Limb Reconstruction in the Early 21st Century: The Indications are Broader and Wider

Until sometime in the 1980s, the limits of reconstruction for bone defects, limb length discrepancy, and soft-tissue damage and loss were clear. Efforts to exceed these limits were known to result is chronic pain and disability and a useless limb. The treatment was often worse than the disease. Children and adults spent countless days, weeks, and months in and out of hospitals. The interruption of their childhood, livelihood, and family life was a frequent casualty. As a result, amputation with prosthetic fitting was an attractive option and shortcut. This all started to change in the 1980s with the introduction of the Ilizarov methods.

While its dissemination and implementation led to a new set of problems, the advent of reliable bone and soft-tissue regeneration through bone transport, limb lengthening, nonunion repair, deformity correction of bones, distraction of joint contractures, etc., removed the artificial limits. Previous rules, such as, a limb was not worth saving if the posterior tibial nerve was damaged were challenged and proven wrong. A 20-cm bone defect was no longer an unresolvable problem. A congenital deficiency was no longer an automatic reason for a Syme's amputation.

The improvement in the field of damage control orthopedics with the introduction of better temporary external fixators, followed by minimally invasive nailing and plating, resulted in the best of both worlds incorporating internal and external fixation. Improvement in treatment of the soft tissues, reduction of the use of transfusion, vacuum-assisted closure, various biologics, acute shortening of the fractured limb, etc., all played a part in making limb reconstruction successful in cases that only a decade or two before would have been impossible. The concept of limb salvage changed to that of limb reconstruction. This is best evidenced by the unprecedented success of limb salvage and reconstruction in civilians and military personnel injured in Iraq, Syria, and Afghanistan.

Advances in the understanding of the pathoanatomy of congenital limb deficiencies (congenital femoral deficiency [CFD], fibular hemimelia [FH], tibial hemimelia [TH]) has also changed what we can do for children born with birth defects. New procedures such as the SUPERhip, SUPERknee, SUPERankle, SHORDT, and patellar arthroplasty have restored the hip, knee, and ankle to nearly normal function and stability in these conditions.

Improvements in external fixation with computer-dependent circular fixators and joint spanning, articulated, monolateral external fixators have greatly expanded what we can treat. Bone- and joint-specific internal fixation with the evolution of ever more adaptable and miniaturized locking plates and nails have removed many of the limits of where internal fixation can be used. Dynamic implants such as implantable lengthening and bone transport nails and plates, have completely transformed the landscape of possibilities. Even pharmacologics and biologics such as bone morphogenic protein (BMP), stem cells, alpha2 macroglobulin (A2M), platelet rich plasma (PRP), and bisphosphonates have opened barriers. For example, BMP (off label use) can be inserted into unossified cartilage to lead to its ossification in pathologies such as CFD, FH and TH. BMP and zoledronic acid can be used synergistically with creation of a cross union to repair congenital pseudarthrosis of the tibia so that it never fractures again.

The limitation of what is possible with limb reconstruction surgery (LRS) is education, experience, and availability of technology. While most surgeons can successfully carry out prosthetic reconstruction surgery (PRS), for example, above knee, below knee, through knee, Syme's, and partial foot amputations, far fewer surgeons can successfully reconstruct a severely mangled extremity or one with a major limb deficiency of congenital origin. To bridge this gap, orthopedic societies and training programs need to better train their surgeons in these methods. The problem is that the most severely traumatized extremities as well as the most severely deficient extremities are not as common and therefore exposure to treating them is limited.

Furthermore, the learning curve to successfully managing such complicated cases is quite high. The skill set required to perform an amputation is much lower, and more ubiquitous, than the skill set required to successful manage a war or civilian mangled extremity or a congenital limb deficiency. Furthermore, the incidence of these conditions is much more rare. Therefore, even in the hands of more skilled surgeons, it is difficult to gain enough experience with such complex reconstructive surgeries unless one is in a practice with enough volume of such complex cases.

Finally, even when a skilled trained surgeon is available in a setting where there is enough volume of these less common pathologies, the technology to reconstruct these

limbs to the level currently possible may be lacking (e.g., in developing countries or due to cost even in developed countries).

Therefore, the argument is no longer which is better amputation versus reconstruction; PRS versus LRS. The argument for each surgeon is whether they possess the skill set, experience, and technology to carry out LRS in an effective manner so that the patient ends up with a functional, painless, limb.

The fact that I can reconstruct a CFD case to equal limb length and normal joint range of motion and gait does not mean that another surgeon who lacks the same skill set, experience, and technology that I have, can do the same job. It is therefore important that each surgeon educate themselves, at least to what is possible with LRS in the hands of specialized centers and surgeons, before recommending PRS as the best option.

It is also important that each surgeon offer the patient the options of treatment based on this knowledge. If not, today's educated patient will find this out via the Internet. Since amputation is irreversible and usually elective, each patient should be given the option to be referred to a center where the LRS can be carried out reliably versus PRS. This is part of the informed consent to the amputation. It then becomes the patient's choice whether to seek a second option at the referral center.

The frontier now between LRS and PRS is different than it was 35 years ago, when I was training as a resident. Frankly, it was simpler then, since the LRS options were more limited and true hard limits were easier to define and justify. It is an exciting time as advances in LRS such as implantable lengthening and bone transport technology and in PRS such as osteointegration prosthetics make the choices much more interesting and the possibilities much more exciting.

I am looking forward to the editorial in this journal 20 years from now entitled *Limb Reconstruction in the Mid 21st Century*; comparing the newest biologic limb and joint regeneration methods versus the latest artificial robotic limb technology. The age of science fiction is upon us as we contemplate which new arm Luke Skywalker will receive. May the force be with us!

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