Correction of Limb Deformities in the 21st Century

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During the 20th century, limb-deformity correction was performed using the “eyeball” technique. Such “ballpark” estimates are no longer acceptable in the 21st century. Limb deformities can be classified according to cause (congenital, developmental, posttraumatic), location (bone or joint contracture, extra-or intraarticular), geometry (angulation, translation, rotation, length discrepancy), severity (magnitude), and progression (static or progressive). Orthopaedic surgical correction must consider all of these factors.

Limb deformities may lead to dysfunction, pain, and joint degeneration. To patients, appearance may be of primary concern. For bone deformities, the mainstay of treatment has been osteotomy, whereas for joint-contracture deformities, extra-and intraarticular soft-tissue releases have been the standard of treatment. Many innovative osteotomies have been developed to treat limb deformities. The results are frequently subjectively acceptable but objectively inaccurate. Secondary deformities often result from primary correction. The significance of this has only recently been recognized (14,17). Inaccuracy of correction in children has often been excused by the time-honored pediatric orthopaedic motto, "It will remodel with time." In some cases, this has been true. In many cases, however, residual and secondary translation and angulation deformities have gone untreated into adult life. Although most of these residual and secondary deformities are asymptomatic in children, many lead to degenerative changes and disability in adults. During the 20th century, high postoperative complication rates were often reported: neurovascular complications owing to acute correction with stretch injury and compartment syndromes (23) and bone complications owing to extensive exposure and methods of fixation.

During the last 10 years of the 20th century, a revolution occurred in the management of children’s deformities because of improved biologic and mechanical techniques. Thanks to Gavril Abramovich Ilizarov, a Soviet orthopaedic surgeon, our understanding of bone and soft-tissue regeneration has lead to a plethora of devices and techniques that use gradual correction methods to correct simple or complex deformities. Gradual correction reduces the operative exposure needed to cut the bone (13). Acute surgical morbidity is greatly reduced by these percutaneous techniques. Furthermore, progressive correction avoids stretch damage to the neurovascular structures that are at risk. The magnitude of correction, which was previously the limiting factor in how much deformity correction could be achieved, is no longer an obstacle with gradual correction of bone or joint deformities. The accuracy of correction, which was usually only ±5°, improved greatly (25) with gradual correction because of postoperative adjustability of external fixation.

Although Ilizarov recommended circular external fixation, others have attempted to achieve gradual correction of deformities with monolateral external fixation (3,5). The monolateral external fixators were more limited in adjustability. Recent designs have become more modular and adjustable and can even incorporate rings. The circular fixator, previously perceived as bulky and difficult to apply, has become more user-friendly and hybridized with half-pins and monolateral components. The external fixator of the 21st century must incorporate more high-technology features, such as biofeedback dynamization and stiffness monitoring, automated lengthening and deformity correction using micromotors, and perhaps, bone, muscle, and nerve stimulation to accelerate union, rehabilitate muscles, and treat pain, respectively. In addition, selling features will include more colorful, lighter weight, and radiolucent designs, greater modularity, and interconnectability between circular and monolateral components that incorporate fixation with wires and/or half-pins.

The direction in this new century is toward more minimally invasive surgery. New designs of plates and nails and their instrumentation are extending the application of...
such techniques to deformity correction in adults (8,15,16). The limiting factors in using many of these new techniques in children are size and growth plates. New expandable rods that cross the growth plates and special rods and subcutaneous plates that avoid the growth plates will allow us to use stable, minimally invasive internal fixation techniques in children. Combining that with the accuracy of fixator-assisted nailing (15) for correction of deformities will offer the accuracy of external fixation while using internal fixation.

With the advent of radiographs just over 100 years ago, our understanding of the geometry of deformities increased greatly. A wide variety of configurations of osteotomy were developed to correct these deformities. The most commonly used have been the opening and closing wedge osteotomies and the dome osteotomy. Computed tomography has allowed us to obtain more accurate images of rotational and intraarticular deformities. Despite improvements in imaging techniques and methods of internal and external fixation, the study of the geometry of deformities remained greatly unexplored until the past 10 years. The level of the apex of deformity was always considered intuitively, and the level of osteotomy relative to the apex depended on the location of the physis and the space needed for the hardware. This approach more often than not created secondary translation deformities. Paley et al. (14,17) described the concept of the center of rotation of angulation (CORA). They demonstrated that when the axis of correction and the osteotomy are at a level different from that of the CORA, secondary translation deformities occur. They developed a simple method to identify rapidly and accurately the level of the CORA. Because the concepts of the CORA and the axis of correction are basic principles of deformity correction, they are independent of the method of fixation used. Although in the past, the tendency has been to make the osteotomy accommodate the fixation, the current concept is to consider the principles of deformity correction as preeminent and to make the fixation and osteotomy adhere to the principles. In other words, instead of osteotomy being slave to fixation, fixation becomes slave to osteotomy. With this approach, we can eliminate secondary deformities after osteotomy.

Pediatric orthopaedic surgeons usually do not follow up or treat patients after the age of 20 years. The effect of residual malalignment of the lower limbs can take 20 to 30 years to cause degenerative changes (9,10,22). As a surgeon who treats both adult and pediatric patients, I have been impressed with the number of patients presenting to me with symptomatic degenerative changes of the hip, knee, and ankle owing to uncorrected or residual malalignment and joint malorientation of pediatric origin. As we live longer and continue to expect an ever higher quality of life at an older age, the role of prophylactic osteotomy to correct asymptomatic deformities and prevent degenerative changes may have to be considered more and more. Despite our best efforts to accurately correct deformities to textbook numbers (14,17), as long as we operate on children with open physes, we face uncertainty, because behavior of the growth plates is often unpredictable. Perhaps the best example of this is the Cozen phenomenon (2), which occurs after any osteotomy of the proximal tibia in children younger than 10 years. On the other hand, a more recent development has been to harness the capriciousness of the physis by temporary hemiepiphyseal stapling. Epiphyseal stapling was a popular method for treating angular deformities in adolescence during the 1960s and 1970s. It became less popular as osteotomy techniques improved during the 1980s and 1990s. Stevens et al. (24) recently showed that it is a safe technique to use in young children, with little risk of growth plate closure.

Although improvements in fixation, planning, accuracy, and magnitude of correction have improved the correction of angular, rotational, and translational deformities, the most impressive change in deformity correction has been in the field of congenital deformities and deficiencies of the lower limbs, especially for fibular hemimelia and congenital femoral deficiency. Although the mainstay of management for these disorders has been amputation and prosthetic rehabilitation, the tide is rapidly changing as our understanding of the science of limb lengthening improves and our techniques of reconstruction advance. With fibular hemimelia, we face the challenge of limb-length discrepancy and foot deformity, whereas congenital femoral deficiency involves hip and knee deformity combined with a short femur. The solution has been to develop new reconstructive techniques for the foot in cases of fibular hemimelia (19) and for the hip and knee in cases of femoral deficiency (12,18), in combination with staged lengthening of the tibia and femur, respectively. Currently, a few specialized centers are reporting good results with this approach (1,6,7,11,21). The challenge for the 21st century will be not only to develop these techniques further but also to teach them so that more centers are able to offer this treatment. This evolution is similar to that of limb-salvage surgery for tumors 20 years ago, when the mainstay of treatment was amputation.
Finally, as with the evolution of management of great orthopaedic diseases such as polio, our mechanically, anatomically, and technically based treatments were relegated to the history books by the biologic engineering of a prevention or cure for the disease. In the 21st century, we hope to see such a revolution through biologic and genetic engineering. Will the deformities owing to genetic conditions such as achondroplasia, spondyloepiphysial dysplasia, and hypophosphatemic rickets be prevented by gene therapy or enzyme replacement? Prenatal diagnosis may permit intrauterine treatment of congenital defects from clubfoot to femoral deficiency. Will growth plate transplants allow us to repair or replace injured or deficient physes? And what about limb regeneration? Will it stay in the domain of salamanders, or will we unlock the key to growing new human limbs? All of this sounds like science fiction right now, as did a trip to the moon sound to the people of Jules Verne's time. For now, we must be content with a better understanding of the geometry and origin of deformities, more accurate and less invasive surgical techniques, and an ever-expanding armamentarium of new devices, such as implantable self-lengthening intramedullary nails (20) for the treatment of deformities.

REFERENCES


