MICROSURGERY IN THE BURN POPULATION – A REVIEW OF THE LITERATURE

LA MICROCHIRURGIE CHEZ LES BRÛLÉS - UN EXAMEN DE LA LITTÉRATURE

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SUMMARY. The management of patients suffering from burn injury poses unique challenges for the reconstructive surgeon, both in the acute and delayed settings. Once resuscitative measures are optimized and hemodynamic stability is achieved, early burn debridement and coverage is performed. Traditionally, this consists of excision of devitalized tissue and subsequent coverage using split thickness skin grafts. However, in certain instances, and depending on the extent and nature of the burn injury, skin grafting (or even local tissue rearrangement) may not be a reasonable option. In these cases, free tissue transfer may provide a viable reconstructive alternative. While free flap reconstruction is rare in burn surgery, particularly in the acute setting, burn injuries that expose vital structures, such as tendon, nerve, bone, or deep vessels, require robust flap coverage. In the delayed setting, unsightly scar formation and contracture often occurs secondary to skin graft coverage. These significant patient morbidities are often amenable to free tissue transfer as well. This review article discusses the indications, applications, and problems with free flap surgery for burn injuries in both the acute and delayed setting, and summarizes the available literature on microsurgical free tissue transfer for burn management.

Keywords: microsurgery, burn reconstruction, acute burn coverage, delayed burn management, free tissue transfer, end-to-end anastomosis, end-to-side anastomosis, flap failure, split thickness skin graft

RÉSUMÉ. *La prise en charge des patients atteints de brûlures pose des défis uniques pour le chirurgien de reconstruction, à la fois dans les cadres aigus et retardés. Une fois les mesures de réanimation sont optimisés et la stabilité hémodynamique est obtenue, il faut faire le débridement précoce et la couverture de la brûlure. Traditionnellement, il s'agit de l'excision des tissus dévitalisés et la couverture par division ultérieure en utilisant des greffes de peau partielle épaisse. Cependant, dans certains cas, et en fonction des dimensions et la nature de la brûlure, une greffe de peau n'est pas toujours une option raisonnable. Dans ces cas, le transfert de tissu libre peut fournir une alternative viable. Alors que la reconstruction de lambeau libre est rare dans la chirurgie des brûlures, en particulier dans le cadre aiguë, les brûlures qui exposent les structures vitales, telles que les tendons, nerfs, os, ou les vaisseaux profonds, nécessitent une couverture robuste. Dans le cadre retardé, la formation de cicatrices inesthétiques et de contractures se produit fréquemment secondaire à une couverture de greffe de peau. Souvent ces morbidités importantes sont aussi prêtent au transfert de tissu libre. Cet article de revue discute les indications, les applications, et des problèmes avec la chirurgie de lambeau libre pour des brûlures dans les cadres aigus et retardés. Cet article résume aussi la littérature disponible sur la microchirurgie du transfert de tissu libre pour la prise en charge des brûlures.*

Mots-clés: *microchirurgie, reconstruction de brûlure, couverture de brûlure aiguë, prise en charge retardée, transfert de tissu libre, anastomose termino-terminale, anastomose termino-latérale, défaillance des lambeaux, greffe de peau partielle épaisse*

Introduction

The management of patients suffering from burn injury poses unique challenges, both in the acute and delayed settings. Acutely, the emphasis is on securing patent airways, ensuring adequate breathing and optimizing cir-

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culation. Essential parameters such as blood pressure, heart rate, urine output, and oxygen saturation, in addition to frequent physical examinations, provide invaluable information pertaining to tissue perfusion. This is of paramount importance as it directly affects future operative management plans, as well as determining prognosis and overall outcome.

Once hemodynamic stability is achieved, early burn wound excision and coverage is performed. Traditionally, this consists of excision of devitalized tissue and subsequent coverage using split thickness skin grafts. In certain instances, however, depending on the extent of injury, the tissue types involved, location of burn, and the certainty of unsightly scarring, skin grafting (or even local tissue rearrangement) may not be a feasible option. In these cases, free tissue transfer, although rarely used in acute burn management, may provide a viable alternative reconstructive option.

When considering free flap reconstruction for burn defects, the context and extent of the wound along with the status of surrounding structures need to be meticulously evaluated. For instance, tissue damage from thermal burns is often markedly different from that caused by electrical injuries. The former produces tissue destruction at the site of burn injury and penetrates tissue layers in a manner directly proportional to factors such as temperature, duration of exposure, and concomitant trauma. As for the latter, it may result in injury to deep tissue structures and, oftentimes, depending on the path of the electrical current, injury may extend to areas distant from the site of injury. It follows therefore, that coverage of these two different types of burn injuries requires different approaches.

This paper aims to evaluate the indications, applications, and pitfalls of microsurgical free tissue transfer for burn management in both the acute and delayed setting.

Acute reconstruction

In the early 1970s, as the application of free tissue transfer began to spread across an increasingly wide range of complex defects, it also started infiltrating the field of burn management.[2,32] Many authors believe that free tissue transfer is reserved for injuries that have exposed vital structures, such as tendon, bone, nerve, and large vessels, and in other cases in which the defect is not amenable to split thickness skin grafts.[1,3,5-9] Although split thickness skin grafting and, to a lesser extent, local tissue rearrangement constitute the mainstay of burn wound management, the literature suggests that free tissue transfer can be successfully utilized in select cases (whether in the acute or delayed setting). Platt et al. reported that free tissue transfer was used in 1.5% of burn patients, specifically in patients with complex wounds in which skin grafts might not take.[1] Similarly, in a study by De Lorenzi et al., 1.8% of burn patients required free flap reconstruction.[5] The majority of free flap reconstructions are used in the delayed setting, often for scar contracture release and optimizing return of function.[1,3,4,5]

The most common indication for early free tissue transfer in burn surgery is for limb salvage when the injury results in exposed vital structures (neurovascular bundles, tendons, joint spaces, bones).[1,5,7,11-13] The majority of such wounds occur following high voltage electrical injuries, but can also occur after deep thermal burns and prolonged contact burns.[3] In either case, infection and subsequent wound breakdown/necrosis is inevitable without adequate free flap coverage.[11] Saint-Cyr and Daigle[7] argue for aggressive debridement and early coverage with free flaps in cases of high-voltage electrical injuries. They state that "any delay in wound closure can increase morbidity as a result of tissue edema, inflammation, and infection, all of which can compromise functional recovery." Furthermore, early free flap coverage decreases morbidity and hospitalization time, leading to earlier rehabilitation and better functional recovery of involved areas.[13]

In cases in which burns affect thin tissue, such as the dorsum of the hand, genitalia, scalp/forehead, or peri-ocular skin, special consideration is given to the use of free flaps for reconstruction. Injury to these areas not only exposes 'vital structures' such as tendon, cartilage, bone, etc., but also results in devastating functional and aesthetic sequelae. Even in cases where 'vital structures' are not exposed in such regions, free tissue transfer may be a better option as compared to split thickness skin graft coverage; the latter might result in aesthetically inferior scar formation and contracture, compromising functional return. In a study of 36 free flaps in 32 patients that sustained head and neck burns, Parrett et al.[4] noted that exposure of cartilage or bone in the head is an absolute indication for flap coverage. They remark that "free flaps provide full-thickness skin and subcutaneous tissue, with improved aesthetics and better resurfacing than skin grafts."[4] In contrast, Stefanacci et al.[12] reported a free flap failure rate of 9% in 11 flaps for 8 patients used for acute repair of extremity burns secondary to either electrical or deep thermal injuries. This failure rate, however, is comparable to that of free tissue transfer performed to the same anatomic regions in non-burn patients. Their study suggested that acute free flap repair needs to be given stronger consideration during initial management of these wounds, especially in light of the improved functional recovery.

Timing of free flap reconstruction for burn injuries requires particular attention, even in the acute setting. Compared to flap failure rates performed for other indications (trauma, breast, head and neck reconstruction, etc.), those performed for acute burn reconstruction tend to be higher, specifically for surgeries performed during days 5-21 post-burn.[3] Infection, post-surgical inflammatory changes, and vascular compromise (most likely from inadequate debridement and wound cleansing) are potential etiological factors contributing to flap failures during this time period. Free flaps performed outside this timeframe have a lower failure rate.[3,7-9] Baumeister et al.[8] performed 75 flaps in 60 patients for thermal (n=49) and electrical injuries (n=26) and reported a flap failure rate of 19% for the high-voltage electrical injury group versus 10% for thermal burns. For the high voltage group, they concluded that their higher failure rate was due to timing and to electrical damage of deep structures, and therefore due to inadequate debridement. Chick et al.[6] advocated that aggressive tissue debridement is necessary and was the reason for their 100% flap success in a series of 5 patients with electrical injuries. Ofer et al.[10] reported a flap failure rate of 15% in a series of 26 free flaps for 19 electrical burn patients; in their study, they note that the nature of electrical injuries results in tissue damage at sites deep to, and distant from, the superficial burn. All of their flap failures occurred between days 5 and 21 and were the result of deep muscular damage, and thus inadequate debridement. They stressed the importance of adequate debridement before flap surgery, and that oftentimes, serial debridements are necessary. Meticulous caution, however, is necessary during initial and subsequent debridement as "further injury may be caused iatrogenically by debridement that leads to devascularization of surrounding muscle, release of toxic mediators and subsequent infection." A group from Turin (Italy) recommended the use of negative pressure therapy after debridement of acute complex traumas of the lower limbs; this modality might be helpful in the setting of burn injuries as it optimizes the wound microenvironment for subsequent free flap coverage.[33]

Free-flap surgery prior to the fifth day post-burn is often prevented by cardiovascular instability or compromised airways. Furthermore, the need for a free flap is not always readily apparent at such early stages.[10] The development of coagulopathies and vascular damage, including injury to the intima or media, vessel thrombosis and/or aneurysm formation, particularly following electrical injuries, often complicates the repair process and leads to missed early operative windows.[14,15] Free flap repair, however, can still be safely performed if the vascular anastomosis is distant from the area of necrosis or zone of injury.[10]

Delayed reconstruction

Free tissue transfer has seen wider usage in delayed burn management (i.e., for secondary reconstruction) as compared to the acute setting. Indications for delayed reconstruction fall into two main categories: functional and aesthetic. Oftentimes however, free tissue transfer can fulfill both functional and aesthetic requirements.

Early use of free tissue transfer is most commonly utilized in the treatment of electrical injuries, whereas its later usage is more likely in the treatment of thermal injuries.[5,8] Sauerbier et al.[9] performed 42 free flaps in 35 burn patients with traumatized upper extremities; delayed reconstruction was used in the majority (88%) of their thermal burn injury group, while it was much less utilized (35%) in the high-voltage injury group. This trend is not surprising as thermal injuries produce burn wounds that are often more superficial and localized, as opposed to the widely dispersed electrical injuries. Whereas the repair of soft tissue defects resulting from electrical injury is trending towards an increasing number of free flaps for initial reconstruction, often thermal injuries are acutely managed with split thickness skin grafts, rather than with free flaps. These grafts result in scar formations that have a tendency towards contracture or other morbidity.

Scar or joint contracture release is the most common indication for free flap reconstruction occurring after the acute time period.[4,5,9,10] Often burn contractures cause profound functional deficits when they occur across thin joint spaces, such as in the hand, or across large functional areas such as the axilla or the anterior neck. For extensive and severe neck burn contractures, Tseng et al.[16] recommend microsurgical free tissue transfer as a primary treatment for resurfacing after release or excision of the scar. They were able to use a combined scapular/parascapular flap for reconstruction of vertical and horizontal components of a neck contracture secondary to chemical burns. Good functional and aesthetic outcomes were achieved with no contracture recurrence. Similarly, Angrigiani[21] was able to achieve good functional and aesthetic results (as measured by cervico-mental angle), with no recurrences of scar contracture after treating 86 patients with anterior neck burn contractures using extended scapular flaps.

In hand burn injury, one-stage coverage and early rehabilitation are particularly important for functional recovery. Furthermore, unsatisfactory functional results occur when traditional methods are used for hand reconstruction, most likely due to prolonged immobilization and secondary contracture. Free flap reconstruction not only provides reliable soft tissue coverage but also allows earlier postoperative mobilization. In a review of 53 free flaps for 39 patients in which the majority of flaps were performed in a delayed setting (92.4%), De Lorenzi et al.[5] were able to achieve a 94% success rate with no reported flap losses for hand reconstruction. They note that "good function was gained in the majority of patients after contracture release" and subsequent free tissue transfer. Baumeister et al.[8] performed 75 free flaps in 60 patients following thermal or electrical burn injuries; they report no flap failures in those performed after 6 weeks for correction of joint contracture or unstable scarring. Free flap coverage for scar or joint contracture release has consistently been shown to produce safe, reproducible, and lasting results that improve functional and aesthetic outcomes.

Tissue expansion of free flaps has gained wide acceptance for large, extensive, and complex wounds that typically pose many reconstructive challenges. Expansion can be performed before or after microsurgical free tissue transfer; it provides a larger flap that covers more body surface area as well as a thinner flap with improved pliability.[10] Pre-expanded flaps have many applications in head and neck reconstruction, as this region is commonly affected in major burn injuries.[19] Santanelli et al.[20] reported two successful cases where pre-expanded free flaps were used to reconstruct burn scar defects. In a 16-year-old male, they pre-expanded a radial forearm flap used for anterior neck resurfacing post release of severe flexion contracture and lower lip eversion. In another patient (a 57-year-old woman), they used a pre-expanded parascapular free flap for axillary reconstruction for severe contracture and limited scapular-humeral joint function. The authors state that despite demanding higher surgical skills, pre-expansion benefits from increased flap vascularization due to the delay phenomenon and that they are thinned by the expansion, resulting in better long term functional and aesthetic outcomes.

Pre-expanded pedicled supercharged forehead flaps were performed by Gan et al.[17] to treat 9 patients with unilateral hemi-facial and temporal region burn damage and scar contracture. Transfer of large forehead flaps based on only one pedicle risks distal necrosis. To overcome the disadvantages of dual pedicles, such as the limited transfer range and short length of the flap, the authors maintain that a distal supercharging technique can be applied to lengthen the flap and extend the transfer range, allowing for greater reconstructive application. They reported no flap losses and all patients were pleased with the improvements in function and appearance.

For cervicofacial burn reconstruction, Woo and Seul[18] pre-expanded arterialized venous flaps in a series of 3 case reports. They placed a tissue expander superficial to the muscular fascia of the proximal forearm, and after expansion, they raised the flap with 2 vein pedicles, one of which was anastomosed to the artery and the other to the vein. The mean expansion period was 44 days. After free tissue transfer, good functional and aesthetic results (with no complications) were achieved.

Applications

Although upper extremities and the head and neck region are the most common locations for burn injuries,[19] free tissue transfer often times is used for the coverage of other body regions with similar end results. In general, muscle flaps are typically used for deep space obliteration, while fascio-cutaneous flaps are used for wound resurfacing and coverage. The selection of the free flap is dependent upon the usual parameters set forth by the recipient site, such as defect size, vascularity, mechanism of injury, exposed structures, contamination, the need to restore sensation, as well as potential donor site availability and morbidity. Similarly, in late reconstruction of burned upper extremities, flap choice also depends on recipient site characteristics and donor site availability.

Upper extremity reconstruction

In cases of shallow wounds requiring gliding surfaces for tendons or joints, fasciocutaneous flaps are frequently employed. The lateral arm flap is a commonly used flap, as it can be raised as a sensate composite flap or as a purely fascial flap. Scapular and parascapular flaps are also available as composite flaps with vascularized bone for lager defects. Radial forearm flaps have become a workhorse flap in microsurgery and have found widespread use in upper extremity burn reconstruction. Donor site morbidity, however, remains a limiting factor for its use. Other flaps such as anterolateral thigh (ALT) flaps, thoracodorsal artery perforator flaps, and serratus fascial flaps, have all been used for upper extremity reconstruction.

For larger and deeper wounds of the upper extremity, latissimus dorsi, rectus abdominis perforator, or gracilis flaps can be used as well.[9,21] In a case report comparing the ALT perforator flap to a free gracilis for reconstruction of burned hands in a 1 year old child, Misani et al.[22] note a shorter operative time and better aesthetic results with the gracilis flap. The authors note that the gracilis flap has low donor site morbidity, consistent anatomy with easy dissection, and has good excursion of the muscle. The ALT perforator flap on the other hand is bulky, requires increased surgical skill during harvest, and is not as pliable as the gracilis flap. De Lorenzi et al[5] prefer temporalis fascia flaps for hand burn contractures, and arterialized venous free flaps for web spaces or small defects.

Lower extremity reconstruction

The principles of lower extremity burn reconstruction are comparable to those of upper extremity reconstruction. For dorsal foot and heel coverage, fascial flaps are typically used. Smaller defects are usually covered with superficial temporalis fascia, whereas for larger defects, serratus fascial flaps are preferred.[8] Muscle flaps such as groin, gracilis, rectus abdominis, or latissimus dorsi flaps are preferred for plantar foot defects.[5,27] For larger defects of the leg and thigh, ALT flaps offer coverage for a variety of wounds. In a series of 21 children that suffered burns (9 of which affected the lower extremities), Burd et al.[23] used an ALT flap for coverage in the majority of cases (66%). They had two flap failures (33%) for lower extremity burn reconstruction utilizing the ALT flap. In both cases the authors attribute the failures not “to the microsurgery per se but to 'environmental' factor." One failure was caused by a traction injury during release and another caused by prolonged hypotension secondary to inexperienced anesthetic support. Often surrounding damage to the lower extremity limits options of flaps derived from the thigh, so frequently other muscle flaps are employed to fill wound defects. Ofer et al.[10] prefer to reconstruct large defects of the leg or thigh with latissimus dorsi or chimeric flaps based on the subscapular system, although they cite that serratus, rectus abdominis, and gracilis flaps offer reliable coverage as well.

Chest wall reconstruction

In trunk/thorax burn reconstruction, the same principles of flap selection apply. Large defects often require muscle or chimeric flaps, such as latissimus dorsi or rectus abdominis flaps. Smaller defects are usually covered with fasciocutaneous or adipocutaneous flaps. Again ALT flaps, radial forearm flaps, and scapular/parascapular flaps are the preferred choices. For larger defects that cannot be covered with conventional free flaps, pre-expanded parascapular or ALT flaps can be used.[20]

Optimizing aesthetics in head and neck reconstruction

Head and neck burn reconstruction carries with it the ever-present burden of high aesthetic expectations (which are not always easily achieved). Restoration of function is always coupled with the desired restoration of symmetry, contour, colour and texture of the face and neck. Often nearby tissue availability is limited for local tissue coverage and therefore distant free flaps have been employed for head and neck burn reconstruction. Though large free flaps may be disadvantageous due to their thickness, certain free flaps have proven useful for head and neck reconstruction.[4] In a retrospective study of 17 severely burned faces, Rose[24] was able to obtain excellent aesthetic results following reconstruction with "pre-patterned" composite flaps, reporting only one flap loss. The flaps were typically fasciocutaneous or thin free flaps, such as radial forearm, scapular, ilio-osteocutaneous, temporoparietal, and SMAS flaps. Intraoperative "sculpting to simulate normal planes and contours" was cited as vital to optimize outcomes. Parett et al.,[4] in a study of 36 free flaps used for head and neck burn reconstruction in 32 patients, highlighted the utility and complications of different types of free tissue transfer. The majority of flaps were used for the management of contractures or hypertrophic scarring. Exposure of bone or cartilage was an important indication for surgery in this series. Their most commonly used flaps were ALT and scapular/parascapular flaps, followed by radial forearm, latissimus dorsi and others. Multiple techniques were used for tissue transfer, including double vascular pedicles in three flaps, pre-expansion in fifteen cases, prefabrication in fourteen flaps, and prelamination in one patient. They noted perfusion problems in four cases (two of which were successfully revised) with a 94% free flap survival rate. The authors stated they had three main indications for flap surgery: vital structures exposure (such as bone and cartilage), extensive and often recurrent neck flexion contractures, and failure of previous skin grafting with accompanied contraction, scar hypertrophy, or wound breakdown. Disadvantages for the use of these flaps included revisions for debulking or sculpting which were required in 64% of the cases.

Pitfalls

There are inherent pitfalls and disadvantages to free flap reconstruction for burn deformities. Clinical context and individual circumstances must always be taken into account. The nature and pathophysiology of burn injuries often serve as an obstacle to successful wound repair. As with any trauma, hypercoagulability is a homeostatic response that is present for a protracted period in burn injuries. This response also progresses and increases during the healing process,[25] and contributes to impaired blood flow, oxidative stress, and compromised vascular patency.[14,15,26] Furthermore, the progression of local wound healing following burn injuries follows an aberrant course relative to normal wound repair. Delayed neutrophil apoptosis, causing further cytokine release and continued inflammation negatively impacts burn wound healing. This augments the chances of small and large vessel occlusion and thrombosis, increases local edema, and decreases local oxygen delivery to tissues. Concomitant bacterial infection and endotoxin production further compound the deleterious effects of burn wound cell infiltrates.[26]

Unlike thermal injuries, electrical injuries result in tissue damage deep to, and distant from, the site of injury. This often produces extensive zones of injury that are not always appreciable upon initial examination.[8,10] Electrical current travels along pathways of least resistance, causing increased thermal destruction along pathways of higher resistance, such as bone and tendinous structures. In parts that have limited cross-sectional area and highly resistant tissues (often deemed 'choke points', such as joint spaces), increased heat may cause severe tissue damage; however, in the experience of Baumeister et al.[8] concerning forearm reconstruction, no 'choke points' were involved.

The site of vascular anastomosis is also a problematic subject. Most authors follow traditional teaching which recommends that the vascular anastomosis needs to be performed outside the zone of injury.[3,10] Other authors remark that with electrical injuries there is no discrete zone of injury, and hence regardless of whether the injury is thermal or electrical, whenever there are visibly patent vessels, the vascular anastomosis may be performed within the wound.[6,12] The choice of microvascular anastomotic technique, end-to-end or end-to-side, is still debatable. A review of the literature showed similar patency rates in animal experiments when there is no size discrepancy,[34,38] end-to-side anastomosis seems to be perform better in cases of significant size discrepancy.[35] The available clinical evidence comes from Godina's[36] early experience showing a higher failure rate with end-to-end anastomoses, and stating that end-to-side anastomosis is the preferred technique. However, looking closely at his report, it seems that factors such as size mismatch and vessel injury, rather than microvascular technique, may have been responsible. Other studies (examining a large number of free tissue transfer) established that end-to-end and end-to-side microvascular techniques are equally effective when properly applied.[37] The choice of technique therefore is dictated by the various factors affecting the recipient vessel, such as the condition of the vessel, its accessibility, and the preservation of distal flow to an extremity.

Lastly, the occurrence of scarring and unsightly aesthetic outcomes with possible functional deficits and contractures needs to be mentioned. This is always a risk with any free tissue transfer or tissue rearrangement, although this risk is generally less than with skin grafts. On the one hand, most authors that have evaluated free flap reconstruction for burn injuries note that z-plasties, subsequent scar revision, skin grafting, or tattooing were necessary at a later date. On the other hand, good functional and aesthetic outcomes after free flap reconstruction were also noted, and the overall benefit of repair to a burned area seems to outweigh the disadvantages of potential scarring.[3,5-7,9,12,17,18,20,24]

Conclusion

In summary, free tissue transfer for burn reconstruction, in both acute and delayed settings, has been shown to be a viable option, and is being increasingly performed owing to its numerous benefits. Although free tissue transfer has not traditionally been considered a first line treatment, microsurgery should not be thought of as a last resort for management, but as an appropriate initial approach for selected patients. In the delayed setting, free flap reconstructions offer diverse options for revision or secondary repair of debilitating burn scar contractures.

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