The New Reconstructive Ladder: Modifications to the Traditional Model

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Summary: The traditional reconstructive ladder has withstood the test of time, serving as a thought paradigm to guide surgeons in choosing their method of wound closure for an assortment of defects. Advances in anatomical understanding and technological innovations have improved our ability to achieve definitive closure in a wide variety of patients. In this article, the older construct is updated to reflect the use of negative-pressure wound therapy and dermal matrices. Perforator flap concepts are also discussed in terms of their inclusion as a rung on the ladder. (*Plast. Reconstr. Surg.* 127 (Suppl.): 205S, 2011.)

The reconstructive ladder is a concept familiar to all plastic surgeons. An early version is illustrated in Figure 1. Although it has undergone gradual evolution over time, the basic concept of methods of reconstruction ranked by complexity has been preserved and propagated in multiple forms. Most descriptions start with closure by secondary intention, followed by direct closure, local flaps, and distant flaps. Various authors have made finer distinctions among local, regional, and free flaps, and inserting tissue expansion somewhere in the spectrum.

As a metaphor, however, the reconstructive ladder has its limitations. Although there is virtue in using the simplest solution to a given problem, at times more complex methods of reconstruction may be preferred, even when simpler methods can achieve wound closure. To address these concerns, several modifications to the reconstructive ladder have been proposed. Mathes and Nahai[1] suggested the "reconstructive triangle," which consisted of tissue expansion, local flaps, and microsurgery (Fig. 2). Gottlieb and Krieger[2] introduced the "reconstructive elevator" which, although still acknowledging the concept of increasing levels of complexity, suggests the freedom to ascend directly to the appropriate level if necessary (Fig. 3). Wong and Niranjan[3] recommended that the rungs be thought of as stages in the development of surgical skills, emphasizing that the difficulty of a reconstructive problem is related to the skill and training of the treating surgeon. Erba et al.[4] integrated the concepts of surgical risk, technological complexity, and surgical complexity into a matrix to help organize the various reconstructive methods and provide a framework for further discussion.

However, despite its many modifications, several major advances in wound healing and reconstruction have yet to be incorporated into the ladder. In particular, the use of negative-pressure wound therapy and dermal matrices, both of which have achieved significant levels of clinical usage, do not fit easily into the existing paradigm. Perforator flaps, which may be either pedicled or free flaps, may also deserve some further consideration for their own rung.

NEGATIVE-PRESSURE WOUND THERAPY

Since its development in the early 1990s, negative-pressure wound therapy has achieved widespread use in many different arenas. Despite extensive research, some basic questions remain regarding the mechanism and physiology of negative-pressure wound therapy. These issues have been reviewed at length by other authors[5–7] and are not the focus of this discussion. The described clinical

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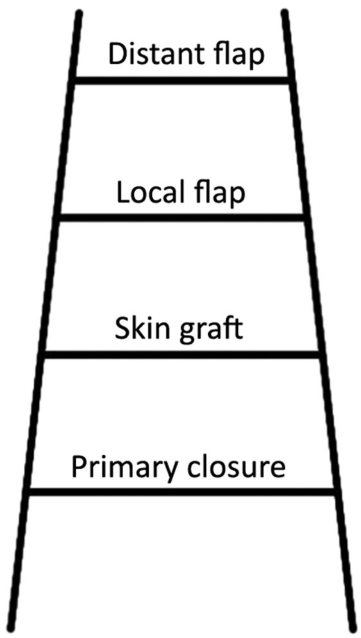

Fig. 1. An early version of the reconstructive ladder.

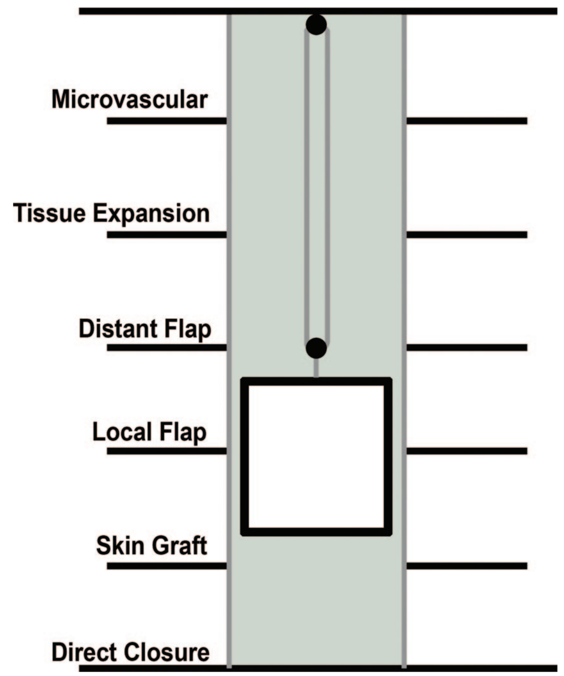

Fig. 3. The reconstructive elevator, as proposed by Gottlieb and Krieger. This formulation emphasizes the importance of selecting the most appropriate level of reconstruction as opposed to defaulting to the least complex. (Reprinted from Gottlieb LJ, Krieger LM. From the reconstructive ladder to the reconstructive elevator. *Plast Reconstr Surg*. 1994;93:1503–1504.)

advantages of negative-pressure wound therapy include an increased rate of granulation formation, decreased periwound edema, decreased time to closure, less frequent dressing changes,[6,8] control of bacterial proliferation, and possible economic advantages.[9,10] Some chronic wounds that have failed traditional wound care may respond to negative-pressure wound therapy.[11,12] Despite its advantages, such uses of negative-pressure wound therapy would conceptually be equivalent to closure by secondary intention or skin grafting.

However, the use of negative-pressure wound therapy has been expanded to wounds beyond this scope. A common clinical problem is the small wound that has poorly vascularized tissue at its base, such as bone or tendon. Attempts at closure by secondary intention may fail because of the inability of these tissues to heal with traditional wound care. Skin grafts may have difficulty adhering or result in thin, unstable coverage. The traditional answer, flap coverage up to or including free tissue transfer, may solve the problem but at

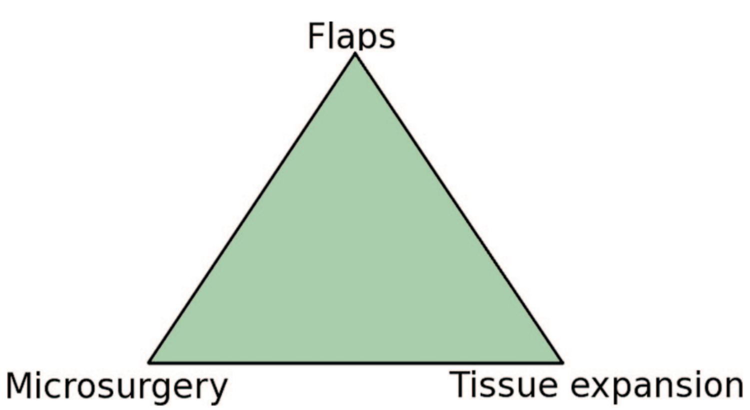

Fig. 2. The reconstructive triangle, as proposed by Mathes and Nahai. (Adapted from Mathes SJ, Nahai F. *Reconstructive Surgery: Principles, Anatomy & Technique*. Vol. 2. New York: Churchill Livingstone; St. Louis: Quality Medical; 1997.)

times may seem disproportionate in terms of effort and risk, given the limited nature of the wound.

Recently, there have been multiple case reports and series describing successfully granulating small areas of bone, tendon, and even hardware with negative-pressure wound therapy, allowing for eventual closure by secondary intention or grafting. DeFranzo et al. noted successful healing of 71 of 75 lower extremity wounds using negative-pressure wound therapy despite exposed bone, tendon, and/or hardware, although the size and nature of the wounds were not clearly described.[13] Lee et al. published a similar case series of 15 of 16 foot and ankle wounds with an average size of 56.4 cm^2 with exposed bone and tendon successfully granulated and grafted with negative-pressure wound therapy.[14] Bollero et al. described their series of 37 complex lower extremity wounds in a high-risk population reconstructed successfully with negative-pressure wound therapy.[15]

Unfortunately, no clear evidence exists to suggest what the largest defect size is that might be successfully treated in this manner. DeFranzo et al. note that ". . . most cases of large surface areas of exposed bone and tendon still need [free flap coverage]," without specifying the exact dimensions of the wounds treated in this fashion. The series by Lee et al. included wounds larger than 100 cm^2 that were granulated successfully, but this figure does not make a distinction between overall wound size and the area of exposed bone and tendon, and whether such structures had intact periosteum or paratenon. Such data are absent from the literature to date, as are data on how well a wound healed by granulation and skin graft holds up over the long term when compared with a similar wound closed by a flap (Fig. 4).

DERMAL MATRICES

Use of dermal matrices is another relatively recent development that has not been incorporated into the reconstructive ladder. Consisting of collagen and chondroitin-6-sulfate and available in sheet and injectable form, such products are vascularized from the native wound bed over the course of weeks. Originally developed for burn reconstruction, their use has been expanded to address many reconstructive problems. When used in conjunction with a graft, the resulting skin is of better quality, with greater thickness and elasticity, than pure split graft reconstructions.[16,17] More importantly, dermal matrices can be used to reconstruct wounds with exposed critical structures such as exposed bone without intact periosteum, exposed tendon without paratenon, and exposed cartilage without perichondrium. The matrix becomes vascularized from the wound margins, eventually covering the poorly vascularized wound bed with vascularized matrix, which can then support a skin graft (Fig. 5).

Unlike using negative-pressure wound therapy to cover smaller areas of exposed bone or tendon, dermal matrices can be used to cover much larger areas of tissue that traditionally would be thought of as nongraftable. Lee et al. described the use of dermal matrices to avoid free flap reconstruction or amputation in complex lower extremity burn reconstruction with exposed tendon, bone, and joints.[18] Dermal matrices have been used successfully in hand, foot, and ankle reconstruction and their associated tendon and joint exposures in both the burn and trauma literature.[19–21] Perhaps one of the most common clinical uses of matrices in complex reconstruction is in the large full-thickness scalp reconstruction, with multiple authors reporting favorable results with matrix reconstruction.[22,23] Use of dermal matrices may be particularly attractive in the pediatric population, in a patient at high risk for a more invasive procedure, and as a secondary option (Fig. 6).

Although use of a dermal matrix might be considered "simpler" than flap reconstruction, meticulous wound care is needed to use it successfully. Engraftment rates have been reported to range from 35 to 96 percent,[24,25] with many of the failures associated with development of seromas, hematomas, and infection. The above potential complications require a great deal of vigilance to detect and treat before the graft is lost. Considering the dressing changes and the secondary operation for epidermal grafting, a dermal matrix may entail more time and effort than a single-stage flap reconstruction. Despite these limitations, however, there is clearly a place for dermal matrix reconstruction in select cases (Fig. 7).

PERFORATOR FLAPS

Our knowledge of vascular anatomy and its application in perforator flaps continues to expand.[26–28] Ranging from fairly well-described anterolateral thigh flaps to freestyle perforator flaps, there are endless possibilities afforded by an understanding of perforator anatomy.[29] Although such flaps could easily be slotted into the local and distant flap categories, it may be profitable to make finer distinctions. Although the common workhorses of reconstruction are deservedly given first consideration when approaching a significant defect, at least considering a perforator flap, either pedicled or free, may be worthwhile. The

Fig. 4. A series of images depicting the treatment of a large open wound over the Achilles tendon. The wound was débrided and treated with negative-pressure wound therapy to stimulate the formation of a granulating bed. The wound was then skin grafted and negative-pressure wound therapy was again used to ensure skin graft take over wound where shear forces could have easily disrupted the take of the split-thickness skin graft. The Achilles has a better blood supply than most tendons, and can be successfully treated with negative-pressure wound therapy and a skin graft without the need for a flap.

knee wound could certainly be addressed with a local pedicled gastrocnemius flap, but a superior geniculate artery propeller perforator flap can accomplish the same goal and might be considered before leaping to free tissue transfer. Although a rectus or latissimus flap is versatile and very familiar to all plastic surgeons, an anterolateral thigh or thoracodorsal perforator flap may achieve the same goal with less donor-site morbidity.

Case 1: Nearly Total Scalp Defect

The various methods of scalp reconstruction have been well described, and existing algo-

Fig. 5. An abdomen reconstructed with a dermal matrix, revealing increased pliability compared with simple skin grafting. (Reprinted from Janis JE, Kwon RK, Lalonde DH. A practical guide to wound healing. *Plast Reconstr Surg.* 2010;125:230E–244E.)

Fig. 6. A dermal matrix used to resurface the anterior surface of the tibia in a pediatric trauma patient.

rithms are well suited to smaller defects on the scalp. However, total or nearly total defects, particularly in the setting of previous surgery or radiation, still present a challenging clinical problem. When local flaps and even tissue expansion are not options, large free flaps or burring and granulating the skull, with or without the use of negative-pressure wound therapy, are the classic solutions.

These two options represent each end of the reconstructive ladder, carry their own benefits and drawbacks, and would both be reasonable solutions to a difficult problem. However, the use of a dermal matrix in this instance would

Fig. 7. The dorsum of the foot was destroyed by necrotizing fasciitis. After radical débridements including removal of the fourth and fifth toes, the wound was initially covered with neodermis. When the neodermis was revascularized, the wound was skin grafted. A large dorsal foot wound was treated with a simple dermal matrix followed by a thin skin graft, obviating the need for free flap coverage.

also be reasonable. Despite requiring multiple trips to the operating room, total operative time and operative risk would be minimized. When compared with directly grafting the skull, the matrix would arguably provide more durable and aesthetically superior results, and minimizes the risk of harvesting a very large skin graft by applying to vascularized matrix as opposed to bone.

In contrast, the matrix carries a significant expense, both for the matrix itself and for the specialized wound care needed to maintain and monitor it postoperatively. A history of infection, or a skull defect with exposed brain or dura, would likely heavily favor the use of a traditional free flap for coverage, whereas a pediatric patient, with a relatively larger head-to-torso ratio, may tilt the balance toward matrix reconstruction.

Case 2: Foot Degloving with Exposed Tendon and Bone

This common scenario has been well described and the classic answer has been free tissue coverage. However, while a free muscle or free fascia flap would be a perfectly acceptable answer to this problem, it is worth considering that several authors have been able to treat these injuries with a multitude of alternatives.

For example, in an otherwise healthy wound with 1 to 2 cm of exposed bone and tendon, negative-pressure wound therapy followed by split-thickness skin grafting would be a reasonable option. In contrast, if a more extensive area of tendon is denuded, a matrix may be reasonable. The threshold at which each of these methods becomes reasonable is frankly arbitrary, as the literature provides very little if any support for a clear boundary, and the decision relies on the surgeon's clinical judgment and the ability and willingness of the patient to undergo more complex reconstructive options. Perhaps even less commonly, various local flaps ranging from the classic sural artery flap to the more modern peroneal artery perforator flap might be considered, depending on the exact nature of the injury, the reach of the pedicled flap, and perhaps most importantly, the surgeon's comfort and familiarity with each of the options at his or her disposal.

Fig. 8. A new reconstructive ladder incorporating the concepts described in this article.

DISCUSSION

The new options can be arranged, perhaps somewhat arbitrarily, among the preexisting options to produce Figure 8. By its very nature, such a hierarchy is a simplification. Negative-pressure wound therapy can be used as an adjunct to any other method of reconstruction, whereas skin grafts are virtually always used with dermal matrices and are commonly used to surface other flaps. Although perforator flaps are an evolution in flap design, their use is more a selection of technique than a reconstructive method. A perforator flap may be local, distant, or free, and perhaps unfairly, they do not lend themselves to conceptualization as a rung on our new ladder.

Even given the relatively simple case examples above, no single best option immediately presents itself. A multitude of factors must be considered when planning a reconstruction. The importance of the nature of the wound and the condition of the patient are obvious. Equally important is the functional result of the reconstruction, which is difficult to evaluate without long-term data for each option. The decision also includes the skill and experience of the surgeon, the facilities and staff available in the preoperative and postoperative periods, the patient's willingness to accept a lengthy operation or weeks of wound care, and the resources available to the patient and the health care system that is caring for him or her, among many, many others. Attempting to create an algorithm or chart that can encompass such a decision-making process is hopeless. Rather, such judgments are at the heart of surgical decision-making.

The inclusion of the newer techniques proposed in this revision of the ladder ultimately is more of a reminder that such options might considered than any sort of prescription. Whatever metaphor is used, the reconstructive ladder is merely a system of thought to bring some modicum of order to the enormous array of options available to the reconstructive surgeon. As such, although excessive simplicity obscures important detail, excessive complexity limits its utility as a mental aid. Perhaps this is why, despite decades of effort and numerous permutations and variations, the simple reconstructive ladder has survived and is still used by trainees and experienced surgeons alike.

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