Burn Reconstruction Techniques

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Due to extraordinary advances concerning the understanding of cellular and molecular processes in wound healing, wound care innovations and new developments concerning burn care have been made; burn care has improved to the extent that persons with burns frequently can survive. The trend in current treatment extends beyond the preservation of life; the ultimate goal is the return of burn victims, as full participants, back into their social and business life [1, 2].

A more aggressive approach in the acute phase has led to a higher survival rates on one side but also to a higher number of patients, who will require reconstructive surgery on the other side. Successful reconstruction requires a profound understanding of skin anatomy and physiology, careful analysis of the defect, and thoughtful considerations of different techniques suitable to execute the surgical plan [3].

11.1 From the Reconstructive Ladder to the Reconstructive Elevator

Based on the concept of the reconstructive ladder by Mathes und Nahai, new advances in the understanding of the anatomy, operative techniques, instrumentation, and surgical skills have led to the concept of the reconstructive elevator: complex procedures are no longer considered as last resort procedures only. In the quest to provide optimal form and function, it is currently accepted to jump several rungs of the ladder due to the knowledge that some defects require more complex solutions. The goal of surgical reconstruction is restoration of preoperative function and appearance. The surgeon must reconstruct the defect with

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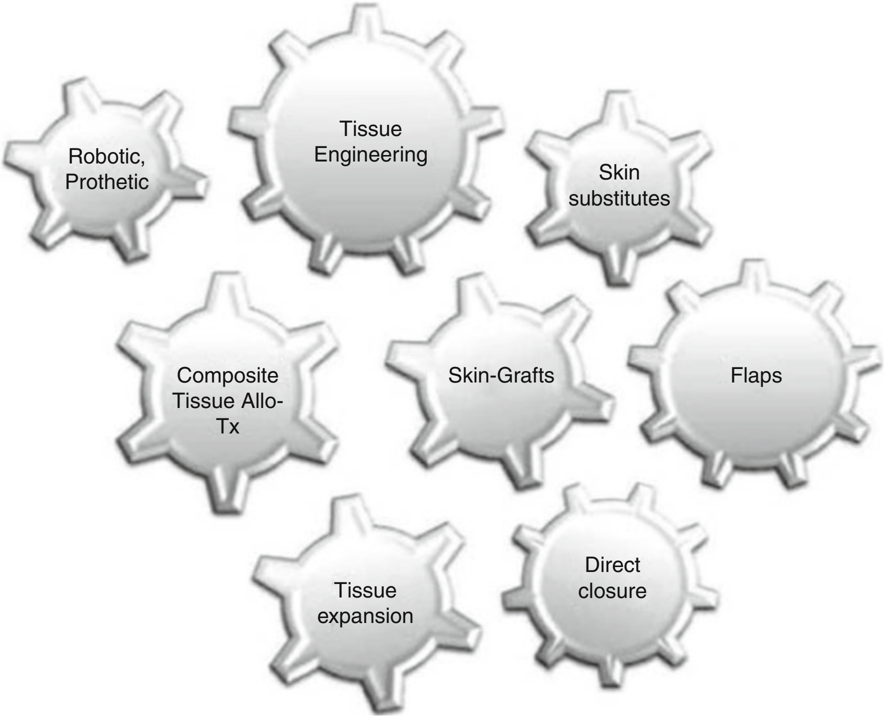

Fig. 11.1 The reconstructive clockwork: the interlocking wheels of a clockwork illustrate the integration of different reconstructive methods

tissues that is missing and which allows defect coverage with tissue of similar contour, texture, and color [4, 5].

11.2 The Reconstructive Clockwork

In clinical daily routine, combinations of different techniques are often applied in order to permit new reconstructive possibilities for the patient, but neither the reconstructive ladders of Mathes and Nahai in 1982 nor the reconstructive elevator permits a real combination of the different reconstructive procedures and techniques.

The image of interlocking wheels of a clockwork [6] (Fig. 11.1) illustrates the integration of different reconstructive methods even more impressive than the conventional reconstructive ladder and elevator.

11.2.1 General Principles

Hypertrophic scars and scar contraction with concomitant functional impairment are the most common problems that require correction or reconstruction. Choosing the right modality depends upon several factors, for example, the age or maturity of the scar. The knowledge of the healing properties of the patient (i.e., whether the patient has a propensity toward keloid or hypertrophic scar production) might also help to dictate how aggressive or how conservative one may wish to pursue the treatment.

Objective assessment of deformities and functional impairment is of utmost importance for planning the right reconstructive procedure. Formulating a realistic plan to restore the functional problems requires analysis of the physical deformities and psychological disturbance of the patient. Psychiatric, psychosocial [7], and physiotherapeutic cares have to be continued while a surgical treatment plan is instituted.

11.3 Indication and Timing of Surgical Intervention

For a surgeon, making a decision *how* to operate on a patient with burn deformities is quite simple. In contrast, deciding *when* to operate on a patient can be difficult. However, the basic principle is based on the following rule:

- Restoring bodily deformities that impose functional difficulties must precede any surgical effort to restore the appearance.

In short, a surgeon's effort must be concentrated upon restoring the deformed bodily parts essential for physical functions, if not for patient survival. In contrast, restoration of deformed regions, in general, can be performed in a later phase.

It is postulated that attempts to correct burn deformities should be delayed for at least 1–2 years. During this time needed for scar maturation, an interim conservative treatment by using pressure garments and splinting is recommended to reduce scarring and to minimize joint contracture because operating on an immature scar is technically more cumbersome and will lead to a higher number of complications. It is never too late to revise a scar, but conversely, it may be too early.

11.4 The Techniques of Reconstruction

There are several techniques routinely used to reconstruct deformities and to close defects related to the burn trauma.

Principally, they are:

- Excision techniques
- Serial excision and tissue expansion
- Skin grafting techniques with or without the use of dermal substitutes
- Local skin flaps
- Distant flaps
- Allotransplantation
- Tissue engineering
- Robotics and prosthesis

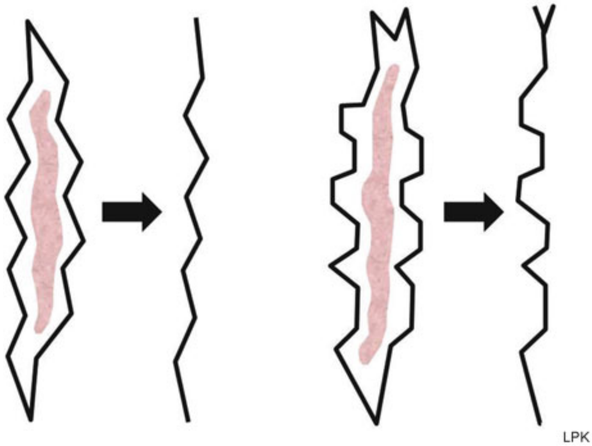

Fig. 11.2 W-Plasty (*left*) and geometric broken line closure (*right*); (scar: *pink*)

11.4.1 Excision Techniques

Excision with direct closure of the resultant wound is the simplest and the most direct approach in burn reconstruction. It is important to determine the amount of scar tissue that can be removed so that the resultant defect can be closed directly. A circumferential incision is made in the line previously marked and is carried through the full thickness of the scar down to the subcutaneous fatty layer. In case of a keloid, an intralesional excision might be better instead of an extralesional one in order to avoid recurrence. In order to minimize vascular supply, interference along the wound edges, undermining of the scar edge, should be kept to a minimum, whenever possible.

11.4.1.1 W-Plasty and Geometric Broken Line Closure

The *W-plasty* [8, 9] is a series of connected, triangular advancement flaps mirrored along the length of each side of the scar, but W-plasty, unlike a Z-plasty, does not result in an overall change in length of the scar; it makes the scar less conspicuous, and it disrupts wound contracture with its irregular pattern. As with all other procedures, it is helpful to mark out the planned design prior to the operation (Fig. 11.2).

The geometric broken line closure (*GBLC*) is a more sophisticated scar regularization technique than the W-plasty and requires more time to execute [10–13]; unlike the W-plasty's regularly irregular pattern, which results in a somewhat predictable scar pattern that can be followed by the observers´ eye, the irregular irregularity of the GBLC allows maximum scar camouflage. This is achieved by various combinations of triangles, rectangles, squares, and semicircles in differing widths and lengths along the scar (Figs. 11.2 and 11.3).

11.4.2 Serial Excision and Tissue Expansion

The goal of surgical reconstruction is the restoration of preoperative function and appearance. The surgeon must reconstruct the defect with tissue of similar contour,

Fig. 11.3 Geometric broken line closure: clinical example

texture, and color. Surgical excision of scars relies upon recruitment of local tissue for closure of the ensuring defect, and thus adjacent skin will usually provide the best match for the defect. In areas where tissue laxity is poor or the resulting defect would be too big, tissue expansion and serial excision are useful techniques to overcome a lack of sufficient local tissue for closure. Tissue expansion allows large areas of burn scar to be resurfaced by providing tissue of similar texture and color to the defect. Moreover, it is combined with the advantage of donor-site morbidity reduction. Issues and disadvantages that need to be addressed are that the technique of pre-expansion requires additional office visits for serial expansion and at least one extra surgical procedure with potential for additional complications. A significant time period between 9 and 12 weeks for progressive tissue expansion is required. Tissue expanders are very versatile tools in reconstructive burn surgery, but still, careful patient selection, correct indications and realistic treatment concepts, large experience and well- selected surgical techniques, precise instruction of the medical staff, as well as detailed and continuous education of the patients are essential [14, 15].

Serial excisions involve the partial excision of the scar with the consecutive advancement of adjunct skin. In a series of sequential procedures, the area of scar is excised completely. The number of procedures needed depends on the elasticity of the surrounding skin and the size of scar being excised. The primary disadvantage of this technique is the requirement for multiple operations. Should more than two operations be needed, tissue expansion should be considered or evaluated as an alternative treatment option.

11.4.3 Skin Grafting Techniques

A Skin Graft without the Combination of a Dermal Substitute – Covering an open wound with a skin graft harvested at a various thickness is the conventional approach of wound closure. A skin graft including epidermis and dermis is defined as a full-thickness skin graft, and a piece of skin cut at a thickness varying between 8/1,000 of an inch (0.196 mm) and 18/1,000 of an inch (0.441 mm) is considered to be a partial- or a split-thickness skin graft. The thickness of a full-thickness skin graft is quite variable depending upon the harvest region.

In case of a full-thickness skin graft, a paper template may be made to determine the size of the skin graft needed to close a wound. The skin graft is laid down to the wound bed and is anchored into place by suturing or stapling the graft onto the wound bed. A continuous contact of the skin graft with the wound bed is essential to ensure an ingrowth of a vascular network in the graft within 3–5 days and thereby for the graft survival. A gauze or cotton bolster tied over a graft has been the traditional technique to anchor and to prevent fluid accumulating underneath a graft, if there is a flat and well-vascularized wound bed. In regions, which are associated with a less good take rate (concave defects; regions, which are subject to repeated motion like joints), or in patients with comorbidities, which may have an impact on graft healing, other techniques [16–18] instead of the bolstering technique are used for skin graft fixation. The use of topical negative pressure or fibrin glue can lead to better skin graft healing [16].

The criteria for using skin grafts of various thicknesses are mainly based on:

- The use of a thin graft is more appropriate for closing wounds with unstable vascular supplies, particularly if the skin graft donor site is scarce.
- Moreover, the quality and the presence of dermis seem to have an influence to the extent of wound contraction. The extent of contraction, which is noted if a thin partial-thickness skin graft is used, is larger than using a full-thickness graft. The presence of a sufficient dermal structure could reduce wound contracture.

Skin Graft in Combination with a Dermal Substitute – For the past several years, artificial dermal substitutes have been used in order to improve skin quality, for example, AlloDerm™ and Integra™ [19]; these materials when implanted over an open wound have been found to form a layer of resembled dermis, thus providing a wound bed better for skin grafting and thereby better skin quality. However, the need for a staged approach to graft a wound using this technique is considered cumbrous. Matriderm ™ is a new dermal matrix, which consists of collagen and elastin and allows a single-step reconstruction of the dermis and epidermis in combination with a split-thickness skin graft [20–22] (Fig. 11.4).

11.4.4 Local Skin Flaps

The approach using a segment of skin with its intrinsic structural components attached to cover a defect follows also the fundamental principle of reconstructive surgery to restore a destructed bodily part with a piece of like tissue. The recent

Fig. 11.4 (**a**) Hypertrophic and contracted scars (*right hand*). (**b**) Hyperextension in the MCP joints. (**c**) Flexion only possible in the PIP und DIP joints, hyperextension in the MCP joints. (**d**) Complete excision of the hypertrophic and contracted scar plate. (**e**) Late results obtained by use of Matriderm® and skin graft in a single-step procedure (6 months postoperative)

technical innovation of incorporating a muscle and/or facial layer in the skin flap design, especially in a burned area, further expanded the scope of burn reconstruction as more burned tissues could be used for flap fabrication.

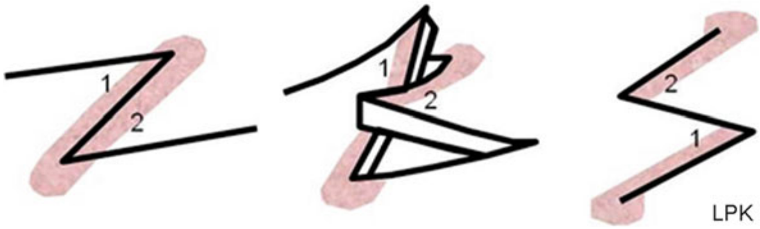

Fig. 11.5 Z-Plasty (scar: *pink*)

No single flap is optimal for every scar excision. Each individual scarred area has to be analyzed for:

- Depth of the scar
- Tissue involved
- Availability of normal tissue for reconstruction

Based on this, the ideal flap or the combination of flaps and techniques is chosen for reconstruction.

Often used skin flaps are the Z-plasty technique, the multiple Z-plasties, and the 3/4 Z-plasty technique.

11.4.4.1 Z-Plasty

There are three purposes to perform a Z-plasty:

- To lengthen a scar or to release a contracture
- To disperse a scar
- To realign a scar within a relaxed skin tension line

The traditional Z-plasty consists of two constant features; first, there are three incisions of equal length – two limbs and a central incision. Second, there are two angles of equal degree – the limbs form 60° angles with the central incision (Fig. 11.6). Ideally, the central incision should go through the axis of the scar; alternatively, the scar itself may be completely excised with a fusiform defect acting as the central incision (Fig. 11.5).

11.4.4.2 Double Opposing Z-Plasty

Two Z-plasty incisions placed immediately adjacent to one another as mirror images will produce an incision known as a double opposing Z-plasty (Figs. 11.6 and 11.7). The advantage of this technique is that significant lengthening can be achieved in areas of limited skin availability. Ideal indication for this technique is the release of web space contractures (Fig. 11.8).

11.4.4.3 ¾ Z-plasty or half-Z

The *¾ Z-plasty or half-Z* is used to refer the technique (Fig. 11.9) with one limb incision being perpendicular to the central one. The incision is created on the scar side, which creates a fissure into the scar in which a triangular flap is introduced. The length gained on the scar side is directly proportional to the width of the triangular flap.

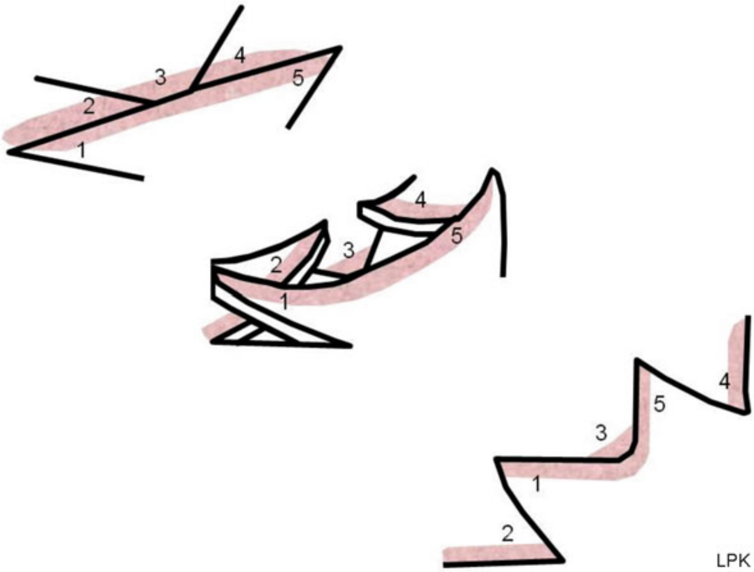

Fig. 11.6 Double opposing Z-plasty (scar: *pink*)

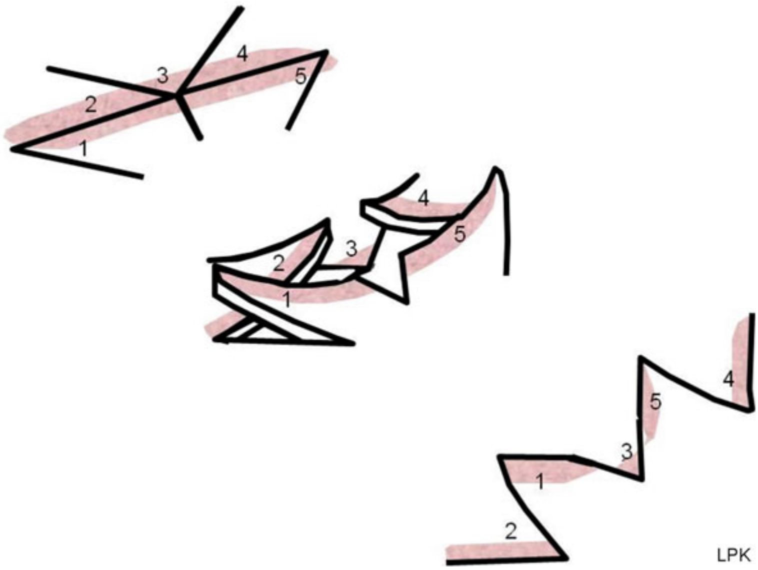

Fig. 11.7 Modified double opposing Z-plasty (scar: *pink*)

Despite its geometric advantage in flap design, fabricating a skin flap or skin flaps for reconstruction of burn deformities is not infrequently plagued with skin necrosis. Aberrant vascular supplies to the skin attributable to the original injury and/or surgical treatment could be the factor responsible for problems. In recent

Fig. 11.8 Scar correction by use of a modified double opposing Z-plasty (1 web space)

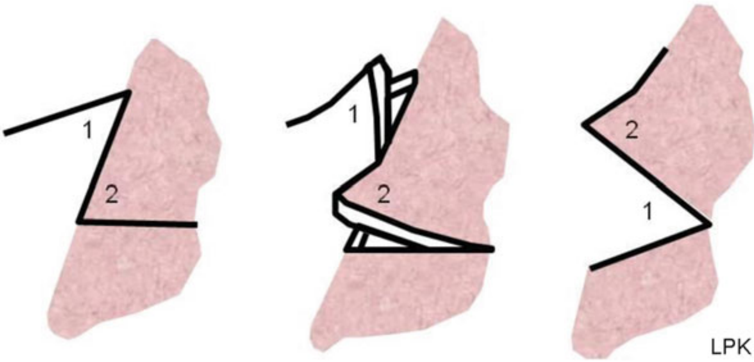

Fig. 11.9 ¾ Z-plasty or half-Z (scar: *pink*)

years, the use of a skin flap designed to include muscle or fascia underneath has expanded further the usefulness of conventional Z-plasty and the 3/4 Z-plasty technique in burn reconstruction.

11.4.4.4 Musculocutaneous (MC) or Fasciocutaneous (FC) Flap Technique

Inclusion of not only the skin but also the subcutaneous tissues and the fascia and the muscle is necessary to fabricate a skin flap to reconstruct a tissue defect in individuals with deep burn injuries. That is, fabricating a flap in a burned area is possible if the underlying muscle or the fascia is included in the design [23].

Moreover, multiple Z-plasties are often used for scar corrections (Figs. 11.10 and 11.11).

11.4.5 Distant Flaps

A distant flap involves a donor site, which is distant from the defect. The mode of transfer might be direct or microvascular. Direct flap, such as the forehead flap or the groin flap, involves direct approximation of the recipient bed to the donor site. These flaps all require a second operation to divide the pedicle.

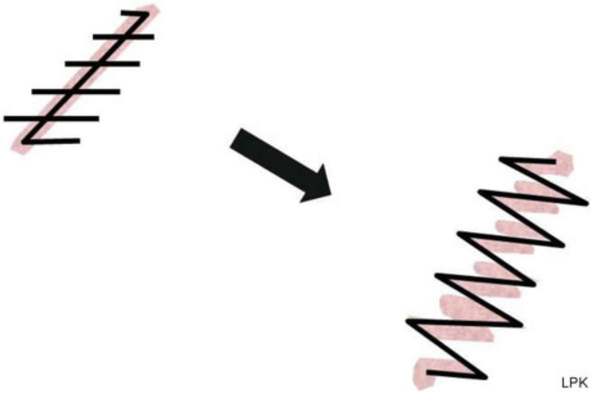

Fig. 11.10 Multiple Z-plasties (scar: *pink*)

Fig. 11.11 Scar corrections by use of multiple Z-plasties (elbow)

11.4.5.1 Free Tissue Transfer

The evolution of microsurgery and free tissue transfer has dramatically expanded the functional and aesthetic potential of reconstructive surgery. Due to microvascular anastomoses, free transfer of single or compound tissues and replantation of amputated parts are possible. Moreover, by using a free tissue transfer, single-step reconstructions are principally possible.

11.4.5.2 Perforator Flaps

Based on the septocutaneous perforator vessels, the perforator flap was developed. Thus, Song and coworkers described in 1984 [24] that the lateral femur region can serve not only as a skin harvest place but also as the donor site for the "anterolateral thigh (ALT) flap" based on a long pedicle. Then Koshima and colleagues from Japan refined exemplarily the ALT transfer subsequently. In 1989, Koshima introduced an abdominal skin and fat flap based on the inferior epigastric vessels and muscle perforators. Recently, the theory of the perforasomes is under evaluation: Every perforator contains a unique vasculatory territory, the perforasome [25]. This knowledge will lead to new useable pedicled and free flaps for reconstruction.

With the advent of microsurgical techniques, transplanting a composite tissue can be carried out with minimal morbidities. The regimen, in caring for burn victims, however, may be limited because of a paucity of donor materials. It is ironic that burn patients with suitable donor sites seldom require such an elaborate treatment, but those who are in need of microsurgical tissue transplantation are inevitably without appropriate donor sites because of extensive tissue destruction.

11.4.6 Composite Tissue Allotransplantation

"Composite tissue allotransplantation" (CTA) of parts of the face or forearms and upper extremities [26–29] is a young area of transplantation medicine. The first clinical results are promising in comparison to the first reports of the organ transplantation, although the medium-term and long-term problems, for example, tumor induction by the immunosuppression as well as the chronic rejection, have to be taken into account. This is not an unimportant fact, because CTA are normally not of vital importance. Nevertheless, for the affected persons, who must live in social isolation with exhausted reconstructive measures or prostheses, such operations may result a dramatic improvement concerning quality of life. However, it is important to mention that currently only a high selected small number of high motivated patients are candidates for a CTA.

11.4.7 Regeneration: Tissue Engineering

Tissue regeneration and tissue engineering has gained relevance for reconstructive surgery [30–32]. Recently, fat transplantation or lipo transfer is utmost interest. Czerny transplanted in 1895 a lipoma for mamma reconstruction, and fat injection was described among other things by Eugene Holländer in 1910 within a patient with "progressive decrease of the fatty tissue." Erich Lexer dedicated in the first part of his book free fat transfers nearly 300 pages. In 2001, it was demonstrated that beside fat cells also, "adipose-derived stem cells" (ADSC) beside other cell populations in the fatty tissue are usable for these purposes. The transplantation of ADSC was able to regenerate full-layered cartilage defects in the animal model [33]. The stem cell-associated fat cell transplantation in patients with a radioderma has led to improved healing. Moreover, fat cell transplantation is not only able to improve volume and contour defects but also skin quality [34–36]; thereby, it seems that fat transfer will play an important part in burn reconstruction in the future.

11.4.8 Robotics/Prosthesis

If all reconstructive measures fail, myoelectric prostheses are a promising resort to go to. In recent years, these have been improved tremendously by introducing targeted muscle transfers (TMR) to the armamentarium of reconstructive surgery [37, 38]. Modern myoelectric prostheses have multiple degrees of freedom that mandate a complex control system to provide dependable use for the patient. Extremity reconstruction in the twenty-first century will see many new avenues to replace the loss of a limb and reconstruct the loss of function. Both biological and technical advances will provide possibilities that may well open up therapies that have been unthinkable only a few years ago. Targeted muscle reinnervation together with the provision of a myoelectric prosthesis with several degrees of freedom is such an approach and will definitely be a solid stepping stone leading to new strategies in extremity rehabilitation and reconstruction.

11.5 Summary

The regimen of burn treatment has changed drastically over the past 50 years. The regimen of an early debridement and wound coverage, initially with biological dressing and later with autologous skin grafts, had enhanced the survival rate. It is, however, ironic that this improvement in survival rate has caused an increase of patients, who will require reconstructive surgery.

Unsightly hypertrophic scar; scar contracture, affecting particularly the joint structures; and missing bodily parts are still the most common sequelae of burn injuries today.

The difficulty concerning burn reconstruction is largely due to a lack of adequate donor sites, but due to the improvements in reconstructive surgery, better results are achievable. New areas like “composite tissue allotransplantation” of compound tissues like arms or parts of the face, the prosthesis, and also the regenerative medicine with “tissue engineering” have already entered the clinical routine and will improve the final results obtained by burn reconstruction.

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