Burn Reconstruction

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The skin is the largest organ, consisting of different layers. Loss of skin integrity and skin functions due to injury or illness may acutely result in a substantial physiologic imbalance with long-term morbidity or even death (Williams et al. 2009; Kamolz 2010). The most common cause of severe skin loss is thermal injury. Over the past decades, extraordinary advances have been made in the understanding of cellular and molecular processes of wound healing. This knowledge has led to wound care innovations and new developments in burn care, having even improved survival of severe burn injuries. The trend in current treatment regimens is beyond the preservation of life; the ultimate goal is to turn burn victims back into society, as full participants into their families and communities.

One of the milestones resulting in improved outcome was a more aggressive surgical approach to burn injuries; early wound debridement and early wound coverage has led to higher survival rates but also to a higher number of patients requiring post-burn reconstruction.

17.1 From the Reconstructive Ladder to the Reconstructive Clockwork

Mathes and Nahai have used the metaphor of the reconstructive ladder in 1982 in their book: *Clinical Application for Muscle and Musculocutaneous Flaps*. They used the term “reconstructive ladder” in order to integrate the use of free flap into the reconstructive repertoire (Mathes et al. 1982). The ladder reflected the idea of a stepwise approach to treat tissue defects starting with direct closure followed by

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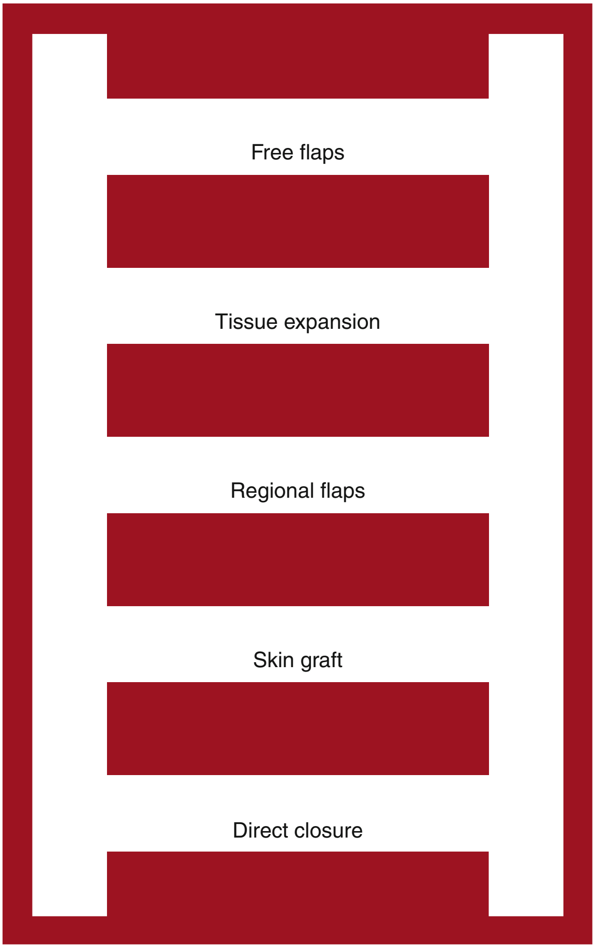

Fig. 17.1 The reconstructive ladder

skin grafting. Regional and local pedicled flaps, tissue expansion, and free tissue transfer were the next steps. This approach offered reconstructive surgeons a structured, thorough, and comprehensive algorithm for the treatment of wounds Fig. 17.1.

Nevertheless, a considerable medicine-technological progress has taken place. New areas like "composite tissue allotransplantation" of compound tissues like arms or parts of the face, robotics/bionics, and also regenerative medicine with "tissue engineering" have become part of a routine clinical application, not being mentioned in the conventional reconstructive ladder.

With the advancement in the understanding of the anatomy, operative techniques, instrumentation, and surgical skills, complex procedures are no longer considered as last resort procedures only. In the quest to reconstruct optimal form and function, it is accepted to jump several rungs of the ladder, with the knowledge that some defects require more complex solutions. The reconstructive elevator (Gottlieb and Krieger 1994) allows one to ascend from the simplest to the more complex techniques, with the freedom to ascend directly to the chosen level of complexity. The decisions will be based upon the needs of the patient, in combination with the knowledge, experience, and technical ability of the surgeon and the multidisciplinary team. This elevator will ensure the use of the most appropriate surgical option necessary to reconstruct a defect, resulting in optimal restoration of form and function for the patient. The elevator acknowledges changes that have been made in plastic surgery. Many of these changes have occurred in recent decades; as with experience, they have become safe and reliable techniques, no longer considered a last resort. Or citing a headline from the journal "Plastic Reconstructive Surgery": "Why climb a ladder when you can take the elevator?" (Bennet and Choudhary 2000).

Recalling these new developments, we suggest that the reconstructive sequence of the twenty-first century takes these developments into account. Neither the reconstructive ladders of Mathes and Nahai in 1982 nor the reconstructive elevator permits a real combination of the different reconstructive procedures. Often, combinations are applied in clinical daily routine, so the combination of new possibilities and methods will permit more and improved reconstructive possibilities for the patient.

The image of interlocking wheels in a clockwork (Knobloch and Vogt 2010) (Fig. 17.2) impressively illustrates the integration of different reconstructive methods, also with reference to their complexity.

17.2 General Principles

17.2.1 An Early Treatment of Deformity

Hypertrophic scars and scar contraction with concomitant functional impairment (i.e., of the eyelids, neck, axilla, elbow, hand, groin, knee, and foot) are two predominant problems following wound healing. The treatment regimens of applying pressure on scar tissues and the use of early mobilization of joints have been advocated to minimize their undesirable consequences.

Although the true efficacy of a nonsurgical regimen to control the deformities has not been established, the frequency of secondary joint release among individuals who had adequate therapy has been noted (Huang et al. 1975; Celis et al. 2003; Kamolz et al. 2009; Brou et al. 1989). The use of pressure garments, especially in the areas such as upper and lower limbs, with proper splinting of the hand and fingers (Kamolz et al. 2009), is strongly recommended early after trauma. The nonsurgical management of burn deformity must include daily physiotherapy and exercise to maintain joint mobility and to prevent muscle wasting.

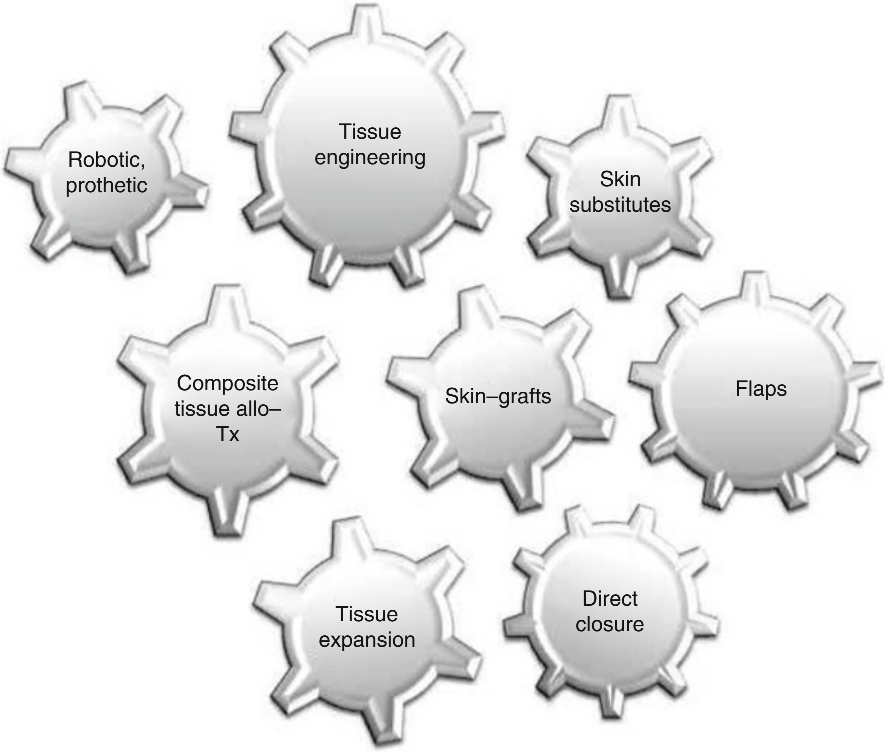

Fig. 17.2 The reconstructive clockwork

17.3 Reconstruction of Burn Deformities

Objective assessment of deformities and functional problems caused by scarring and scar contracture requires a detailed understanding of the extent of the original injury and a precise treatment approach to manage burn wounds. Formulating a realistic plan to restore physical problems and to alleviate pain and discomfort in the area of injury also needs a profound analysis of the physical deformities and psychological disturbance sustained by the patient. Psychiatric, psychosocial (Titscher et al. 2010), and physiotherapeutic care must be continued while a surgical treatment plan is instituted.

17.3.1 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 and where* to operate on a patient with burn deformities can be difficult. The dilemma, however, may be alleviated, if a basic principle is understood and followed:

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

In short, a surgeon's effort must concentrate on restoring the deformed bodily parts essential for physical functions, if not for patient survival alone. An exposed skull or calvarial defect, contracted eyelids, constricted nares, contracted major joints, and a urethral and/or anal stricture in individuals with severe perineal burns are the prime indications for an early surgical correction. In contrast, restoration of deformed regions in general can be performed in a later phase.

It is advocated that attempts to correct burn deformities should be delayed for at least 1–2 years (the time needed for scar maturation). During the interim, conservative treatment by using pressure garments and splinting is recommended to reduce scarring and to minimize joint contracture.

The 1- to 2-year moratorium on early burn reconstruction, in some instances, is appropriate and justifiable. Operating on an immature scar characterized by redness and induration is technically more cumbersome and will lead to a higher number of complications; e.g., a high rate of recontracture is expected, notably if partial-thickness skin grafts are used for releasing a wound still showing clinical evidence of active inflammatory processes.

17.3.2 The Techniques of Reconstruction

There are several techniques (Fig. 17.2) routinely used to reconstruct bodily deformities and to close defects in burn injuries, i.e., unsightly scars, scar and joint contractures:

- Direct closure techniques
- Skin grafting
- Skin grafting in combination with a dermal substitute
- Local and regional flaps
- Free flaps
- Tissue expansion techniques in combination with the above
- Composite tissue allotransplantation
- Tissue-engineered substitutes
- Bionics and prostheses

17.3.2.1 Direct Closure

Scar excision with layered closure of the resultant wound is the simplest and most direct approach in burn reconstruction. The margins of the scar requiring excision are marked. It is important to determine the amount of scar tissue that can be removed so that the resultant defect can be closed directly.

17.3.2.2 Skin Grafting

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. Whole components of the skin removed

Fig. 17.3 (**a**) Scar contracture and hypertrophic scars right arm. (**b**) Scar release and scar excision; wound bed already covered with the collagen/elastin matrix Matriderm(R); in the same operation coverage of the matrix with a split-thickness skin graft. (**c**) Fixation of the matrix and of the skin graft by use of V.A.C.™. (**d**) Five days after the operation → removal of the V.A.C.™ dressing. 100 % take rate of Matriderm(R) and skin graft. (**e**) Early result after single-step reconstruction of dermis and epidermis

as an intact unit – i.e., epidermis and dermis – are 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 on the donor side region.

A paper template may be made to determine the size of the skin graft needed to close the defect. The skin graft is placed on the wound bed and anchored into place by suturing or stapling it to the wound edges. A continuous contact of the skin graft to the wound bed is essential to ensure an ingrowth of a vascular network in the graft within 3–5 days for its survival, well noting that any mechanical barriers – i.e., blood clot or pool of serous or purulent fluid – can restrain the vascularizing processes, leading to a graft loss. A gauze or cotton bolster tie-over dressing has been the traditional technique to anchor and to prevent fluid accumulating underneath a graft, while also other techniques exist (Mittermayr et al. 2006; Pallua et al. 2010; Roka et al. 2007). The use of negative pressure therapy or fibrin glue has been associated with a better take rate (Mittermayr et al. 2006) (Fig. 17.3).

The basis for using a skin graft of various thicknesses is not entirely clear. The use of a thin graft is appropriate for closing wounds with unstable vascular supplies, particularly if donor sites are scarce. The quality and the presence of dermis have influence on the extent of wound contraction with the more viable dermal components present the less graft contraction observed.

Skin Graft in Combination with a Dermal Substitute

For the past several years, artificial dermal substitutes have been manufactured from alloplastic or xenographic materials, e.g., Alloderm™ and Integra™ (Nguyen et al. 2010), which have been found to form a layer of “neo-dermis,” thus providing improved dermal thickness and wound coverage in combination with an autologous

Fig. 17.4 (**a**) Hypertrophic and unstable scar in the popliteal region. (**b**) Scar excision and grafting with Matriderm™. (**c**) In the same operation skin grafting (Mesh 1:1, 5). (**d**) Early result. (**e**) Longtime result (1 year after the operation) after combined reconstruction of dermis and epidermis in a single-step procedure

skin graft. While a staged approach with two required operations is more cumbrous to the patient, single-step matrices, like Matriderm™ (based on collagen and elastin), have become available (Haslik et al. 2007, 2010; Bloemen et al. 2010) (Figs. 17.3, 17.4, and 17.5).

The simultaneous use of MatridermTM and split-thickness skin grafting is considered safe and feasible and leads to significantly improved results with respect to skin elasticity and range of motion (Haslik et al. 2007, 2010; Bloemen et al. 2010; Ryssel et al. 2010).

17.3.2.3 Skin Flap

The approach using a segment of skin with its intrinsic structural components attached to restore a destroyed and/or missed bodily part follows the fundamental principle of reconstructive surgery. The loss of the skin flap, more commonly encountered in burn patients because of altered vascular supply to the skin attributable to injuries and surgical treatment, could render this technique unsuitable. Despite the drawbacks, the approach to restore a destructed bodily part with a piece of like tissue is technically sound and the procedure can provide restored bodily function and contour. The recent technical innovation of incorporating a muscle and/or facial layer in the skin flap design, especially in a burned area, further expanded the scope

Fig. 17.5 (**a**) Hypertrophic scars and scar contracture at the dorsum of the right hand → hyperextension of the MCP joints → massive functional impairment. (**b**) Scar excision. (**c**) Longtime result (1 year after the operation) after combined reconstruction (Matriderm(R) and split-thickness skin graft) in a single-step procedure → no functional impairment → full range of motion achieved

Fig. 17.5 (continued)

of burn reconstruction as more burned tissues could be used for flap fabrication. Despite its geometric advantage in flap design, fabricating a skin flap or skin flaps for z-plasty reconstruction burn deformities is not infrequently complicated by skin necrosis. Aberrant vascular supply to the skin attributable to the original injury and/or surgical treatment could be the factor responsible for these problems. In recent years, the use of a skin flap designed to include muscle or fascia underneath has expanded further the applicability of conventional z-plasty and the 3/4 z-plasty technique in burn reconstruction.

17.3.2.4 Musculocutaneous (MC) or Fasciocutaneous (FC) Flap

Musculocutaneous z-Plasty

While the skin pattern is identical to the conventional z-plasty technique, the muscle underneath must be included in the flap fabrication. Although physical characteristics of the normal skin – i.e., the skin pliability and expandability – are absent if scarred skin is included in the flap design, a "scarred-skin" MC or FC flap could be safely elevated and transferred to close an open wound. In practice, an MC z-plasty technique is useful in the neck release and in the eyelid because of the underlying muscle; i.e., platysma and orbicularis oculi muscles are thin, pliable, and easily movable.

Fasciocutaneous z-Plasty

This is a technical modification of the MC z-plasty technique by including the muscular fascia only. Separation of the skin and its subcutaneous tissues from the underlying fascia must be avoided in order not to impair the blood supply to the flap. In practice, the technique is useful in reconstructing contractures around the knee and ankle.

17.3.2.5 Tissue Expansion

Indications for the use of tissue expanders in burn reconstructions are instances, where there is not enough adjacent tissue to resurface or close a defect primarily or with a local flap. The same criteria used to select a suitable patient for a regional skin flap are applicable in the selection for tissue expanded skin or flap reconstruction. Ideally, the patient should have no serious medical problems (e.g., diabetes, hypertension) and should not be a heavy smoker.

Tissue expansion allows large areas of burn scar to be resurfaced by providing tissue of similar texture and color to the defect. It is combined with the advantage of reduced donor site morbidity. Issues and disadvantages that need to be addressed are that the technique of preexpansion requires additional office visits for serial expansion and at least one extra surgical procedure with potential for additional complications. A significant period between 9 and 12 weeks for progressive tissue expansion is required. Tissue expanders are very versatile tools in reconstructive burn surgery, but careful patient selection, correct indications and realistic treatment concepts, experience and well-chosen surgical technique, precise instruction of the medical staff, as well as detailed and continuous education of the patients are essential (Bozkurt et al. 2008).

17.3.2.6 Free Tissue Transfer

The use of free flaps was an important step to cover large and complex tissue defects due to trauma, tumor, or hereditary. After the description of the pedicled M. latissimus dorsi transfers by Tansini more than 100 years ago, the free transplantation of the M. latissimus dorsi also took place for defect coverage several decades ago. Nahai has described in 1979 his experiences with 60 transplanted M. latissimus dorsi flaps for functional muscle transfer to the shoulder and for defects of the upper extremity, for the use of mamma reconstruction and as a free flap (Bostwick et al. 1979). Other free flaps adjacent to the thoracodorsal bundle were also introduced in the 80s.

Free Flap: Perforator Flaps

Based on the septocutaneous perforator vessels, the perforator flap was developed. Song et al. described in 1984 that the lateral femoral region can serve not only as a skin harvest place but also as the donor side for the “anterolateral thigh flap” based on a long pedicle. Koshima and colleagues from Japan refined 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 supplies a unique vasculatory territory, the perforasome (Saint-Cyr et al. 2009).

The surgical progress concerning perforator flap surgery is directly related to increasing surgical experience, and new technologies improve the preoperative visualization of the vessels, also allowing a reduced duration for perforator dissection.

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 sites. 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.

17.3.2.7 Composite Tissue Allotransplantation

"Composite tissue allotransplantation" (CTA) of parts of the face, or forearms and upper extremities (Brandacher et al. 2009; Siemionow et al. 2010; Gordon et al. 2009; Siemionow and Gordon 2010), 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 is normally not of vital importance. Nevertheless, for the affected individuals, who forced into social isolation with exhausted reconstructive measures or prostheses, such operations may lead to a dramatic improvement of quality of life. However, it is important to mention that, currently, only a highly selected small number of suitable patients are actual candidates for CTA.

17.3.2.8 Robotics/Bionics/Prostheses

If all reconstructive measures fail, myoelectric prostheses are a promising option. This technique has improved tremendously by introducing targeted muscle transfers (TMR) to the armamentarium of reconstructive surgery (Aszmann et al. 2008; Hijjawi et al. 2006). 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 deemed unthinkable only a few years ago. Targeted muscle reinnervation in combination with a myoelectric prosthesis with several degrees of freedom is such an example and is a solid stepping stone leading to new strategies in extremity reconstruction and rehabilitation.

17.3.2.9 Regeneration: Tissue Engineering

Tissue regeneration and engineering have gained more relevance in reconstructive surgery (Kamolz et al. 2008; Beier et al. 2010; Mansbridge 2009), with autologous fat transplantation being one of them. Czerny transplanted a lipoma for breast reconstruction in 1895. The fat injection was described among other inventions by Eugene Holländer in 1910 in a patient with "progressive decrease of the fatty tissue." Erich Lexer dedicated the first part of his book to free fat transfers, comprising of nearly 300 pages. In 2001, it was demonstrated that beside fat cells also "adipose-derived stem cells" (ADSC) and 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 (Dragoo et al. 2007). The stem cell-associated fat cell transplantation in patients with damaged skin following radiotherapy has led to healing. Moreover, fat cell transplantation is not only able to improve volume and contour defects but also skin quality (Klinger et al. 2008; Mojallal et al. 2009;

Rennekampff et al. 2010); thereby, it seems that fat transfer will play an important part in burn reconstruction.

17.4 Summary

The regimen of burn treatment has changed dramatically over the past 50 years. The regimen of an early debridement and wound coverage has enhanced the survival rate. However, this improvement in survival rate has also caused an increase of patients who will require reconstructive surgery.

The difficulty concerning burn reconstruction is largely due to a lack of adequate donor sides, but due to the improvements in reconstructive surgical techniques, better results have become achievable. New areas like "composite tissue allotransplantation" of compound tissues and regenerative medicine approaches have become available in clinical routine and will lead to an improved final outcome in burn reconstruction.

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