that in the most frequently appearing cases this scheme can be reduced to a few arithmetic manipulations for which the use of a pocketcalculator will be sufficient.

6.2 Expanders of arbitrary shape

All currently available expanders may be characterized by (at most) three geometrical parameters, for example width w, depth d, and height h. All geometrical properties such as volume and surface-area gain are thus functions of the triplet w, d and h. For a given expander shape it is always possible to express volume and area gain explicity in terms of this triplet. This does not mean that mutual relations between these properties can be derived in a direct way. In the following we shall show how these relations can still be derived in an indirect way.

Denoting volume and area gain by V and AG respectively, we want to establish the relation V(AG), i.e. V as a function of AG. Let us denote the needed value of AG by AG_0. The parameters w and d in V(w,d,h), which determine the dimensions of the bottom of the expander, follow directly from geometrical considerations and are thus also known. Then the height h of the expander remains to be calculated from the equation

$$(1)\ AG(w,d,h) = AG_0$$

Though, as already stated above, one may find an explicit expression for AG as a function of w, d and h, it is rather the rule than the exception that inversion of equation (1) appears to be very difficult, so that an explicit expression for h as a function of w, d and AG_0 is seldom available. In general one is thus forced to solve this equation by computer, using some iterative algorithm. To assure the convergence of such an algorithm one should be aware of the necessary mathematical precautions. Having calculated, in some way or another, the height h for given values of w, d and AG_0, the corresponding volume is obtained by substituting the particular values of w, d and h in the expression for V(w,d,h).

6.3 Spherical expander

In case of a spherical expander only two instead of three parameters characterize the geometry, thanks to the existing symmetry. In terms of the diameter d of the bottom and the height h (see figure 6.1) the functions AG and V are given by

$$(2)\ AG = \pi h^2$$

$$(3)\ V = \frac{1}{8}\pi d^2 h + \frac{1}{6}\pi h^3$$

The constant π is approximately given by $\pi = 3.1415926$. Similar expressions are also given by Rektorys[2]. Recently, Shively[3] presented the listing of a computerprogramme to handle the inversion of this kind of formulae. However, it appeared

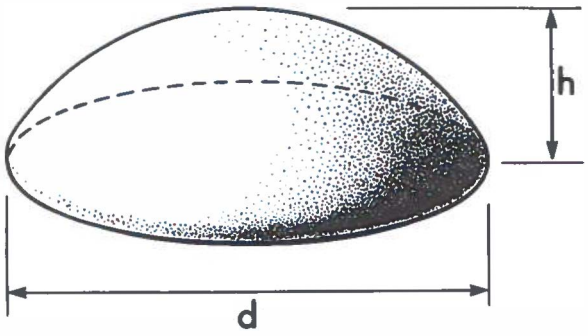

Fig. 6.1: Spherical tissue-expander, characterized by the geometrical parameters diameter d and height h.

possible to rewrite the expression for AG given there into the present simple form. This simplicifation implies that use of the computer is superfluous in this case, because V as a function of AG for given value of d is directly given by:

$$(4)\ V = \frac{1}{8}d^2\sqrt{\pi AG} + \frac{1}{6}AG\sqrt{\frac{AG}{\pi}}$$

We note that AG only depends on the height h and not on the diameter d of the expander. This remarkable phenomenon is quite typical for the geometry under consideration. It does not mean that in practice the diameter should not be of importance. Increasing the implant base does indeed not affect the skin-are again, but the corresponding decrease of tension in the skin flap may be favourable to the obtained skin quality.

6.4 Flat and parallel sides

The sides of a considerable number of expanders are nearly flat and parallel. As examples we present expanders of rectangular and crescent form in figures 6.2 and

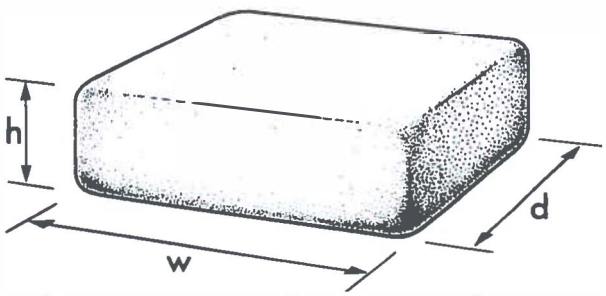

Fig. 6.2: Rectangular tissue-expander, characterized by the geometrical parameters depth d, width w and height h.

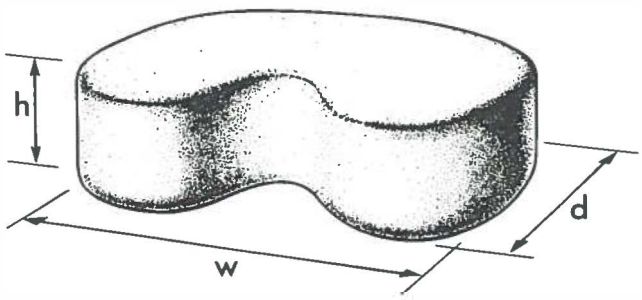

Fig. 6.3: Crescent tissue-expander, characterized by the geometrical parameters depth d, width w and height h.

6.3. In view of the limited accuracy required in practice the rounding off at the edges is negligible. Important features of this type of expanders are that both AG and V are proportional to h and that the top and bottom faces are identical. Denoting the area and circumference of top and bottom by A and C respectively, we have the following relations (w is the width and d is the depth)

$$(5)\ AG = hC(w,d)$$

$$(6)\ V = hA(w,d)$$

In this notation we imply that C and A do not depend on h because the sides are parallel. For this class of expanders the relation between AG and V simply reads

$$(7)\ V = AG\frac{A(w,d)}{C(w,d)}$$

If top and bottom are rectangular, A and C are given by:

$$(8)\ C = 2(w+d)$$

$$(9)\ A = wd$$

More irregularly shaped geometries, as for example the crescent-shaped expander, lead to more complicated expressions for C and A. The essence of relation (7) is that V and AG are directly proportional to each other. This connection implies that measurement of the corresponding constant of proportionally yields all the needed information. If the manufacturers would publish these constants it could be of great help in clinical practice. We emphasize that relation (7) might also be a useful rule of thumb in case of rounded edges. For rounding the sides leads to volume and area gain corrections, which are in the first approximation equal both in order of magnitude and sign.

6.5 Examples and discussion

Let us first give two examples of the application of the mentioned formulae.

1. Suppose the needed skin-gain is 100 cm^2 and the appropriate expander is of the round type with a diameter d of 10 cm. Substitution of these parameters into equation (4) shows that at least a volume of 316 cc will be needed to provide sufficient skin to cover the defect adequately.

2. A skin-area gain of 100 cm^2 is required and the expander to be used is rectangular with width $w = 10$ cm and depth $d = 5$ cm. Combination of the equations (7), (8) and (9) proves that at least a total volume of 167 cc must be used.

The values of area gain and volume calculated by the method described in this paper, will slightly underestimate the practical values because of the rounded edge, but this aberration is not a serious disadvantage in view of the other intrinsic uncertainties of the method. Experts in the field will have noticed immediately that the calculated area gains are unrealistically high. We again emphasize that the present way of mathematical modelling ignores several practical aspects. In the introduction we already mentioned some examples of discrepancies between the models and the real situation. To estimate the seriousness of these discrepancies one has to study the relation between theoretical and measured results. To that end we are running an extensive programme in which calculated and measured area gain data are systematically compared. The measurements are performed both 'in vitro' and 'in vivo'. Pigs are used in these latter experiments since the skin properties of these animals resemble these of humans well. Until now the results coherently show that the formulae above overestimate the real area gain by a factor of 2.5. This strongly suggests that all discrepancies between practice and models can be taken into account simply by applying a constant correction factor. The details of the experimental design will be presented elsewhere[4], being beyond the scope of this paper.

The overall conclusion may be that a mathematical approach, in spite of its lack of simulating a lot of practical features, may lead to a reliable method to convert tissue-expander volume to surface-area. This kind of knowledge could be used, e.g. from the manufacturer side, to supply the appropriate conversion table for each type of expander. Such tables could be of great help in the clinical practice, provided that the appropriate care is taken.

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Chapter 7

SURFACE-AREA INCREASE IN TISSUE-EXPANSION

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SURFACE-AREA INCREASE IN TISSUE-EXPANSION

'Some system to convert tissue-expanders volume to surface-area is needed so the surgeon can select the proper size expander for specific needs'
Shively et al., 1985

7.1 Introduction

A serious problem in the tissue-expansion technique is the selection of the proper size implants together with the frequency and volume of inflation. The discrepancy between the shapes, sizes and volumes of tissue-expanders advised by different authors is enormous. Radovan (1984)[1] and Morgan and Edgerton (1985)[2] advised that the expander base should have the same size as the defect to be closed. In this way a doubling of the surface area would be obtained so that both donor site and the defect can be covered. On the other hand Gibney (1984)[3] recommended that the base of the expander should have 2.5-3 times the size of the defect. Manders et al. (1984)[4] advised to place an expander as large as possible. These recommendations are based on empirically obtained results without the knowledge of exact figures of the tissue gain to be expected.

Strictly speaking, one needs to establish and thus answer two main questions raised in this subject. First of all, how much new tissue is required to accomplish the reconstruction in a given situation and secondly how should one select and calculate the size and shape of a tissue-expander that will yield the amount of the new tissue required? For the latter, Shively (1985)[5] created a mathematical approach but his method resulted in an extensive and therefore hardly practical computer programme.[6]

This paper deals with an attempt to determine the increase in surface-area accomplished by tissue-expansion. Moreover, attention will be given to accessory factors influencing the final result, in order to estimate the value of the methods used.

7.2 Material and methods

– Mathematical approach

With relatively simple mathematics it is possible to calculate the relation between volume and surface increase of a reservoir filled with fluid. Nowadays several shapes and volumes of tissue-expanders are available, but only the round, rectang-

ular and crescent shapes are commonly used. With some inevitable assumptions it is possible to find formulae that relate surface-area increase to volume and other specifications of the three main shapes.
For the round expander we assume the surface to be part of a sphere. Then it appears that the area gain (AG) is given by a remarkably simple expression, depending on the expander height (h) alone (see ref. 7):

$$AG = \pi h^2$$

Measurement of h is a simple task in practice.

For the rectangular expander the area gain (AG) is given by:

$$AG = 2(w + d)h$$

w, d and h represent the width, depth and height of the expander. This formula is derived under the assumption of right angles. In practice, the corners are always rounded off, leading to a decrease in volume and thus area loss. Correction of this deviation is automatically taken into account if, instead of the formula above, one uses the expression:

$$AG = \frac{2(w + d)}{wd} \cdot V$$

in which the real volume is inserted as V, obtained by measurements or from the manufacturers specifications.

In case of a crescent shape the expression for area gain (AG) in terms of w, d and h is particularly complicated and therefore omitted here. In practice it is often attractive to relate AG to the volume V. This relation appears to be linear, i.e. we have:

$$AG = cV$$

with the constant c given by the ratio of circumference and area of the base of the expander. The most appropriate way to obtain this constant of proportionality is by measurement. In the present paper we use a theoretically derived formula for it.

– 'In vitro' approach
To measure surface-areas, casts of the different volumes of the three commonly used shapes of tissue-expanders were created. All casts were then cut perpendicularly to the base. The slices had a width of exactly 1 cm. Precise measurements of the outline on both rims of the different slices were taken. These two data were

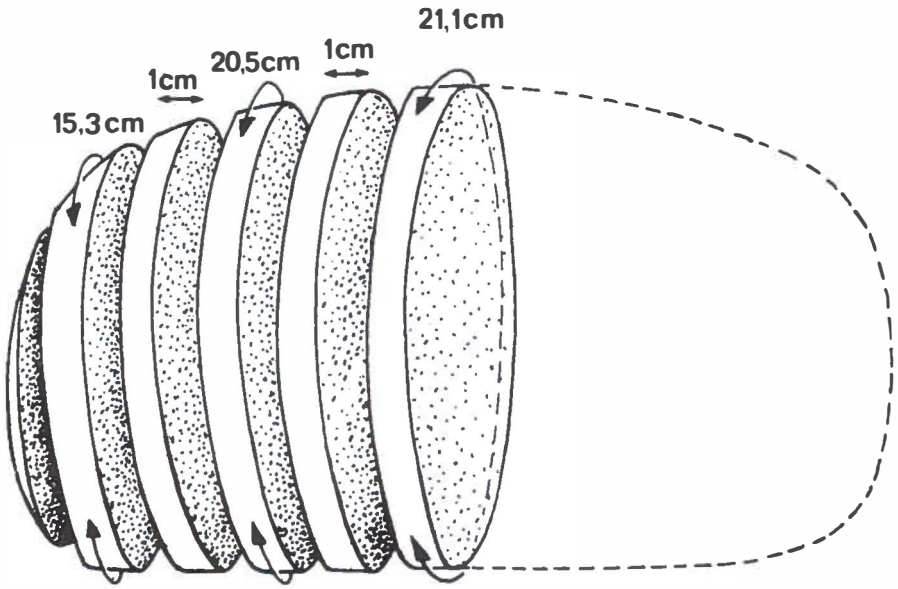

Fig. 7.1: Schematic drawing representing the method of calculation of surface-area increase in the 'in vitro' approach.

added and divided by two. The resulting figure is the surface of the slice in square centimeters (Fig. 7.1). The surface-areas of the different slices were added, yielding the surface of the expander under consideration. The bases of all expanders were calculated and subtracted from the gained data. In this way the net increase in surface-area of the different expanders was obtained.

– 'In vivo' approach

We performed our in vivo experiments on tissue-expansion on pigs, since pigskin is widely believed to resemble that of humans surprisingly well (Ordman and Gillman 1966).[8] To rule out the factor of area increase because of natural growth during the experiments, full-grown Göttinger Minischweinen (minipigs) were chosen.

A series of ten mixed breed, male, castrated pigs were used. Operation of each pig was performed only over the gluteus maximus areas (Fig. 7.2). Each animal was marked in this area on the left as well as on the right side using a specially designed square grating. This grid, measuring 16-16 cm and composed of 64 squares of 2×2 cm^2, was then tatooed in the skin. Centrally under the grid, implantation of the different volumes of each commonly used shapes (round, rectangular, crescent) of tissue-expanders with remote filling dome took place. In total 19 tissue-expanders (Cox-Uphoff International) were inserted. The pockets were created between the deep fascia and the subcutaneous fat layer. The fill domes were placed towards the

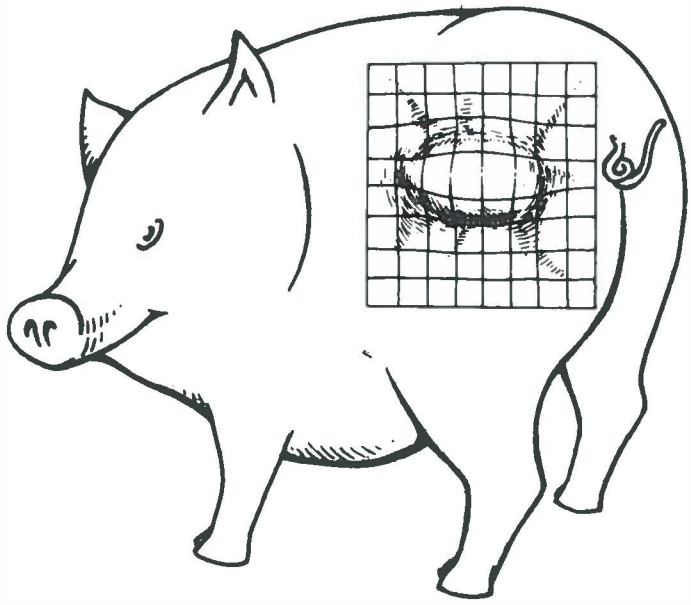

Fig. 7.2: Schematic drawing representing the method of calculation of surface-area increase in the 'in vivo' approach.

midline of the back as much as possible. Expanders were inflated to 25% of the manufacturers stated total volume immediately after insertion. Each week 25% of the volume was added so that the expanders were filled up completely in three weeks time. Two weeks after the maximal volume had been reached, measurements were taken. The length and width of each square in the grid was measured with the help of an electrodigital marking gauge (MituToyo Digimatic Caliper) which had a discrimination rate of one tenth of a millimeter. In this way the increase in surface could be measured fairly accurately.[9]

As an example, to clarify the three approaches mentioned above, the total calculations of a rectangular tissue-expander of 250 cc, specifications 10-6-5 cm is demonstrated in table 7.1.

7.3 Results

The surface-area gain for several round, rectangular and crescent expanders are charted in table 7.2. To get a clear insight of the different surface changes, the data are given in percentages of area increase related to the mathematically calculated area gain of the respective expanders. The results of the mathematical approach and the 'in vitro' approach match with each other with deviations of 15% at the most. Therefore the assumptions in our mathematical calculations are justified.

Table 7.1: Calculations of surface-area gain in a rectangular tissue-expander (specifications: 250 cc volume, 10 cm width, 6 cm depth and 5 cm height) via different approaches.

- *Mathematical approach*

$$\text{Area Gain} = \frac{2(10 + 6)}{60} \times 250 = 133.3\ \text{cm}^2$$

- *'In vitro' approach*

10 slices of exactly 1 cm depth + 2 slices of 0,25 cm depth
1.5+14.3+18.8+20.5+20.9+21.1+21.0+20.8+20.3+19.0+13.9+1.4 = 193.5 cm²

Estimation of the surface-area of the basis = 57.4 cm²

Area gain = 136.1 cm²

- *'In vivo' approach*

Addition of the calculated surface-areas of al 64 squares = 302.4 cm²

Addition of the surface-areas of the 64 unexpanded squares = 256.0 cm²

Area gain = 46.4cm²

When the result of the mathematical approach in these calculations is fixed at 100%, the data of area gain in the different approaches will be:

Mathematical approach : 133.3 cm² = 100%
'In vitro' approach : 136.1 cm² = 102%
'In vivo' approach : 46.4 cm² = 35%

The findings in the in vivo approach agree more or less with observations, reported earlier by Brobmann and Huber (1985).[9] However a wide discrepancy exists between the theoretically and the in vivo obtained results. We found that for expanders with a round base the measured gains are 25% of the average of the calculated ones. For the rectangular and crescent ones these percentages are 38% and 32% respectively. It is remarkable that these factors are nearly independent of expander sizes and seem to be only determined by the shape of the expander. Because of the low number of observations and the fact that there is no clear linear correlation between the different volumes in the different shapes one has to be careful with jumping to conclusions.

7.4 Discussion

Much disagreement on the choice of shape and volume of expanders in relation to the defect to be closed is encountered in the literature.[1-4] A correcting factor in

Table 7.2: Surface-area increase of different shapes and volumes of tissue-expanders in the 'in vitro' and 'in vivo' approach in percentages of the surface-area increase in the mathematical approach. The volumes and specifications are cited from manufacturer information.

Tissue-expanders (shape and specifications)		mathematical approach in cm^2	in vitro approach in % of mathematical approach	in vivo approach in % of mathematical approach
Round				
60 cc	(6.9-1.4 cm)	6	106	27
80 cc	(7.6-2.3 cm)	16	88	22
100 cc	(8.1-3.1 cm)	30	94	33
200 cc	(10.0-3.9 cm)	47	86	19
300 cc	(11.4-4.2 cm)	55	102	27
400 cc	(12.5-5.4 cm)	91	105	31
500 cc	(13.0-6.3 cm)	124	86	23
600 cc	(13.5-6.7 cm)	141	97	22
700 cc	(14.7-6.9 cm)	149	89	26
800 cc	(15.2-7.1 cm)	158	111	20
1000 cc	(16.4-7.6 cm)	181	92	24
average % of all round expanders:			97%	25%
Rectangular				
70 cc	(6.0-4.0-3.5 cm)	58	85	28
140 cc	(8.0-5.0-4.0 cm)	91	114	44
250 cc	(10.0-6.0-5.0 cm)	133	102	35
340 cc	(12.0-6.0-5.0 cm)	170	93	37
680 cc	(15.0-8.0-6.5 cm)	260	89	46
average % of all rectangular expanders:			96%	38%
Crescent				
80 cc	(7.0- 4.5-4.0 cm)	94	92	36
200 cc	(10.0- 8.0-4.0 cm)	147	107	29
500 cc	(14.5-10.5-5.0 cm)	255	115	31
average % of all cresent expanders:			104%	32%
average % of all three shapes of expanders:			99%	32%

chosing the adequate volume to obtain the needed skin area gain, can be found by looking at our data (table 7.2). Multiplication of the needed area gain by a factor 4, 2.5 or 3 in case of a round, rectangular and crescent shape respectively seems to work out well, but several points have to be considered apart from the area gain. To provide some insight into the complexity of the subject we mention the following aspects. First of all, undermining of the tissue on either side of the defect takes place in general. This unexpanded tissue is then stretched using its inherent extensibility (Gibson 1977).[10] In this way a contribution to the total of surface-area gain is obtained. Moreover, if tissue-expansion is really based on newforming of tissue

instead of stretching of skin only (Austad et al. 1982, 1986)[11,12], this expanded tissue has its own new inherent extensibility and in this way some extra surface area can be gained. On the other hand, if tissue-expansion is partly based on 'mechanical creep' as described by Gibson (1977)[10] and Hirshowitz (1986)[13] the surface-area gain also deals with displacement of tissue fluid from the interstices of the collagen network. Whenever fluid returns the phenomenon of 'stretchback' as described by Nordström, may occur.[14] In this way a broad scar will develop afterwards. When we assume that these two phenomena virtually neutralise each other, we are still left with another problem. In advancing the 'newformed' or 'stretched' skin not all the gained skin-surface-area is used. Specially the surface gained in the direction perpendicular to the advancement direction will mostly not be used. This results in diminishing the effect of the expansion with about one third, for which reason the factors calculated above roughly have to be multiplied by 1.5. This implies that the following procedure should be used in practice. Determine the amount of tissue required and the shape of an appropriate expander. Multiply the required surface-area by a factor of 6, 3.75 or 4.5 in case of a round, rectangular and crescent shape respectively. Select next from table 7.2 the expander(s) which yield(s) this gain mathematically. Looking at the data presented in this table, one observes that this procedure implies that the expander base should roughly be 2.5 times as large as the defect to be closed, when using rectangular or crescent expanders. In case of round expanders this correction factor is found to hold true for the diameter of the expander rather than for the area of the base.

In view of all these considerations, together with the relatively poor tissue gain in the in vivo experiment, it is difficult to forecast the area gain very accurately. However, the mathematical approach appears to be quite a good guide in choosing the right expander. In combination with a sound clinical judgement, which takes into account all specific details of the defect under consideration, it is an useful tool, especially if the calculations remain simple. Furthermore, the consequent rule of thumb to choose the expander base area 2.5 times that of the defect to be closed, is in line with earlier work.[2,3] Since we observed these rules our clinical results have been very much improved. Scar broadening, though still present, has diminished enormously.

Nevertheless, the phenomena related to tissue-expansion are apparently so complex that more and extensive experiments need to be performed to improve the present insights. Especially the role of the capsule and the location of the expander in the body deserve extra attention.

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Part III

CLINICAL TISSUE-EXPANSION

Chapter 8

TISSUE-EXPANSION

8.1 Introduction

Tissue-expansion is based on mechanical stretching of soft tissues to create a larger surface-area. Like physiological adaptation of skin and subcutis during growth, pregnancy and obesity, skin and subcutis adapt to a gradual increase in volume of tissue-expanders. The skin surplus after pregnancy or obesity demonstrates the potential of lasting effect after tissue-expansion. With the help of this artificially created skin surplus an adjacent defect can be closed.

In principle all types of soft tissues can be stretched but in practice, tissue-expansion concerns mainly with the expansion of skin and the subcutaneous layer. For that reason we have restricted our study to these tissues.

The advantages of the use of tissue-expanders over the conventional methods for closing a defect are:

- an optimal functional and cosmetic result
- avoidance of complications with flaps
- avoidance of donor defects
- minimal new scars
- minimal disturbance to sensibility
- safe vascularisation
- minimal operative procedures with respect to:
    - surgical time
    - anaesthesia
    - hospitalisation
    - reconstructions
    - complications

The disadvantages are:

- two operations
- frequent visits to the out-patients' department
- costs

8.2 The tissue-expander

A tissue-expander can best be described as a pre-shaped silicone reservoir that can be filled with liquid (Fig. 8.1). This filling is performed by transcutaneous punction into a small compartment that is connected to the reservoir. This way of tissue-expansion is called 'controlled expansion'. The smaller compartment (dome) has a self-sealing wall, which prevents leakage (Fig. 8.2). Incorporated in the back of the dome there is a round stainless steel or hard plastic needle stop, which helps to prevent inadvertent needle perforation of the silicone envelope through the valve. These domes can be incorporated in the anterior of the prosthesis or can be placed at some distance from the prosthesis, attached by a connecting tube. The former, the so-called self-contained valve, includes an elevated rim that encircles the valve for easy palpation through the skin, facilitating the injection. The remote valve, can be low profiled, high profiled, micro or microcylindrical The choice of the profile is defined by the area to beexpanded. With the help of a stainless steel tubing connector the length of the tube is adjustable. Besides this valve some expanders (those engineered by Cox-Uphoff International) possess a posterior flat-fill valve for quick filling during surgery. This is convenient for quick testing of the implants. Becker (1984 and 1987) and Gibney (1986) developed an inflatable breast implant with a detachable reservoir to reduce the second stage operation to only a very small intervention that can be done under local anaesthesia.

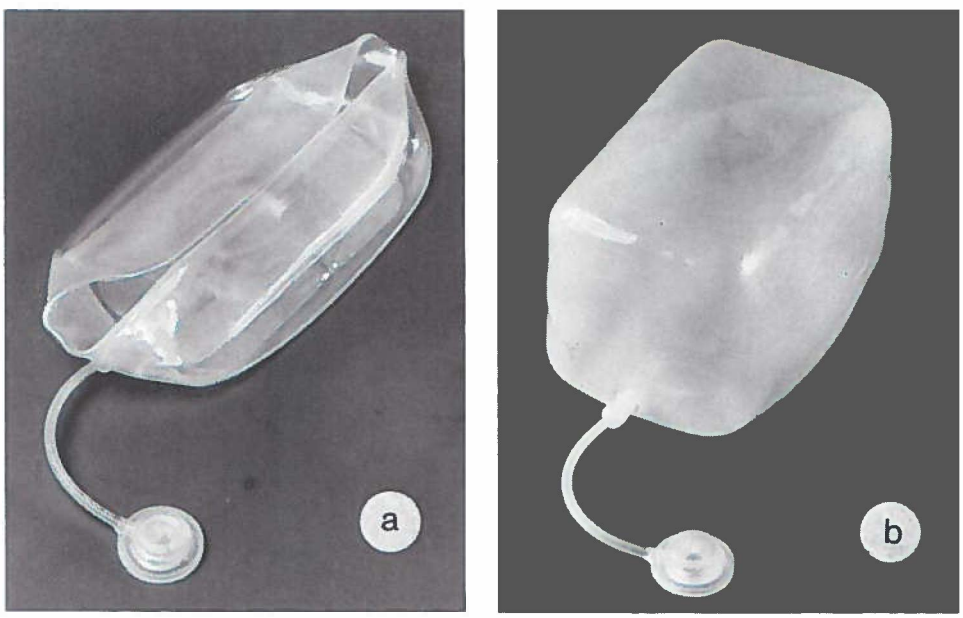


Fig. 8.1: A rectangular tissue-expander of 250 cc with connecting tube and remote fill-valve, before (a) and after (b) inflation.

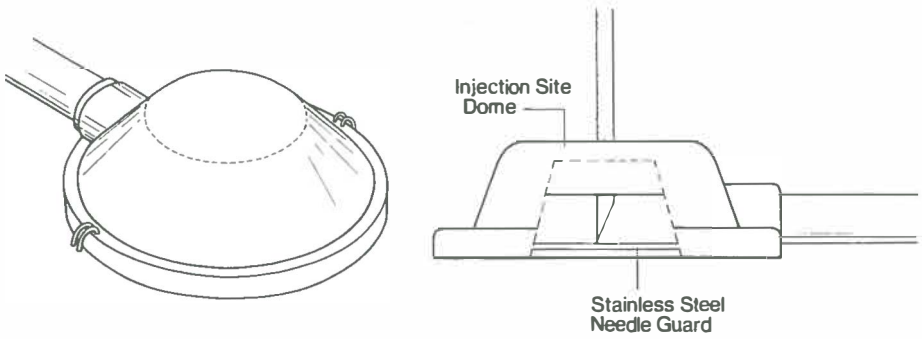


Fig. 8.2: Schematic drawing of a self sealing fill-valve.

Apart from tissue-expanders which require repeated transcutaneous inflations (controlled tissue-expansion), there are so-called self-inflating tissue-expanders. These utilize an osmotic gradient to draw extracellular water through the wall of the silicone envelope (Austad and Rose 1982[1]). The greatest advantage of this self-inflating tissue-expander is a very constant rate of 'inflation'. However, the disadvantages are the long inflation period (8-14 weeks) and the risk that results from large amounts of intraluminal hypertonic sodium chloride. Rupture of such implant in a stage of less than approximately 75% inflation would result in necrosis of the surrounding tissue. Because of these disadvantages the self-inflating tissue-expander did not fulfil the expectations. They are not used any more and for that reason will not be discussed in this thesis.

The industry supplies tissue-expanders in various standard shapes: round, tear-drop, rectangular, crescent and longitudinally curved, and their volume varies from 50 to 1000 cc. However, custom-made implants for any location can be ordered. Special small tissue-expanders are used in e.g. maxillo-facial, orbital and handsurgery. Some designs provide the facility to suture the envelope to the underlying tissue by means of attached silicone lips. The problem of 'wrinkling' of the not yet inflated expanders has been avoided by the construction of so called flat expanders. In these expanders the silicone envelops expand in stead of unfold themselves.

8.3 The technique of tissue-expansion

Controlled tissue-expansion is 'generating' tissue by gradual inflation of a prosthesis, placed beneath muscle or skin. When adequate expansion has been achieved, the prosthesis is removed. The generated surplus tissue can now be used to close a defect or provide cover for implanted bone or a prosthesis (e.g. breast implants).

In order to achieve an adequate expansion, several points have to be considered

(table 8.1). Creation of skin to cover an endoprosthesis differs from the closure of defects. This technique will be discussed separately in section g (table 8.1).

Table 8.1: Considerations in the practical use of tissue-expanders.

- location of the tissue to be expanded
- type of tissue-expanders
- size and / or number of tissue-expanders
- first stage operation
- inflation period
- second stage operation
- breast reconstruction by means of tissue-expansion

a) Location of the tissue to be expanded

There must be enough healthy tissue bordering the defect to be closed. The second consideration is the location of area to be expanded. Anatomical regions differ in tolerance to tissue-expansion. In general there is a decreasing tolerance as given in table 8.2.

Table 8.2: Decrease in tolerance to tissue-expansion.

- scalp (tolerant)
- breast
- trunk
- face
- neck
- back
- upper leg
- upper arm
- fore-arm
- lower leg (intolerant)

Selection of the adjacent skin to be expanded has to be based on the degree of matching and on the amount of surplus skin that will be required. Often more than one adjacent part will be expanded.

b) Type of tissue-expander

The type of tissue-expanders depends mostly on the surgeon's preference. Tissue-expanders with remote or self-contained domes have certain advantages as well as disadvantages. The remote dome decreases the risk of puncture of the envelope but makes the operation somewhat more complicated because an extra pocket has to be created. The self-contained dome simplifies the operation and decreases operation time but on the other hand there is an increased risk of damaging the expander. Moreover, the palpation ring may cause a higher chance of erosions like those seen over wrinkles of the expander as described in section 8.6. The choice of shape of expander depends on the aim of the expansion and the shape of the defect.

Except for breast augmentation rectangular expanders are almost always used. In chapter 7 this item was discussed in greater detail, while in several sections of chapter 9 the general preference in the different cases will be noted.

c) The size and/or number of tissue-expanders

The size of the expander depends on the surface-area of the defect to be created and closed. During the initial phase of the development of tissue-expansion the general opinion was that the base of the expander should have the same surface as the defect to be closed (Radovan 1984). Later on, Manders et al.(1984[2]) advised to use a tissue-expander as big as possible. Our experience in using rectangular tissue-expanders showed that the base of the tissue-expander should have minimal 2.5-3 times the surface-area of the defect to be closed. The length of the tissue-expander always has to be minimally 10-20% longer than the length of the defect.

If defects have not enough adjacent expandable tissue on one side one has to use two or more expanders at various locations. In chapter 7 we tried to be objective about these problems.

d) First stage operation

Before the operation the tissue-expander(s) needed is (are) chosen. In contrast with especially American literature we hardly use antibiotics. The very few exceptions, as for example in scalp reconstructions, will be pointed out in chapter 9. The operations are performed under general anaesthesia. A pocket is carefully dissected above the deep fascia, under the subcutaneous fat layer. The incision is made intralesional, paralesional or remote. The paralesional incision is been used when a defect is to be covered. The intralesional incision is only used in breast reconstruction. When there is no possibility to place the incision paralesional, in general the incision is placed remote from the lesion. In that case one must realise that an extra scar is created which should be parallel to the skin lines and be as small as possible. The pocket should be about 10 percent bigger in diameter than the base of the expander. Between the pocket and the defect to be covered there should be a strip of undetached tissue of about 1.5 cm wide. This is to avoid expansion of the defect itself. A second, smaller pocket is dissected to insert the fill-valve when a tissue-expander with a remote dome is used. Care should be taken that the dome is situated at an acceptable distance from the envelope. After adjusting the length of the tubing, the stainless steel tubing connector is placed and fixed. In this way the envelope can not fold over the injection site, what may lead to puncture of the envelope. After rinsing the cavity with a Betadine solution (1/10) and after checking the expander by means of the quick-filling valve, the prosthesis is placed into the pocket accurately. Then, the tissue-expander is inflated to 10-20% of its ultimate volume to unfold it. The surgeon has to verify whether the tissue-expander is completely flat, since folds and pleats in the tissue-expander can threaten the covering skin and, moreover, they can hamper the filling. Thereafter, the filling valve is inserted into its pocket and the various layers of the skin are closed. Usually

a drain is left to avoid haematoma.

Shaw (1986) and Jackson et al. (1987) describe the so called 'external valve technique'. In this technique the connecting tube is channeled through the skin and the fill-valve is placed outside the skin. The advantages of this technique are: short operation times, no valve pocket, no subcutaneous valve complications, the possibility to replace a leaking valve without surgery, no pain during injection (very important in children) and last but not least the tubing channel acts as a persistent drain for possible haematomas or seromas. As a disadvantage the risk of infection has to be mentioned.

e) Inflation period

A simple technique for ensuring accurate puncture of the tissue-expansion fill-valve is described by Dickson and Batchelor (1987). Simple instilling of 1 ml of methylene blue BPC into the expander will ensure the permanent staining of the contents of the expander no matter what volume is subsequently added. The appearance of blue-green fluid in the syringe or extension catheter upon withdrawal after puncture of the dome is an absolute indication of the correct placement of the needle.

In general the inflation is started two weeks after the first stage operation in cases where the expander has been placed through a paralesional incision. When it is placed through a remote incision inflation can be started almost immediately after insertion. Before every injection, which is done in the out-patients' department, the skin overlying the dome has to be prepared with a desinfectant (e.g. Betadine) meticulously. It is important to minimize the number of injections. This is achieved by leaving the needle in place in the injection site while refilling the syringe. The McGhan Tissue-Expander Fill Kit provides a closed sterile single-puncture system to prevent multiple punctures and so avoids damage of the device and prevents risk of infection. In case of using multiple expanders in one patient it is advisable to use a new needle for each expander. In this way carrying infection from one location to the other is avoided. Through a 21 or 23 scalp vein butterfly needle, which is attached to the syringe by means of connection tubing, the expander is inflated with sterile isotonic saline until overlying tissues become tense or the patient feels uncomfortable. Often, this situation appears after inflation of 10-20% of the maximal volume of the expander. When the overlying tissue demonstrates a pale discoloration (blanching) as a sign of embarrassed deteriorated circulation, some saline should be asperated.

In general no precise time-table for tissue-expansion can be given. It is very important to take into account the area of the body which is expanded. Average time intervals for inflation of the expanders in the different areas of the body is presented as in table 8.3. The data are based on experciences described by Sasaki (1985); our experiences are similar.

Table 8.3: Average time intervals for expander inflation.

Area of the body	*Inflation time intervals*
– scalp	3- 7 days
– breast	4- 6 days
– trunk	4- 6 days
– face	5- 7 days
– neck	5- 7 days
– back	6- 8 days
– upper leg	7- 9 days
– upper arm	7- 9 days
– hand	7- 9 days
– fore-arm	8-10 days
– lower leg	9-11 days

The maximal rate of inflation still has to be determined. Some surgeons even use daily injections (Roberts et al., 1986).

The maximal volume to be inflated in the different expanders is stated by the manufacturer. Our personal experience is that expanders may be over-inflated up to 200% of this prescribed volume. In this way it is possible to expand a same surface-area to a much wider extent as is done in regular expansion techniques. Up to now no implant rupturing or leakage because of over-inflation was seen by us.

Expanded tissue often demonstrates a bluish or pink discoloration during the whole period. This symptom probably represents a degree of revascularisation and does not necessarily mean circulatory embarrassment(Cherry et al., 1983). After the final reconstruction the discoloration will fade.

By fast expansion, capsule formation will be less troublesome but it does increase the risk of complications (see chapter 5). By slow expansion the capsule can become so firm that further inflation is difficult and may be uncomfortable to the patient. Nowadays the general opinion is to do the expansion as quickly as circulation permits. Having reached its final volume the tissue-expander is left in situ for at least two weeks. For more easy inflation a special device was developed by Ditmars (1983).

f) Second stage operation

A second stage operation is needed to accomplish the final goal. The pocket is opened through the original incision or through a paralesional one in case of a primarily placed remote incision. Tissue-expander and dome are removed and the defect is closed by means of advancement or rotation. A capsule has developed around the expander which can be mobilized by performing a number of incisions perpendicular to the direction of transposition. These incisions provide a higher mobility to the flap. One has to be careful not to cut the bloodvessels under the skin. When shifting the skin, the direction of bloodsupply and innervation are to be taken into account. Drains are left and the wound is closed in layers.

g) Breast reconstruction by means of tissue-expansion

Tissue-expansion in breast reconstruction is essentially the same procedure as mentioned above. In this situation there is no defect to be closed. Extra tissue is needed to cover a definite prosthesis.To reach the aim of symmetry and produce a mound with an adequate projection and natural ptosis a proper planning is necessary. Besides the normal standard expansion technique breast reconstruction has its specific points of consideration.

1) choosing the expander
2) pre-operative marking
3) first stage operation
4) inflation period
5) second stage operation
6) third stage operation
7) fourth stage operation

1) Choosing the expander.
   With the help of templates one can measure the 'volume' of the non-operated breast. A tissue-expander approximately 200-300 cc larger has to be used. Whether to use a round or teardrop expander depends on the preference of the surgeon but does not make a lot of difference to the final result.
   In order to eliminate the second part of the operative procedure, Becker (1984 and 1987) and Gibney (1986) developed a prosthesis with a detachable fill-valve. The breast implant functions initially as a tissue-expander and then remains in position as a permanent implant. This fill-valve is removed through a small incision under local anaesthesia.

2) Pre-operative marking.
   The patient is marked in the standing position prior to surgery. In this way the exact position of the breast to be reconstructed can be lined out. The inframammary fold is marked in comparison to the opposite breast. The inframammary incision is usually placed one or two centimeters below the marking because this line creeps cranially during expansion.

3) First stage operation.
   The patient is operated under general anaesthesia and lying in a supine position with the torso elevated to 30°. The arms are extended on arm boards. If possible the incision is made in the original mastectomy scar. The pectoralis major muscle is split in the direction of its fibers. A large subpectoral pocket is bluntly dissected over three or four ribs separating the serratus from its origin and elevating it. Extension of the pocket caudally to 3-4 cm below the inframammary line is performed. A remote valve should be placed in the upper anterior axillary line or the anterior chest wall. Care is taken to avoid the brassière line. Now the expander can be inserted in the pocket and the connecting tube

adjusted. If enough room is available, the expander is inflated to 10-20% of its maximal volume to forecome wrinkling of the expander and to decrease seroma and haematoma formation. A suction drain is left and the muscle and skin are closed in layers. In irradiated patients the remote incision is to be prefered. In the initial description of this technique by Radovan, the expander was placed in the subcutaneous layer. Nowadays, the tendency is to create a subpectoral pocket if possible.

4) Inflation.
The inflation of the expander is started when the wound is healed and the stitches have been removed. Inflation can take place with time intervals of 4-6 days. Each time usually about 10% or more of the stated volume can be inflated. As mentioned above the total volume to be inflated must be 200-300 cc more than the definite endoprosthesis, necessary to achieve symmetry.
Special attention must be paid to irradiated tissues. In general inflation starts later, all time intervals are longer and initial filling is lower. Blanching appears sooner so the quantity of saline injected each time has to be less than usual. These precautionary measures almost double the time of the whole procedure compared to that of a regular expansion.

5) Second stage operation.
The second stage operation takes place about 2-3 months after the planned volume is reached. In this way some natural ptosis may develop thus achieving more symmetry with the normal breast. After this period the thick capsule will not contract so much over the smaller definite prosthesis. Again the original mastectomy scar or the newly planned submammary fold is used to remove the expander. If needed a new submammary fold is created by means of a lower thoracic advancement flap (Ryan, 1982 and May et al., 1987). In this way the mobilised distal part of the pocket is fixed to the sixth rib. If possible the original amputation scar will be excised. The definite prosthesis is inserted, a drain is left and the wound is closed in layers.

6) Third stage operation.
After three months the procedure is completed with nipple reconstruction. It is an empirical finding that about 30% of the patients are content with volume and shape reconstruction and therefore renounce nipple reconstruction.

7) Fourth stage operation.
When the total reconstruction is completed, possible discongruence can persist. In most cases ptosis of the non-operated breast is more pronounced than in the reconstructed one. In this case lifting or reduction of the non-operated side can be done. In the literature (Kissin and Kark, 1984) it is stated that in about 30% of the cases this fourth stage operation is required, particularly when the non-

operated breast is very large. This correction can also be performed in the same time as the nipple reconstruction.

8.4 Indications

In almost all parts of the body wherever skin is needed for reconstruction,tissue-expansion can make it available. The technique can be used to enlarge local skin as is applied in e.g. breast reconstruction, or to close a skin defect with adjacent skin as e.g. after scar excision. The best-known indications can be put together in the following groups:

a) Breast reconstruction
Until now, reconstruction of the breast after ablative surgery has been the best-known indication for tissue-expansion. This can be done as a primary or secondary procedure. Even reconstruction before or after irradiation is possible. Also reconstruction of large breasts up to permanent endoprostheses of 600-800 cc has been described (Argenta, 1984[1]). Congenital absence of the breast as in Poland syndrome and other causes of asymmetry of the breast are all good indications for tissue-expansion. In the Poland syndrome it is possible to leave the expander in situ and inflate every six months with the amount of saline that is necessary to keep up an acceptable breast symmetry during puberty. When growing out has stopped the prosthesis can be exchanged for a definite endoprosthesis.
When using a so called 'Becker' or 'Gibney' prosthesis with a detachable reservoir the second stage operation can be reduced to a minor intervention. By using the tissue-expansion technique it is stated that capsule contracture (Baker II-III) is decreased to 7% (Goin, 1985).

b) Defect closure after excision of a skin tumour
After excision of skin tumours as naevi, haemangioma's, etc. the defect can be closed by adjacent expanded skin. In this way an excellent matching of skin color and texture can be achieved. Especially in the head and neck area this will be very worthwile.

c) Defect closure after scar excision
Scars leading to disfigurement or functional restriction are often good indications for correction with the help of tissue-expansion techniques.Besides an improved cosmetic aspect the newly created tissue usually offers a much better functional result than obtained with the conventional methods i.e. primary closure or skin grafting.

d) Congenital deformities

As mentioned already defects resulting from excision of lesions as haemangioma's, thierfellnaevi, etc. are to be considered for treatment with tissue-expansion. But also more complicated congenital abnormalities, such as syndactily (Morgan and Milton, 1985) or Siamese twins (Shively et al., 1985) have been corrected successfully using tissue-expansion.

e) Amputation or agenesis of nose or ear

In reconstruction of striking areas as nose or ear, a perfect tissue matching is highly important. Tissue of the frontal region provides this requirement. With the aid of tissue-expansion in this area disfiguring grafted donor areas will be avoided.

f) Alveolar ridge resorption

Loss of teeth causes remodelling and resorption of the alveolar bone leading to a reduction in ridge height and thickness. Special tissue-expanders can be placed subperiosteally. Hydroxylapatite can be brought into the created envelope to reconstruct the alveolar ridge. In this way better results in terms of post-operative resorption and loss of ridge height can be achieved than with the conventional onlay bone graft (Bonomo, 1986 and Lew, 1986).

8.5 Contra-indications

There are several contra-indications. Some of these are more obvious than others, but all are of substantional importance. If, however, a surgeon decides to do a tissue-expansion in spite of the existence of one or more of these contra-indications, he/she should have in mind the risks taken. The following circumstances are clear contra-indications.

a) Not radical excised malignancy

Any form of malignancy should be radically excised. Only then reconstruction by means of tissue-expansion is justified.

b) Infection

In case of infection no foreign-body, such as a tissue-expander, may be implanted.

c) Irradiated tissue

Irradiation leads to fibrosis of all tissues. This will reduce the potential for cell regeneration and wound healing. These effects do not decrease in time. Even after 5, 10 or 20 years, so called 'late irradiation effects' can be seen. Nowadays, doses of irradiation are much lower and more localised as in the past. Neverthe-

less, tissue-expansion in irradiated tissue is not a good choice. In case it is done, special care should be taken. Inflation should be done with much longer time intervals and with considerably less saline per inflation.

d) Poorly vascularised tissue for reasons other than irradiation
In cases of morbus Bürger or Raynaud syndrome expansion of distal parts can cause problems. For example correction of leg or arm stumps after amputation can be risky procedures. Diabetes mellitus is not always a contra-indication for tissue-expansion. Gradual expansion in such cases will not produce extra problems except in the below knee area.

e) Chemotherapy
Patients receiving chemotherapy should not undergo tissue-expansion. The fall in the white bloodcell count that follows chemotherapy increases the risk of infection around the expander. Contrary to irradiation, chemotherapy does not have long term effects. On appearance of normal blood counts tissue-expansion will be justified.

f) Psychologically unsuitable patients
The whole procedure needs full cooperation of the patient. Therefore, patients who cannot accept temporary disfiguring or who can not withstand the pain, are unsuitable for this technique.

8.6 Complications and 'how to handle'

Like in most techniques tissue-expansion has its complications too. Manders et al. (1984[2]) gave a conveniently arranged classification of complications (table 8.4).

Table 8.4: Complications in soft tissue-expansion.
a) Pain
b) Haematoma
c) Seroma
d) Infection
e) Circulation problems
f) Leakage of the expander
g) Exposure of the expander
h) Skin shortage after expansion
i) Dog-ears
j) Scar widening
k) Psychological problems

Ad a) Pain
The patient may complain of pain during the inflation. Mostly the pain is experienced as an unpleasant tightened sensation. The intensity of this sensation

depends on the area of the body and the rate and quantity of inflation. This 'region related pain' is easily demonstrated by the experience that expanding of breast or scalp is seldom painful. In contrast, however, patients whose back or arms are expanded, frequently complain of an unpleasant feeling. The larger the amount of inflation the higher the pressure on the skin the more painful the sensation can be. This pain subsides after one hour and is over in 12 hours. When some liquid is taken out after inflation the discomfort improves almost immediately. De Greef (1986) described several patients who had noted mild discomfort due to the expansion and required sedation at night. Another cause for pain is the percutaneous injection itself. Particularly for children this can be very frightening and be the reason to stop the procedure.

Ad b) Haematoma
Haematomas are nearly always the result of insufficient haemostasis. Disturbed clotting mechanism can also be the cause. After implantation of the expander usually one or two suction drains are left. Initial filling of the expander during the first stage operation, causing increased pressure on the surrounding tissues, probably diminishes the occurrence of haematomas.

Ad c) Seroma
The body reacts to an expander with the production of extra tissue fluid, like to any foreign-body. In general this produces no problems.

Ad d) Infection
Every implantation and following inflations carry the risk of infection. Therefore, optimal sterile circumstances are necessary. Desinfection before inflation can minimise the problem. In general the use of antibiotics is not indicated. Only when infection is suspected antibiotics are prescribed. In some cases interruption of the procedure can be prevented in this way.

Ad e) Induced ischemia
If too much saline is injected the skin is exposed to an unacceptable high pressure. Circulation will be reduced and necrosis may follow. Blanching of the skin over the tissue-expander is a sign of possible trouble. However, should this occur, it is advisable to wait first for half an hour and look for return of colour and capillary refill. If blanching remains some saline will be taken out till normal colour returns. Maximal caution for pressure induced ischaemia is necessary in irradiated areas.

Ad f) Leakage of the expander
Sometimes the expander is damaged accidentally. The envelope may be perforated and liquid may slowly leak out into the tissues. This will do no harm but a new expander has to be placed. When, however, the error takes place at the end of the expansion procedure, one still has the possibility to obtain an acceptable result

using the already created skin surplus. To avoid puncture the fill-dome is best situated at a clear distance from the envelope at a slightly more superficial level. A stitch to fix the fill-valve may be helpful.

Depending on the area in the body a low or high profiled dome is used. Specially in areas of the body where the skin is thick, e.g. the upper leg, a high profile dome to avoid problems during the filling period is preferred. In submuscularly placed tissue-expanders it is not advisable to use incorporated valves because in the beginning it is very well possible to miss the valve and damage the expander.

To minimise the risk of leakage of the fill-valve Thomas Lawrence (1986) advised the use of so-called Huber needles which are used in Port-A-Cath type implantable vascular access devices. The orifice of the Huber needle is situated on the lateral aspect of the tip of the needle, unlike standard needles where the orifice is located at the bevel on the tip.

Apart from surgical or other external causes some device problems are known. Manders et al. (1984[2]) described a defective injection port where the port lacked a plastic disk to stop the needle. Sauër (1986) and Chisholm et al. (1986) presented device problems in the tubing at the connection of the tubing with the body of the expander and at the stainless steel tubing connector. Yang (1986) described a special pitfall which he experienced in using the Cox-Uphoff International expander. The injection-dome of this kind of expanders consists of two small chambers. The upper one is the dependable and convenient self-sealing valve system. The lower one has only a tiny space for saline filling. Its flow to the expander goes through the connective tube and only a thin membrane isolates it from the upper chamber. If the needle is not pushed down till it meets the needle stop it may still be in the upper chamber. Inflation then results in leakage, moreover the expander fails completely to fill.

Ad g) Expander exposure

This problem can result from wound dehiscence, infection or necrosis. Initially 10 to 20% of the expander is filled during the first stage operation to prevent folds in the envelope which can cause erosions and exposure of the expander. But, to prevent wound dehiscence we do not inflate the expander any further until two weeks after the first stage operation. When inflation causes unacceptable pressure on the skin the circulation will be hampered. This may result in necrosis and exposure of the expander.

Ad h) Skin shortage after expansion

When not enough tissue is gained by the expansion procedure it is impossible to close the whole defect. In such a situation it is sometimes possible to expand the already expanded tissue during the second stage operation in a similar way as is described in 'intra-operative sustained limited expansion' (see section 8.7). In this way one or two extra centimeters of skin can be gained. The other possibility is to repeat the whole procedure. After excision of only a part of the pathological tissue,

the defect is closed leaving the expander in situ. Afterwards the same procedure can be started again, now expanding the already expanded skin. In this way one extra operation is needed to reach the final goal.

Ad i) Dog-ears
After expansion, defects are mostly closed by advancement or rotation. Dog-ears in this situation are not always avoidable. Immediate correction is contra-indicated because of the possibility of to damage the circulation. Usually after some months the dog-ears have flattened out spontaneously or can easily be corrected.

Ad j) Scar widening
A major problem is scar widening after the final stage operation. This can partly be avoided by over-expanding the skin to obtain surplus to work with. By creating a large skin surplus one can prevent wound tension and possibly reduce the phenomenon of 'stretchback', described by Nordström and Devine (1985).

Ad k) Psychological problems
Depending on the area in which the expander is situated, the patient is more or less psychologically stressed. Some patients can not stand this temporary disfiguring by the procedure and stay at home all the time.

8.7 I.S.L.E. (= intra-operative sustained limited expansion)

As is described by Gibson (1977, 1986) there are three possible ways in which skin may be stretched:
- by using its inherent extensibility
- by mechanical creep
- by biological creep.

'Inherent extensibility' is the reversible tension, naturally present in the skin and is presumably a property of the elastic fiber network. Collagen fibers have no power of retraction. Inherent extensibility is the phenomenon that is used in primary closure of small defects.

'Mechanical creep' results, when constant stretching is applied to the skin. In this way the skin will stretch beyond the limits of its inherent extensibility. The greater the load applied, the more rapidly the required extension is reached. Mechanical creep in addition to stretching skin beyond its inherent extensibility has two qualities:
- the stretched skin does not retract
- the blood supply seems not to be interfered with.

'Biological creep' is the phenomenon that takes place in physiological gradual stretching as is seen in pregnancy or obesitas. In this way new tissue is probably formed and is also permanent.

Hirshowitz e.a. (1986) described that 'loaded cycling' of skin could best be done during a 15-minutes period with each load lasting three minutes, with a time interval of 30 sec. to one minute between each period. In this way he could harness extra skin for reconstruction of a nose. Because of the firm fixation of the harnessed skin the nasal skin did not contract or return to its former position.

Based on the findings of Gibson (1977, 1986), Sasaki (1986) presented his I.S.L.E. technique. He demonstrated several cases in which primary closure of defects was not possible in the regular way. Therefore, he created a pocket under the adjacent normal skin and inserted a tissue-expander as is done in the regular tissue-expansion technique. The remote fill-valve was left out of the wound which was closed by means of several Backhaus clamps. Then the tissue-expander was inflated to its maximal volume in spite of blanching. This 'loading' lasted three minutes and was separated from the subsequent load by two minutes of deflation. This manoeuvre then took place three to four times. The tissue-expander was then removed and the defect was closed with the extra skin gain.

Because this technique is only based till now on some empirical findings, it is not possible to present objective data.

8.8 Cost-effectiveness

Because medical care is increasingly expensive it is important to compare new techniques with more conventional methods regarding costs and efforts. Tissue-expansion of course has its financial demands: costs of the tissue-expander, two short operations and frequent visits to the out-patients' department have their prices. In comparison to simple grafting after e.g. excision of a naevus on a leg, the procedure of tissue-expansion is expensive. In such a case it is acceptable to discuss whether the efforts, costs and risks are worthwhile the cosmetic or functional advantages. In comparison to extensive myocutaneous or free flap procedures as e.g. in breast reconstruction or post traumatic defects, tissue-expansion is very cheap. The length of operating room time, depth of anaesthesia and the length of hospitalisation and post-operative recovery are minimal when compared to those required for extensive flap surgery. Patient and doctor together have to decide in each case whether tissue-expansion is desirable in that particular situation.

8.9 References (See part IV)

Chapter 9

EMPIRICAL OBSERVATIONS IN TISSUE-EXPANSION

9.1 Introduction

As mentioned in 'Aims of study' all developments in reconstructive surgery are based on an empirical background. The development of tissue-expansion is no exception. The physiological investigations of tissue-expansion have been dealt with in chapter 3 to 8. Now the present-day clinical situation will be discussed.

This is best done by enumerating various empirical findings according to the different locations in the body. Of each part a case history will precede the special problems or pitfalls in these locations. With the help of experiences gained in a Dutch and an American population of 'expanded patients', insight will be given in type and percentages of complications and pitfalls.The Dutch population consists of patients from hospitals associated with the University of Nijmegen and of Groningen, while the American group is composed of patients treated by John Gibney, M.D., Diplomate of the American Board of Plastic and Reconstructive Surgeons, from the Department of Plastic, Reconstructive, Cosmetic and Hand Surgery, Scottsdale, Arizona. The data of both groups were gathered by means of the forms shown on the next page. Those of the Dutch group were filled in by plastic surgeons of the different departments. In contrast, John Gibney, presented his own data. Some cases of expansion in the alveolar ridge are included for a matter of completeness. Albert Wittkampf, M.D., D.D.S. from the department of oral and maxillo facial surgery, University Hospital of Utrecht has presented some of his results. The total number of patients treated with tissue-expansion in Nijmegen and Groningen was 65, while the number of tissue-expanders used in this group was 83. The American group consisted of 211 patients, in whom 297 expanders were used. Albert Wittkampf presents eight of his patients.

The following areas where expanders were used will be presented in short case histories:

- head and neck:
  - scalp region
  - nose region
  - ear region
  - eyelid region
  - alveolar ridge
  - neck region

- trunk:
  - breast
  - back/trunk/buttock
- extremities:
  - shoulder region
  - upper arm/elbow region
  - fore-arm region
  - hand region
  - upper leg/knee region
  - lower leg region
  - foot region

The results will be classified as good, acceptable or bad, and are based on the following criteria:

- in reconstructions others than breast or alveolar ridge reconstruction:
  - good = defect well closed, result as planned.
  - acceptable = defect closed, broad scar, patient content.
  - bad = tissue loss, very broad scar, patient discontent.
- in breast reconstruction:
  - good = good symmetry, natural look, ptosis and feel.
  - acceptable = symmetry in volume, no ptosis, patient content.
  - bad = no symmetry even with bra, patient discontent.
- in alveolar ridge reconstruction:
  - good = firm and stable reconstructed processus alveolaris; good retention potentials; temporary sensibility disturbances of the lower lip; no Hydroxilapatite migration, no complaints by patient and prosthodontist.
  - acceptable = good retention potentials; minor Hydroxilapatite migration without consequences and/or minor permanent sensibility disturbances or pain, well accepted by the patient.
  - bad = non or minor improved stability for a prosthesis and/or permanent anaesthesia, paraesthesia or causalgia of the mental nerve. Patient, prosthodontist and surgeon discontent.

Only major complications as circulatory problems resulting in necrosis or exposure, infection, haematoma, expander problems or severe scar widening will be considered as complication. Minor irregularities as pain, seroma, dog ears, etc. will only be marked under 'special pitfalls and remarks' when of any special significance.

Copy of the standard forms that have been used to gather data on the application of tissue-expanders:

FORM I: general sheet

APPLICATION OF TISSUE-EXPANDERS

* cross out what does not apply.

Name of clinic : .....

Indication : .....

Total number of patients : .....

Total number of tissue-expanders : .....

Regular inflation time:
per operative : .... % of the total volume
post operative : start after : .... days
time interval : .... days
quantity (per inflation) : .... % of the max.volume

Results (number of): good : .....
acceptable : .....
bad : .....

(good = defect well closed, result as planned)
(acceptable = defect closed, broad scar, patient content)
(bad = tissue loss, very broad scarring, patient discontent)

Number of complications (total) :

subdivision of complications (number of patients) :
- early complications
  - pain : .....
  - infection : .....
  - haematoma : .....
  - circulation problems : .....

- late complications
  - · dog-ears : .....
  - . scar widening : .....
  - . psychological problems : .....
  - . others, number : .....
    discription : .....
- expander problems
  - · failure : .....
  - · deflation : .....
  - · exposure : .....
  - · all others : .....

Mean follow-up (roughly) : ..... months/years*

Special standard treatments:

- · antibiotics : .....
- · drainage : yes/no*
- · rinsing cavity : yes/no*; how .....
- · others : .....
  .....

Special pitfalls or remarks (technical, clinical, etc, etc.):

- .....
- .....
- .....

FORM II: breast reconstruction sheet.

APPLICATION OF TISSUE-EXPANDERS

* = cross out what does not apply.

Name of clinic : .....

Indication/application : BREAST RECONSTRUCTION

Total number of patients : .....

Total number of tissue-expanders : .....

The tissue-expanders regular used:

type : · round* · teardrop · Becker/Gibney
valve : · remote* · self-contained

First stage operation:

pocket level : · subpectoral* . subcutaneous
drains : · yes/no*

Inflation period:

per operative : .... % of the max. volume
post operative : start after .... days
time interval.... days
quantity .... % of the max.volume

What is the average difference in maximal volume of the expander and definite prosthesis (in cc) : cc

What is the average time interval between reaching the maximal volume and the definitive implantation : ..... weeks/ months*

Second stage operation:

- only changing expander for permanent prosthesis*
- creating new submammary fold (e.g. modified Ryan technique)
- excising original amputation scar

What percentage of operated patients had nipple reconstruction : ..... %

In what percentage of operated patients lifting or reduction of the opposite breast was performed : ..... %

Results (number of): good :.....
acceptable :.....
bad :.....

(good = good symmetry, natural look, ptosis and feel
(acceptable = symmetry in volume, no ptosis,patient content)
(bad = no symmetry even with bra,patient discontent)

Number of complications (total) : .....

subdivision of complications (number of patients) :
- early complications
  - · pain : .....
  - · infection : .....
  - · haematoma : .....
  - · circulation problems : .....
- late complications
  - · dog-ears : .....
  - · scar widening : .....
  - · psychological problems : .....
  - · others, number : .....
    discription : .....
    : .....
- expander problems
  - failure : .....
  - deflation : .....
  - exposure : .....
  - all others : .....

Average follow-up (roughly) : ..... months/years*

Percentage of patients previously irradiated : ..... %

Special care in irradiated patients : .....
.....

Percentage of complications in irradiated population : ..... %

Special standard treatments:
- · antibiotics : .....
- · drainage : yes/no*
- · rinsing cavity : yes/no*; how: .....
- · others : .....

Special pitfalls or remarks (technical, clinical, etc, etc.):
- – .....
- – .....
- – .....

9.2 Tissue-expansion in head and neck

9.2.1 Scalp reconstruction

Case history
A 40 year old female had been operated seven years ago for a brain tumour. As a result of the post-operative irradiation, persistent alopecia resulted (fig. 9.1.a). To cover the defect the patient wore a wig. Because of the fact that her wig was irritating the skin and because of psychological factors she wanted to get rid of her prosthesis and asked for reconstruction.

The area to be excised was an oval of 8 × 21 cm with a total surface area of about 120 cm^2. For illustrative purposes measuring techniques as described in chapter 7 will be demonstrated. In general we use rectangular expanders for this kind of patient. Therefore on mathematical grounds the surface-area needed has to be multiplied by 3.75 (see § 7.4). Now the volume/expander(s) has(ve) to be chosen from tabel 7.2, which yields this mathematically calculated area gain of 450 cm^2 (3.75 × 120 cm^2) best. Two rectangular expanders of 680 cc were chosen. Via a paralaesional incision on the dorsal side of the alopecia region the tissue-expanders were both well situated under the hairbearingscalp just above the galea. The remote fill-domes were situated in the bald area. The initial filling was 90 cc in each expander, further inflation was started two weeks later. This inflation was done weekly in a very gradual way because of earlier irradiation. Ten weeks after the first operation the definite volume of 680 cc in each expander was reached (fig. 9.1.b). Three weeks later the second stage operation was performed. Advancement and reconstruction of a normal anterior hairline could be done. Some dog ears just in front of the ears remained. After a follow up of eight months the result is still good. There is slight scar broadening, while the dog ears have faded away spontaneously after some months (fig.9.1.c and d).

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	4	7	1	2G	2A	
Amer. population	5	12	1	3G	1A	1B
TOTAL	9	19	2	5G	3A	1B

Special standard treatments
- Pre-operative hairwash with Betadine iodine the evening before operation and on the morning of operation.
- No shaving pre-operatively or intra-operatively.
- Prophylactic systemic antibiotics in this area are advised.

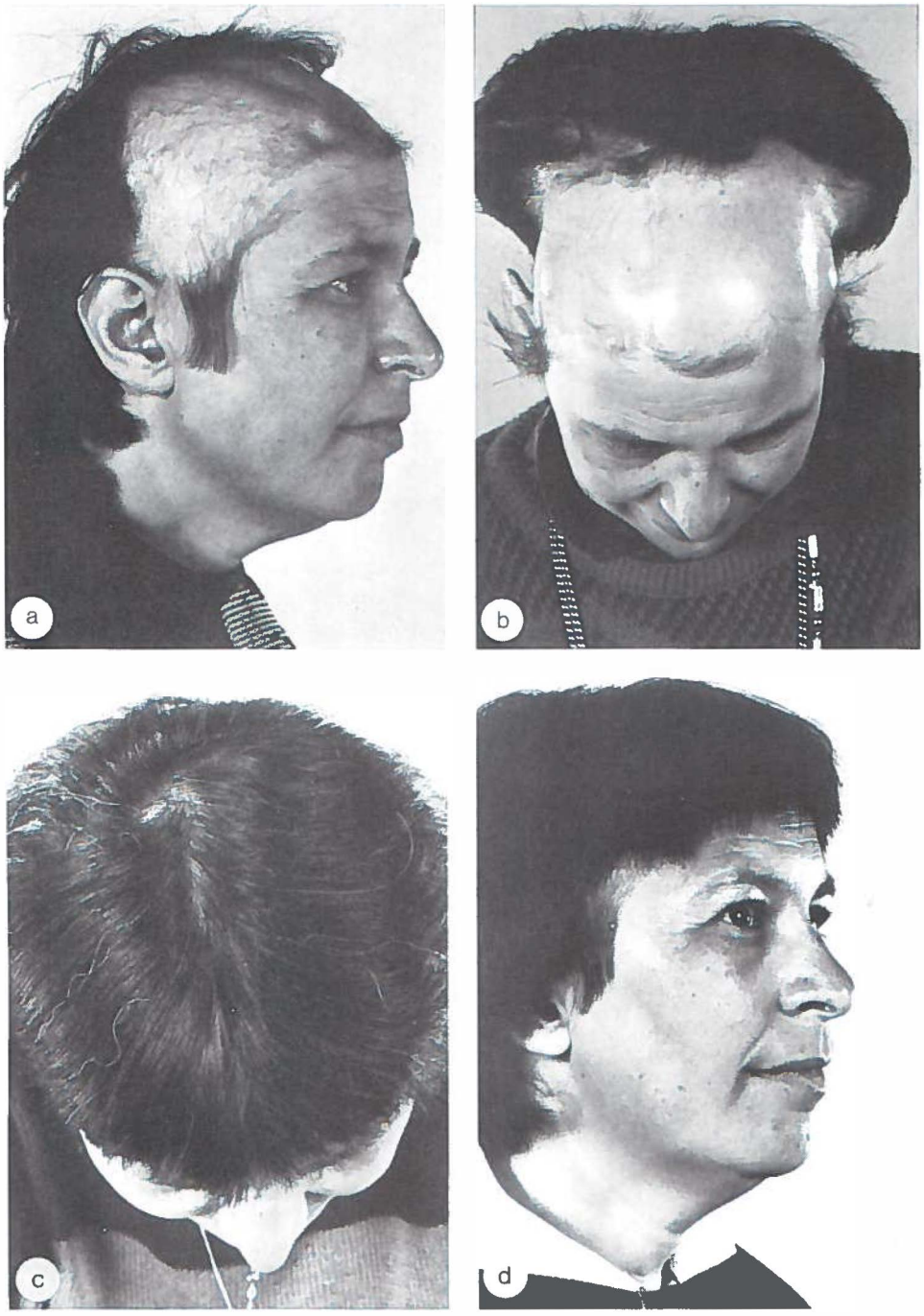


Fig. 9.1: A 40 year old female with persistent alopecia before (a), during (b) and after (c, d) scalp reconstruction by means of tissue-expansion.

- In literature it is recommanded to place the expander under the galea aponeurotica but above the pericranium (Manders et al., 1984[1], Pierce, 1985, Leighton, 1986). However, we performed some expansions above the galea aponeurotica without any problems. No hair loss was observed while the inflation and the ultimate advancement both went smoothly. Nevertheless insertion is probably safer under the galea and blood loss is limited.
- Rinsing the cavity before insertion of the expanders is advised. This is done by a Betadine solution or Cephalosporin in saline (1 gram per litre).
- In the first as well as in the second stage operation suction drains are left.
- Sutures in the scalp remain for at least 3 weeks.

Special pitfalls and remarks

- One of the complications marked above was an exposure of the fill-dome by trauma induced by the patient; the other was caused by infection.
- To prevent necrosis over the fill-dome a low profile one is prefered and placed in a location where it will not be pressed against the pillow during sleep.
- The amount of saline that can be inflated in every subsequent session increases. Start with small amounts, specially when the expander is situated under the galea aponeurotica.
- It is advised to leave the expanders 4-6 weeks before advancing the flaps. This will help to prevent recoil and 'stretchback'.
- If necessary, the implant capsule is scored with a diathermic knife to release the galea. Care must be taken not to damage the vascular supply of the flap.
- Additional expansion is often required. In that case leave the expander in situ for re-expansion, but only start re-expansion after three to four weeks.
- Only when the hair density has been reduced by more than 50% (=area stretch over 100%) this decrease will be noticable (Nordström, 1985 and Spilker et al., 1985).
- Cullen et al. (1986) described reversible radiological changes suggestive of erosion of the outher table of the skull. We have observed 'bathtub' deformity in muscle or soft tissues but never experienced similar radiological changes in the bone.
- When in acute traumatic situations the pericranium is absent, immediate tissue-expansion should be considered if the defect is too large to be closed directly, bearing in mind the size of the defect, the degree of scalp laxity and the patients lability (Matthews and Missotten, 1986).
- In reconstruction of aplasia cutis congenita, involving the scalp, skull and dura, total reconstruction was achieved by tissue-expansion in combination with split-rib grafting within the capsule of the expanded tissue (Argenta and Dingman, 1986).
- Separation of craniopagus twins utilizing tissue-expanders is described by Shively et al. in 1985.
- Scalp expansion may also be readily used to treat male pattern baldness (Kabaker et al., 1986 and Adson et al., 1987).

Case history

A 62-year old man with a squamous cell carcinoma of columella and dorsum of the nose had had his nose amputated. With a follow-up of half a year there was no laboratory or clinical evidence of local recurrence. First the patient was provided with an external nose prosthesis. Because of irritation of the skin under this device and because of the fact that his upper lip gradually was pulled up, he desired nose and upper lip reconstruction. The upper lip was brought downwards by a bilateral nasolabial flap, while the nose reconstruction would be done by means of a forehead flap.

The area gain needed for a total nose reconstruction in this patient was assessed at about 50 cm^2. As mentioned in chapter 7 and illustrated in § 9.2.1 a rectangular tissue-expander of 340 cc (12-6-5 cm) was chosen (400 cc needed) to create enough skin for the total rhinoplasty and to avoid free skin grafting of the donor area on the forehead. By means of a trans-coronal incision the expander was positioned under the galea and above the pericranium of the forehead. The fill-dome was placed more cranially in the hearbearing area. Initial inflation took place up to 100 cc during the first stage operation. One week later gradual expansion was started. At weekly intervals 50 cc was inflated, in this way reaching the definite volume of 400 cc in six weeks (fig. 9.2.a and b). Three weeks later a 9 cm wide flap based on the left supratrochlear artery was folded to fashion a new nose. Eighteen days after that the pedicle was cleft (fig. 9.2.c). The donor side could easily be closed by advancing the expanded skin. Finally only a fine linear scar rested (fig. 9.2.d.).

In spite of the histological findings that the initial nose amputation had been radical, the patient developed a recurrent tumour, which was diagnosed very shortly after the reconstruction was performed.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	4	4	-	2G	1A	1B
Amer. population	2	2	-	1G	1A	
TOTAL	6	6	-	3G	2A	1B

Special standard treatments

- The same special treatments as marked under § 9.2.1 do apply.

Special pitfalls and remarks

- Lining of the nose is needed as usual, the thick pseudo capsule will not persist and will not act as a physiologic lining.

- In total nasal reconstruction the skin needs to be fully expanded for 4-6 weeks prior to moving the flap to avoid 'stretchback'.
- Tissue-expansion is also very useful in resurfacing skin grafted areas in the forehead (Coleman, 1987).

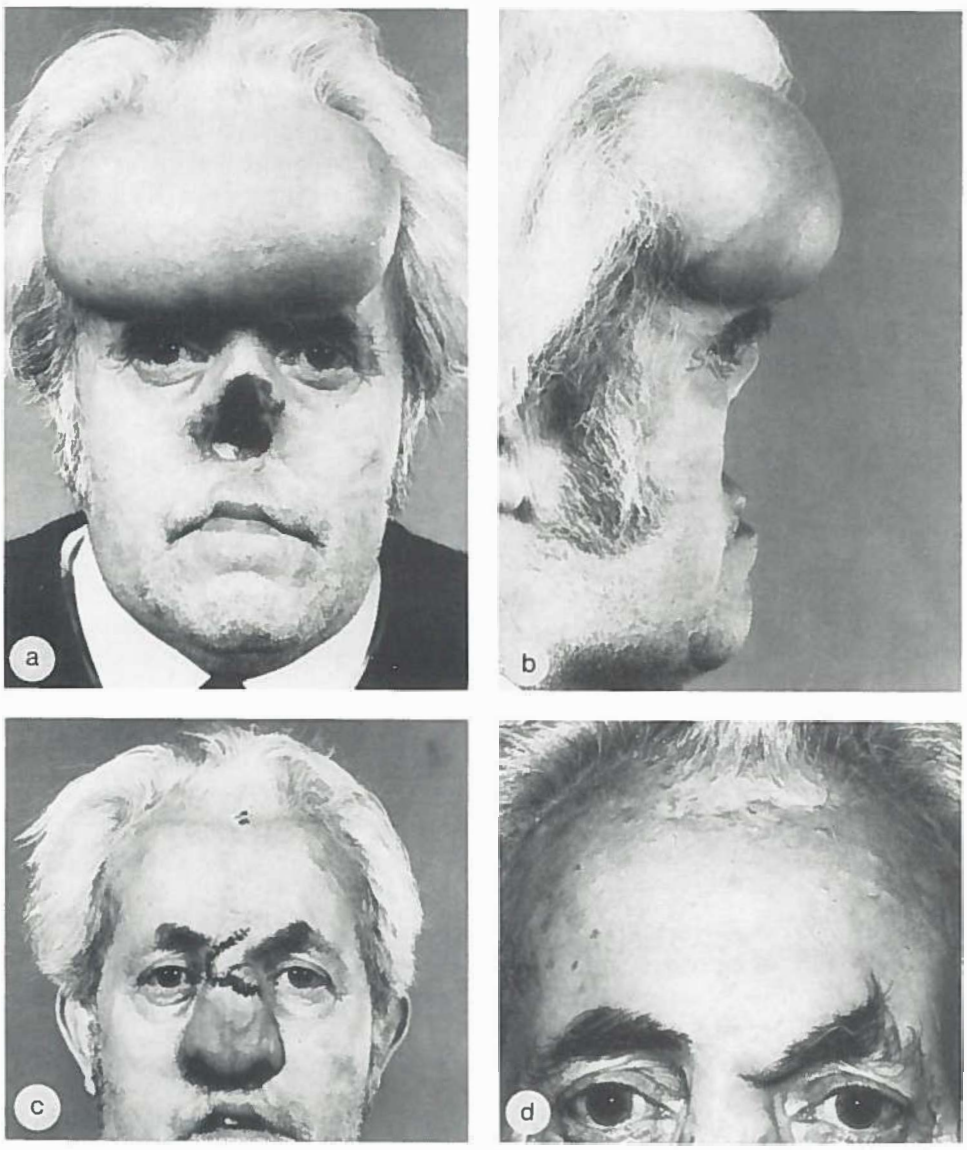


Fig. 9.2: A 62 year old man had had his nose amputated. After expansion of his forehead (a and b), reconstruction by means of a forehead flap was performed (c). Nevertheless a 9 cm wide flap was excised only a fine linear scar rested (d).

9.2.3 Ear reconstruction

Case history
A 20 year old male had a congenital microtia of the right ear with absence of the external meatus (fig. 9.3.a). Because of aesthetic reasons he wished to have the auricle reconstructed.

A 100 cc rectangular tissue-expander was chosen and inserted in the post auricular region. The remote fill-dome was placed dorsally in the neck. Initial filling was done with 15 cc sterile saline. After 2 weeks gradual filling was started. With weekly intervals 10 cc saline was injected. Four weeks after the definite volume of 95 cc had been reached (fig. 9.3.b), the second stage operation was carried out. By means of Z plasties the earlobe was placed caudally. The expanded skin was advanced over a Chondroplast® skeleton and the newly formed ear was fixed with cotton wool (fig. 9.3.c). Half a year later another operation had to be done to separate the helix from the skull. This was done by grafting the retro auricular region with a full thickness skin graft from the groin. The definite result was bad, nevertheless the patient was content (fig. 9.3.d).

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	2	2	1		1A	1B
Amer. population	-	-	-	-	-	-
TOTAL	2	2	1	-	1A	1B

Special standard treatments
- The same special treatments as indicated under § 9.2.1 do apply.

Special pitfalls and remarks
- The above mentioned complication concerned haematoma which could be drained.
- Crescent shape, flat span tissue-expanders are advised (O'Neal et al., 1984).
- A relatively small expander is preferable which can be over expanded when needed. In this way expansion of too much hair bearing area as well as wrinkling of the expander might be avoided.
- The expander has to be situated closely to the residual ear under the hairless post-auricular skin.
- By performing the expansion as rapid as possible a rather thin flap is created which simplifies the definite reconstruction.
- Homolog rib cartilaginous grafts are prefered to silicone (O'Neal et al., 1984) or Chondroplast®.

- Subcutaneous fixation of the advanced flap to the underlying temporal fascia has to be done to prevent tenting because of recoil.
- When hair bearing area has been used in the reconstruction, electro-desiccation of the hairfollicles of the skin of the reconstructed ear can be carried out.
- Ear reconstruction is difficult with or without tissue-expansion.

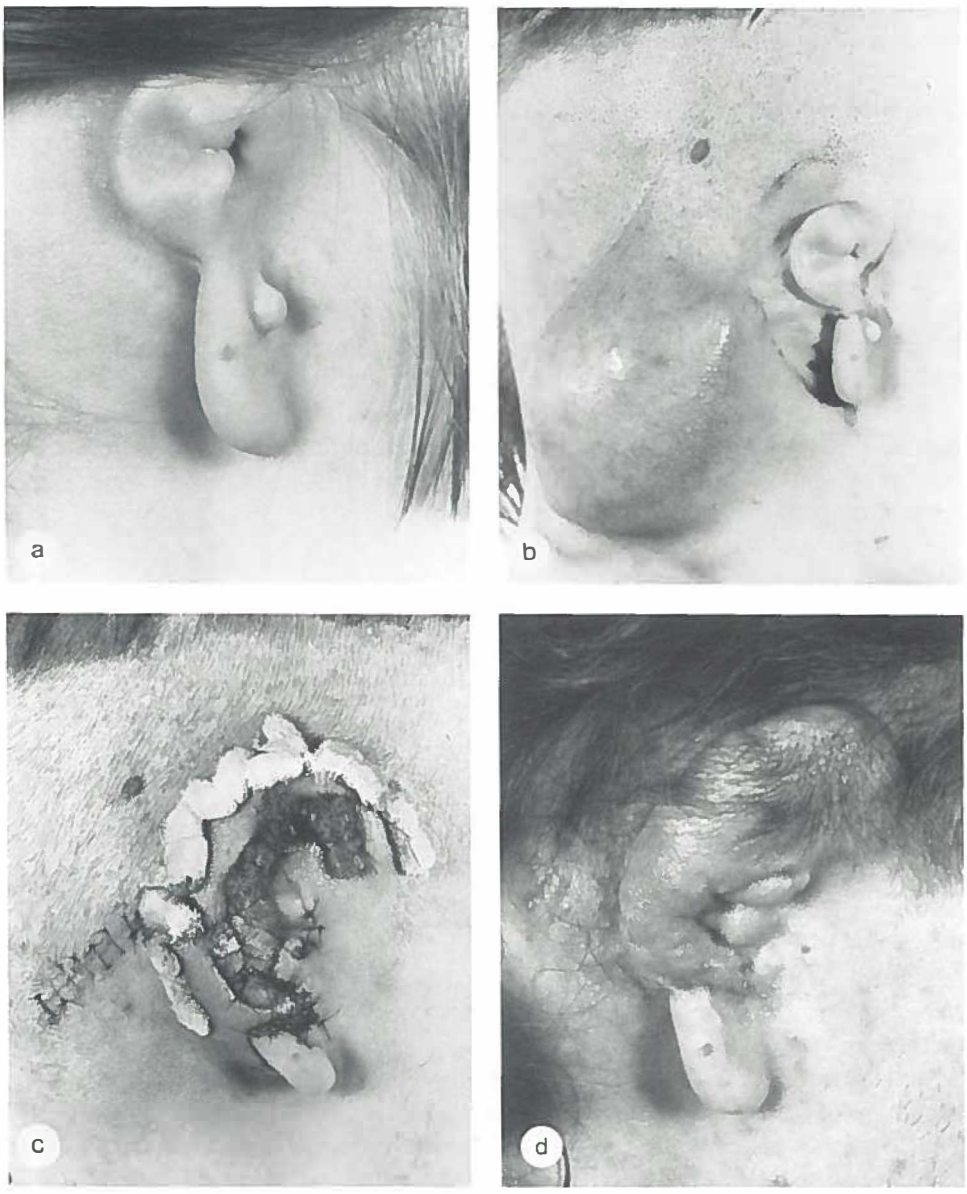


Fig. 9.3: A 20 year old man with a congenital microtia of the right ear before (a), during (b and c) and after (d) reconstruction by means of tissue-expansion.

9.2.4 Eyelid reconstruction

Case history
A 57 year old man lost his left eye in an accident twenty years ago. He used a prosthesis. Several operations were performed over the years because of asymmetry in the eye level. There was also entropion of the left upper and lower eyelids. Because of aesthetic reasons he asked for reconstruction.

Two special difficulties arise in this area: Skin reduction of the lower eyelid would show to much of the prosthesis. By skin reduction of the upper eyelid problems would arise in the retention of the prosthesis. For these reasons tissue-expansion of the deeper layers of the upper as well as the lower eyelid was carried out. Two custom-made tissue-expanders of a shape between rectangular and crescent ($3\text{-}\frac{3}{4}\text{-}1\frac{1}{2}$ cm) were implanted. In the upper as well as in the lower eyelid a submucosal pocket was created from the lateral side over the orbital rims. The fill-domes were situated on the lateral side of the orbit. Initial inflation took place with 2 cc and one week later gradual inflation was continued with 1 or 2 cc weekly. Eight weeks after the initial operation the maximal volume of 15 cc in each expander was reached. Three weeks later the expanders were removed, resulting in an absence of entropion. The patient was content with the result. After a follow-up of three months entropion recurred.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	1	2	-	-	-	1B
Amer. population	-	-	-	-	-	-
TOTAL	1	2	-	-	-	1B

Special pitfalls and remarks
The expression of Victor and Hurwitz (1984) 'The potential for tissue-expansion in oculoplastic surgery is exciting' is not supported by our findings. Alternative methods for eyelid reconstruction have proven themselves to be reliable, yielding in general satisfactory aesthetic results. As described earlier tissue-expansion probably concerns more 'stretching' of skin than 'new formation' of tissue. Keeping in mind that 'stretchback' develops more easily when no fixation to the underlying tissue is secured one can easily imagine that this phenomenon will take place particularly in areas where stretching is not maintained. Thinking along these lines we feel that the end result of expanded tissue in the orbital region will hardly show any improvement. We are not in favour of tissue-expansion in eyelid surgery.

9.2.5 Alveolar ridge reconstruction

(Courtesy Albert Wittkampf, M.D., D.D.S.)

Case history

In 1973 a Morbus Hodgkin was diagnosed in a 21 year old female; she received radiotherapy of which a total dose of 40 Gy was delivered to her mandible. She lost her teeth because of caries and periodontal disease. In february 1975 her remaining teeth were extracted and a full denture was provided. A rapid bone resorption took place, possibly accelerated by decreased blood supply as result of the radiotherapy. The patient was refurred to the department of oral and maxillo facial surgery of the University Hospital of Utrecht. She complained about lack of retention of the dental prosthesis during chewing and speaking. Twelve years after the last extraction the residual height of the mandible was about 10 mm (fig. 9.4.a). Intra-orally no retention for dental prosthesis was possible (fig. 9.4.b). The mandibular atrophy was classified as Cawood type v (Kent type iv), less suitable for direct Hydroxylapatite application. Especially in this type of resorption the Hydroxylapatite granules are likely to migrate to the floor of the mouth or to the buccal side. This results in loss of reconstructed alveolar height. The choice had to be made between several preprosthetic procedures:

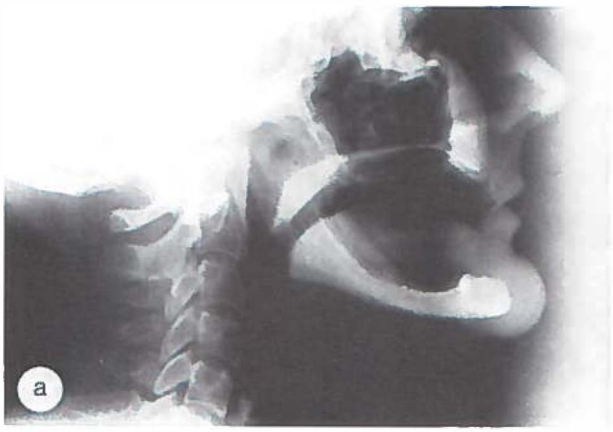
- vestibulum plasty and deepening of the floor of the mouth in this patient promissed little gain, because of the strongly reduced total mandibular height.
- permucosal and transmandibular implants in an irradiated mandible were considered to be hazardous.

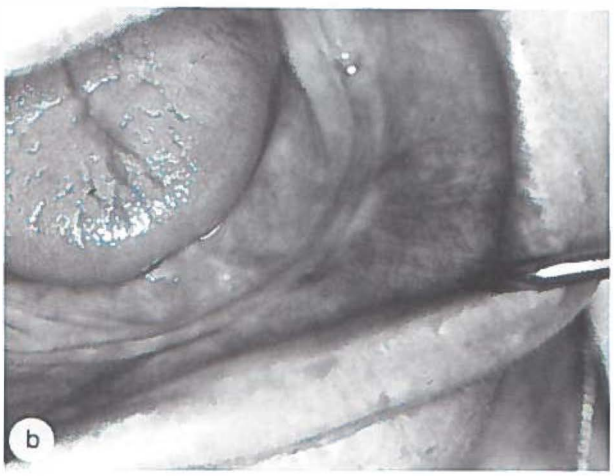
For this particular patient the tissue-expansion procedure was chosen. First the subperiostal tissue-expander was implanted to create an envelope in which Hydroxylapatite granules could be implanted in a second stage. By special request of the patient implantation took place under general anaesthesia. A 1.5 cm horizontal mucoperiosteal incision in the residual vestibulum of the front region was performed. After careful tunneling a subperiosteal pocket was created on the top of the mandible from the front region up to the retromolar pad on both sides. To avoid nerve damage dissection was performed very much on the lingual side in the mental foramen region. Mersilene sutures attached to the teflon tabs at the end of the expander, inserted through the eye of an awl were passed into the tunnel through the mucoperiosteum in the retromolar pad area again into the oral cavity. By pulling the mersilene into a dorsal direction the expander was implanted. By means of the awl the filling tube was positioned paramedially in the lower lip. The wound was carefully closed. The expander was filled with 1.5 cc sterile saline. The patient was put on intra-muscular high dose of penicillin for three days. On the third day postoperatively the 1.5 cc saline was removed by fingerpressure from the retromolar pad towards the midline on both sides simultaneously. One week postoperatively the sutures were removed and two weeks later the expansion was started. The total amount of 3.6 cc expansion had been achieved in four sessions

during the third week. One week after the maximum expansion the subperiostal tissue-expander was removed under local anaesthesia and the envelope (fig. 9.4.e) was filled with approximately 8 grams of Hydroxylapatite granules. Immediately postoperatively a firm stable ridge was present (fig. 9.4.c and d). With a follow up of one year a firm and stable reconstructed processus alveolaris with good retention potentials was seen. No sensibility disturbances nor Hydroxylapatite migration showed up. Both patient and prosthodontist were content.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good A = acc. B = bad
Utr.population	8	8	2	8G
Amer. population	-	-	-	
TOTAL	8	8	2	8G





Special standard treatments

- A three day high dose penicilline regime is advised.
- Preoperatively mouth wash with chlorhexidine 0.2%.

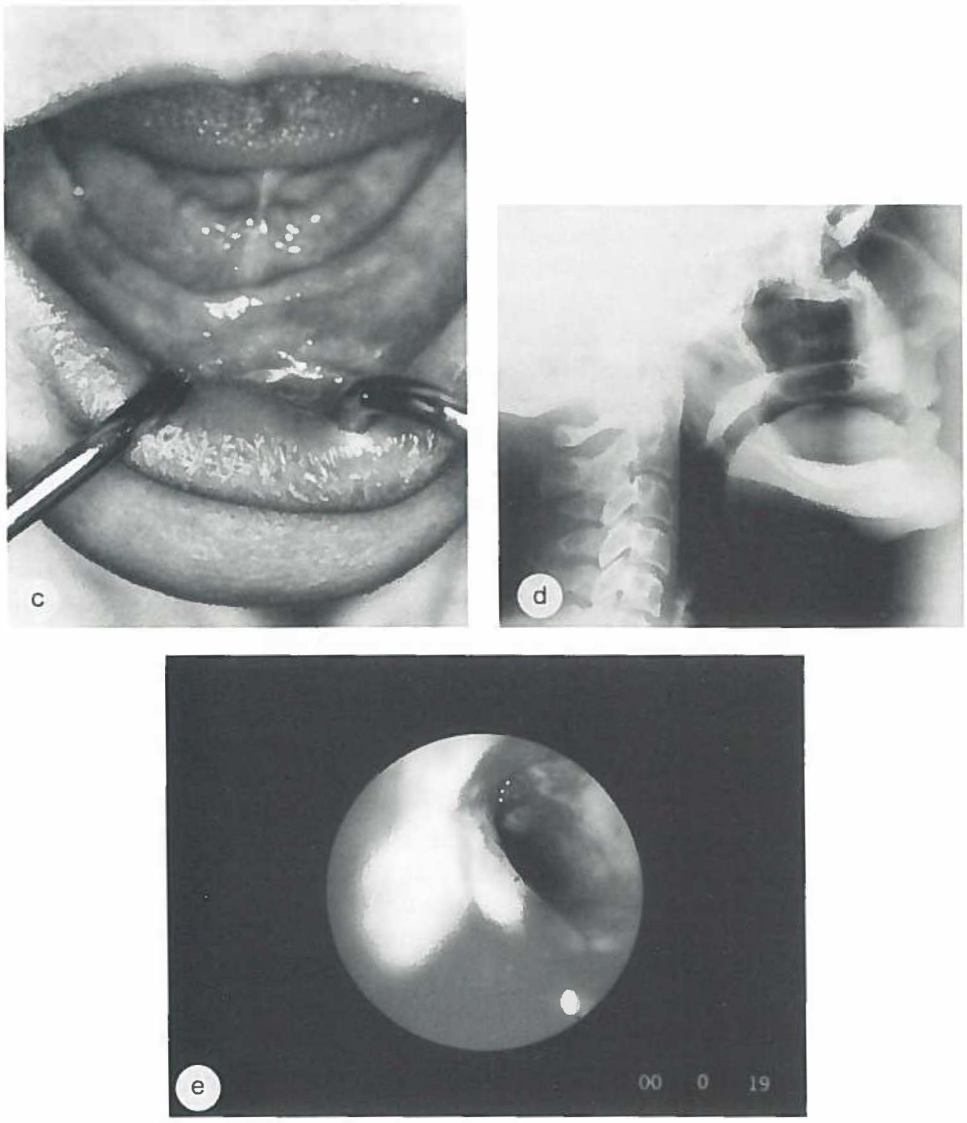


Fig. 9.4: A 35 year old female who lost her teeth after irradiation, now 12 years ago, before (a and b) and after (c and d) reconstruction of the alveolar ridge by means of tissue-expansion. The well formed envelope and capsule just before filling with Hydroxylapatite is shown in (e).(Courtesy Albert Wittkampf, M.D., D.D.S.)

Special pitfalls and remarks

- There were two complications. In one patient in whom a vestibulum plasty was performed earlier, the split-skin-graft was firmly attached to the underlying periosteum. During the operation three perforations occurred because of the firm attachment of the split-skin-graft to the underlying bone. Therefore, implantation of the expander was considered to be hazardous. A direct (so without tissue-expander) alveolar ridge reconstruction using Hydroxylapatite granules and fibrin glue was performed with a good result. The second complication occurred in a similar case. A patient had undergone a vestibulum plasty and a transmandibular implant elsewhere. The mandibular had fractured. Here too a perforation took place. The perforation was carefully closed and the expander was implanted in the usual way. One week postoperatively dehiscence on the perforated side was noticed; therefore expansion was carried out more rapidly. During the expansion the dehiscence became larger. Infection did not occur. After removal of the expander the dehiscence was sutured and the envelope filled with Hydroxylapatite. No migration or loss of implant material occurred and the result is classified as good.
- In patients who have undergone previous mandibular surgery or vestibulum plasties tunneling procedures are difficult to perform because of adherent tissues.
- The ideal indication for subperiosteal tissue-expanders are the Cawood type V (Kent type IV) alveolar ridge resorption with a flat ridge, inadequate in height and width. In case of a knife edge or depressed type of alveolar ridge resorption (Cawood type IV or VI) expansion is not indicated because a direct Hydroxylapatite alveolar ridge reconstruction is the method of choice.
- In literature a vertical midline incision is described (Bonomo, 1986 and Lew et al., 1986); in the Utrecht expercience a horizontal incision, away from the expanded region is more logical and preferable. No dehiscences were seen in our patients, using this type of incision.
- In the mental foramen region a very lingual preparation is advised to avoid nerve damage. By the time of insertion of the Hydroxylapatite granules, a firm envelope around the silicone expander has formed; therefore migration of Hydroxylapatite into the floor of the mouth does not occur.
- Special care has to be taken to avoid any perforation during dissection.
- Perforations have to be sutured before implantation of the expander.
- To avoid collection of haematoma in the subperiosteal tunnel the expander is filled with about 1.5 cc. saline immediately. This saline is removed together with a possible haematoma on the third postoperative day by finger pressure from the retromolar pad towards the midline on both sides simultaneously.

9.2.6 Expansion in the neck region

Case history

A 51 year old female with an ulcerating and fibrosing neurodermatitis recidivans dorsally in the neck had been operated three times over the last 4 years. The lesion had been excised and grafted respectively with split skin grafts and full-thickness skin grafts. Each time the fibrosing proces reappeared within half a year. She suffered from persistent pain and limited flexion of the head and asked for a definite solution.

The area to be excised measured 5.5 × 6.0 cm with a total surface-area of 33 cm^2 (fig. 9.5.a and b). A small rectangular expander (140 cc, 8-5-4 cm) was chosen. Via a paralaesional incision the expander was inserted cranially. The remote filling dome was placed cranio-laterally in the neck. The initial inflation was 40 cc. After one week further inflation was started. About 15 cc sterile saline was inflated twice a week. In this way the definite volume of 160 cc was reached in 4 weeks time (fig. 9.5.c). Two weeks later the fibrotic area was excised, the expander removed and the 'gained' tissue advanced. The superficial capsule was scored perpendicularly to the direction of advancement and was well fixed to the deep capsule. The wound was closed in layers. The painfull, pulling, limiting feeling had gone and the patient was content (fig. 9.5.d). A follow up of one year showed scar broadening and the patient felt some pulling again although the fibrosing neurodermatitis had not recurred.

Eventhough the definite result was acceptable it would have been probably wiser to use a bigger expander, to obtain more tissue surplus, thus preventing the return of a pulling sensation and obtaining a finer scar. Another possibility could have been a re-expansion by leaving the expander under the advanced skin.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	4	6	1	2G	2A	-
Amer. population	7	10	2	5G	2A	-
TOTAL	11	16	3	7G	4A	-

Special standard treatments

- For expansions dorsal in the neck see § 9.2.1.
- For expansions ventral in the neck only saline or Betadine solution is used in rinsing the cavity; prophylactic antibiotics are not used.

Special pitfalls and remarks

- The complications as marked in the table concerned infection, scar broadening and wound dehiscence (wrong size and/or bad positioning of the expander are the main causes).

- The pocket should be extra large and is best situated over the platysma.
- It is difficult to advance expanded neck skin onto the face and achieve a smooth, sculptured contour at the crossing over the mandible (Manders, 1986).
- Correction of anterior (midline) defects require multiple expanders, to avoid direct pressure on the trachea.

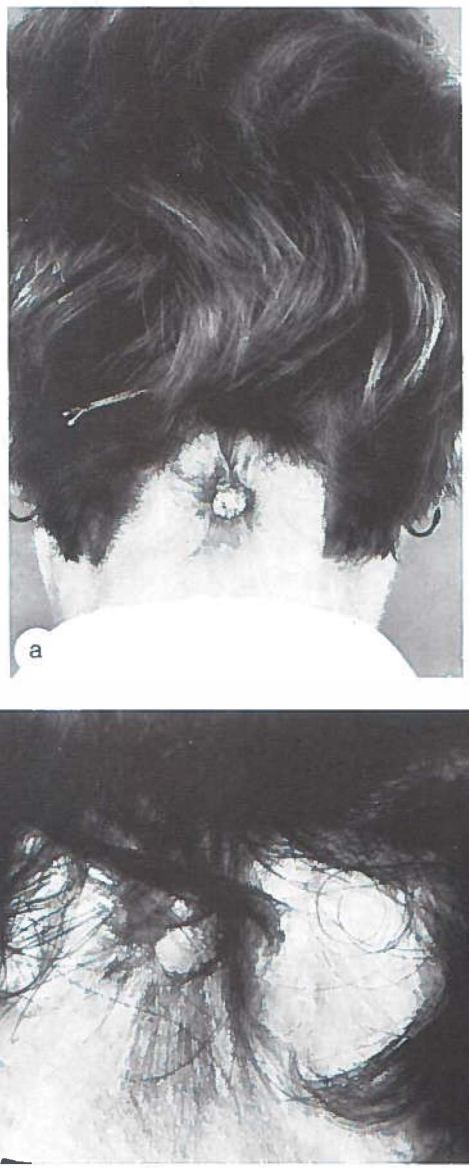
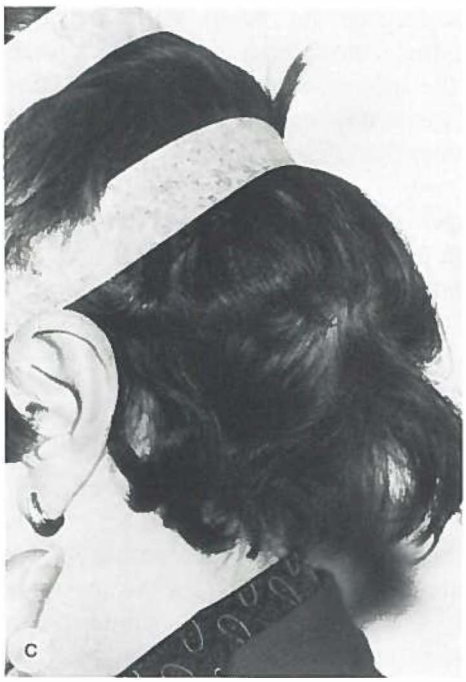
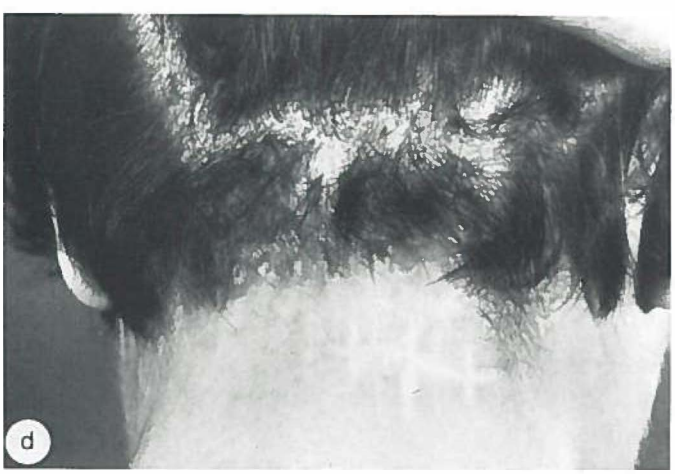


Fig. 9.5: A 51 year old female with an ulcerating and fibrosing neurodermatitis recidivans dorsally in the neck before (a and b), during (c) and after (d) reconstruction by means of tissue-expansion.

- A limiting scar in the neck region may be expanded itself, alleviating some or all of the tissue deficiency. The chance that the advanced tissue will again contract to the preexpanded size has been described (Hagerty and Zubowitz, 1986).
- In head and neck region muscle atrophy is seen in some areas after rapid expansion. This is of particular concern in the facial musculature (Bauer et al., 1986).





9.3.Tissue-expansion in the trunk

9.3.1 Breast

Case history (courtesy John Gibney, M.D.)
A 46 year old American housewife underwent a modified radical mastectomy on the left side three years earlier (fig. 9.6.a). Pathological anatomic examination showed an infiltrating ductal carcinoma in the lower lateral quadrant. All lymph-nodes removed with the specimen, were free of metastases. Irradiation was not indicated. Because of cystic fibrosis of the remaining breast and a cancerfobia of the patient the right breast had to be amputated as wel.

In one and the same operation the simple mastectomy on the right side was carried out and reconstruction of both breasts by means of tissue-expansion was started. Via a transpectoral approach on each side a large subpectoral pocket was bluntly dissected over two or three ribs separating the serratus from its origin and at the same time elevating it. In this way the pocket extended caudally 3 to 4 cm below the pre-operatively marked infra-mammary line. Two round shaped tissue-expanders of 500 cc were inserted while care was taken that the bases of the expanders were totally flattened out. Initial filling was 100 cc on both sides. The wounds were closed in layers. Two weeks later inflation was continued with 60 cc at weekly intervals. After seven weeks the definite volumes of 500 cc were reached (fig. 9.6.b and c). Two months later the second stage operations were performed. Via the most lateral parts of the original incisions the tissue-expanders were replaced by permanent 300 + 50 cc bilumen implants. One month after the second stage operation had been performed, nipple reconstruction by means of tattooing was carried out in the outward-patients' department. With a follow-up of 18 months the patient is content and the result can be valued as good. (fig. 9.6.d and e).

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	19	20	5	7G	10A	3B
Amer. population	179	250	15	200G	40A	10B
TOTAL	198	270	20	207G	50A	13B

Special standard treatments
- Infra-mammary fold should be marked pre-operatively with the patient in standing position.
- Antibiotics are not indicated (see § 9.6 for differences between Dutch and American approach).
- Rinsing the cavity with Betadine or saline.

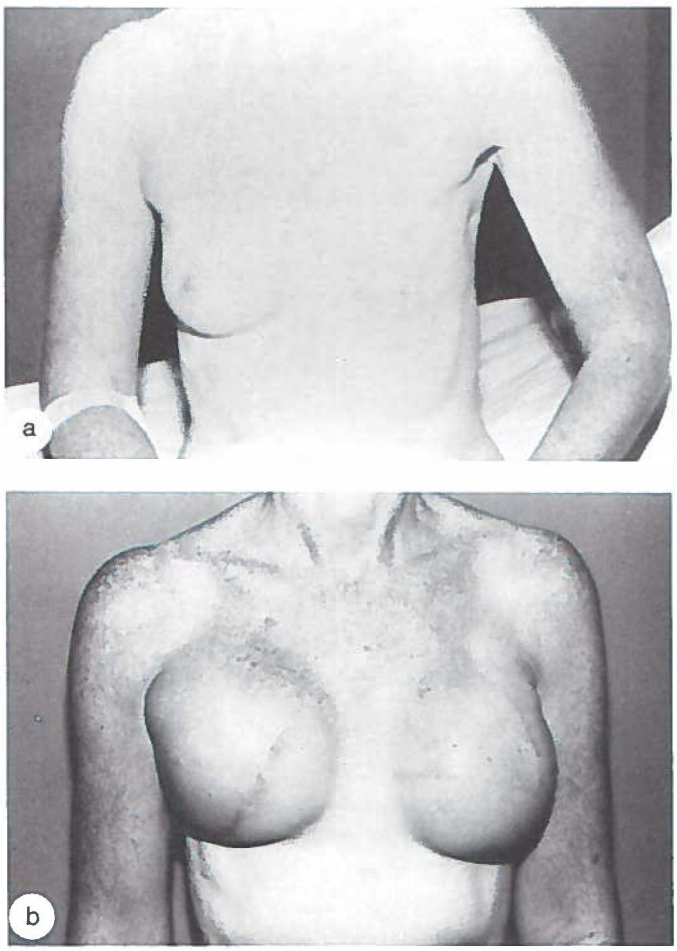
- Drains are advised for the first 24 to 48 hours.
- Overexpansion up to 100 to 200 cc more than the size considered to be necessary to achieve symmetry with the opposite side is advised.

Special pitfalls and remarks

- The complications as marked in the table have a broad variety and can best be presented in the following way. Infection (6), haematoma (1), leakage by damage or production fault of the fill-valve (3) or expander (1), exposure of the fill-valve (4) or expander (3), displacement of fill-valve (1) or expander (1).
- There is no agreement about the level of insertion of the expanders. Both subcutaneous as well as subpectoral techniques are used. The submuscular technique is prefered nowadays (Paul, 1985, Lapin et al., 1985, Chisholm et al., 1986, etc.). We feel that a better cosmetic result and a safer, rapid expansion is achieved in that way. Moreover the chance of capsule contracture is reduced.
- The fill-valve should not be positioned beneath scar tissue but in the subcutaneous fat preferably in the axillar region.
- Expansion in irradiated tissue must be done very gradually. Complication percentages of previously irradiated thoracic walls were over 30% in both the Dutch and the American population.
- When the definite volume of inflation is reached, the expander is left in place for 2 to 4 months. In this way a more ptotic shape would be achieved, moreover later capsule contracture would be less (Radovan, 1982[1])
- To create a natural infra-mammary fold the lower thoracic advancement flap can be very usefull (May et al., 1987).
- Symmetry in bilateral reconstructions is easier to achieve.
- Nipple reconstruction can be accomplished when the expander is taken out and the definitive endoprosthesis is inserted (Argenta 1984[2]). Nevertheless, better results are achieved when this is done three months after the second stage operation.
- When patients were treated with large skin grafts to close the defect after mastectomy, reconstruction with adequate tissue from another place of the body is required. To avoid skin grafting of the back when using a latissimus dorsi myocutaneous flap, expansion of this area under the muscle can be done before reconstruction is started. In this way no donor defect is left. Moreover, expansion can take place after transposition of the latissimus dorsi myocutaneous flap. In such case the expander is placed beneath the transposed latissimus dorsi flap at the initial operation and after several weeks serially expanded until a defenite prosthesis can be inserted (Argenta et al., 1983[2]).
- The use of tissue-expanders offers significant advantages in the reconstruction of congenital breast deformities e.g. in Poland syndrome. In young girls periodic inflation of saline provides symmetry while the opposite breast matures (Argenta et al., 1985[2] and Versaci, 1985).
- By using a permanent tissue-expander e.g. the Gibney RDL expander or the

Becker prosthesis, a different type of expansion can be performed that will reduce the second stage operation to a minor intervention (Gibney, 1986 and Becker, 1987).

- Also in patients with very large breasts, reconstruction by means of the tissue-expansion technique is possible. Submuscular expansion up to 1000 cc followed by an insertion of a definitive prosthesis of 600-800 cc have been described (Argenta, 1984[1]).
- The tissue-expansion technique has made immediate breast reconstruction a safer procedure. Specially when enough time is allowed before the first inflation will be done (Argenta, 1984[1]).



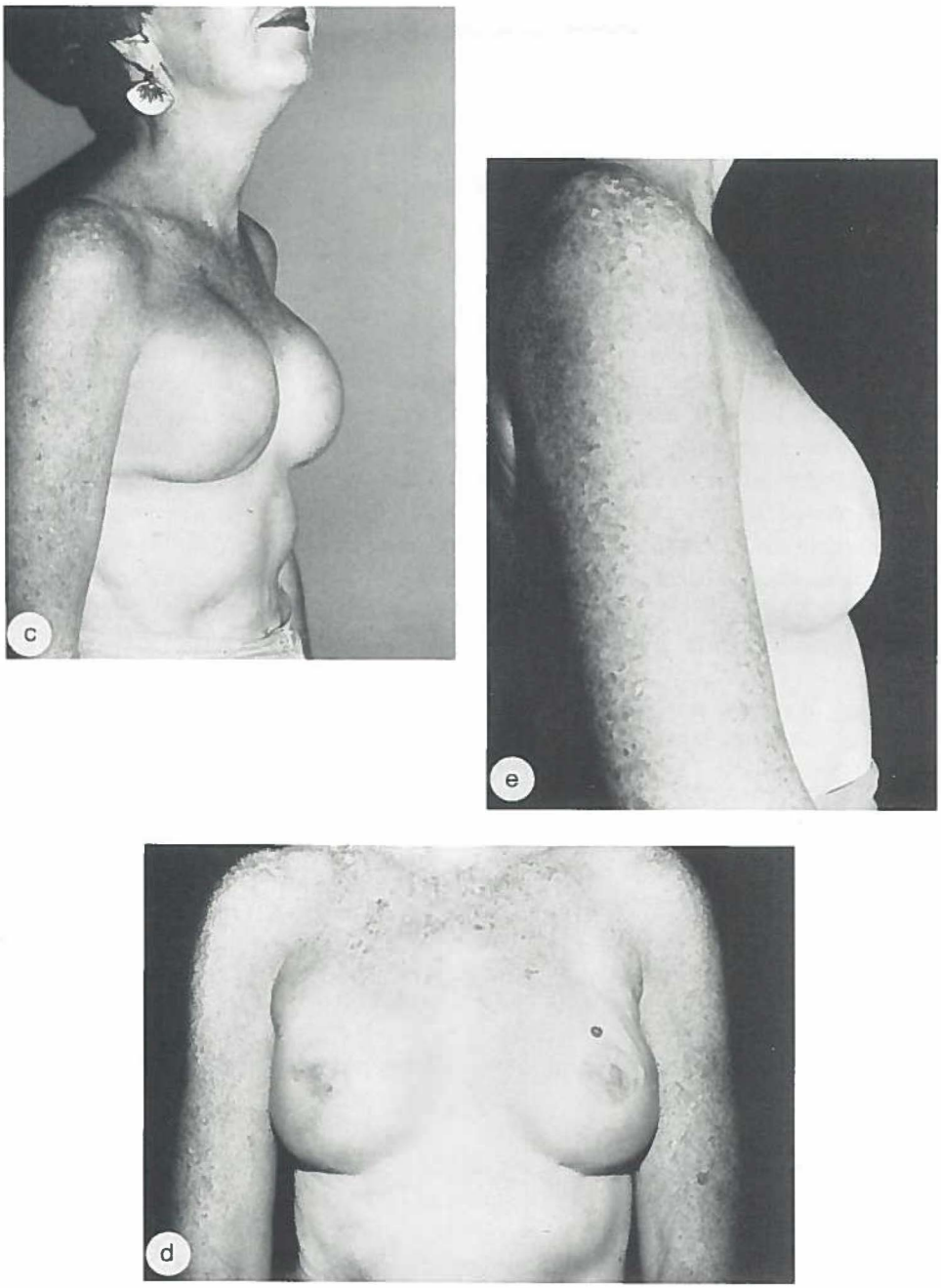


Fig. 9.6: A 46 year old female underwent a modified radical mastectomy on the left side (a). Three years later a simple mastectomy on the right side had to be carried out. Immediate reconstruction after the simple-mastectomy was performed on both sides with tissue-expansion techniques (b and c). The follow-up was 18 months (d,e). (Courtesy John Gibney, M.D.)

Case history

An 18 year old female was involved in a severe car accident 6 years earlier. A large soft tissue defect on her right buttock had been closed by split skin grafts. A large contour defect remained. She asked for reconstruction.

The grafted area measured 30 × 25 cm with a total surface area of about 750 cm^2 (fig. 9.7.a). In an attempt to correct the contour as much as possible two rectangular tissue-expanders were used. Through a paralesional incision the expanders were inserted under the subcutaneous layer but above the deep fascia. One expander of 1000 cc was situated craniolaterally of the grafted area, while the other, which had a volume of 800 cc was implanted caudally of the defect in the craniodorsal part of the right upper leg. Initial inflation was 100 cc saline in each of the expanders. Two weeks after the first stage operation regular inflation was started. At weekly intervals about 100 cc was inflated. Both expanders were overinflated and after 12 weeks volumes of 1200 cc and 900 cc were reached (fig. 9.7.b). Two weeks later the expanders were removed and advancement was undertaken. The defect could not be reconstructed totally but the patient was very content and did not want any further correction (fig. 9.7.c and d).

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	5	8	0	3G	2A	-
Amer. population	5	7	2	3G	2A	-
TOTAL	10	15	2	6G	4A	-

Special standard treatments

- Antibiotics are only indicated in gluteal area reconstructions. In back and trunk reconstructions they are not necessary.
- Rinsing cavity with saline, Betadine or cephalosporine (1 gm per litre) is advised.

Special pitfalls and remarks

- The complications mentioned above concerned wounddehiscence (1), and scarwidening (1) to a larger extent than in other regions.
- Specially in the back some extra over-expansion is advised. Because of the tendency of scarwidening, the use of multiple expanders is recommanded.
- The skin in the lower back expands more slowly than the rest of the trunk (Bauer et al., 1986).
- Management of radiation necrosis of the chest wall following mastectomy by means of tissue-expansion is described by MacMillan et al. (1986).

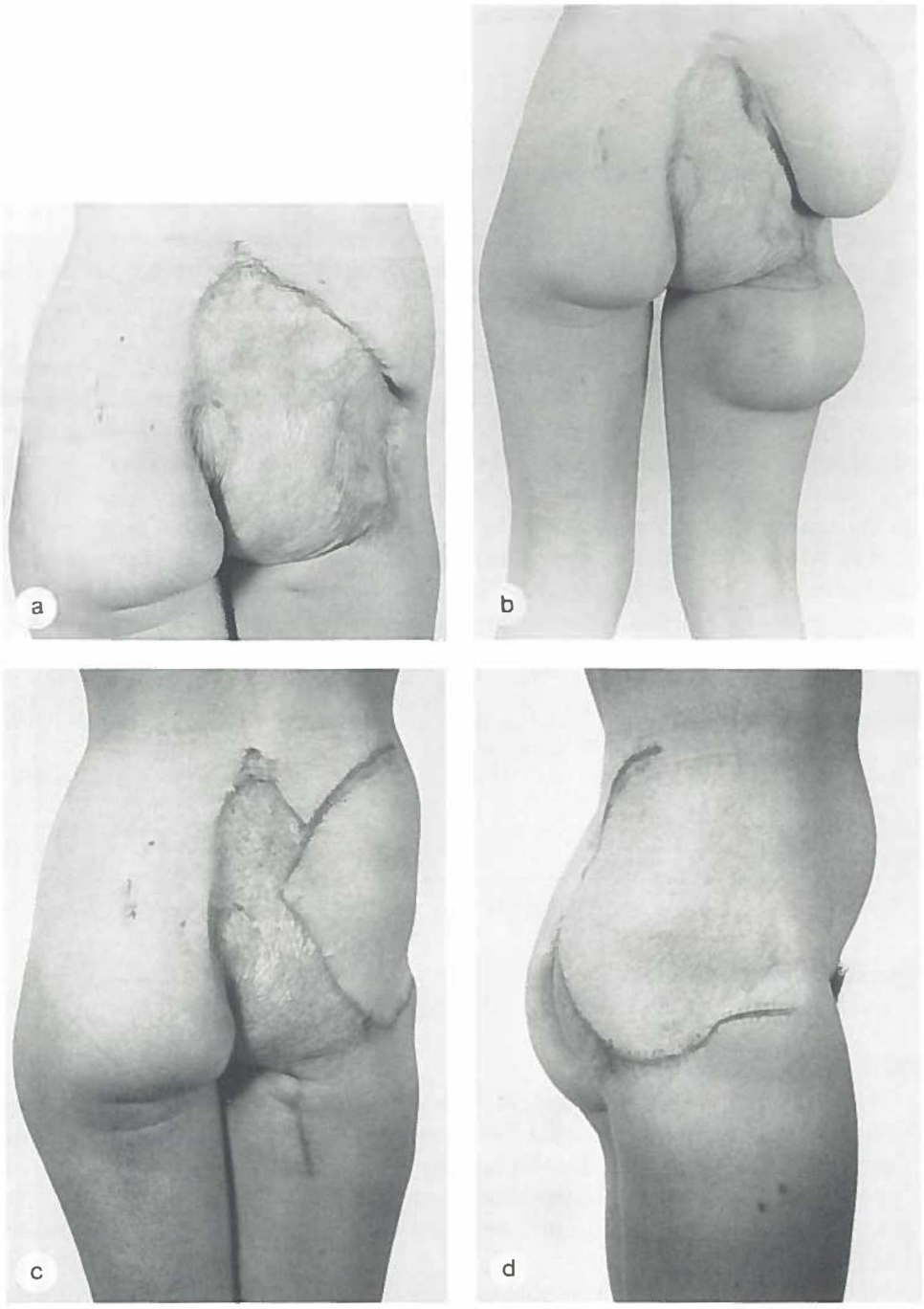


Fig. 9.7: An 18 year old female with a large soft tissue defect on her right buttock before (a), during (b) and after (c and d) reconstruction by means of tissue-expansion.

9.4. Tissue-expansion in the extremities

9.4.1 Shoulder region

Case history

A 20 year old male had undergone a forequarter amputation for an osteosarcoma involving his left upperlimb (fig. 9.8.a). Ten years after radical surgery there was no evidence of recurrence. Because clothes over his left 'shoulder' were always hanging down he wore an external shoulder prosthesis. He wished to get rid of this prosthesis and therefore requested reconstruction of his shoulder contour.

Casts were made to assess the desirable endoprosthesis, which was then made of silicone and had a volume of 1430 cc (Silicone Médicale R) (fig. 9.8.b). At the same place where the definite endoprosthesis had to be situated a round tissue-expander of 1000 cc was placed. This was done through an intralesional incision and a pocket was created under the subcutaneous layer. The fill-valve was placed ventrally on the thoracic wall. Initial filling was 250 cc. Three weeks later further inflation was started. At weekly intervals 150 cc were added. After 8 weeks the definite volume of 1550 cc was reached (fig. 9.8.c). Four weeks later the original scar over the shoulder was excised and the definite implant was inserted (fig. 9.8.d). With a follow-up of 4 months the patient is content, although some slight scar broadening is present.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	4	5	1	1G	3A	-
Amer. population	1	1	1	-	1A	-
TOTAL	5	6	2	1G	4A	-

Special standard treatments

- Usual technique as described in § 8.3, no special treatments required.

Special pitfalls and remarks

- The first complication mentioned above concerned extreme scar broadening because of insufficient expansion, while the second concerned displacement of the expander downwards. By this wandering the expanded tissue was situated too far from the defect to be used for reconstruction.
- Scar broadening in this location is very obvious, for this reason over-expansion is needed.
- The fill-valve should not be placed over the scapula because of pressure during sleep.
- Mackinnon (1985) describes a shoulder reconstruction after forequarter ampu-

tation in which the temporary expander was not replaced by a definitive prosthesis. The fill-valve situated in a subcutaneous position ventral in the trunk did not give any problems to the patient.

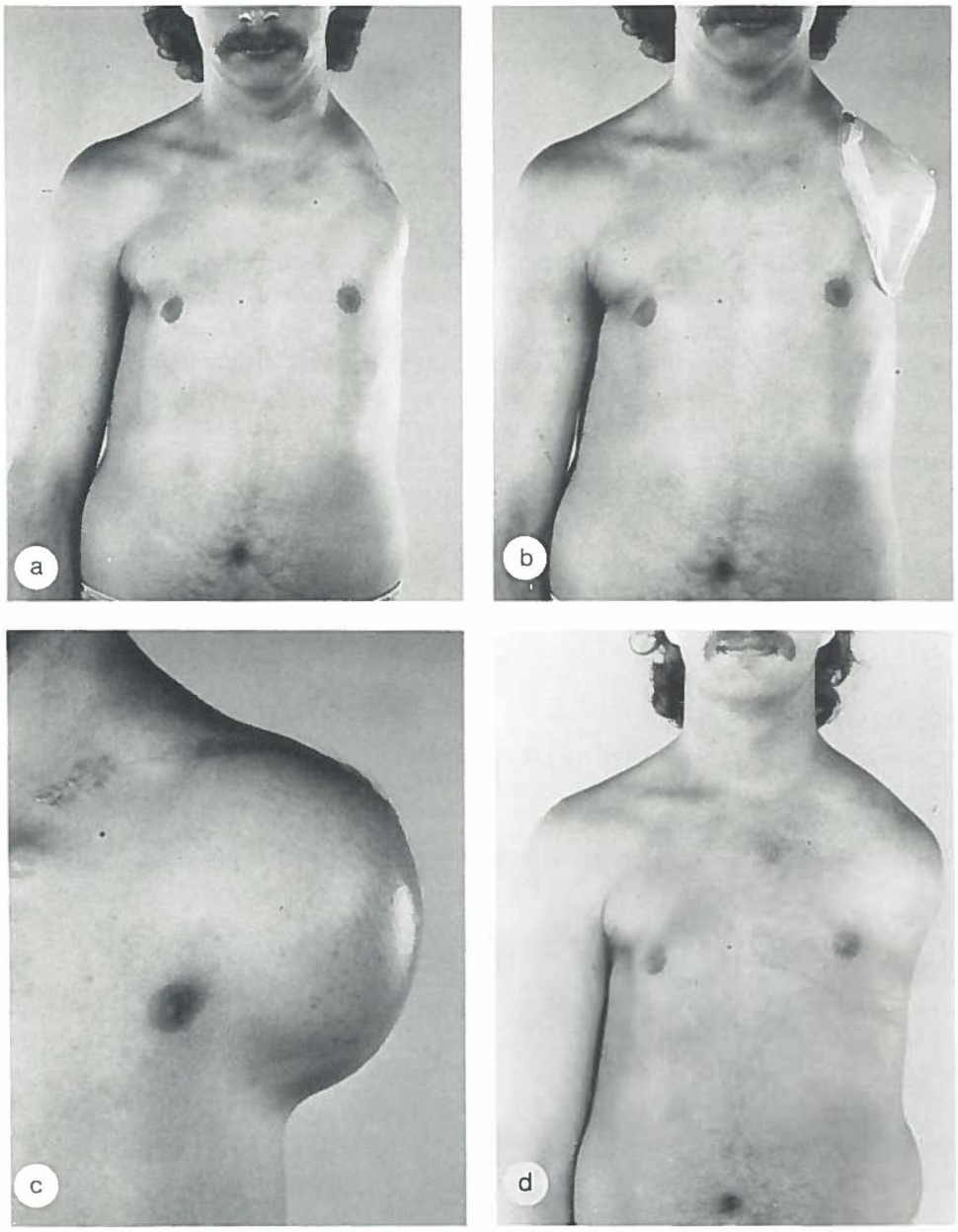


Fig. 9.8: A 20 year old male had undergone a forequarter amputation (a);to implant a custom made endoprosthesis (b) tissue-expansion was performed (c) in this way reaching a good reconstruction (d).

9.4.2 Upperarm / elbow region

Case history

A 35 year old female suffered from von Recklinghausen neurofibromatosis. She had persistent pain and swelling in the medial epicondylar region of the right elbow. The process involved the skin and the ulnar nerve. Therefore a big part of subcutis of this region was excised three years earlier (fig. 9.9.a).

A rectangular tissue-expander of 340 cc was inserted on the lateral aspect of the elbow. Initial filling was 100 cc. Ten days later gradual inflation was started. A volume of 480 cc was reached in eight weeks (fig. 9.9.b). Two weeks later the pathological skin and subcutis were excised (fig. 9.9.c). Neurofibrotic tissue seemed to invade the ulnar nerve which was released out from the sulcus to a more ventral position. By advancing the expanded tissue the defect could be closed without any problem. A follow up of 6 months showed an acceptable result without any pain (fig. 9.9.d).

Summary of empirical data

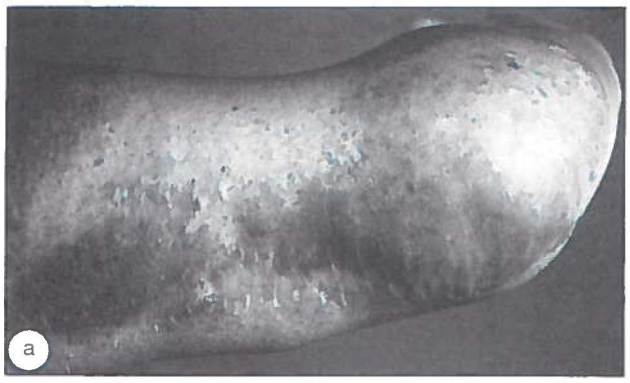
	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	7	9	2	3G	2A	2B
Amer. population	5	8	1	3G	2A	-
TOTAL	12	17	3	6G	4A	2B

Special standard treatments

- Usual technique as described in § 8.3, no special treatments required.

Special pitfalls and remarks

- The complications mentioned above concerned wound dehiscence (1), partial necrosis of the flap (1) (probably because of too rapid expansion) and infection



(1) which, in spite of antibiotic treatment, forced interruption of the procedure.
- Care must be taken not to compromise vascularisation or innervation.
- It is better to use multiple smaller expanders than one large expander.
- Expanders are better situated medially and laterally to the defect than inferior and superior.
- Leave expander at full expansion for 4-6 weeks prior to moving the flap.

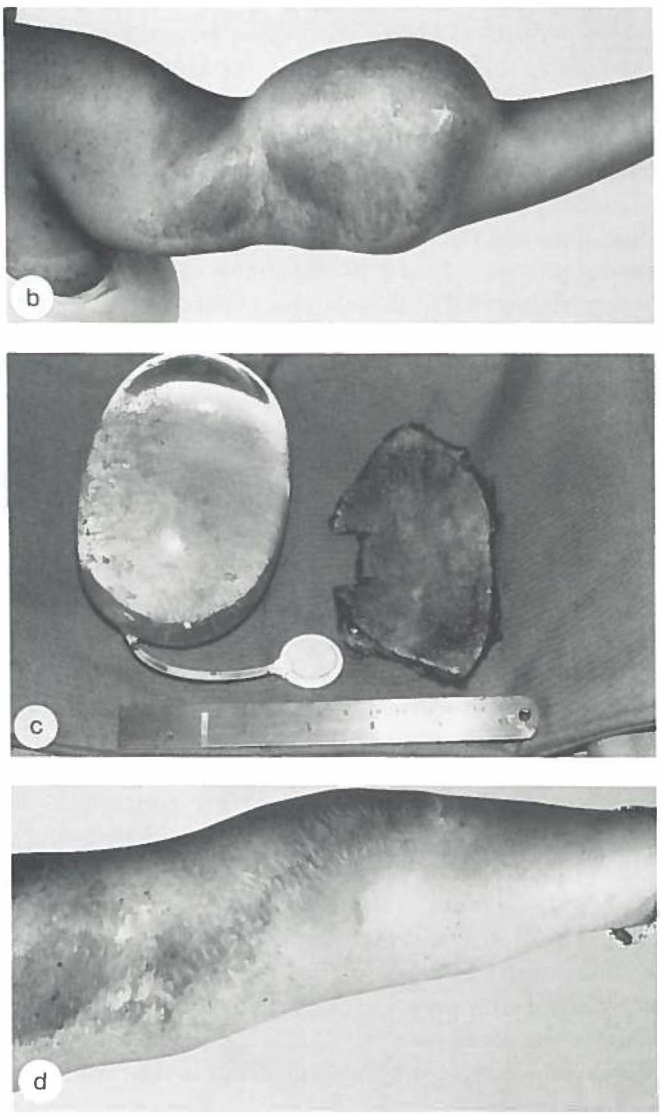


Fig. 9.9: A 35 year old female who suffers from von Recklinghausen neurofibromatosis before (a) and during expansion (b) of the right elbow. After excision of the pathological skin and subcutis (c), reconstruction was performed (d).

9.4.3 Fore-arm region

Case history
An 18 year old student fractured his fore-arm. He was treated with two osteosynthesis plates. He did not like the remaining broad scars (12 × 2 cm and 10 × 1.5 cm) and asked for correction.

Two rectangular expanders of 680 cc and 140 cc were inserted under the subcutaneous layer and above the deep fascia. The largest expander was situated on the ulnair side while the smaller was placed in between the two scars. Initial inflation of both expanders was 10% of the volume. After 3 weeks inflation was started. With intervals of about 10 days 10 to 15% of the volume was inflated. Up till 400 cc and 80 cc no problems were met. Then leakage appeared in the largest expander. Six weeks earlier than planned the expanders were taken out, the scars were excised and the defects were primarily closed. With a follow up of 1 year both scars showed widening. This is probably due to the insufficient expansion.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	2	3	1	-	1A	1B
Amer. population	2	2	1	1G	1A	-
TOTAL	4	5	2	1G	2A	1B

Special standard treatments
- Scrubbing and desinfection with Betadine the night of the preoperative day and the morning of the operation day is advised.

Special pitfalls and remarks
- The complications as mentioned above both concerned leakage of the expanders. In the Dutch case the leakage was caused by perforation the hard plastic backing of the fill-valve with a needle. The leakage in the American case was probably based on failure in manufacturing.
- As mentioned in § 9.4.2. the placement of expanders has to be medial/lateral and not superior/inferior to the lesion.
- Circulatory problems and pain are frequently seen in expansion in the lower arm; expansion should be carried out at a very slow rate.
- Wearing a sling can prevent lymphoedema distal to the expanded area.
- Leave expander at full expansion for 4-6 weeks prior to advancing the flap.
- Neuropraxia is seen, but no definite sensibility loss.
- Herndl and Mühlbauer (1986) described the use of a tissue-expander for direct closure of the donor defect of a radial forearm flap.

9.4.4 Hand region

Case history
A 4 year old Caucasian boy was born with syndactily of digits III and IV of both hands and feet. Because of pain one foot was operated. The toes were separated while the skin defects were closed by means of split skin grafts taken from his right upper leg. At the acceptor- as well as donorsite enormous keloid formation appeared. To prevent keloid formation after the syndactily correction of the fingers, tissue expansion was decided to be performed. In this way there would be less scaring in the hand while no donorsite would be necessary.

A custom made rectangular tissue expander of 20 cc (4-2-2.5 cm) was inserted on the dorsal side of the syndactily of the right hand just under the subcutaneous layer (fig. 9.10.a). The micro cylindrical fill-valve was situated on the dorsum of the hand. Initial inflation was 2 cc. The first postoperative day a blue discoloration was seen over the wrinkles of the expander for which reason all saline was taken out of the expander. After 3 weeks, expansion was started again very gradually. At weekly intervals only 1 to 2 cc was inflated. After 12 weeks a volume of 16 cc was reached (fig. 9.10.b). The overlying skin looked very red as if infected. Moreover the skin overlying the expander felt very thin. Waiting a longer time before doing the second stage operation or continuing inflation seemed not justified. The expander was taken out, no sign of infection was seen and remodelling of the two fingers was performed. Only on the distal ends of the fingers where the phalanges had to be separated, full-thickness grafts, from the left groin were applied. The post operative result was acceptable. Only one fibrotic keloid like scar was seen. Little limitation in finger movements was seen (fig. 9.10.c and d). The same procedure using the same, now re-sterilised expander was performed in the other hand three months later.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G=good	A=acc.	B=bad
Dutch population	2	2	1	-	2A	-
Amer. population	1	1	1	1G	-	-
TOTAL	3	3	2	1G	2A	-

Special standard treatments
- Scrubbing and desinfection the extremity with Betadine the night before and the morning of the operation.

Special pitfalls and remarks

- The above mentioned complications both concerned circulation problems for which reason saline had to be taken out of the expanders. In one expansion partial flap loss was seen; however this did not interfere with the final result.
- Expansion in the hand is very painfull, especially in children this can be a big problem. To avoid the extra pain of the transcutaneous punction it is advised to leave the fill-valve outside the skin (see § 8.3.d.).
- Neuropraxia is seen. In some months the sensibility returns to normal.
- The prescence of surgical scars makes secondary corrections in syndactily more difficult with a higher complication rate (Morgan and Edgerton, 1985).

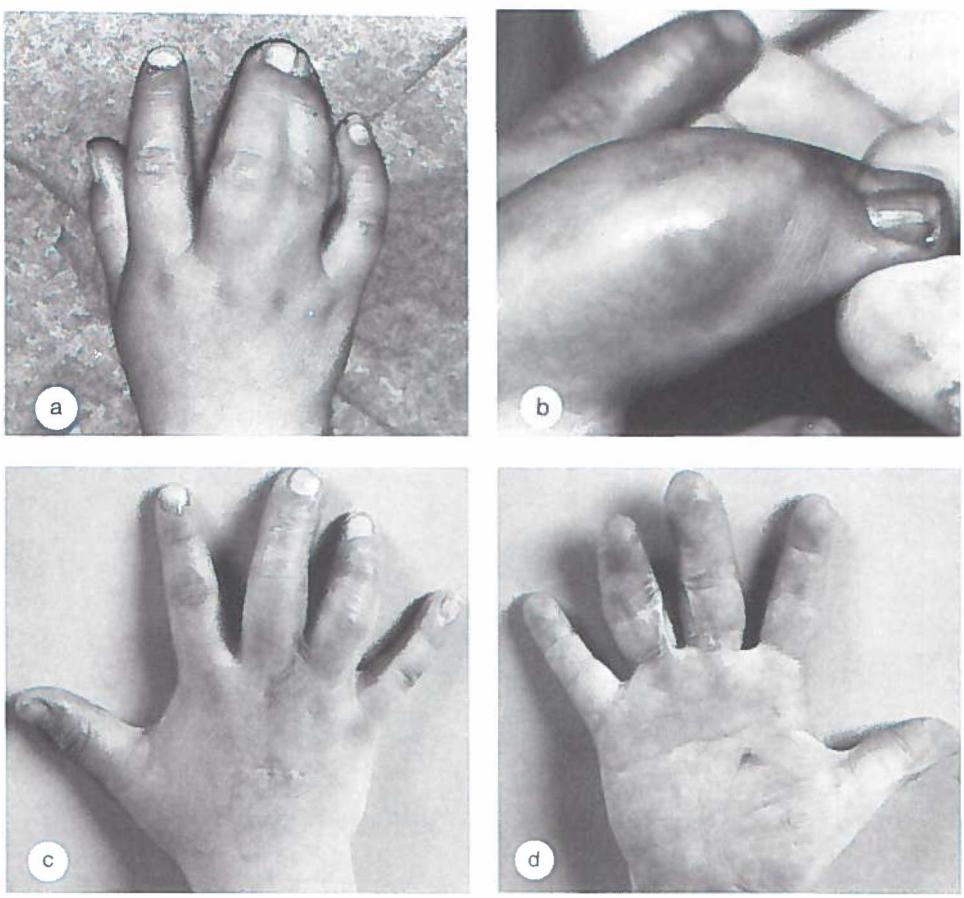


Fig. 9.10: A 4 year old boy with syndactily of digits III and IV of the right hand before (a), during (b) and after (c and d) reconstruction by means of tissue-expansion.

9.4.5 Upperleg / knee region

Case history
A 27 year old female was burnt at the age of 4. The third degree burns had partly been treated with skin grafts. Over the last few years serial excisisions had been performed. She asked for further reconstruction.

On the ventral part of the right upperleg scars with a total surface-area of about 100 cm^2 existed, and the partly circular scars on the left upper leg measured about 150 cm^2. The ventral part of the left lower leg was scarred too (fig. 9.11.a). In both upper legs rectangular tissue-expanders of 680 cc and 340 cc were placed paralesionally at the subcutaneous level via an intralesional incision. In the same operation partial excision of scar tissue of the left lower leg took place. Initial inflation was 20%. After two weeks controlled expansion was started. After two months of weekly inflation 120% of the respective volumes was reached (fig. 9.11.b and c). At that time the patient suffered from pain in the right leg when walking. She could not be motivated to continue the expansions to the volumes which were required. For this reason the expanders were taken out some weeks earlier than planned and advancement as far as possible was done. A maximal amount of scar tissue excision was attempted, but this resulted in too much tensile on the wound edges. This situation, combined with the fact that the wound was positioned between scar tissue at both sides, caused partial flap necrosis and infection of the wound area. Antibiotics and Eusol parafin application prevented further loss. After about 6 weeks all defects were healed (fig. 9.11.d). Nevertheless the aim to remove the total scarred area was not reached, the patient was fairly content with the result after a follow up of 9 months. In time re-expansion will be undertaken again.

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	8	13	2	1G	6A	1B
Amer. population	2	2	1	-	2A	-
TOTAL	10	15	3	1G	8A	1B

Special standard treatments
- Usual technique as described in § 8.3; no special treatments required.

Special pitfalls and remarks
- the above mentioned complications concerned circulation problems caused by too tight advancements and intralesional wound closure (1), infection (1) and scar widening (1).
- for circulatory reasons expanders are better placed medially and laterally to the

defect than inferior and superior.

- leaving the implant in fully expanded stage for 4-6 weeks prior to advancement helps to reduce stretchback.

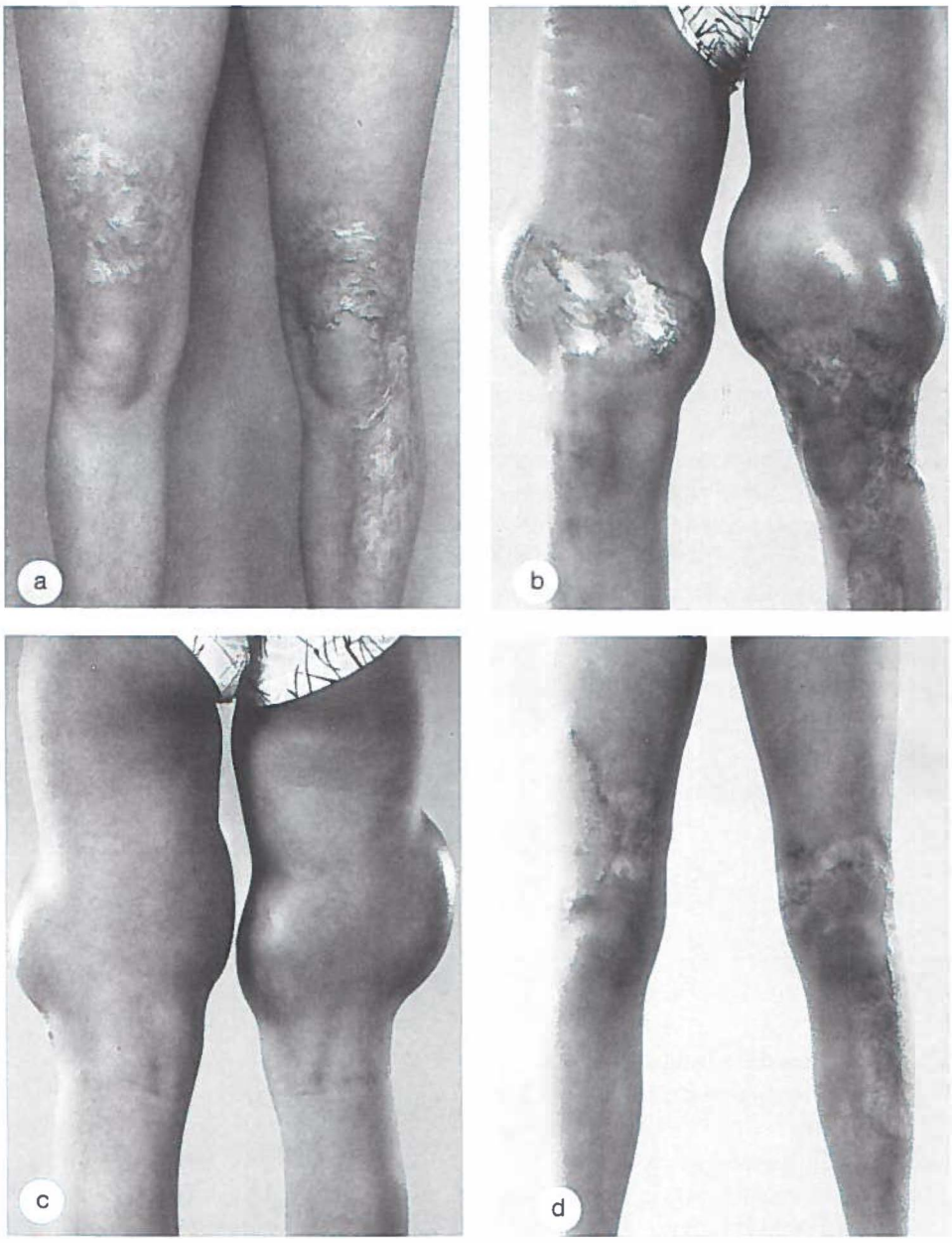


Fig. 9.11: A 27 year old female with burn scars on both legs before (a), during (b and c) and after (d) reconstruction by means of tissue-expansion.

9.4.6 Lowerleg region

Case history

A 53 year old male suffered from Morbus Bürger. Because of this disease he had a below knee amputation of his right leg three years ago. The amputation scar was situated ventrocaudally on the stump. Centrally in this scar there was a persistent fistula (fig. 9.12.a and b). Several operations took place without definite repair. At the request of the department of rehabilitation an attempt was made to displace the amputation scar to a more dorsal position. In this way the scar tissue would not be involved by pressure of the prosthesis. The fistula would probably not return after wide excision.

Through a remote incision a 680 cc rectangular tissue-expander was placed on the ventral part of the stump, proximal to the scar. It was inserted as deep as possible over the residual part of the tibia. Two weeks after the first stage operation gradual inflation was started. With weekly intervals very small amounts (less than 10% of the maximum volume) of saline were injected. In this way the definite volume of 600 cc was reached after 12 weeks (fig. 9.12.c). Two weeks later excision of the old amputation scar and some healthy tissue dorsally from the scar was performed. The expanded tissue was advanced so that the scar could be placed more dorsally, not over the bony stump. Six weeks after the second stage operation the patient was able to wear his lower leg prosthesis without any problem. With a follow up of one year and a half no recurrent fistula has been seen (fig. 9.12.d).

Summary of empirical data

	number of patients	number of expanders	number of complic.	results G = good	A = acc.	B = bad
Dutch population	3	3	1	1G	1A	1B
Amer. population	2	2	1	-	1A	1B
TOTAL	5	5	2	1G	2A	2B

Special standard treatments

- Usual technique as described in § 8.3; no special treatments required.

Special pitfalls and remarks

- One of the above mentioned complications was based on circulatory problems, while the other concerned valve damage by inflation with a thick needle.
- Expansion has to take place in a very gradual way. In the below knee region circulation problems are often met.
- Expanders should not be placed proximal or distal to the defects because this will produce circulatory problems.
- Prior to insertion of implants for calf augmentation tissue-expansion is per-

formed under the deep fascia. In this way capsular contracture around the definite implants would not be a problem (Carlsen, 1985).

- The expression: 'Tissue-expansion techniques in stump reconstructions must be reserved for the skin of the healthy amputee' (Rees et al., 1986); is not supported by us.

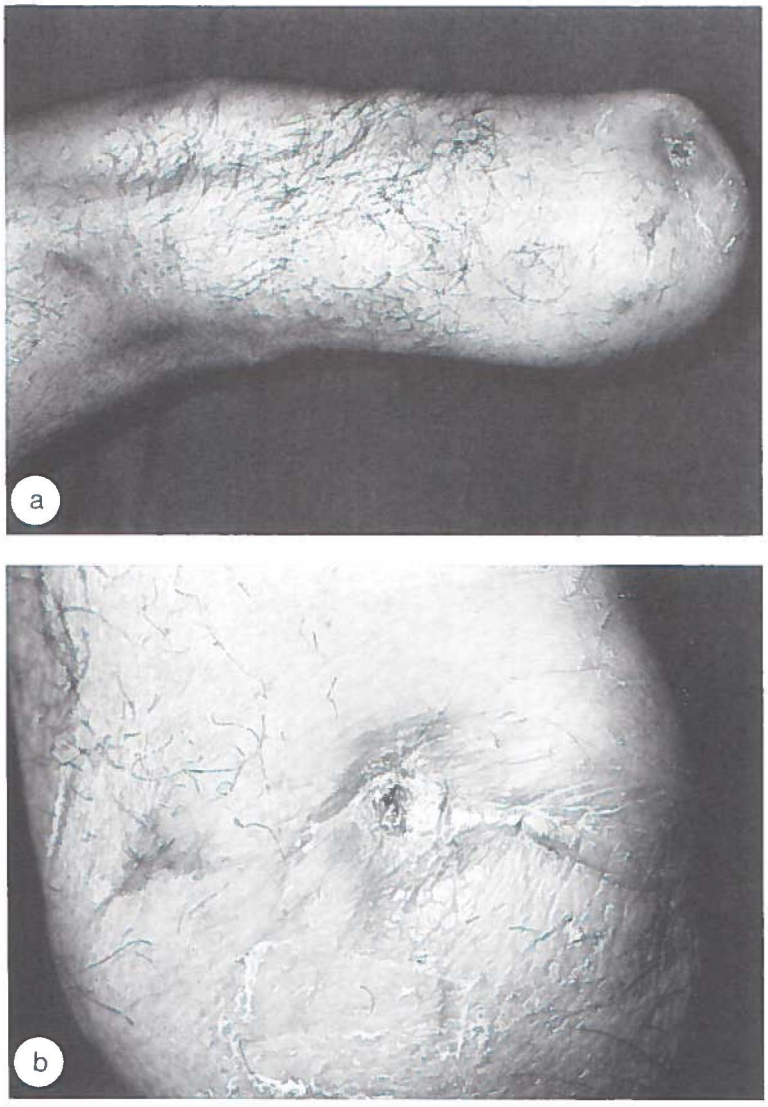
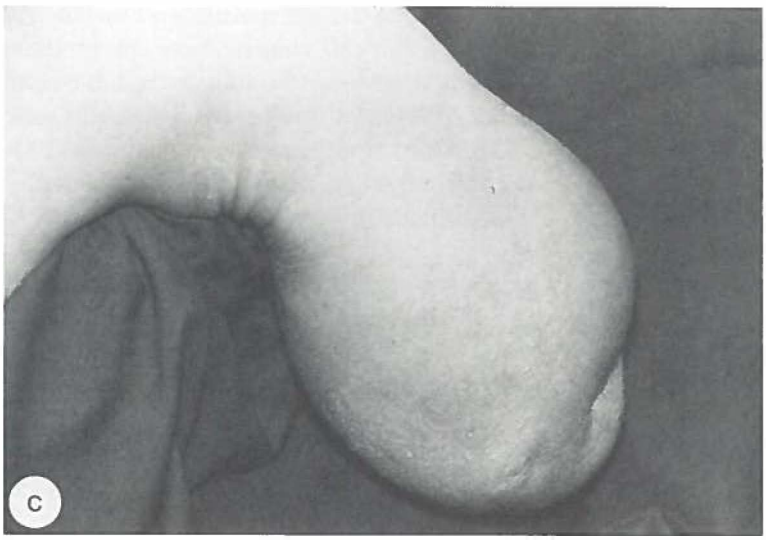
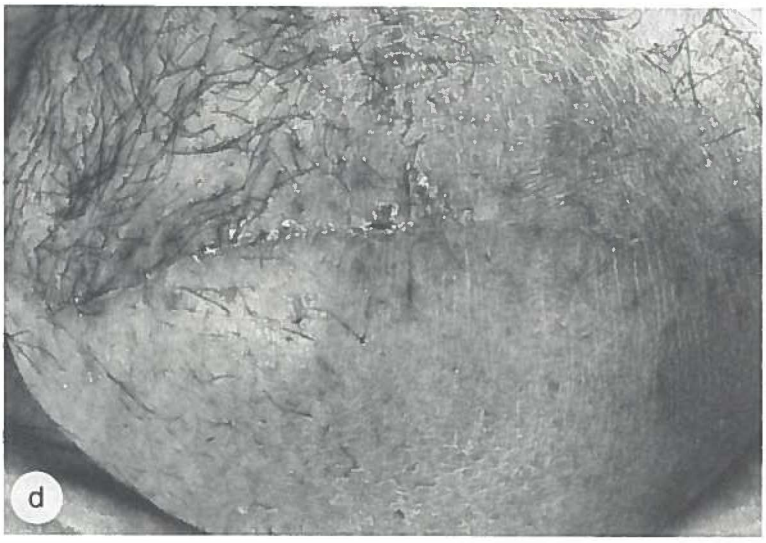


Fig. 9.12: A 53 year old male who had a below knee amputation of his right leg before (a and b), during (c) and after (d) correction of the amputation stump by means of tissue-expansion.

– Tissue-expansion as a first choice to treat defects in the distal third of the lower leg is not advised. It is better to expand a cross-leg flap or select another approach.





9.4.7 Foot region

Neither John Gibney nor we have ever considered using tissue-expansion in the foot. Moreover in literature no cases of expansion in feet have been described. The reason for this is clearly based on the predictable circulation problems.

9.5 Discussion

The technical considerations for the use of tissue-expanders are outlined in chapter 8. Clinical experience as demonstrated in this chapter have shown that different locations ask for different measures, necessary to obtain acceptable results. As in all operations care has to be taken with the various tissues. Especially vascular and nerve damage has to be avoided. Apart from the usual precautions that go with adequate tissue handling, one is confronted in tissue-expansion with an extra factor: the implant. Adequate handling of this implant is important too. First of all it is clear that any damage to the expander during the first stage operation can make the implant, and therefore the whole procedure, useless. Furthermore, wrong placement of fill-valve or expander can lead to leakage or may result in expansion of another area than planned. Moreover circulatory problems can lead to exposure of the implant. Frequent transcutaneous injections to inflate the expander are asso-

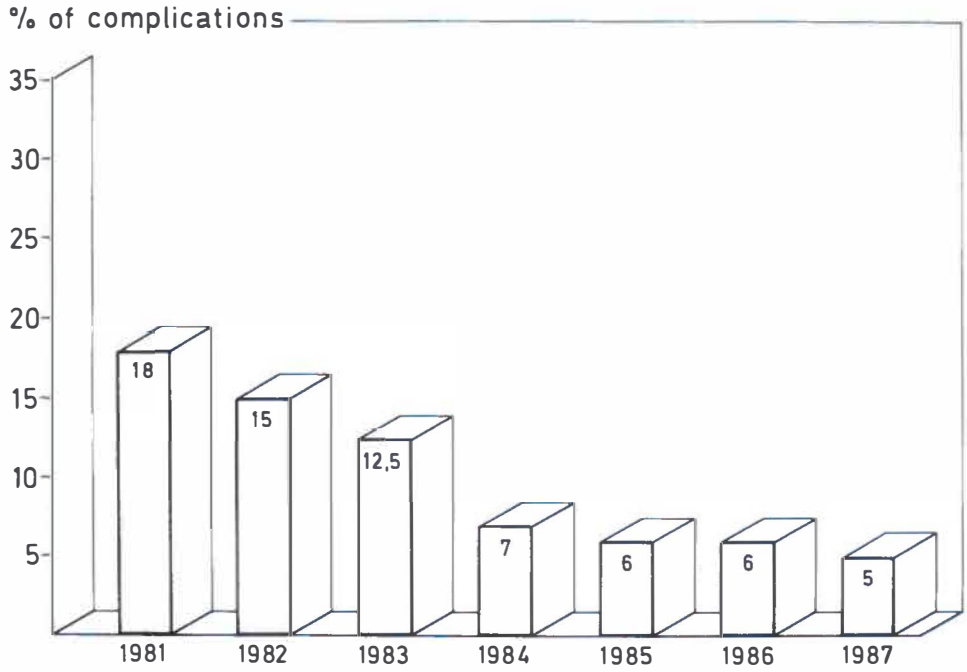


Diagram 9.1: Percentages of complications in patients, treated with tissue-expansion techniques by John Gibney over the years (N = 211).

ciated with a risk of introducing infection. Altogether the surgeon is confronted with a higher complication rate when using tissue-expanders when compared to other techniques. There are lots of pitfalls in the different locations of the body which can lead to complications.

As reported in the literature percentages of major complications (as haematomas, infections, circulation problems, implant problems or severe scar broadening) vary from less than 5% up to 35% (Manders et al., 1984[2]). Diagram 9.1 and 9.2 show that these percentages probably are dependent on the experience of the surgeon. In John Gibney's as well as in the Dutch population a remarkable decrease in complications was observed with time. In the experienced hands of John Gibney the complication rate has gone down to approximately 5%. We think that a complication rate of 10% is an average.Strict indications form an important factor to keep this figure low. It has become clear now that expansions in irradiated tissues, below knee regions or in patients with metabolic disorders must be considered with reserve. In this way tissue-expansion can and will be a very reliable technique in reconstructive surgery.

In the total population of American and Dutch patients infections were seen in 10 patients. These concerned 7 out of 211 (3.3%) in the American group and 3 out of 65 (4.6%) in the Dutch group. Only once interruption of the procedure had to be decided because of severe infection. This concerned a patient in the Dutch group.

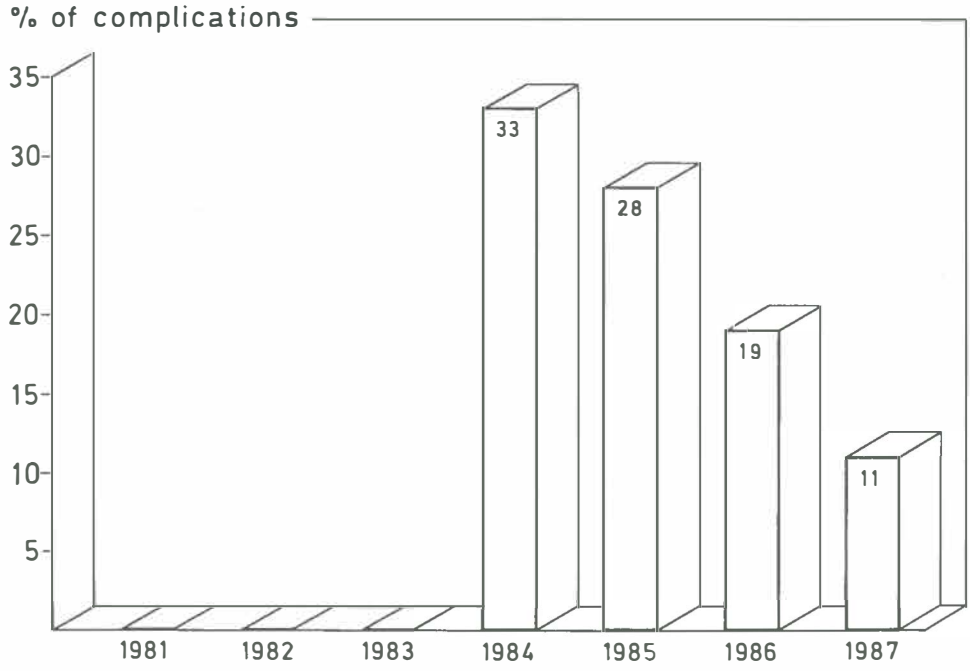


Diagram 9.2: Percentages of complications in patients, treated with tissue- expansion techniques in the university hospitals in Nijmegen and Groningen over the years (N = 65).

Prophylactic antibiotics were given during the first stage operation in all patients in the American group. In the Dutch group this was only done in special locations of the body e.g. in scalp reconstructions. Another difference in strategy apart from antibiotic treatment was the practice that in the American group no drainage was performed while in a great deal of the Dutch group suction drainage was used in the first as well as in the second stage operation. The relatively minimal differences in infection rate or haematoma formation between the two groups could signify that both antibiotics and drainage are probably not indicated. To get a better comparison of the two different populations a summary of the various data are piled up in table 9.1 and 9.2.

- Table 9.1: Summary of the total enumerations of the empirical data of the American population.

- Number of patients (N)	: 211
- Complications in % of N	: 9%
- Results in % of N	
good	: 77%
acceptable	: 19%
bad	: 4%

- Table 9.2: Summary of the total enumerations of the empirical data of the Dutch population.

- Number of patients (N)	: 65
- Complications in % of N	: 24%
- Results in % of N	
good	: 34%
acceptable	: 49%
bad	: 17%

In reviewing these tables one has to keep in mind that complication rates and results are average data. From the diagrams it is clear that the complication rates are decreasing in time and the results will improve in relation to experience. So, when starting the tissue-expansion technique one must be aware that complication rates in general will be higher than is usually presented in the literature.

9.6 References (See part IV)

Part IV

MISCELLANEA

SUMMARY AND CONCLUSIONS

Tissue-expansion is a technique that was developed some years ago to close skin defects. This technique offers various advantages above the conventional methods. Tissue-expansion can be described as follows: an inflatable balloon is implanted next to an existing skin defect – or next to skin that has to be excised later. Its volume is enlarged by regular injection of physiologic saline. This inflation 'expands' the overlying tissue, thus increasing surface-area. After removal of the 'tissue-expander' a skin surplus remains, which is used to close the adjacent skin defect. Obviously this method can also serve other reconstructive purposes. Several of the numerous possible aspects of tissue-expansion are put forward in this thesis.

Chapter 1 concerns study of the literature on tissue-expansion. It is obvious that relevant published data can be subdivided according to the different fields of information. To begin with, historical features are shown, demonstrating that tissue-expansion can be observed as a natural physiological process as e.g. during pregnancy. Most illustrative of this phenomenon is the artificial expansion of lips, earlobes and necks among some African civilisations/cultures. Clinical application started in 1957 when Neumann described a primitive form of tissue-expansion. However, the virtual rediscovery and development of the present application of tissue-expansion was made by Radovan only in the middle of the seventies. At first the indication field was almost completely restricted to breast reconstruction but was gradually extended to the total body.

Questions arising from clinical experience demanded further experimental research. This was first done by Austad and Pasyk who can both be called the most important pioneers in tissue-expansion research. Further clinical and experimental activities led to new questions.

Chapter 2 deals with the aims of the present study to try to bring clarity to some of the questions which are raised in chapter 1.

By means of animal experiments an attempt is made to give an insight into:

- cytohistological changes which take place under the influence of tissue-expansion.
- capsule formation around tissue-expanders.
- methods to objectify the surface-area increase, related to volume and specifications of the different available tissue-expanders.

By means of clinical research an attempt is made to give an insight into:

- the most desirable technique of tissue-expansion in the different parts of the body.
- the correlation between experience in tissue-expansion techniques and rate of complications and hence the influence of experience on the results.

Chapter 3 deals with morphohistological changes of expanded soft tissue. These were studied in pigs. It is demonstrated that damage occurs in all expanded tissue layers with the exception of the epidermis. This phenomenon can be explained by the fact that the skin as an organ is too specialised for regeneration and can therefore only heal by scar formation. We were unable to observe new-formation of tissue in this part of the experiment. Although statistical proof of the influence of expansion rate on the histomorphology of expanded skin was not fully demonstrated, it was shown that tissue damage increased when faster expansion procedures were used. Therefore, the conclusion that tissue-expansion is more 'stretching' than 'proliferation' of tissue, seems justified.

Chapter 4 deals in particular with changes in the epidermal layer. Again in pigs, flowcytometric techniques were used to study a possible increase in mitotic activity. The percentages of cells with DNA values greater than diploid (percentages of cells in S-phase and G_2M-phase) were measured as a function of time after expansion. After a decrease on day 5 after the operation, two or three peaks were observed at roughly eight day intervals. These statistically significant observations prove that there really is a rise in mitotic activity and hence new formation of tissue. For this reason the question 'Does new formation of tissue take place under the influence of tissue-expansion?' can be answered positively. Whether this increase in cell proliferation is used totally for cell repair or at least partly contributes to cell gain, cannot be concluded and needs further research. Influence of the rate of inflation on the proliferation of cells could not be demonstrated.

Chapter 5 deals with the phenomenon of capsule formation being a foreign-body reaction around tissue-expanders. Due to several technical research problems it appeared not to be possible to prove a statistically relevant difference between capsule formation around tissue-expanders which were inflated at high inflation rates and those which were filled at a low inflation rate. Nevertheless, a tendency towards formation of a thicker capsule is seen around expanders which are inflated gradually in order to reach the ultimate volume. Besides the inflation rate the time of incorporation was studied. In spite of the fact that no statistical proof could be given, there seemed to be a positive correlation between capsule thickness and incorporation time.

Chapter 6 deals with a mathematical approach regarding surface-area increase of the different shapes and volumes of the commonly used tissue-expanders. There

seem to be relatively simple formulae, which represent the correlation between expander specifications and surface-area increase. It is clear that this mathematical approach represents only the surface-area increase of the expanders and not the surface-area increase of the soft tissues.

Chapter 7 deals with the problem of skin surface-area increase under the influence of tissue-expansion. The problem is approached from three angels. With the help of the mathematical approach, described in chapter 6, the theoretical increase in surface-area was calculated based on the specifications of the various expanders. In an 'in vitro' model, in which the surface areas of the different inflated expanders were measured by means of casts, the mathematical data were confirmed to be reliable. To determine the real surface-area gain that takes place in vivo, measurements in pigs were performed. It appears that only about 35% of the mathematically expected increase in surface area is yielded in vivo. Moreover, a clear difference was observed between the surface-area gain for the different shapes of tissue-expanders.

Chapter 8 deals with the clinical and technical aspects of the tissue-expansion procedure. Extensive insight is given into the generally accepted operation technique. Attention is paid to indications, contra-indications and complications. The I.S.L.E. (= intra operative sustained limited expansion), still being investigated, is discussed in short. Finally, in these days of cut down expences cost-effectiveness has been analysed.

Chapter 9 deals with the empirical observations which were gathered in the university hospitals of Nijmegen, Groningen, Utrecht (the Netherlands) and Scotsdale (Arizona, USA). Illustrated by case histories, experiences in various parts of the body in which tissue-expansion was carried out, are discussed. Extensive attention is paid to 'special pitfalls and remarks', which the surgeon has to take into account. A comparison is made between empirical data of, in this field relatively unexperienced surgeons (Dutch group) and a very experienced user of tissue-expansion techniques (John Gibney, USA). It is clearly demonstrated that there is a negative correlation between experience in tissue-expansion techniques and complication rates. For this reason the definite results seem largely dependent on experience. On the grounds of the total of empirical data it can be stated that, when following strict indications, tissue-expansion can be considered as a very valuable contribution in reconstructive surgery.

In conclusion the following statements can be made:

- Despite the fact that an increase in mitotic activity is seen in the epidermis, tissue-expansion gains more from 'stretching' than 'new formation' of tissue, in contrary to what is suggested in literature.
- It can be alleged that capsule formation takes place more extensively around an

expanding prosthesis than a non-expanding one.

- The effective surface-area increase by means of tissue-expansion is about a factor 2.5 less than, on ground of specifications and volumes of the different expanders, would be expected.
- The result of reconstructions by means of tissue-expansion is more highly dependent on experience than would be expected in view of the simplicity of the technique.
- When using strict indications, tissue-expansion techniques can be considered as a very valuable contribution in reconstructive surgery.

SAMENVATTING EN CONCLUSIES

Tissue-expansion is sinds enige jaren een nieuwe reconstructiemethode voor het sluiten van huiddefecten. Deze biedt verschillende voordelen ten opzichte van conventionele operatiemethoden. Tissue-expansion komt in het kort op het volgende neer: naast een huiddefect – of een op een later tijdstip nog te creëren huiddefect – wordt onder de huid een opblaasbare ballon gebracht waarvan het volume vervolgens gedurende enige weken geregeld door inspuiting met een fysiologische zoutoplossing wordt vergroot. Hierdoor wordt het boven deze ballon gelegen weefsel 'uitgerekt'; het oppervlak wordt dus vergroot. Na het verwijderen van deze 'tissue-expander' is er een huidsurplus ontstaan waarmee het aangrenzende huiddefect kan worden gesloten. Het zal duidelijk zijn dat met deze methode ook andere reconstructies kunnen worden uitgevoerd. In dit proefschrift worden enkele van de vele mogelijk denkbare facetten van tissue-expansion aan de orde gebracht.

In **hoofdstuk 1** wordt een literatuuronderzoek over tissue-expansion beschreven. Het blijkt mogelijk de relevante informatie in groepen te verdelen. Allereerst is er het historisch aspect waaruit blijkt dat tissue-expansion als een geheel natuurlijk fysiologisch proces kan worden waargenomen zoals dat wordt gezien in de loop van oppervlakte toename van weke delen, bijvoorbeeld gedurende zwangerschap. Zeer illustratief voor dit fenomeen is het kunstmatig oprekken van lippen, oorlellen en halzen in o.a. Afrikaanse culturen. De klinische toepassing begint in 1957 wanneer een primitieve vorm van tissue-expansion wordt beschreven door Neumann. De eigenlijke herontdekking en ontwikkeling van de huidige toepassing van tissue-expansion wordt gedaan door Radovan halverwege de jaren '70. Nadat eerst vooral de indicatie op het gebied van de borstreconstructie heeft gelegen, wordt het gebied van toepassingen geleidelijk aan uitgebreid tot over het gehele lichaam. Aan de hand van klinische ervaringen rijzen vragen welke verder experimenteel onderzoek rechtvaardigen. Austad en Pasyck zijn in deze experimentele ontwikkeling de grote voortrekkers. Uit de kliniek en met name uit het experimentele werk blijken nog meer vragen naar voren te komen.

In **hoofdstuk 2** worden de doelstellingen van deze studie, welke gebaseerd zijn op een deel van de in hoofdstuk 1 weergegeven vragen, opgesomd.

Middels dierexperimenteel onderzoek wordt getracht inzicht te geven in:

- de cytohistologische veranderingen welke plaatsvinden onder invloed van tissue-expansion.

- de kapselvorming rond tissue-expanders.
- de mogelijkheden ter objectivering van oppervlaktetoename, gerelateerd aan volume en vorm van de verschillende beschikbare tissue-expanders.

Middels onderzoek van klinische ervaringen wordt getracht inzicht te geven in:

- de meest gewenste wijze van tissue-expansion in de verschillende delen van het lichaam.
- de invloed van ervaring in tissue-expansion technieken op complicatie percentages en uiteindelijk resultaat.

In **hoofdstuk 3** wordt middels experimenteel onderzoek bij varkens inzicht gegeven in de histomorfologische veranderingen welke plaatsvinden onder invloed van 'controlled' tissue-expansion in verschillende weefsellagen. Bij beschadiging passende weefselveranderingen worden in vrijwel alle weefsellagen aangetoond. Uitzondering hierop is de epidermale laag welke door zijn relatief geringe mate van orgaandifferentiatie nog in staat zou kunnen zijn tot regeneratie in plaats van reparatie. Nieuwvorming van weefsel in dit deel van het onderzoek kon niet worden aangetoond, bovendien was adequaat herstel van de verschillende weefsellagen afwezig. Hoewel statistische significantie niet kon worden aangetoond, leek er een duidelijke tendens te bestaan dat toename van expansiesnelheid een toename in weefselbeschadiging bewerkstelligde. De veronderstelling dat tissue-expansion meer "oprekking" dan "nieuwvorming" van weefsel betreft is gerechtvaardigd.

In **hoofdstuk 4** wordt eveneens in experimenteel onderzoek bij varkens dieper ingegaan op de veranderingen welke onder invloed van tissue-expansion plaatsvinden in de epidermale laag. Met behulp van flowcytometrische technieken werd onderzoek gedaan naar een eventuele toename in mitotische activiteit. Het percentage van cellen met DNA waarden groter dan diploid werd als functie van tijd na de expansie gemeten. Na een afname rond de 5e postoperatieve dag was er een toename van deze waarden. Twee tot drie pieken werden waargenomen met een interval van ongeveer 8 dagen. Deze statistisch significante waarnemingen zijn bewijzend voor een toename in mitotische activiteit en dus in de nieuwvorming van weefsel. De vraag of er daadwerkelijk nieuwvorming van weefsel plaatsvindt onder invloed van tissue-expansion kan hierdoor positief beantwoord worden. Of deze verhoogde proliferatie geheel gebruikt wordt voor celreparatie of ook minstens gedeeltelijk ten goede komt aan celwinst kan niet worden geconcludeerd en moet verder worden onderzocht. Invloed van inflatiesnelheid op de mate van nieuwvorming bleek niet te kunnen worden aangetoond.

In **hoofdstuk 5** wordt ingegaan op het fenomeen van kapselvorming als reactie op een vreemdlichaam. Mede als gevolg van verschillende onderzoeksproblemen bleek het niet mogelijk in het varkensmodel een statistisch relevant verschil aan te tonen in kapselvorming tussen expanders welke in kortere dan wel langere perioden tot eenzelfde volume werden geëxpandeerd. Wel blijkt er een tendens te be-

staan tot dikkere kapselvorming onder invloed van meer frequente, dus meer gelijkmatige insufflatie. Ook de invloed van incorporatieduur op de mate van kapselvorming werd onderzocht. Er konden echter geen significante verschillen worden aangetoond tussen kapsels die ontstaan waren gedurende langere en kortere perioden dat totaal geïnsuffleerde expanders in het lichaam aanwezig waren geweest. Wel lijkt er een positieve correlatie te bestaan tussen kapselvorming en de duur van incorporatie van de expander.

In **hoofdstuk 6** wordt een mathematische benadering gegeven omtrent de oppervlakteberekening van verschillende vormen en maten van tissue-expanders. Er blijken, door mathematici als zeer simpel gekenschetste, formules beschikbaar te zijn, die de correlatie tussen volume, expanderafmetingen en oppervlaktetoename weergeven. Duidelijk wordt onderstreept dat deze mathematische berekening niet overeenkomt met de daadwerkelijke oppervlaktetoename van het opgerekte weefsel.

In **hoofdstuk 7** wordt getracht het probleem omtrent de oppervlaktewinst die onder invloed van tissue-expansion plaatsvindt te objectiveren. Het onderwerp wordt vanuit drie invalshoeken beoordeeld. Met behulp van de in hoofdstuk 6 beschreven mathematische benadering wordt de theoretische oppervlaktetoename van de verschillende vormen en maten van de in het algemeen gebruikte tissue-expanders berekend. In een 'in vitro' model, waarbij de oppervlakten worden vastgesteld van afgietsels van de verschillende expanders, worden deze mathematische waarden als representatief bevestigd. Om de daadwerkelijke oppervlaktetoename welke in vivo plaatsvindt, vast te stellen, werden metingen in geëxpandeerde varkenshuid uitgevoerd. Er blijkt slechts ongeveer 35% van de middels mathematische berekeningen verwachte oppervlaktetoename plaats te vinden.

In **hoofdstuk 8** wordt ingegaan op het klinisch/technisch aspect van de tissue-expander procedure. Uitgebreid inzicht wordt gegeven in de als algemeen gangbaar beschouwde operatiewijze. Aandacht wordt besteed aan indicaties, contra-indicaties en complicaties. De in experimentele fase verkerende I.S.L.E. (= intra-operative sustained limited expansion) wordt kort belicht. Als laatste lijkt een korte kosten-baten analyse in deze tijd van bezuinigingen onvermijdelijk.

In **hoofdstuk 9** worden de empirische bevindingen weergegeven die werden verzameld in de respectievelijke universiteitsklinieken van Nijmegen, Groningen, Utrecht en Scotsdale (Arizona, USA). Geïllustreerd met 'case histories' worden ervaringen in de verschillende delen van het lichaam waarin tissue-expansion werd verricht, besproken. Uitgebreide aandacht wordt besteed aan 'special pitfalls and remarks' waarmee de operateur rekening zou moeten/kunnen houden. Een vergelijk van empirische data tussen enerzijds de op het gebied van tissue-expansion relatief nog onervaren Nederlandse operateurs van de universiteiten van Gronin-

gen en Nijmegen en de op dit gebied zeer ervaren dr. John Gibney vindt plaats. Het blijkt duidelijk dat er een zeer forse negatieve correlatie bestaat tussen ervaring in de tissue-expansion techniek en complicatie percentages. Dat daarom het uiteindelijk resultaat in belangrijke mate afhankelijk is van de mate van deze ervaring, mag duidelijk zijn. Op grond van het totaal van empirische gegevens mag worden gesteld dat vooral bij een strikte indicatiestelling tissue-expansion als een zeer waardevolle bijdrage in de plastische en reconstructieve chirurgie kan worden beschouwd.

Concluderend kan het volgende worden gesteld:

- Ondanks het feit dat er een verhoogde mitotische activiteit wordt waargenomen in de epidermis betreft tissue-expansion toch meer 'oprekking' dan 'nieuwvorming' van weefel, dit in tegenstelling tot wat over het algemeen in de literatuur wordt gesuggereerd.
- Er zijn redenen aan te voeren dat kapselvorming rond tissue-expanders in hogere mate plaatsvindt dan rond niet-expanderende protheses.
- De daadwerkelijke weefseloppervlaktewinst welke onder invloed van een tissue-expander wordt bewerkstelligd is ongeveer een factor 2.5 lager dan op grond van zijn afmeting en volume zou kunnen worden verwacht.
- Het resultaat van reconstructies middels tissue-expansion is in hogere mate afhankelijk van ervaring dan men met het oog op de eenvoud van de techniek zou veronderstellen.
- Indien indicatiestelling strikt plaatsvindt kan tissue-expansion als een zeer belangrijke bijdrage in de reconstructieve chirurgie worden beschouwd.

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