The Role of Microsurgery in Burn Surgery

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KEYWORDS

• Burns • Microsurgery • Prelaminated flaps • Prelamination • Prefabricated flaps • Prefabrication • Burn reconstruction • Tissue engineering

KEY POINTS

- Microsurgical reconstruction in patients with burn is seldom the primary approach due to the clinical status of patients with burn, prolonged surgery, postoperative care demands, and the need for specialized training. Free flaps in acute burns exhibit a higher failure rate (approximately 10%), likely linked to the hyperinflammatory and hypercoagulable state of the severe burn patient. Strategies to improve outcomes include preoperative clinical status and nutrition optimization, careful anticoagulation, and considering timing and burn etiology in reconstruction planning.
- Burn contractures can severely impact range of motion and functional outcomes, affecting daily activities and overall well-being. Delayed burn reconstruction focuses on functional and aesthetic restoration, with free flaps being a primary choice for extensive contractures whereby local options are inadequate. Unlike in acute burns, elective reconstructive procedures show a comparable, low rate of flap loss. Additionally, free flaps reduce the risk of contracture recurrence by providing abundant, well-vascularized tissue that supports proper wound healing and minimizes tension on the scar. However, thorough removal of contracted tissue and addressing underlying structures are crucial to prevent persistent contractures and functional limitations.
- Prefabricated and prelaminated flaps have proven as effective reconstructive options in challenging facial burn reconstructions, showing optimal functional and aesthetic results. Despite the intricate nature of these cases, which often necessitate multiple surgeries, including revision and debulking procedures, prefabricated and prelaminated flaps prove to be able to dramatically improve burn survivors quality of life.

BACKGROUND

Burn injuries represent a worldwide health problem, registering over 8 million incidents globally in 2019.[1] Acute and reconstructive burns are a great challenge. Over the years, skin grafting has remained the mainstay treatment for acute partial and full-thickness burns, allowing coverage of large defects with minimal donor site morbidity. In cases whereby wounds are not amenable to immediate skin grafting, the temporary use of innovative technologies such as skin substitutes or negative pressure dressings can be chosen as bridge therapies between injury and reconstruction of acute burn injuries.[2,3] These approaches foster the formation of granulation tissue and neovascularization, frequently allowing for later skin grafting through a two-step approach. Nevertheless, when critical structures such as bones, cartilage, tendons, or neurovascular bundles are extensively exposed, opting for the flap reconstruction often emerges as the more suitable and appropriate strategy by granting a more robust and reliable coverage.[4–6] Flaps allow one-stage coverage of complex defects, shortening the healing time and reducing the risk of complications

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related to delayed wound healing, such as the dehydration and infection of the exposed structures. In circumstances whereby local flaps are unavailable or deemed unsuitable according to the extent of the injury, defect size and site, free tissue transfer remains the only option. Free flaps allow for the transfer of healthy and well-vascularized tissue from donor areas distant from the zone of injury, and allow for the coverage of deep and large defects in both acute and delayed burn reconstruction settings.

ACUTE BURN RECONSTRUCTION

Burn injuries lead to various anatomic and physiologic alterations in the body. They cause local and systemic responses due to the release of inflammatory mediators, potentially leading to organ dysfunction in more severe and extensive cases.[7] Key improvements in resuscitation and infection control have allowed a shift in focus toward more aggressive reconstructive plans for these challenging patients with acute burn.[7]

Reconstruction following an acute burn is generally classified as acute when carried out within 6 weeks from the day of injury.[8,9]

Burn injuries necessitating wound coverage are primarily managed with the use of skin grafts, which can cover a large surface area, particularly if meshed. Flap reconstruction is rarely required, with the usage of free flaps being even rarer. Perrault and colleagues queried the Nationwide Inpatient Sample database and found that out of 306,923 patients with acute burn, only 0.17% required a flap reconstruction (pedicled or free).[10] Following the principle of the reconstructive ladder, free flaps are reserved for severe and/or extensive wounds involving the exposure of critical structures (eg, bone, joints, tendons, and neurovascular structures) when local options are inadequate.[6,11–13]

Among the reasons why microsurgical reconstruction is seldom chosen as the primary approach for patients with acute burn there is the inherently prolonged nature of the surgery, which can be challenging for severely burned patients who often present with an unstable clinical status due to the systemic inflammatory sprout. Moreover, the postoperative period after a free flap procedure demands meticulous care and strict patient compliance, which may be difficult to achieve in patients with a wavering clinical condition. Furthermore, the intricate techniques involved in performing a free flap require specialized training; not every burn service may have access to a surgeon skilled enough to perform microsurgery. Lastly, despite the advancements in the knowledge of the anatomy and physiology of free flaps, they still exhibit a variable, yet high, failure rate in patients with acute burn, further discouraging their use in this patient population. Among the largest series of free flap reconstruction in patients with acute burn, Baumeister and colleagues[8] reported a 23% rate of free flap failure in 43 patients. Shen and colleagues[14] counted a 13% failure rate in 49 patients undergoing 54 microsurgical flaps. Conversely, Pan and colleagues showed no failures in a cohort of 38 patients undergoing the microsurgical reconstruction of acute burn injuries of the upper extremity.[15] Our group recently performed a systematic review and meta-analysis showing a free flap failure rate of 10% in acute burns, with more than 20% of free flaps requiring revision and acute return to the operating room.[16] Therefore, the rate of free flap loss in acute burns appears to be much higher than the traditionally quoted free flap loss rate (between 2% and 5%) reported in other populations, such as patients undergoing elective postoncological reconstruction.[17,18] For these reasons, free flaps in the acute setting should be considered only if the wounds are not amenable to skin substitutes, skin grafts, or local flaps.

Despite the limited evidence is still available to shed light on the factors determining a higher flap loss rate in acute burns different mechanisms likely come into play, such as the local and systemic hyperinflammatory states that follow burn injuries. Such injuries increase vascular permeability and disrupt vascular integrity, leading to enhanced interstitial pressure and edema. The resulting edema can exert compressive forces, potentially hindering venous outflow. Moreover, the trauma and inflammation induce perivascular scarring, which may reduce the pliability of vessels, compromising both arterial inflow and venous outflow, and promote thrombi formation.[19] Burn injuries also cause endothelial damage and impair the contractility of perivascular smooth muscles. This damage, as observed by DeSpain et al.,[20] can lead to increased extracellular matrix protein expression, suggesting compromised vasodilation capacity. These processes combined with the significant inflammatory response determine a hypercoagulable state in patients with burn.[21] Research indicates that this hypercoagulability emerges 24 to 48 hours postburn and peaks around 2 to 3 weeks.[22,23] Consequently, this combination of a hypercoagulable state and endothelial damage may elevate the risk of arterial and venous thrombosis at the microvascular anastomosis site, explaining the observed high incidence of free flap failures in acute burns.

Despite still limited to clinical experience, several strategies may be used to improve surgical outcomes. Preoperative considerations include the need for preoperative clinical and nutrition optimization, and nerve blocks to reduce the vasospasm. Patients need to be off organ support including pressors and renal replacement therapy. Nutrition status needs to be monitored closely and it should be optimized by means of protein and vitamin supplementation. Edema should be optimized by wrapping and elevating the extremity. The authors have a very low threshold to start tube feeds if the patient is unable to maintain optimal nutrition by oral means. Good communication with the critical care, nutrition team, and anesthesia and regional anesthesia team are essential for planning and ensuring the patient is ready and safe to proceed with surgery. Careful consideration for intraoperative and postoperative anticoagulation is needed both during the anastomosis procedure and in the postoperative stage. Patients are routinely anticoagulated at the time of anastomosis and postoperatively. At the time of anastomosis, a 5000 units bolus of intravenous heparin is given. Postoperatively the following protocol is used: intravenous heparin at a rate of 500 units per hour, aspirin at 325 mg per rectum at the end of surgery followed by daily 81 mg, use of sequential compressive devices while in bed, bair hugger and warm room temperature, and early mobilization based on the location of the flap. Secondly, optimizing venous outflow and arterial inflow can be achieved through various maneuvers including performing the anastomosis outside the zone of injury, adventitial stripping, end-to-end anastomosis, 2 venous anastomoses, avoiding very large flaps, which might have higher requirements and the potential of partial necrosis, avoiding pedicle kinking, and prevent pedicle exposure, which is often challenging due to the absence of available viable soft tissue coverage.

Further understanding of the processes involved in acute burn injuries can contribute to the optimization of surgical strategies, aiming to reduce the risk of complications such as flap loss. For instance, the timing of the reconstruction is likely to play a pivotal role. Baumeister and colleagues[8] observed that the highest risk of flap failure occurred between day 5 and day 21 postinjury (8 out of 10 losses). This finding echoes the results reported by Pessoa Vaz and colleagues,[24] who experienced a 13% flap loss rate with all failures falling between day 5 and day 21 postinjury. Similarly, Pedrazzi and colleagues[25] documented a 17% flap failure rate, again with all losses confined to the same time window. The authors of this article conducted a systematic review and meta-analysis of 17 articles and 275 free flaps performed on 260 patients with acute burn. The study showed that the pooled prevalence of free flap failure was higher between 5 and 21 days from the day of injury (16.55%), or during the first 4 days (7.32%); however, the free flap failure rate was lowest after day 21 (6.74%).[26] Since the timing of the reconstruction appears to influence surgical outcomes, the senior author routinely delays free flap reconstruction until day 22 from the day of injury to reduce risk of flap loss.[26]

The role of the burn etiology and location are other factors under scrutiny. However, no definitive conclusion can still be drawn about their impact on the free flap failure rate. Perrault and colleagues[10] reported a significantly higher risk of flap loss in case of electrical burns compared with thermal. However, they included in the analysis any type of flap and not free flaps only. Baumeister and colleagues[8] found that flaps used for coverage of burns to the lower extremities had twice the failure rate compared with the upper extremities (21% vs 10%). Moreover, studies reporting lower rates of flap loss include patients with defects predominantly involving the upper extremity.[4,5] However, further studies are needed to confirm these findings. A summary of preoperative, intraoperative, and postoperative considerations can be found in **Table 1**.

Patient selection is critical to ensure optimal outcomes of patients (**Figs. 1** and **2**). Since microsurgical reconstruction may be the only alternative in limb salvaging situations, continued investigation into strategies to reduce the risk of free flap failure in acute burn is needed. This could ultimately result in better care and an enhanced quality of life for these patients.

DELAYED BURN RECONSTRUCTION

Advances in burn care over the years have reduced complications and mortality, increasing the importance of the quality of life and functionality of burn survivors.[27] Indeed, despite the developments in the acute management of burns, patients develop hypertrophic scars and contractures.[28] These contractures can then in turn have a great impact in the patient's life including decrease in range of motion, compromised functional outcomes.[29] The head and neck, as well as the upper/lower extremities are regions of high functional demand for fine and wide movements.[29] Impairment in the range of motion due to scar contracture and fibrosis results in an inability to perform everyday activities, impacting patients' physical well-being and overall quality of life.[30,31] The depth of the burn and the healing time directly correlate to the amount of scarring and the chance of developing a hypertrophic scar.[32–34] Various

Table 1
Preoperative, intraoperative and postoperative considerations in patients with acute burn requiring microsurgical reconstruction

Preoperative	Intraoperative	Postoperative
• Wait until day 21 from burn injury • TEG • Nutrition optimization • Edema optimization • Off organ support • Nerve blocks if reconstructing extremity	• Anastomosis outside of zone of injury when possible • Adventitial stripping • End-to-end anastomosis • Two vein anastomosis • Avoid pedicle kinking • Avoid pedicle exposure • Anticoagulation	• Anticoagulation • Maintain warm environment • Limb elevation

methods such as compression garments, massage, laser therapy, intense pulsed light, steroids, exercise, and fat grafting have been used to minimize hypertrophic scarring.[35] Despite providing benefits, these treatments alone may not be sufficient due to the evolving nature of burn scars and recurrence of contractures. Therefore, recurrent rounds of laser therapy, contracture release, and/or adjacent tissue transfer are generally needed.

Delayed burn reconstruction is performed on patients that have already received definitive acute burn surgical care and it aims at functional restoration by release of the contractures limiting the movement, at aesthetic and psychological improvement by reconstructing areas causing disfigurement by removing hypertrophic scars which are often raised, pigmented and cosmetically unpleasing; at pain and discomfort alleviation, by rearranging the scar tissue, which can cause pain, itching, and altered sensation.[36]

Free flaps are primarily used in burn delayed reconstruction in case extensive areas are involved in the contracture and no local option is deemed suitable for coverage of the soft tissue defect resulting after scar tissue excision.[37]

Contrary to the risk of flap loss seen in acute burns, patients undergoing reconstructive procedures are elective and seem to have a flap loss rate comparable to that in other elective patient populations. Among the largest studies available on the outcomes of free flap burn reconstruction, Angrigiani and colleagues[38] reported a rate of flap loss at 5.6% in 150 patients. De Lorenzi and colleagues[39] experienced 5.7% failure rate in 53 patients. Similarly, Ohkubo and colleagues[40] reported a flap loss rate of 5% in 99 patients undergoing free flap delayed burn reconstruction. In addition, many recent studies, despite including a smaller sample size, showed no flap losses in similar patient cohorts.[36,41,42]

Besides flap loss, contracture recurrence is one of the most important complications when treating a burn contracture.[43] The available studies reporting this outcome showed either no or very rare occurrence of this complication.[40,42,44–46] Indeed, free flaps allow the transfer of abundant, healthy and well vascularized tissue, alleviating tension on the scar, supporting proper wound healing, and reducing the likelihood of scar contracture recurrence. However, it is paramount to remove all the contracted tissue, including the margins of the scar, and to release the underlying ligamentous and tendinous structures under the skin contractures. If not completely addressed, they might lead to a persistent contracture and functional limitation. Free flaps allow coverage of extensive resections and especially when large areas are involved in the contracture, they represent an optimal reconstructive option.[47]

PREFABRICATED FLAPS

In patients who have sustained extensive burns, there is frequently a limited availability of healthy skin available for complex reconstructive procedures in unique areas such as the head, neck, and hands. Reconstructing burn injuries on the face and neck represents one of the most challenging tasks in reconstructive surgery, due to both functional and aesthetic aspects.[48] Serious scarring and deformity can follow facial burns, especially when they are healed by secondary intention. Traditional strategies such as skin grafts often present issues including color mismatch and unpredictable deformities. Local flaps might be an option but in extensive burn, local flaps might be unavailable.

A useful strategy in these complex scenarios is prefabrication, which is a term that was first introduced in the 1970s.[49–51] This technique involves the engineering of an axial flap from local or distant tissue by introducing a vascular pedicle into a body of tissue followed by a transfer of this neovascularized tissue into the defect based on its recently

Fig. 1. 51-year-old male who sustained an electrical injury to the left foot. Following burn excision the defect involved exposure of the left fifth metatarsal bone and metatarsophalangeal joint (*A*). A right radial forearm free flap was harvested (*B*) and anastomosed to the left anterior tibial vessels (*C*, *D*). Three month follow up demonstrates a well healed flap with the full function of the foot (*E*, *F*).

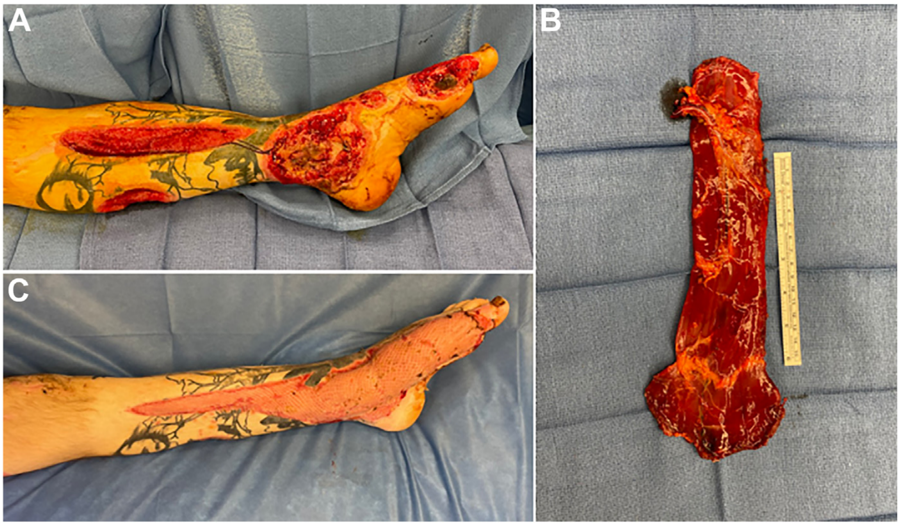

Fig. 2. 29-year-old male who sustained an electrical injury to the left foot. Following burn excision the defect involved exposure of the left first metatarsal bone and metatarsophalangeal joint, left tibia, ankle flexor and extensor tendons (*A*). A right rectus abdominis muscle free flap was harvested (*B*), anastomosed to the left posterior tibial vessels and skin grafted. One month follow up demonstrates a well healed flap and skin graft (*C*).

implanted vascular pedicle.[52] The benefit of this technique is first, the ability of transferring vascularized tissue despite the lack of flap donor site availability (due to extensive burn injuries), and second the ability to find the best tissue match, with the skin above the clavicle often being the preferred choice because of its unique characteristics.[48,53] The prefabrication process is carried out in 2 main stages. In the first stage, the necessary tissue is identified and a vascular pedicle, which is essentially a blood vessel that can foster neovascularization, is introduced to a recipient tissue that originally lacked a suitable pedicle, thus introducing a new axial pedicle to the overlying subcutaneous tissue and skin. A variety of local or distant pedicles can be used as for prefabrication.[52] Common pedicles used for free tissue transfer include the lateral femoral circumflex artery or radial forearm. Some studies have found that there is a proportional relationship of pedicle size and the rate of neovascularization and flap survival.[54] To prevent scarring around the pedicle and to facilitate secondary harvest of the prefabricated flap, a segment of polytetrafluoroethylene tubing can be wrapped around the pedicle. One may even consider using silicone or other nonadhesive sheeting.[52] The tissue is then kept in place for ideally 8 weeks to allow proper neovascularization.[52] The addition of a tissue expander facilitates easier flap raising in the subsequent stage and favors further neovascularization. The expander is generally filled until the desired volume is achieved. In the second stage, the fabricated flap is elevated, supported by new blood supply networks, ensuring its viability and facilitating proper blood circulation in and out of the flap. Though there might be minor venous congestion issues initially, they typically resolve within the first 36 to 48 hours. In rare cases whereby congestion is severe, additional measures may be required including flap delay, lengthening maturation time, or increasing the contact area between the pedicle (usually in the form of a fascial flap) and the donor tissue.[52,55] By meticulously guiding the tissue development and ensuring a rich blood supply to the new flap, prefabrication seeks to provide a more natural, harmonized appearance in the reconstructive surgery of severe burn injuries on the face and neck. This method is grounded on fostering neovascularization, using tissue expanders effectively, and leveraging the best-matching tissue to optimize the aesthetic and functional outcomes of the surgery. Various studies have demonstrated its value and success. Pribaz and colleagues[48] shared their 10-year experience of prefabricated flaps in the head and neck. Out of 17 prefabricated flaps, 15 flaps were transferred successfully in 12 patients. Tissue expanders were used in 11 flaps and 7 flaps were transferred as free flaps. Zan and colleagues shared their 12-year experience using pre-expanded and prefabricated perforator flaps for total facial resurfacing in 42 patients demonstrating improved aesthetic and functional outcomes.[56] Other innovative prefabrication techniques have been further proposed including free prefabricated flaps with purely implanted arterialised venous loop,[57] prefabricated

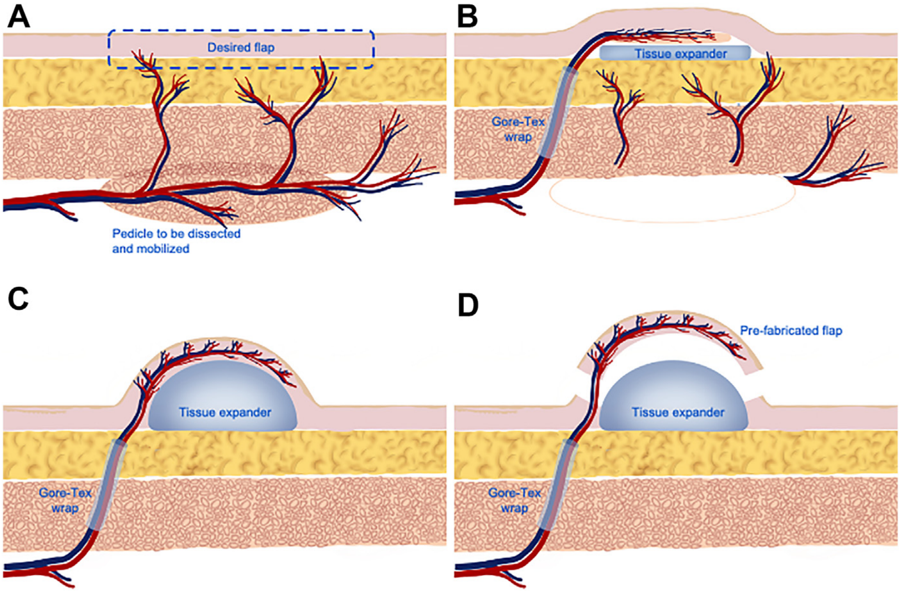

Fig. 3. Schematic diagram of the creation of prefabricated flaps. The desired flap is marked and the pedicle to be mobilized is identified (*A*); the pedicle is transposed to a recipient tissue that originally lacked a suitable pedicle, and it can be placed over a tissue expander (*B*); the expander is then filled until the desired volume is achieved (*C*); the fabricated flap is elevated and transferred to the desired location (*D*).

tissue-engineered Integra free flaps.[58] Many more applications have been used and often utilized in combination with prelamination, which demonstrates that this technique should remain the plastic surgeon's armamentarium when considering complex reconstructive challenges (**Fig. 3**).

PRELAMINATED FLAPS

The term prelaminatation was proposed by Pribaz and colleagues[59] referring to the implantation of tissue or other devices into a vascular territory prior to its transfer. The aim of prelamination is to modify a primary axial flap into a layered flap by incorporating the necessary support and lining components essential for composite reconstruction.

The first prelaminated flaps were forehead flaps prelaminated with bone and cartilage for nasal reconstruction. This technique was first attributed to Lexner in 1914, as mentioned by Denecke and Meyer, when he used tibial bone to prelaminate a forehead flap for reconstructing the nose.[59]

Prelamination is a two-stage procedure, in which a complex multilayered flap is created with the addition of grafts of different tissues and designed with a known vascular territory, and subsequently transferred through a microvascular anastomosis. This differs from prefabricated flaps because in a prelaminated flap the graft material is integrated into a pre-existing vascular territory, while prefabricated flaps are designed on a newly created vascular territory.

Prelamination of a flap at a distant site can provide the layers needed for the reconstruction of extensive and complex defects and they are used predominantly for facial defects.[53] Prelaminated flaps respond to the need of bringing tissue able to framework, lining and support at first stage. The tissue used include cartilage, bone, and porous polythlene scaffolds, and bioabsorbable scaffolds. Refinements are often needed but can be accomplished secondarily. In addition, prelaminated flaps offer the advantage of simultaneously reconstruct adjacent structures. In particular, they offer unique advantages in case of complex defects whereby it is necessary to reconstruct also areas surrounding the nose, such as nasolabial folds, the lip or the cheek.[60] The forearm is the most commonly used site for flap prelamination but other flaps have also been used. Both radial and ulnar arterial territories can be used and the thin skin and the reliable vascular supply facilitate the incorporation of grafts. Despite the complexity and the number of surgeries often required, including revision and debulking procedures, prelaminated flaps represent a durable and satisfactory reconstructive option for complex defects, especially when involving multiple subunits of the face.

SUMMARY

In summary, microsurgery emerges as a crucial instrument for delivering exceptional care in both acute and delayed burn reconstructive surgery, particularly for complex patient cases. While skin grafting remains the primary treatment for partial and full-thickness burns, the need for more advanced strategies arises in severe burns associated with large and deep areas of soft tissue compromise and limb-threatening situations. In such cases, flap reconstruction, including microsurgical techniques, becomes essential for providing robust and reliable coverage, and minimizing complications. Today, flap reconstruction is rarely used in burn reconstruction, especially in the acute setting. The reluctance to use microsurgical reconstruction as a primary approach for patients with acute burn is due to several factors including the inherently prolonged the duration of free flap reconstruction, the need for a meticulous care and strict patient compliance in the postoperative period, the need of a specialized training, and the high risk of free flap failure in acute burns reported in literature. However, in some instances microsurgical reconstruction may remain the only reconstructive option, therefore further efforts are needed to improve surgical outcomes and obtain the best possible management of these rare but challenging patients. It is likely that the inflammatory sprout which follows the severe burn injury increases the risk for microvascular complications. Indeed, free flaps performed after 21 days from the day of injury (once the inflammatory cascade has settled down) demonstrated a higher probability of free flap survival. Further strategies to improve surgical outcomes involve preoperative optimization, including clinical and nutritional factors, nerve blocks, and careful management of organ support. Postoperatively, anticoagulation protocols are crucial, along with measures to optimize venous outflow and arterial inflow.

In delayed burn reconstruction, microsurgical reconstruction plays a key role in functional restoration, aesthetic improvement, and pain alleviation. Unlike in acute burns, the risk of flap loss in delayed reconstructive procedures is comparable to other elective patient populations. Microsurgical free flaps proved effective in minimizing the risk of contracture recurrence and maximizing the functional restoration, providing abundant, healthy, and well-vascularized tissue for optimal wound healing.

In complex facial reconstruction, the use of prefabricated and prelaminated flaps have expanded even more the tools available for reconstructive surgeons, demonstrating significant improvements in burn survivors quality of life in cases not curable with conventional free flaps. However, the technical difficulty of prefabricated and prelaminated flaps necessitates a meticulous preoperative planning in addition to a skilled and experience microsurgeon.

CLINICS CARE POINTS

- In acute burn injuries, the risk of free flap failure is influenced by various factors, including local and systemic hyperinflammatory states. Burn-induced vascular changes, such as increased permeability and disrupted integrity, can lead to edema, compressive forces, and impaired venous outflow. Strategies to enhance surgical outcomes involve preoperative optimization, including clinical and nutritional support, nerve blocks, and organ support. Careful intraoperative and postoperative anticoagulation is crucial. Timing of reconstruction plays a significant role, with the highest flap failure risk between days 5 and 21 postinjury. Further research is needed to evaluate the influence of burn etiology and location on reconstructive outcomes and improve surgical strategies.
- Burn contracture free flap reconstruction demonstrates free flap failure rates similar to those observed in other elective patient populations. The use of free flaps reduces the risk of contracture recurrence by supplying ample, well-vascularized tissue that facilitates optimal wound healing and mitigates tension on the scar. It is imperative, however, to meticulously remove contracted fibrotic tissue and address underlying structures to prevent persistent contractures and associated functional limitations.
- Prefabrication emerges as a valuable strategy for facial reconstruction, involving the preparation of optimal tissue for transfer. This technique, carried out in 2 stages, introduces a vascular pedicle for neovascularization and uses tissue expanders to facilitate flap raising. Prefabrication aims for a more natural appearance and improved functional outcomes in severe burn reconstructive surgery. Studies have demonstrated its success, leveraging factors such as neovascularization, tissue expanders, and careful tissue development.
- Prelaminated flaps address the requirement for initial tissue providing framework, lining, and support. Secondary refinements are often necessary. Prelamination is primarily used for nose reconstruction but it allows the simultaneous reconstruction of adjacent structures, particularly beneficial in complex cases involving areas around the nose, such as naso-labial folds, the lip, or the cheek.

DISCLOSURE

The authors have no disclosures.

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