Distraction Histiogenesis: Principles and Indications

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Abstract

Distraction histiogenesis is a biologic phenomenon that can be utilized to induce the formation of new bone and soft tissue. This technique has been used after corticotomy or osteotomy of bone to treat patients with limb-length inequality, angular deformities, segmental bone loss, nonunions, and contractures. A distraction force is applied with an external fixator, such as the Ilizarov circular fixator or a uniplanar fixator. The authors review the extensive preoperative planning required, the performance of osteotomy, the application of external fixators, and the timing between the osteotomy and the initiation of correction (the latency phase). The subsequent distraction phase involves active lengthening, transport, or angular correction through frequent small steps (e.g., 0.25 mm every 6 hours). This results in the formation of new bone, or regenerate, in longitudinal columns along the plane of distraction. The consolidation phase begins after the desired correction has been achieved; this period allows for maturation of the regenerate and corticalization before fixator removal.

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Distraction histiogenesis refers to the use of a distraction force to stimulate the formation of skin, muscle, nerve, vascular structures, connective tissue, lymphatic vessels, and bone. When bone is involved, the process is termed "distraction osteogenesis." The earliest devices were used for the purpose of limb lengthening. However, this biologic phenomenon is now used to treat an array of other musculoskeletal conditions, such as nonunion; malunion; angular deformities due to congenital, developmental, or traumatic conditions; segmental bone loss due to trauma or osteomyelitis; joint contractures; burn contractures; and clubfoot. Table 1 lists some other potential indications for use of this modality.

History of Limb Lengthening

Alessandro Codivilla, former director of the Rizzoli Institute in Bologna, Italy, is recognized as the father of limb lengthening. In 1905, he reported lengthening shortened extremities by applying traction in stages with a calcaneal pin after a femoral osteotomy. He stressed the resistance of the soft tissue to lengthening and the need to gradually elongate the extremity.[1]

In 1921, Codivilla's student Vittorio Putti described the "osteoton," a device used to lengthen the femur.[2] After a femoral osteotomy, pins were placed in the proximal and distal fragments of the femur and interconnected with a spring-loaded mechanism that permitted gradual distraction; a plaster cast was not necessary. He too stressed the need for slow distraction to prevent contracture or paralysis.

Many variations of the external fixator followed. In 1932, Dickson and Diveley[3] and Haboush and Finkelstein[4] described the use of Kirschner wires rather than pins, which can be considered the earliest prototype of the thin-wire external fixator. Haboush and Finkelstein also described a technique of osteotomy designed to maximally preserve the periosteum in order to promote healing. In 1938, Bosworth[5] was the first to recommend a post-osteotomy latency period before beginning lengthening. He recommended 10 days, which is not

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Table 1
Potential Indications for the Application of Distraction Histiogenesis

Acquired limb-length inequality (e.g., due to trauma, infection)
Angular deformity secondary to trauma
Angular deformity secondary to developmental or metabolic conditions (e.g., Blount's disease, rickets, coxa vara)
Arthrodesis
Benign bone tumors (e.g., Ollier's disease)
Burn contractures
Chronic dislocations
Chronic osteomyelitis
Clubfoot
Congenital pseudarthrosis of the tibia
Congenital shortening of long bones (e.g., congenital short femur, fibular hemimelia)
Coverage of soft-tissue defects
Developmental dysplasia of the hip
Dwarfism
Fractures (especially periarticular fractures, including tibial plateau and pylon types)
High tibial osteotomy
Joint contractures
Malunions and nonunions
Proximal femoral focal deficiency
Radial clubhand and other congenital and developmental deformities of the upper extremity
Segmental bone defects secondary to osteomyelitis
Segmental bone defects secondary to trauma
Segmental bone defects secondary to tumor resection
Stump elongation
Vascular insufficiency

unlike the latency periods used today.

In 1963, the Wagner technique was introduced. The first of three sequential operations included a diaphyseal osteotomy and application of a monolateral external fixator that served as a lengthening device. Acute distraction of the osteotomy by about 0.5 cm was performed. No latency phase was used, and there was no expectation that bone would form within the distraction gap. The desired limb lengthening was accomplished as rapidly as tolerated, with distraction applied at a rate of 1.5 to 3 mm per day. Because the regenerated bone was often of poor quality, the second operation was bone grafting of the distraction gap and application of a plate. The third operation consisted of removal of the plate. The Wagner technique had a high rate of complications, including acute hypertension at the time of distraction, infection, and early and late fracture.

Ilizarov is credited by many as being the person who consolidated the information about distraction histiogenesis. His device consisted of Kirschner wire bows connected by threaded rods, which he used for correction of a knee-flexion contracture. He subsequently incorporated circular rings and modularity into his device. More important, he began to study the underlying process, which he termed "transosseous osteosynthesis."

In 1987, De Bastiani et al[6] published the results of limb lengthening with the use of a monolateral external fixator after corticotomy of the femur, tibia, or humerus in patients with either limb-length inequality or achondroplasia. They used the term "callotasis," meaning distraction through callus. A latency period of 10 to 15 days was generally used. Their device allowed dynamization during the consolidation phase. In 100 lengthened segments, they had a relatively low complication rate of 14%.

In addition to attempts to lengthen extremities or correct angular deformities through a corticotomy or osteotomy site, Ring,[7] Ilizarov,[8] Monticelli et al,[9] and others have attempted to do so through the physis. The term "distraction epiphysiolysis" denotes the use of large forces to achieve separation or fracture of the physis in the zone of hypertrophy. De Bastiani et al[10] used the term "chondrodiastasis" to describe the gradual use of force to achieve stimulation of the growth plate without fracture, resulting in less trauma to the surrounding tissue and vascular supply. It is unclear whether the risk of these procedures outweighs any advantages over traditional osteotomy or corticotomy.

Components of Distraction Histiogenesis

The basic components of distraction histiogenesis generally include (1) use of an external fixator that provides stability and applies the forces that produce lengthening, angular correction, or transportation of bone; (2) corticotomy or osteotomy of the bone; and (3) a postoperative period, which can be divided into latency, distraction, and consolidation phases. The latency phase refers to the period from frame application and corticotomy or osteotomy to initiation of lengthening or angular correction. This is followed by the distraction phase, during which the desired correction takes place with the formation of new bone, termed the "regenerate." The consolidation phase allows maturation and corticalization of the regenerate before frame removal.

Techniques of Osteotomy and Corticotomy

Ilizarov[8] advocated performing a corticotomy by transecting approximately two thirds of the circumference of the cortex and completing the corticotomy by osteoclasis produced by rotating the external fixation rings proximal and distal to the corticotomy site in opposite directions. Another method involved inserting an osteotome into the corticotomy site and rotating it 90 degrees until the remaining cortex fractured. The goal was to preserve the periosteum, the endosteum, the medullary contents, and the nutrient artery. Ilizarov noted an improved quality of regenerate bone in dogs when at least part of the medullary canal was preserved.

Others have used a complete transverse osteotomy to ensure division of the entire cross section of the bone. Another technique is to perform an osteotomy by connecting multiple drill holes with an osteotome. Frierson et al[11] found no histologic, density, or perfusion differences between the regenerate of dogs that underwent corticotomy with osteoclasis and the regenerate of dogs that underwent osteotomy with multiple drill holes and completion with an osteotome. However, they did find an increased rate of delayed consolidation in the group that underwent osteotomy performed with an oscillating saw, which they thought resulted from thermal necrosis. Yasui et al[12] found that transverse osteotomy was as reliable as corticotomy in rabbits as long as the periosteum was protected.

Histologic Events

Ilizarov[8] has used histologic, histochemical, electron-microscopic, and vascular studies to analyze the regenerate in dogs. He has described a "growth zone" in the middle of the regenerate (Fig. 1), in which fibroblastlike cells become metabolically active and secrete collagen, which eventually forms fibers that align parallel to the distraction force. Osteoblastic activity results in osteoid and eventually new bone formation, which is greatest at the proximal and distal ends of the regenerate.

Ilizarov demonstrated that when a well-stabilized construct was present, endochondral ossification often did not occur; instead, he observed direct formation of bone resembling intramembranous ossification. In specimens in which gross instability had been present, intervening fibrous and cartilaginous tissue formed, similar to a pseudarthrosis. When there was intermediate (suboptimal) stability, consolidation eventually occurred, but by a slower process similar to endochondral ossification.

Other factors affecting the quality of the regenerate include the rate and the rhythm of distraction. In the canine tibia, Ilizarov found that 0.5 mm of distraction a day often resulted in premature consolidation, while 2.0 mm a day produced a poor regenerate, often with intervening fibrous tissue. Distraction of 0.25 mm four times a day produced an excellent regenerate. Results were further enhanced when distraction was carried out with an autodistractor that broke the 1.0 mm daily lengthening into 60 equal steps.

Fig. 1 Radiolucent line in center of regenerate bone represents "pseudo-growth plate," or fibrous interzone, which is surrounded by ossification fronts. Orientation of lines of ossification is parallel to plane of distraction.

The location of the corticotomy or osteotomy may also play a role in the quality of regenerate and the time to consolidation. The advantages of a metaphyseal site include a larger surface area, improved blood supply, and a larger cancellous component, all of which tend to improve the quality of regenerate formation. This was recently confirmed in canine studies by Aronson and Shen,[13] who found more new bone formation and mineralization in metaphyseal lengthening sites than in diaphyseal sites.

Although the optimal length of the latency period remains controversial, most investigators still advocate a delay before distraction. Ilizarov[8] stated that 5 to 7 days is optimal, and De Bastiani et al[10] used a latency period of 10 to 15 days. The length of the latency period should be individualized for each patient, based on age and the quality of the bone to be lengthened.

Ilizarov[14] also noted that distraction produces growth changes in muscle, vascular structures, nerve, connective tissue, and lymphatic vessels. In muscle cells, he found not only cellular hypertrophy but also formation of new muscle cells. New capillary formation occurred in the direction of the tension vector. As soft-tissue elongation progressed, the development of nerves to innervate the tissue progressed as well.

Ilizarov[15] also correlated the rate of distraction with these cellular changes. In arteriolar tissue, he found that use of an autodistractor to achieve 0.017 mm of distraction every 24 minutes produced more pronounced hypertrophy of organelles, greater cytoplasmic volume, and increased length and complexity of intracellular contacts compared with use of 1.0 mm of distraction once a day. Thus, there appear to be different "ideal" distraction rates for various types of tissues, which is evidenced when soft-tissue histiogenesis does not keep pace with osteogenesis. This possibility may underlie the nerve palsies and joint contractures that may occur after extensive lengthenings.

The following clinical practices tend to optimize the formation of a healthy regenerate and improve outcome[8]: (1) maximum preservation of marrow and periosseous blood supply by performing a percutaneous corticotomy-osteoclasis or low-energy osteotomy instead of an open transverse osteotomy; (2) external skeletal fixation stable enough to eliminate torsional and bending moments at the osteotomy site, yet allow micromotion parallel to the axis of the bone; (3) latency period of 5 to 7 days; (4) overall distraction goal of 1.0 mm a day, modified as needed; (5) distraction in frequent small steps, at least four times a day; (6) period of neutral fixation to allow regenerate to fully ossify; and (7) normal physiologic use of the extremity, which promotes healing and range of motion of joints.

Biomechanical Factors Influencing Distraction Histiogenesis

Numerous studies have examined the biomechanical properties of various frame designs used in distraction histiogenesis, but conflicting results among the available data make it unclear whether a single-frame design is superior. Certainly, clinical success has been achieved with both circular and monolateral frames. Ilizarov stressed the need for maximal stability with a rigid frame that alleviated micromotion at the corticotomy site except in the axial plane.[8]

Paley[16] found that use of a monolateral frame with 6-mm half-pins produced a very rigid construct compared with a tibial Ilizarov frame consisting of two complete rings, two half-rings, and 1.5-mm wires. Paley speculated that the Ilizarov frame may allow axial micromotion and thus prevent stress shielding of the regenerate, which he thought would have a beneficial effect on bone formation and healing. The femoral frame Paley studied requires the use of half-pins proximally and was found to have a stiffness somewhere between that of the monolateral frame and that of the tibial frame. This "hybrid" circular frame with a combination of tensioned thin wires and half-pins is commonly used and permits increased rigidity as well as placement of fixation in planes not amenable to use of wires, such as in the proximal femur and the anterior tibia.

Podolsky and Chao[17] have studied various mechanical properties that affect the stiffness of circular external fixators. The variable with the greatest effect on stiffness was wire diameter (1.8 mm provided greater stiffness than 1.5 mm), but orientation (90 degrees provided greater stiffness than 45 degrees) and the amount of bone contact were also important. Other factors that increase the rigidity of a frame include wire number, tension, and use of a beaded, or "olive," wire. The number, spacing, and size of the rings also influence the rigidity of the frame. A decrease in the diameter of the rings results in increased stiffness, especially axial stiffness. Kummer[18] and others have noted that a "less rigorous" pin configuration is needed for distraction than for compression, because of the self-aligning effect of the soft tissue. (A complete discussion of external fixators is beyond the scope of this article.)

Indications

The indications for distraction histiogenesis are now numerous in both the pediatric and the adult populations.

Limb-Length Inequality

Most authorities agree there is still a role for epiphysiodesis in the treatment of limb-length inequality in the pediatric population. A child with a projected discrepancy of up to 2 cm often requires no treatment. With discrepancies in the range of 2 to 5 cm, use of a shoe lift or epiphysiodesis may suffice. When the projected disparity is greater than 5 cm, a lengthening procedure should be considered. The 5-cm guideline may be reduced if the patient is expected to be short and it is desirable to avoid a procedure, such as an epiphysiodesis, that will further decrease the eventual height. As a general rule, total treatment time is 30 days for each centimeter of lengthening performed.

There are different treatment options for adults with limb-length inequality, although the guidelines are similar. Most discrepancies less than 2 cm require no treatment. A shoe lift may suffice for discrepancies ranging from 2 to 5 cm. An alternative to a large shoe lift is closed femoral shortening of the longer extremity, performed with use of an intramedullary saw and stabilized with an intramedullary nail. This has been used successfully to treat discrepancies up to 6 cm.[19,20] A lengthening procedure should be considered for discrepancies larger than about 5 cm and for patients who wish to avoid a shortening procedure.

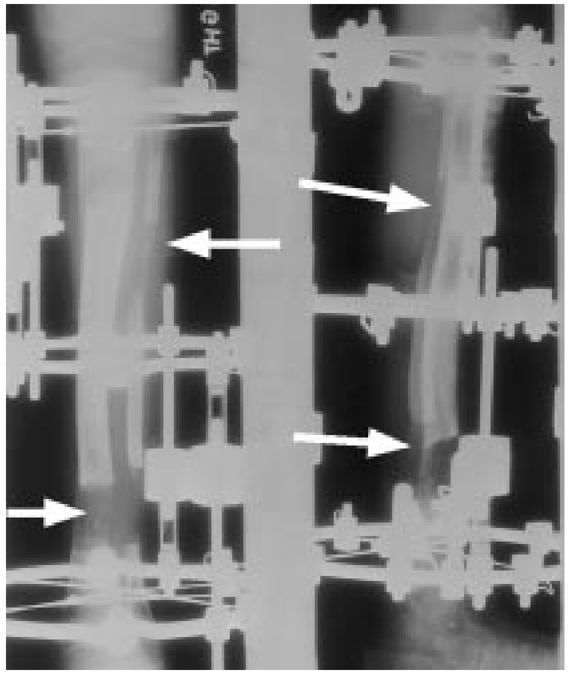


Fig. 2 Radiographs of a child with congenital posteromedial bowing of the tibia and a projected limb-length discrepancy of 7 cm. Two-level corticotomies (bifocal lengthening) were performed to achieve lengthening at two sites in the tibia and thereby shorten the treatment time. Regenerate bone (arrows) is visible in the proximal and distal tibial lengthening sites.

Angular Deformities

When a pediatric patient has both a limb-length inequality and an angular deformity, an acute angular correction with an opening- or closing-wedge osteotomy and traditional fixation coupled with epiphysiodesis may suffice.

The Ilizarov external fixator can be used to achieve lengthening as well as simultaneous correction of an angular deformity with coupled translation at the corticotomy site, which allows realignment of the joint. This feature allows the use of distraction histiogenesis in the treatment of limb-length inequality and angular deformities seen after trauma, Blount's disease, or other causes. It has also been used to lengthen the femur, tibia, and humerus in patients with achondroplasia.

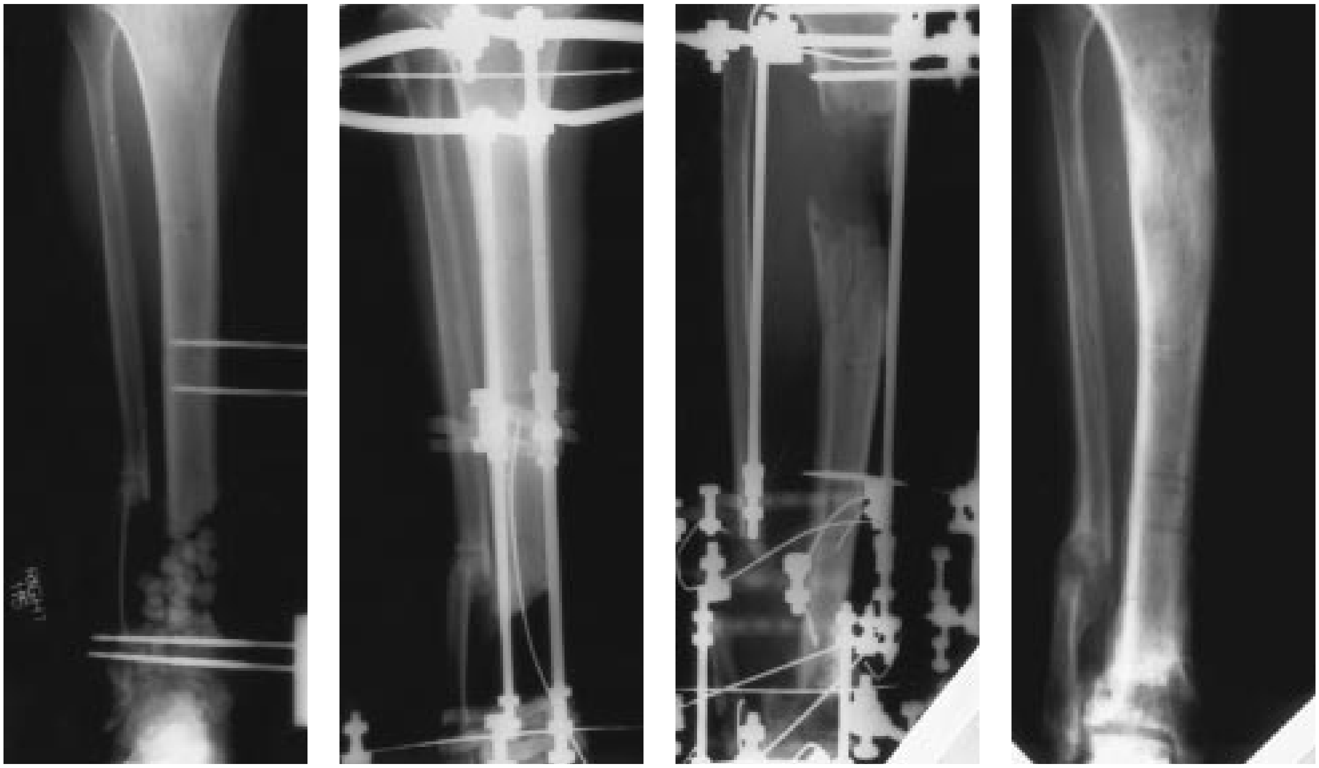
Complex deformities, such as those caused by rickets, are multiapical and may require corticotomies at multiple levels to achieve the best results. Two-level corticotomies (bifocal lengthening) in the tibia have also been utilized to achieve lengthening at two sites in the same segment, which shortens treatment time (Fig. 2).

Bone Defects

Defects can be filled by means of bone transport, in which a distraction force is exerted on a segment of bone to transport it across a defect, thereby filling it (Fig. 3). This technique is most commonly used in the tibia and allows "creation" of new bone to fill a void created by osteomyelitis or trauma. The corticotomy is usually performed proximally, and the segment of bone is transported distally until it eventually reaches the "docking site" with the distal fragment of bone. The trailing regenerate eventually consolidates. Bone grafting is often performed at the time of docking (after removal of granulation tissue) to prevent the common complication of nonunion.

Infection

In 1969, Ilizarov and Ledyaev[21] reported on the use of distraction histiogenesis in a number of patients with osteomyelitis of the tibia, segmental bone loss due to open fractures without osteomyelitis, or congenital pseudarthrosis of the tibia. The success with treating osteomyelitis may be related not only to the removal of infected bone but also to the significant increase in blood flow that occurs during distraction osteogenesis. In a canine model, Aronson[22] found that blood flow at the distraction site increased to nearly ten times control values after 2 weeks. After this peak, flow decreased to four to



A B C D

Fig. 3 Radiographs of an adult diabetic patient with segmental loss of bone secondary to osteomyelitis as a result of infection after open reduction and internal fixation. **A,** Segmental defect was packed with antibiotic-impregnated methylmethacrylate beads. **B,** External fixator constructed to perform bone transport. Intraoperative film shows reference wires and intraosseous guide wire in place. **C,** Appearance after docking distally. Proximal regenerate is beginning to be visible. **D,** Film obtained after frame removal shows successful healing of the docking site and regenerate formation. Length of treatment until device removal was 7 months; bone grafting was not necessary.

five times control during the remainder of the distraction period and remained two to three times control during the consolidation phase.

Cierny and Zorn[23] compared the use of conventional and Ilizarov methodologies in the treatment of segmental tibial defects due to osteomyelitis. The conventional method consisted of aggressive debridement, administration of pathogen-specific antibiotics, large cancellous bone grafts, and soft-tissue coverage of vital structures. The Ilizarov method obviated the use of large cancellous bone grafts, and fewer soft-tissue coverage procedures were required. The overall success rate in both groups was 95%, but the Ilizarov group averaged 9 fewer hours in the operating room, 23 fewer days in the hospital, a shorter period of disability (17 versus 22 months), and approximately $30,000 in savings. Of note, the average length of the segmental defect in the Ilizarov group was 6.5 cm, compared with 8.5 cm in the group treated with traditional methods.

Nonunion

Ilizarov and Catagni have speculated that distraction can be used to treat hypertrophic nonunions. A clear advantage of this method is simultaneous correction of shortening, if present, as well as angular and translational deformities. The tibia is the most commonly involved bone. Concurrent infection, if present, may be obliterated. Catagni et al[24] recently published their results in treating stiff hypertrophic nonunions with the use of the Ilizarov external fixator and distraction at an average rate of 0.25 mm twice a day. The mean treatment time was 6.5 months. All patients achieved union and correction of their axial, angular, and translational deformities, and 86% had equalization of their limb-length discrepancy to within 1 cm. Five of six patients had resolution of a chronic infection. No patient required bone grafting or debridement.

Other potential indications include treatment of contractures and clubfoot. Herzenberg et al[25] used the Ilizarov device to treat severe knee-flexion contractures of various etiologies and found an average decrease in the measured contracture from 60 degrees to 16 degrees after a mean follow-up period of 1.6 years. The total arc of motion did not dramatically improve, however, although it was considered to represent a more functional range. The device was used by de la Huerta[26] to treat neglected clubfoot in patients who had never undergone surgery and walked on the dorsum of the foot. Complete correction was obtained in all 12 cases, although joint range of motion was limited. Calhoun et al[27] successfully used the Ilizarov external fixator and incremental correction to treat patients with burn contractures that resulted in pes equinus, pes cavus, rocker-bottom, and other foot deformities.

Surgical Considerations

As with other techniques, a successful outcome requires extensive preoperative evaluation and planning, as well as an understanding of the nature of the condition to be treated. For example, patients with fibular hemimelia have an array of limb abnormalities that may compromise efforts at tibial lengthening (Fig. 4). These include coronal and sagittal deformities of the tibia, valgus deformity of the distal femur, and knee and ankle instabil-

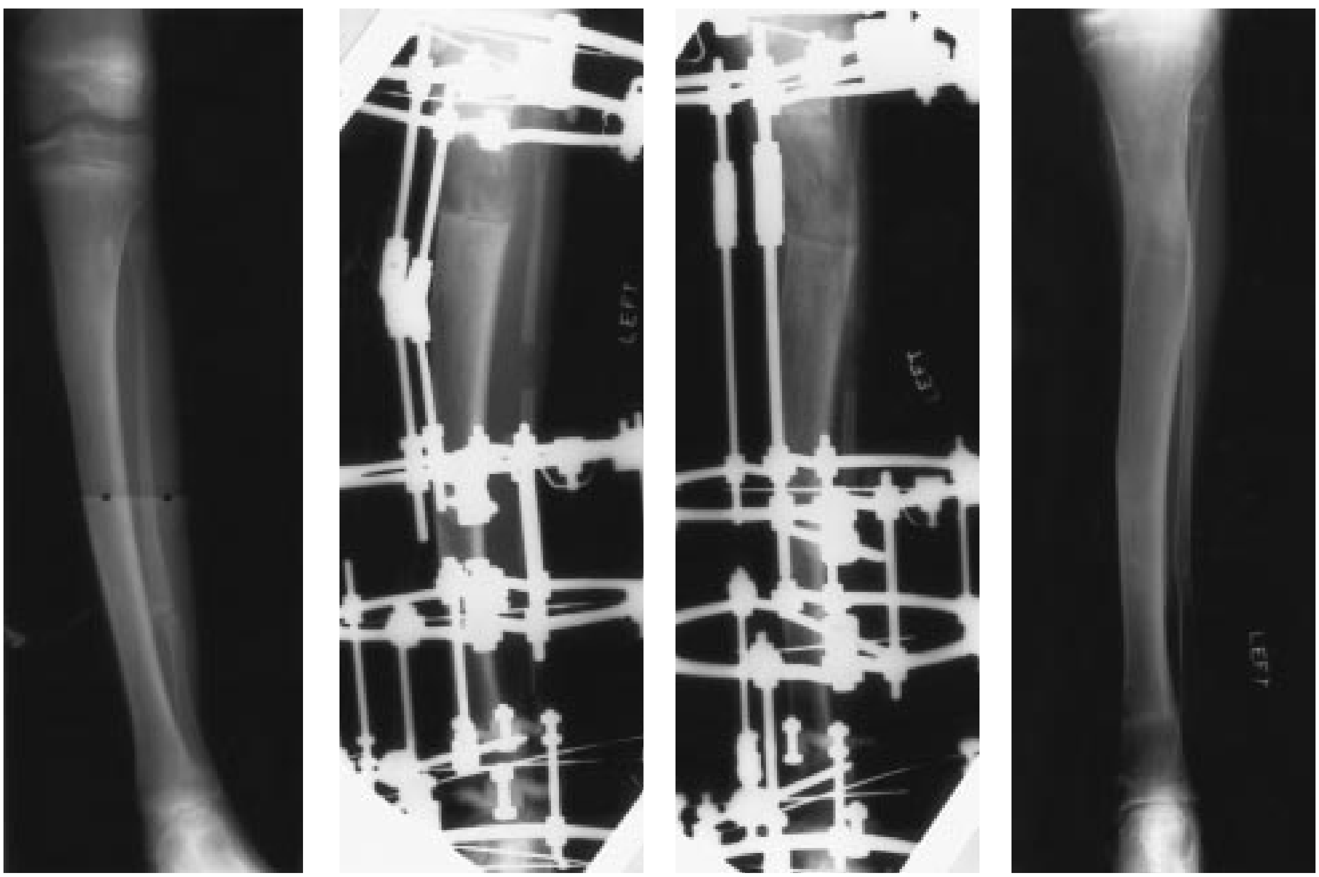


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Fig. 4 Radiographs of a child with a 6-cm limb-length discrepancy due to fibular hemimelia. **A,** Anteroposterior radiograph depicts proximal and distal tibial valgus, as well as ball-and-socket ankle and hypoplasia of the fibula. Patient previously underwent tibial lengthening with a monolateral fixator. **B,** Acute correction of distal tibial valgus deformity was performed. Frame was constructed to first lengthen the proximal tibia and then achieve angular correction. Note hinge application at apex of proximal tibial valgus deformity distal to site of corticotomy. Frame extends to foot to prevent subluxation or contracture. **C,** Radiographic appearance after desired lengthening. Progressive correction of proximal tibial valgus was then sequentially performed, with desired bending of regenerate. **D,** End result, with equalization of limb length and mechanical-axis realignment.

ity. Preoperatively, the surgeon must decide whether associated deformities require simultaneous or staged correction. During lengthening, the ankle needs to be protected by application of a cast or a monolateral fixator or by extension of a circular frame to include the foot. The knee must be monitored with periodic radiographs during lengthening to monitor for the development of posterior subluxation or dislocation.

The expected biologic response of the patient to distraction osteogenesis is critical. Age is a well-known determinant of the quality of regenerate. However, many other conditions require special consideration. The regenerate may be poor in patients with metabolic bone diseases, such as renal osteodystrophy and hypophosphatemic rickets, as well as in patients who are receiving corticosteroid therapy. Patients with postpolio deformities may have a prolonged consolidation phase, which is probably related to the poor muscle envelope surrounding the bone. Patients with posttraumatic deformities involving dysvascular bone and/or a poor soft-tissue envelope also may have a deficiency in quality of bone formation.

To treat deformities, one must be familiar with the normal mechanical axis of long bones (Fig. 5) and the method of locating the site and plane of the deformity. Deformities can be in the coronal, sagittal, or oblique plane and are often accompanied by a translational or rotational component. Deformities should also be classified as either aggravating or compensatory. For example, a patient with adolescent Blount's disease may have a valgus deformity of the ankle compensating for varus deformity of the proximal tibia. Correction of the proximal tibial varus can result in even greater ankle valgus.

Further complicating operative planning in children is the need to perform correction at a location different from the site of the deformity. A classic example is infantile Blount's disease in which the deformity is at the level of the proximal tibial physis but the site of correction is below the tibial tubercle. In this circumstance, achieving a normal mechanical axis will require lateral translation of the shaft of the distal fragment.

All of these factors must be carefully considered, as pointed out in the comprehensive reviews by Paley and Tetsworth.[28,29] The corrective procedure also can produce deformity. For example, a tibial lengthening can cause valgus and procurvatum deformities. This can be managed by prestressing the system into slight varus and recurvatum angulation at the time of frame application or by increasing the rigidity of the external fixator by increasing the number and/or size of wires and pins. In some instances, the surgeon may disrupt the initial deformity and correct it at the conclusion of lengthening by using a hinge to apply forces through regenerate bone.

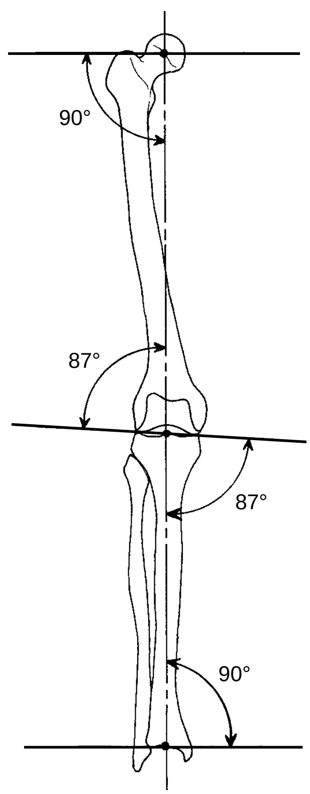

Fig. 5 Normal frontal-plane mechanical axis.

Complications

The potential complications of limb lengthening and deformity correction with the use of external fixators of any type are numerous. The wide range of reported complication rates stems from the lack of uniform methods of determining what constitutes a "true" complication. Likewise, the severity of the deformity or limb-length inequality will influence the risk of major complications. Regardless of how a complication is defined, there is a learning curve, and rates decrease as surgical experience is gained.

Wire and pin problems are among the most common complications. Other complications include neurologic and vascular injuries, contractures, angular deformities, fracture after frame removal, joint subluxation, joint stiffness, premature consolidation, delayed consolidation, and conditions such as deep vein thrombosis and pulmonary embolism.

Contractures

Contractures most commonly involve large muscle groups that cross two joints. In tibial lengthenings, the triceps surae may cause a knee-flexion contracture or an equinus deformity of the foot. These problems are often avoided by the use of physical therapy and splinting. Large lengthenings may require extension of the frame across the joint to prevent contracture. Established contractures may require dynamic splinting or correction with forces applied by the frame. Resistant contractures after frame removal may necessitate tendon lengthening.

Joint Subluxation

Joint subluxation or dislocation occurs most commonly in the knee and in patients with congenital instability. Radiographic monitoring of the knee during femoral lengthening is essential. To avoid this problem, passive full extension of the knee must be maintained through either physical therapy or splinting. Subluxation or dislocation may require extension of the frame across the knee joint with distraction and then reduction of the displacement.

Neurologic Complications

Nerve injuries may be due to direct injury during wire or pin insertion or to traction injury during lengthening. The former is usually recognized immediately postoperatively; if it is suspected, the wire or pin should be removed or replaced. Traction causes delayed-onset deficits; if it is suspected, the lengthening process may have to be slowed or reversed temporarily.

Problems With the Regenerate

Poor quality of the regenerate may be addressed by slowing the distraction process. Alternatively, the "accordion method" may be used; this involves intermittent compression and lengthening of the regenerate at a slower rate.

Premature consolidation may be secondary to an incomplete osteotomy at the time of surgery or an excessive latency period. This may be treated with continued frame lengthening, which eventually results in fracture through the consolidated region. The patient must be warned that this may be a painful event. When the fracture occurs, the frame should be acutely shortened by several millimeters to prevent a large gap at the osteotomy site and to relieve pain. With the patient under anesthesia, a repeat osteotomy may be done, or osteoclasis may be achieved by rotating the rings adjacent to the osteotomy site in opposite directions.

Controversies

Type of Device

It has become increasingly clear that the type of device used is not critical, as long as the surgeon has a thorough knowledge of the capabilities and limitations of the device used. Both circular and monolateral fixators have their advantages and disadvantages. The circular fixator is especially applicable to angular correction because of its modularity. However, Price et al[30] have demonstrated that a monolateral frame can be used successfully to accomplish the same goal in the technique of acute correction of an angular deformity with subsequent lengthening. The strategies are quite different, but the end results may be comparable.

Wires Versus Half-pins

Classic Ilizarov surgeons have traditionally used transfixion wires exclusively. Today, most surgeons who use circular fixators combine fine-wire fixation with strategic placement of half-pins, usually on the anterior surface of the tibia and the proximal femur.

There is a great deal yet to be learned about the mechanical effects of half-pins on frame rigidity. Half-pin fixation is thought by some to increase axial rigidity, which theoretically may be less desirable for the formation of healthy regenerated bone. To date, however, practical experience has failed to show this to be a legitimate concern.

Bone Defects

The optimal use of bone transport in either posttraumatic or postsurgical resection is still unclear. Although this is an alternative therapy, other forms of treatment should not be abandoned prematurely. For example, free vascularized fibular grafts have been shown to be effective and to provide excellent results in the management of intercalary defects. Conventional posterolateral bone grafting for less extensive defects should not be abandoned either.

Lengthening Over a Nail

Some centers are experimenting with combining internal and external fixation for lengthening. At the time of the surgical procedure, an intramedullary nail is inserted into the tibia or femur, and an external fixator is used to apply distraction. Once the desired length has been achieved, the nail is interlocked, and the external fixator is removed. The proponents of this technique believe that the length of time an external fixator is necessary can be dramatically reduced. Although patient convenience and acceptance are theoretically enhanced, the downside is an increased risk of sepsis. We believe this procedure must still be considered experimental.

Amount of Lengthening

Although the method of lengthening and the predicted success of forming healthy regenerated bone have improved, the amount of lengthening that one should attempt has not changed. Generally speaking, a 15% increase in the length of the bone is considered safe. Beyond that, the risk of complications rises exponentially. Therefore, the surgeon should resist the temptation to perform extremely long lengthenings, particularly in cases of congenital deformity (e.g., congenital short femur). Several small staged lengthening procedures preserving joint function are preferable to a single heroic lengthening attempt.

In the case of a severe congenital or posttraumatic deformity, amputation and prosthetic fitting must still be considered part of the armamentarium of the surgeon. The neurologic condition of the extremity, the quality of the soft tissue, the stability of the joints, and the function of the foot should all be taken into account. More than 20 cm of predicted discrepancy at maturity should be considered an indication for amputation.

Autodistractors

Commercially available autodistractors displace the bone fragments in frequent small increments (e.g., less than 0.25 mm, more than four times per day, for an overall rate of 1 mm per day). The quality of regenerated bone can be enhanced by this method. Particularly in children, however, bone formation is generally excellent, and the added expense of an autodistractor is therefore not indicated. Theoretically, premature consolidation could be a concern in patients in whom a healthy regenerate is expected.

Summary

Distraction histiogenesis is an exciting method with an extensive list of potential applications. It allows the surgeon to treat an array of orthopaedic problems in the pediatric and adult populations. The choice of the external fixation device used to accomplish this technique is dependent on the surgeon's preference. Modifications and refinements of these devices will surely occur, but the principles developed by Ilizarov and others are here to stay. Preoperative planning, attention to detail, respect for the soft tissue, and sound judgment are necessary to achieve the desired result with an acceptably low complication rate.

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