The Evolution of the Ilizarov Technique
Part 1: The History of Limb Lengthening

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Abstract
The history of limb-lengthening surgery can be traced back to the nineteenth century. Since that time, the orthopaedic community has made tremendous progress in performing successful lengthening procedures. Among the important contributors to the field, Dr. Gavril Ilizarov remains one of the most significant innovators. Because of advancements over the past century, limb lengthening has become a viable method of treating severe bony deformities and defects. This article, the first of a two-part series, reviews the history of distraction osteosynthesis.

The difficulties to be encountered in lengthening a shortened limb are found, in operation, to be greater as regards the fleshy parts, than as regards the bones. It is comparatively easy to remove the splinters of a fractured bone which is wrongly consolidated; to separate a curved bone; or to perform an oblique osteotomy, but a decided limit is arrived at in the correction of a displacement, or in the lengthening of the bones, by reason of the contraction, or resistance, of the muscles. – Codivilla 1905

Early Attempts at Limb Lengthening
The history of limb lengthening dates back to the 19th Century, as surgeons struggled to treat the sequelae of war injuries, malunited femoral shaft fractures, and post-polio myelitis deformities. Initial attempts at limb lengthening were performed as single stage lengthening osteotomies, performed by pioneers such as Von Langenbeck (1869), Hopkins and Penrose (1889), and Von Eiselberg (1897), (Fig. 1).

However, modern techniques of limb lengthening did not begin until the early 1900s with the work of Alessandro Codivilla in Bologna, Italy (Fig. 2). Codivilla was an Italian surgeon who practiced orthopaedics exclusively. He published 124 articles in 25 languages, reporting new ways to treat many conditions, including polio residuals, clubfoot, scoliosis, and congenital dislocation of the hip. His initial reports on the use of external pin fixation and traction for lengthening appeared in the Italian literature in 1903. This was followed by a presentation at the Annual Meeting of the American Orthopaedic Association in June of 1904 and the first English-language report in 1905.

Codivilla recognized that others had previously tried limb lengthening, writing “The greater number have applied constant traction, after having separated the bone; others have used great stretching under narcotics, followed by constant extension of the muscles, by means of weights; others again, after the stretching have applied the plaster apparatus.” However, Codivilla noted that surgeons’ choices of technique were largely empiric ones without much evidence to support their techniques. He presented two separate techniques. For relatively small degrees of shortening, he recommended acute forced lengthening with narcotic medication. However, for larger degrees of shortening, he presented a method called “continuous extension” (Fig. 3). This technique involved the application of moderate traction applied through a pin in the calcaneus. He used a chisel to make an oblique osteotomy in the femur, followed by the application of a medium amount of traction (25 to 30 kg). He then placed the patient in a “plaster jacket,” which encircled the thorax, pelvis, and leg, incorporating the calcaneal pin. If the lengthening was insufficient, he cut the cast at the level of the osteotomy and added more traction in stages (not exceeding 25 to 30 kg per stage). He found that, using this
technique, the desired length could be obtained in 20 days but could continue for 30 to 35 days without pin complications. In 1905 Codivilla presented his results in 26 patients with limb shortening secondary to a variety of causes. All patients achieved the desired lengthening, ranging from 3 to 8 cm. Complications utilizing this technique included severe nerve lesions, skin complications, and uncontrollable persistent convulsions. Despite the complications observed, he wrote: “The method, has borne the very best results, correcting the deformity, and diminishing, or completely removing the shortness of the limb.”

Over the next few years, Codivilla’s technique was disseminated and implemented throughout the United States and Europe. Magnuson performed the first experimental studies of this technique in Chicago, in 1908. Magnuson utilized a dog model to demonstrate that single stage lengthening of 5 to 7.5 cm could be performed without damaging the soft tissues. He advocated a Z-shaped osteotomy after making several drill holes and dividing the periosteum longitudinally, reporting that this technique would minimize damage to the periosteum and endosteum.

Codivilla performed bone lengthening of 5 to 7 cm in one session and opposed the divergent limbs of the Z with ivory screws to maintain the length of the leg. Over the next few years, Magnuson translated this technique into humans and performed 14 lengthening procedures. However, he described severe complications, including shock both before and after surgery in all of his patients, and the resultant death of one patient on the operating table.

**Further Evolution of Limb Lengthening**

Many surgeons sought to advance the science of limb lengthening by improving on Codivilla’s technique. Freiberg, working in Cincinnati in 1911, recommended performing the lengthening technique over several sessions in order to overcome the problem of shortening of the soft tissues. Freiberg operated largely on polio patients. He developed an operating table with a built-in sidepiece resembling a saddle to exert sufficient counter traction. Distal traction was produced with a screw, and a spring served as dynamometer. He found that the force necessary for lengthening ranged from 25 to 50 kg.

In 1913, Ombredanne modified the technique further by recommending an oblique osteotomy with a slow, gradual...
lengthening. He fixed one pin above and one pin below the osteotomy by means of an apparatus fitted to the side of the thigh. Using this technique, he was able to achieve up to 4 cm of lengthening. However, the operation was frequently followed by osteomyelitis, and the technique was soon abandoned.

In Seattle in 1913, Fassett developed a one-stage operation in which he lengthened the femur by 3 cm. He inserted bone chips into the osteotomy site and stabilized the osteotomy with a plate. However, he too noted multiple serious complications. Fassett wrote “With modern surgical technique, almost everything is possible, but not everything which is possible is necessarily worthwhile.”

Taylor presented 10 years of experience in performing lengthening operations to the American Orthopaedic Society in 1916. Taylor’s technique consisted of a Z-shaped osteotomy, which he encircled in plaster. He cut the plaster in half and over 10 days, distracted the two halves by means of threaded rods with blocks of magnesium or ivory bolted into the distraction gap. His technique was complicated by grave infection, and he came to favor shortening the unaffected healthy limb.

Putti succeeded Codivilla as director of the Rizzoli Institute of Bologna, in 1912, and continued his work on limb lengthening. In 1921, Putti lectured to the American Medical Association in Boston, reporting on several cases of femoral lengthening. He stressed the need for an osteotomy with minimal trauma and for a gradual, controlled lengthening. Putti’s technique involved one to two pins inserted proximal and distal to the osteotomy in both cortices of the femur without pre-drilling with a Z-shaped osteotomy.

Putti utilized a telescopic tube, which he called an “Osteoton,” mounted to one side, which provided continuous distraction for 30 days (Fig. 4). This construct resembled modern unilateral external fixators. The mean length gained using this technique was 8 cm. However, it was not widely received secondary to the impossibility of controlling axial positioning with the insufficiently rigid apparatus. Moreover, as the force built up, the pins pulled out of the bones. The method became more practical once the frame was converted into a 3-dimensional fixator. Putti abandoned his technique in favor of a distraction performed by using piano wires and a stationary extension device fitted to the patient’s bed. However, he was not the first to utilize wires for limb lengthening. This technique was first used by Klapp in 1913 during the Balkan War. In 1918, Herzberg applied traction to wires by means of a frame and showed that this could be continued for a considerable amount of time without infection. These devices enabled the surgeon to reposition the fragments at will and effect axial correction.

After hearing Putti’s lecture in 1921, Abbott and Crego adopted the Osteoton and began performing limb lengthening operations in St. Louis in 1924. The two corrected the Osteoton’s main weakness of unilateral fixation with drill wires inserted proximal and distal to the osteotomy through the entire cross section of the tibia. They connected the wires on both sides to telescopic tubes or threaded rods, resulting in a stable frame construction. After performing the osteotomy, Abbott carried out an intraoperative distraction of 1 to 2 cm. After waiting 7 to 10 days after surgery, he began a gradual distraction of 1.5 to 3 cm daily.

By the 1930s, Abbott and Crego had performed the operation on 73 patients; however, they noted multiple complications. Equinovarus deformity of the foot resulted from a disproportionate lengthening response of soft tissue in the lower leg and a dissociation in the tibiofibular joint. They also observed restricted movement in the hip joint, procurvatum or recurvatum of the distracted tibial fragments, weakening of the muscles of the lower limb, paralysis of the peroneal or tibial nerves, pin infections, pressure necrosis of the skin, aseptic and septic necrosis of the fragments with severe osteomyelitis, and delayed fractures. In an attempt to address these complications, Abbott performed extensive anatomic studies and made modifications to his original technique. He attempted to solve the problem of soft tissue resistance with excessive dissection of the fascia, periosteum, and intersosseous membrane. All of the muscle origins on the proximal part of the tibia initially were separated by subperiosteal dissection, with the actual lengthening procedure performed in a second operation. In addition, he waited up to 2 weeks after the osteotomy before commencing the process of lengthening.

Abbott made lengthening procedures acceptable to both patients and surgeons throughout the United States, and it was adopted by professionals on multiple levels. However, the widespread implementation lacked proper patient selection and was without sufficiently safe operative and orthopaedic techniques. This indiscriminate use resulted in amputation, septicemia, and even death. The operation was eventually condemned, and Abbott wrote: “We believe that this is not an operation for the uninitiated and should be reserved for those whose experience renders them competent to perform this technically difficult and delicate procedure.” And, while Abbott himself remained loyal to his procedure, he advocated contralateral shortening for the “uninitiated.” Throughout the 1930s, modifications were made to Abbott’s technique. The main problem that emerged was the lack of qualified surgical instrument manufacturers to construct the complicated apparatus. Subsequent modi-

Figure 4 Schematic representation of Vittorio Putti’s Osteoton.
fications were directed towards simplification.

In Dallas in 1928, Carrell advocated for a more conservative osteotomy in which he preserved the periosteum and broke through the cortical bone on the opposite side. White, in 1930, used Steinmann pins incorporated into an encircling plaster. After dividing the plaster, he attached two threaded rods and performed distraction along these rods. His technique required 30 days for 5 cm of lengthening. This was the first time the apparatus was portable, allowing the patient to get out of bed. Dickson and Divelet, in Kansas City in 1932, used Kirschner wires stretched between half stirrups. This modification allowed for better control of the fragments in the axial plane. Roger Anderson, in Seattle, similarly used a horseshoe shaped half stirrup for each pin, providing improved rotational control.

Haboush and Finkelstein, working in New York in 1932, reported a number of complications arising from the use of Abbott’s technique. They concluded that radical dissection of the deep structures did not prevent foot deformity and instead caused infections and failure of the regenerate. They conducted multiple cadaveric experiments and developed a new technique, advocating a more conservative dissection of the deep rigid structures and recommended performing the dissection away from the circular incision of the periosteum. This allowed the regenerate to develop within a tube or a sleeve of periosteum.

Compere also described complications of lengthening operations. He pointed out that every surgeon had encountered multiple complications and that patients were often more severely handicapped after their treatment than before. His paper significantly dampened enthusiasm for the procedure. However, the paper was also the first to recognize the problem of devascularization and established rules to avoid devascularization.

In New York throughout the 1930s, Bosworth worked to improve the technique of limb lengthening. He was the first to use the term “bone distraction” and emphasized the importance of a rigid frame. He wrote that the level of the osteotomy had no influence on outcome and advocated for a second osteotomy site to divide the distraction factor between the two sites. Additionally, he argued against a radical dissection of the fascia. He reported his results in 24 patients and described multiple complications, including infections, delayed union, nonunion, recurvatum in five patients, and eversion of the foot in six patients. However, he found that, in all of the uncomplicated cases, a new marrow cavity had developed within 6 months after the operation.

In Chicago, Moore critically examined limb lengthening surgery. He performed 52 limb lengthening operations and found that in most cases the shortening had been corrected and the limbs were of the same length. However, he too noted a high rate of complications, including deformities of the foot. Foot eversion and internal rotation at the knee joint induced by the procedure led to altered gait, and the procedure failed to improve ambulation in most cases. He also found that the procedure was associated with a serious loss of muscle strength. Moore argued for the importance of function over cosmesis.

In Los Angeles, Brockway and Benjamin performed 105 limb lengthening procedures using Abbott’s apparatus and technique in its original form. Their results were good or satisfactory in 87% of their patients. However, their satisfactory group included delayed unions, sequestrations, and foot and knee deformities. Outcomes in the remaining 13% were worse than the preoperative states. In addition, osteomyelitis occurred in 22% of their patients. Interestingly, in 1944, Wittmoser devised a ring fixator for lengthening the tibia and fibula. His device resembled the fixator system used currently. However, his teacher Bohler failed to recognize the brilliance of the underlying idea and could see no link with earlier studies. He convinced Wittmoser not to publish studies on his device.

In 1950, Allan described his results for limb lengthening in 105 patients in Birmingham. He emphasized that most patients strongly desire limb lengthening and were disinclined to accept a shortening procedure on the contralateral limb. He stated that a lengthening procedure restores the patient’s height, while the alternative procedure leaves the patient deformed through disproportionate shortening. Allan performed a relatively atraumatic osteotomy, breaking through the bone after making a unilateral chisel osteotomy on the opposite side. He secured the fragments with tensioned Kirschner wires in several planes to provide control in the axial plane and used threaded rods to produce controlled progressive distraction. Daily distraction was performed at a rate of 1.6 mm per day, and lengthening was interrupted if pain occurred. He maintained that excessive soft tissue dissection was not necessary and believed that the soft tissues could be overcome with slow, gentle distraction. With this technique, Allan was able to achieve bony union in all patients.

While these techniques were developing in the United States, European surgeons were developing their own modifications to the limb lengthening procedure. In Edinburgh, in 1933, Cochrane adopted Abbott’s technique and forged a link between the United States and Europe. Successive modifications were introduced by Anderson and Green. The frequency of malpositioning of the foot led to the development of screw synostosis of the distal tibiofibular joint. When a lengthening procedure was marred by the occurrence of a new fracture, a less traumatic percutaneous osteotomy technique was developed. Early limb lengthening techniques were severely limited by the poor dissemination of information. All of the crucial elements required for the development of modern techniques had been introduced by the 1930s. However, the knowledge remained localized to isolated surgical centers in the United States, England, Germany, Italy, and France and was not readily shared amongst these centers. In addition, poor un-
The Work of Ilizarov

While Wagner advanced his technique in the West, Ilizarov, working in Kurgan, Siberia, introduced the technique that would successfully unite the surgical principles of limb lengthening with the biology of distraction histogenesis (Fig. 6). He first used his technique in 1951 for the treatment of a bone defect caused by tuberculosis.8,35 He developed a circular external skeletal fixation system that attached to the bone with tensioned transfixion wires. The rings of the apparatus were connected to each other with threaded rods. The technique was designed to stimulate and exploit the biologic potential of the tissues.

In 1952, Ilizarov introduced the modular ring fixator.8,35 This allowed for precision in technique while rendering predictable results. In 1954, Ilizarov used his technique to heal pseudarthroses and fibrous nonunions, using a combination of local compression followed by distraction.36 He understood the stimulatory effect of compression on bone healing and distraction on new tissue formation. Following distraction, he utilized compression again to transform the cartilaginous interface into new bone. In 1956, Ilizarov observed new bone formation with a distraction space while correcting an ankylosed knee flexion deformity by open osteotomy, distraction with an external fixator, and bone grafting.35

In 1969, Ilizarov reported on lengthening without the use of bone graft.37 He wrote that “living tissue, when subjected to slow steady traction, becomes metabolically activated in both the biosynthetic and proliferative pathways.”37 Ilizarov used the stimulus of pure distraction applied to a special corticotomy that preserved the medullary vascularity and involved osteotomy of the cortex alone. Using this technique, he was able to induce new bone formation at the site of the lengthening. Ilizarov stated that the application of these principles would allow the physician to achieve38:
1. The percutaneous treatment of all closed metaphyseal and diaphyseal fractures as well as many epiphyseal fractures,
2. The repair of extensive defects of bone, nerve, vessel, and soft tissues without the need for grafting and in one operative stage,
3. Bone thickening for cosmetic and functional reasons,
4. Percutaneous one-stage treatment of congenital or traumatic pseudoarthroses,
5. Limb lengthening or growth retardation by distraction epiphysiolysis or other methods,
6. Correction of long-bone and joint deformities including resistant and relapsed club feet,
7. Percutaneous elimination of joint contractures,
8. Treatment of various arthroses by osteotomy and repositioning of articular surfaces,
9. Percutaneous joint arthrodesis,
10. Filling in of solitary bone cysts and other such lesions,
11. Treatment of septic nonunions by favorable influence on infected bone of the stimulating effect of tension-stress on regenerating bone,
12. The filling of osteomyelitic cavities by the gradual shifting of one cavity wall,
13. Lengthening of amputation stumps,
14. Management of hypoplasia of the mandible and similar conditions,
15. Overcome certain occlusive vascular disease without bypass grafting, and
16. Correction of achondroplasia and other forms of dwarfism.

The Ilizarov technique is based on simple set of principles. The principles focus on the superior biologic quality of the regenerated bone due to the performance of a percutaneous corticotomy that minimizes trauma to the periosteum and bone marrow while maximizing the preservation of marrow and periosteal blood supply. The technique also emphasizes the importance of a post-operative waiting or “latency” period. Multistep, incremental distractions totaling 1 mm per day and the use of a compression and distraction procedure involving full weightbearing are also central tenets. The technique uses a ring fixator with fragments that are held by Kirschner wires under tension that enables the surgeon to exert planned control in all planes while allowing the correction of multidirectional deformities. Ilizarov developed the technique of segment transport for defects of the bone shaft. He also cited the promotion of good tissue nutrition and joint mobility by means of mobile device that allows full weightbearing and physiotherapy.

The development of Ilizarov’s techniques decreased reservations attached to older procedures. Initially, the technique was largely unknown outside of Russia. Wagner’s technique was largely used in German speaking countries and eventually the United States. However, concerns over the number of procedures required and high rates of complications with the Wagner technique allowed focus to shift to Ilizarov’s technique. Subsequently, more than 2,000 papers have been published from Ilizarov’s Institute in Kurgan describing the clinical results, biologic studies, and technical considerations related to the use of transosseous compression and distraction osteosynthesis. As of 1983, more than 15,000 patients had been treated at the Institute. Currently, 9,000 patients are treated there annually, and more than 300,000 have been treated worldwide. The clinic was started in 1949 in a log cabin and has developed into a 1,000-bed clinical and research institute staffed by 300 orthopaedic surgeons, 60 full-time PhDs, and more than 100 machinists on the grounds of the institute, who fabricate the components of the Ilizarov apparatus.

Conclusion
The development of limb lengthening and bone transportation techniques has a long history, fraught with complications. Early pioneers in the field made important advances,
but their attempts at limb lengthening were frequently associated with significant patient morbidity. Ilizarov unified many theories of biology and biomechanics in his experiments, which allowed the development of safe and effective techniques to treat a wide variety of deformities and bone defects. His basic principles of limb lengthening have been applied worldwide and now form the foundation of modern practices.

**Disclosure Statement**
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