(sensory, motor, skeletal, skin) are; what secondary procedures will be required (e.g., tendon grafting, nerve grafting, implant placement, etc.); what the durability requirements (plantar or palmar surfaces, weightbearing surfaces, e.g., ischial, trochanter, other joints) are; and finally, what the contour and aesthetic requirements (e.g., low profile at hand/wrist and foot/ankle) are. Following the algorithm of the reconstructive ladder/elevator, one would choose the simplest method, among the vase myriad of reconstructive options that currently exist, that would achieve the optimal long-term outcome. Both local and distant tissue options need to be considered, as well as the potential donor site disability. For some problems, simply allowing closure by secondary intention may in fact result in the best outcome, as in a volar soft tissue defect of a digit, where healing by wound contracture for defects up to 1–2 cm$^2$ will bring surrounding sensate skin in to close the defect, resulting in a sensate and durable reconstruction that is preferable to any flap or graft that one might consider. The same choice may be true for a facial tumor defect in an unhealthy elderly individual. For another young and healthy patient with bilateral hand amputation or a severe facial deformity from burn or trauma, the highest rung of the ladder/elevator may be the most appropriate, i.e., vascularized composite tissue *allo*-transplantation (VCA) – hand or face transplantation, along with its burden of lifelong immunomodulatory therapy, as the lifelong rewards may outweigh the risks and costs. Every choice should be tailored to the individual problem and the individual patient.

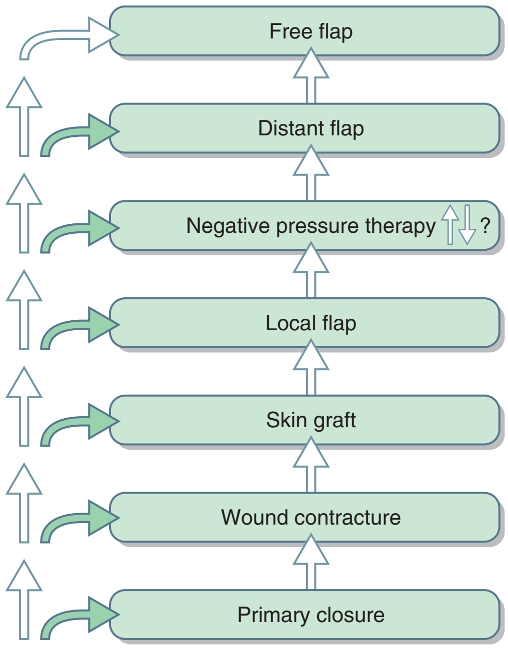


**Figure 1.1 The reconstructive “ladder” or “elevator.”** Both are really saying the same: do not merely use the simplest technique possible; use the simplest technique that will achieve optimal form and function. It all comes down to surgical judgment.

## A MODIFIED RECONSTRUCTIVE LADDER/ELEVATOR

In recent years, numerous additional reconstructive options have been presented and embraced, including tissue expansion, negative pressure therapy, perforator flaps, freestyle free flaps, as well as simple expansions of current flap approaches, e.g., the keystone flap for large defects. These are, of course, in addition to the paradigm-changing introduction of VCA, whereby like can truly be reconstructed with like, although currently with a commensurate penalty of lifelong immunomodulatory therapy. In light of the above, a modified reconstructive ladder/elevator could be considered, taking into account most of the current reconstructive options, their risk and donor morbidity, and most importantly, their long-term outcomes. In this ladder/elevator (Fig. 1.1), not only should the simplest option be chosen, but also the simplest option that will achieve the best long-term outcome in terms of form and functions, and with the least donor morbidity. Again, it is all about surgical judgment.

## RECONSTRUCTIVE MICROSURGERY

There is no question that the advent of microsurgery opened the potential of reconstructive surgery to possibilities never contemplated in the past. In the past we had to rely upon either devascularized grafts that were by necessity either small or thin so that they could revascularize from the graft bed, or pedicled flaps that were limited in size or length, with microvascular surgery and free tissue transfer. Microsurgery literally freed us to pursue limitless reconstructive possibilities. In addition, the introduction of the operating microscope opened new possibilities for micro-nerve, and more recently, microlymphatic surgery.

The field of hand surgery, and in particular hand trauma surgery, exploded with the advent of microsurgery, by making it possible to replant amputated digits, hands, and more. The ability to transfer free vascularized tissue allowed missing digits to be reconstructed with functioning, sensate toes. Free flaps allowed coverage of complex defects that in the past were treated with an awkward tube pedicled groin flap, and allowed the vascularized transfer of a myriad of tissue types, including bone and nerve with sensate skin. The free functioning muscle transfer used both microvascular and microneural techniques to restore muscle function in an extremity when it was literally absent, and has done the same in facial reanimation surgery.

Oncologic reconstruction is another area that has been truly transformed by microsurgery. Defects that in the past could only be reconstructed by grafts or pedicled flaps of limited tissue type, with the most critical portion of the flap often the most vulnerable to ischemia, can now be reconstructed with large or small, well-tailored, well-vascularized segments of tissue that can include a myriad of tissue types, including skin, fat, fascia, muscle, and bone, usually in one stage. The result is not only a far more aesthetic result, but a better functional result as well. Perhaps this is best illustrated in head and neck cancer reconstruction where local tissues are often limited, and the ability to bring in well-vascularized tissue of the correct size, shape, and type is critical for both appearance and function.[15]

The treatment of complex surgical infection has also been revolutionized by microsurgery. In the past, advanced tibial osteomyelitis often resulted in amputation. With the advent of free muscle flaps, a thorough excisional debridement of the osteomyelitis was possible, and coverage with a large free muscle flap and later bone grafting resulted in both cure and limb salvage.[16]

The first free flaps performed in the 1960s were fasciocutaneous flaps – the free groin flap. With the development of myocutaneous flaps, free myocutaneous flaps became the more dominant type of free flap employed. But they tended to be very bulky, so the skin and fat were often left behind, and a thinner free muscle flap used, with skin graft coverage, especially in extremity reconstruction. More recently there has been a shift toward the use of perforator flaps, i.e., skin plus subcutaneus tissue alone, without the underlying muscle or fascia, by carefully dissecting out and preserving the supplying perforator vessels, down through, and preserving the muscle, to the deeper major pedicle vessels that can then be used for microvascular anastomosis.[17] Though technically demanding to perform, these flaps have the advantage of skin with just the right amount of underlying fat, which can be tailored as needed, while preserving the underlying muscle function. The two most common examples are the anterolateral thigh (ALT) flap, typically used for extremity or head and neck reconstruction, and the deep inferior epigastric artery (DIEP) flap, used for breast reconstruction. A further extension of the perforator flap concept is the development of "freestyle" flaps, often based on a single perforator vessel, identified by Doppler, dissected down to its larger feeding vessels, and transferred locally, or distantly as a free flap.[18] The versatility and flexibility of this approach is obviously profound, the technical demands of this approach notwithstanding.

A further expansion of versatility and customizability of reconstruction that microsurgery brought was the concept of prelaminated and prefabricated flaps.[19] These composite flaps can be created *de novo* by bringing together multiple autologous tissue types, including skin, subcutaneous tissue, cartilage, bone, etc. to create a unique body part, such as a nose, from multiple donor tissues, all built and based on an arteriovenous vascular pedicle that is later transferred to the recipient site with microvascular anastomosis. Again, the potential of such reconstructions is nearly limitless.

Supermicrosurgery, which involves anastomosis of vessels ranging from 0.3 to 0.8 mm in diameter, has further expanded the field of microsurgery and allowed fingertip replantation with small venule grafts, toetip transfers for tip loss, and lymphaticovenular anastomoses for lymphedema.[20] Lymphaticovenous anastomosis with standard microsurgical techniques, to larger veins, proved to be unsuccessful, but with supermicrosurgery, using 12–0 suture and small, low-pressure venules, such procedures can be done under local anesthesia with significant demonstrated success.[21]

Robotic surgery has been used for over a decade to assist in surgical approaches where access is limited, without creating a wide new defect for approach. With the additional benefit of eliminating hand tremors, it would seem ideal for microsurgical applications. Its extremely high upfront cost and steep learning curve, however, have kept its application limited in microsurgery, but where it has been successfully applied, such as in microsurgical reconstruction after oropharyngeal tumor resection, it has transformed treatment.[22]

The emerging field of VCA is one of the most exciting developments in all of reconstructive surgery. The ability to replace a complex anatomic structure, such as a hand or an entire face, with actual like tissue is truly the ultimate reconstruction.[23–26] The challenges, though, include the extremely advanced technical requirements; the enormous infrastructure required to support such a program, with exceedingly high costs; the need for lifelong immunosuppression, with its attendant risks; and the limited supply of donors. The induction and maintenance of immunologic tolerance is the "holy grail" of transplantation, and is the focus of intense current research. As long as these barriers remain, VCA will be limited to a few advanced centers with a limited patient population.

## THE FUTURE OF MICROSURGERY

The development of microsurgery has been a paradigm-altering technology, whose course has merely begun. The education and broader skills acquisition by microsurgeons in freestyle flaps, supermicrosurgery, prelamination and prefabrication of flaps, and robotics, are all areas where expanded application seems inevitable, as technology progresses. Certainly, VCA is an area that is in the process of exploding, as more and more centers around the country and around the world are developing clinical VCA programs. As the science of immunology progresses toward the development of true immune tolerance, VCA will widely become acknowledged as the standard of care for many complex situations.

The emerging fields of tissue engineering and regenerative medicine may someday supplant some applications of microsurgery, and create new opportunities for the application of microsurgery. The use of adipose-derived stem cells to reconstruct a breast may someday replace the free DIEP flap. Yet, at the same time, the ability to engineer autologous composite tissue, including a vascular supply, and transfer it with microsurgical techniques is an equally exciting possibility. The future potential for microsurgical applications in patient care is truly without limit.