Problems, Obstacles, and Complications of Limb Lengthening by the Ilizarov Technique

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Difficulties that occur during limb lengthening were subclassified into problems, obstacles, and complications. Problems represented difficulties that required no operative intervention to resolve, while obstacles represented difficulties that required an operative intervention. All intraoperative injuries were considered true complications, and all problems during limb lengthening that were not resolved before the end of treatment were considered true complications. The difficulties that occurred during limb lengthening include muscle contractures, joint laxation, axial deviation, neurologic injury, vascular injury, premature consolidation, delayed consolidation, nonunion, pin site problems, and hardware failure. Late complications are those of loss of length, late bowing, and refracture. Joint stiffness may also be a permanent residual complication. Pain and difficulty sleeping are other problems that arise during limb lengthening, especially in the more extensive cases. Forty-six patients had 60 limb segments lengthened between 1.0 and 16.0 cm, with a mean of 5.6 cm. The average treatment time was approximately one month per centimeter for single-level lengthenings with no deformity and 1.2 months per centimeter with deformity correction. The lengthening index for double-level lengthening was 0.57 month per centimeter with no deformity and 0.90 month per centimeter with correction of deformity. In adults, the lengthening index was 1.7 months per centimeter for single-level and 1.1 months per centimeter for double-level lengthening. There were 35 problems that had to be resolved in the outpatient clinic. There were 11 obstacles that required additional operative intervention to resolve. There were 27 true complications, of which 17 were considered minor and ten were considered major complications. Of the major complications, three interfered with achieving the original goals of treatment. All three required further operative intervention to achieve the original goal. These were nonunion in one and late bowing in two. Despite these problems, obstacles, and complications, the original goals of surgery were achieved in 57 of the 60 limb segments treated. Patient satisfaction was achieved in 94% of 46 cases.

Complications have plagued limb-lengthening techniques since Codivilla introduced surgery for elongation of the lower limbs. High complication rates, particularly those related to the healing of the bone, became the hallmark of the conventionally accepted Wagner technique. A recent study reported an average of two complications per lengthening, of which at least one was usually serious enough to prevent achieving the original goals of the surgery. With the introduction of more physiologic methods of lengthening pioneered by Ilizarov and based on the biology of bone and soft-tissue regeneration under the conditions of tension stress, the bone-healing problems have become far less common and difficult to manage and the goals of treatment are usually achieved. It has become apparent, however, that despite the more physiologic nature of these methods, the spectrum of potential complications remains the same irrespective of the technique used. The incidence and severity of these complications have changed as well as the ability to achieve one's goals.
It is also difficult to compare results among limb-lengthening series due to a lack of standardization as to what constitutes a complication. Depending on the criteria used, complication rates range from 1% to 200%. 1, 2, 4-6, 9-12, 14-16, 21 On the other hand, some authors have suggested there is a difference between problems that occur during limb lengthening and true complications. 20 Unlike other operative procedures, the procedure in limb lengthening does not end with the conclusion of the surgery but rather when the apparatus is removed several months later. Problems that arise during any surgical procedure that are corrected before the end of the procedure are not usually considered complications. Therefore, how should problems that arise during the lengthening and are resolved before the end of the lengthening be classified? Are these complications, or are they more like intraoperative difficulties?

The purpose of this paper was to develop a working classification for the difficulties and complications that arise from limb lengthening and to apply this classification to a prospective group of patients having lengthening. Furthermore, the aim of this study is to evaluate whether this classification scheme is successful at separating and representing the difficulties that arise during limb lengthening from the true complications. Should this be possible, it would also serve useful to standardize between studies of different authors.

CLASSIFICATION

Complications of any procedure are usually considered (1) local or systemic and (2) intraoperative, early, or late. With limb lengthening, one must add an additional two groups: during distraction and during fixation. Since the procedure is a gradual one with daily physiologic changes in the bone and soft tissues, many potential expected difficulties arise during the distraction and fixation periods. In most instances, appropriate adjustments and manipulations, including unplanned operative interventions, lead to resolution of the difficulty prior to apparatus removal. In such instances, the difficulty is classified as a problem or an obstacle, respectively.

A problem of lengthening is defined as a potential expected difficulty that arises during the distraction or fixation period that is fully resolved by the end of the treatment period by nonoperative means. An obstacle of lengthening is defined as a potential expected difficulty that arises during the distraction or fixation period that is fully resolved by the end of the treatment period by operative means. Complications include any local or systemic intraoperative or perioperative complication, a difficulty during distraction or fixation that remains unresolved at the end of the treatment period, and any early or late posttreatment difficulty. True complications were divided into minor or major. The major true complications were further divided into those that did not interfere with the original goals of treatment and those that did.

MUSCLE CONTRACTURES

Muscle contractures are usually a result of the tension generated on the muscle due to distraction. They tend to occur to the overpowering muscle group. This is due to the imbalance of strength between flexors and extensors. In lengthening of the tibia, for example, the triceps surae muscles offer the greatest resistance to lengthening due to their large strength and muscle mass (Fig. 1). They will tend to flex the knee and plantarflex the ankle rather than lengthen if they are left unopposed (Fig. 1). In lengthening of the femur, the hamstrings are the largest and bulkiest muscle group. The muscles most frequently involved in contractures are those that cross two joints. It is known that muscles crossing two joints have fibers of various lengths as opposed to those that cross only one joint and have fibers of equal length. This may lead to variations in tension within the same muscle. Tension on the muscle is
Fig. 1A-1D. Lateral view of the tibia and associated muscles. (A) Before lengthening. Gastrosoleus muscles and tendo achilles. (B) After lengthening of tibia. Ideally, the muscle should lengthen to the same extent as the bone. (C) Knee contracture. This occurs when knee extension is not maintained throughout lengthening. A relative shortening of the muscle to the new bone length has been produced. (D) Equinus contracture. This occurs when ankle dorsiflexion is not maintained during lengthening.

should focus on passive stretching exercises of the muscle groups most involved. Since these usually cross two joints, it is not sufficient to stretch the muscle only at one end. In the case of the triceps surae, the foot should be dorsiflexed maximally with the knee in flexion. Then with the ankle held in dorsiflexion, the knee should be passively extended. The patient should be encouraged to repeat these exercises throughout the day. Active exercises as well as electrical stimulation are believed to also help stimulate muscle regeneration. The role of continuous passive motion is as yet unknown.

The principle of avoiding contracture is to place the muscle under tension for as many hours as possible. It has been shown that stretching exercises do not lead to prevention of contracture unless they can be maintained for at least six hours per day. It is highly inconceivable that most patients would exercise their muscles to that extent. It is interesting to note that Ilizarov’s rehabilitation program involves approximately six hours of physiotherapy and functional loading per day.

Other means are needed to maintain tension on the muscles that have the greatest difficulty regenerating. For this purpose, the present author developed a knee extension orthosis (Fig. 2) and an ankle dorsiflexion orthosis (Fig. 3) to maintain these joints in full extension for the knee and at 90° for the ankle. The knee orthosis is worn predominantly at night when the patient has a tendency to sleep with the knees bent and the ankle plantarflexed. This would mean approximately eight hours of minimal tension on the muscles and, thus, no stimulus for muscle growth. The ankle orthosis is worn all day and night.

It has been suggested that, in spastic muscles, greater growth occurs at night since the muscles are more relaxed. This may also be the case in limb lengthening. The present author has had far fewer problems with contractures since using extension splinting. During longer lengthenings and in patients
FIG. 2. Knee extension brace to prevent a knee flexion contracture from occurring. The knee is braced in extension throughout the night. This orthotic consists of a thigh cuff and an adjustable metal extension bolted to the apparatus. It is important for this extension to lever on the ring closest to the knee to maintain knee extension. The apparatus shown is being used for simultaneous lengthening of the tibia and a complex correction of postoperative club foot deformities.

who are developing contractures, the knee splint should be used on and off during the day for a total of 12 hours daily. The splint is discontinued several weeks after the distraction phase is completed when muscle tone is returning to normal. The most common problem patients have is intolerance to the splint at night. Maintaining the knee in full extension for prolonged periods of time leads to significant discomfort and the urge to relieve the discomfort by flexing the knee. Similarly, dorsiflexion pressure from the shoe on the sole of the foot may lead to numbness and, thus, intolerance to the shoe. In an effort to improve the tolerability of the splinting, the present author has begun using a more physiologic splint that applies a constant extension force on the joint through an adjustable loaded spring (DynaSplint Systems, Baltimore, Maryland) (Fig. 3). The DynaSplint allows the patient to flex the knee or ankle actively in order to relieve their discomfort. When they relax, the splint takes over and passively, gently extends the joint. This is a much more physiologic way of splinting and acts to passively stretch the tight muscle groups.

In large lengthenings of the tibia (≥ 6 cm) and particularly in double-level lengthenings of the tibia, the foot should be fixed to the apparatus by means of pins. This is simple to do with the Ilizarov technique (Fig. 4). This prevents the ankle from going into equinus and yet avoids the discomfort of splinting. The gastrocnemius muscle is kept in its maximally stretched position by combining this usage with knee splinting. If an apparatus is placed on both femur and tibia, the two can be connected in extension to act as an extension splint. Ilizarov uses one wire in the heel for tibial lengthenings. The present author currently prefers to use two wires in the heel for greater stability and to avoid the inevitable wire breakage that tends to occur due to repetitive cycling of a single wire.

If a significant contracture has developed, then one must resort to other modalities of treatment. The DynaSplint can be used not only as prevention but also as treatment. Another useful modality is overlengthening
and then shortening. Once the length sought is achieved, lengthening is continued for another 10 mm. The present author then shortens 15 mm. This usually results in only 10 mm of total shortening due to the flexibility of the wires. Shortening the limb acts to loosen the taut soft tissues. The soft-tissue contracture sometimes literally melts away.

Up to this point, it has been possible to deal with the problem of muscle contracture by nonoperative means. If a more severe contracture develops, it may be necessary to apply the apparatus across the joint and to distract out the contracture. If a significant contracture remains after removal of the apparatus and is resistant to physiotherapy, it may become necessary to perform a tendon lengthening.

Thus, using the classification scheme above, if the contracture is dealt with by nonoperative means, it is considered a problem. If the contracture is dealt with success-
fully by operative means before the end of treatment, it is considered an obstacle. If the contracture remains at the end of treatment and is resolved by nonoperative means, it is considered a minor complication. If it requires tendon and capsular releases after the end of treatment, it is considered a major complication.

JOINT LUXATION

Subluxation and dislocation of an adjacent joint may occur during limb lengthening. The most common predisposing factor is preexisting joint instability, usually due to congenital causes. Even in the absence of preoperative instability, the imbalanced muscle tension that develops during lengthening may lead to subluxation, especially in the knee. For this reason, it is crucial to avoid the development of a muscle contracture, which is the manifestation of the imbalanced muscle pull on the joint. The knee is the most susceptible joint to this complication because of the inherent lack of bony stability. On flexion of the knee, the hamstring muscles can work unopposed to pull the tibia posteriorly on the femoral condyles (Fig. 5). If full extension of the knee joint is maintained, this complication cannot occur. While it is important to maintain knee flexion range of motion, it is crucial not to lose passive extension of this joint.

Joint subluxation can be treated by physiotherapy to stretch the deforming muscle force. This may work in milder cases. Traction is another modality of treatment. A cast may be applied and connected to the modular parts of the Ilizarov apparatus using a hinge mounted on a translation rail in order to relocate the tibia on the femur while maintaining motion at the knee (Fig. 6). In more severe cases and in the case of dislocation, the apparatus may need to be extended across the joint in order to first distract the joint and then relocate it immediately or gradually.

If left untreated or unrecognized until after the apparatus is removed, treatment with physiotherapy, traction, Quengel’s casts, and Dynasplint may be tried. More likely, tendon and capsular releases or reapplication of the Ilizarov apparatus may be necessary.

Using the classification scheme, a knee subluxation, which is dealt with by the above nonoperative means, would be considered a
calf musculature is located posteriorly and laterally. As these muscle groups become increasingly tense due to distraction, the tibia will tend to deviate laterally and posteriorly, causing valgus and procurvatum, respectively. Once again, the culprit is the muscle. It has become apparent that the muscle is the single largest limiting factor in limb lengthening today.

The other cause of axial deviation is instability. This may be caused by an inadequate construct, loss of tension in the pins, or loosening of the pins.

The best treatment is prevention. The pins should be placed 5°–10° inclined to the opposite direction of the expected deviation in the proximal tibia (Fig. 7). For example, the proximal ring of the Ilizarov should be in-

**AXIAL DEVIATION**

During lengthening, there is a tendency for the limb segment being lengthened to gradually deviate. Again, this occurs due to the imbalance between muscle forces on different sides of the bone. The characteristic direction of deviation depends on the bone involved and the level of the osteotomy. Osteotomies of the proximal femur tend to go into varus and procurvatum. Osteotomies of the distal femur tend to go into valgus and procurvatum. Osteotomies of the proximal tibia tend to go into valgus and procurvatum and in the distal tibia into varus and procurvatum. In the proximal tibia, for example, this is easily understood since the bulk of the

**FIG. 5A.** (Left) During lengthening the proximal pull of the hamstrings is resisted by the axial alignment of the tibia on the femur when the knee is in full extension. (Middle) When the knee is in flexion, there is no bony resistance to the proximal pull of the hamstrings. Posterior subluxation of the tibia on the femur is resisted only by the capsular and ligamentous structures about the knee. (Right) In patients with preexisting joint instability, there is a high risk of posterior subluxation of the knee. This may also occur in patients without recognized preexisting instability due to the unresistive force of the hamstrings. Maintenance of knee extension is, therefore, essential to prevent this complication.

**FIG. 5B.** Knee subluxation can easily go unrecognized because of its subtle roentgenographic findings. (Left) In full extension, the midpoint of the femoral condyles on the lateral knee roentgenogram should line up the midpoint of the tibial condyles. (Right) If there is a break in this line, the knee is subluxed.
Figs. 6A and 6B. (A) Posterior subluxation of the knee during a double-level femoral lengthening. (B) The femoral Ilizarov apparatus is connected to a below-knee fiberglass cast using a flexion translation hinge. This articulation allows knee flexion and extension at the same time as translation of the tibia forward. This tends to relocate the posteriorly subluxed tibia without losing knee range of motion. At night, the anterior threaded rod can be connected between the tibia and the femur to maintain knee extension. This rod is removed during the day. The knee subluxation was completely reduced before apparatus removal.

If axial deviation is noted early and is mild (less than 5°), it may be sufficient to overlengthen on the side of the deviation as compared to the opposite side (e.g., five 0.25-mm turns per day on the lateral side versus three 0.25-mm turns per day on the medial side). Once the axial deviation is greater than 5°, modification of the apparatus to include a hinge is usually required (Fig. 8). In larger lengthenings, it may be necessary to insert an additional olive wire to pull the bone out of its deviated position (Fig. 8C). For recurvatum deviation, the proximal fragment can be tilted posteriorly to correct the deformity (Fig. 9).

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probably cause little damage, while wrapping up the nerve due to the rapidly revolving wire would probably cause significant local mechanical and thermal damage. For this reason, unless one is sure about the exact location of the nerve, one should drill from the side opposite the nerve. Thus, when the wire passes by the nerve, it is not spinning but simply being tapped. The anesthesiologist is instructed not to paralyze the patient, so that, should a wire brush by or perforate a nerve, a muscle contracture would be seen. The proximity of the wire to a nerve would thus be recognized and the wire would be removed. If a pin-related nerve injury is not recognized until after surgery, the patient frequently awakens with severe pain localized to the area of the offending pin. The diagnosis can be made by tapping on the pin with another metal object. If the wire is through the nerve, this will elicit paresthesias in the distribution of that nerve. The pin should then be removed. The other surgical cause for a nerve injury is related to the corticotomy. This may be due to direct injury from the osteotome in the case of the tibia, from the oscillating saw in the case of the fibula, or more likely, a stretch injury from the osteoclast maneuver used to ensure that the corticotomy is complete. In the case of the proximal tibia, the rotational osteoclast maneuver should be performed with external rotation to avoid stretching the nerve where it is entrapped around the fibular neck with internal rotation.

A final cause for a nerve deficit is compartment syndrome. This will be discussed in greater detail under the section on vascular injury.

Distraction-related nerve injury is a much less common etiology. It is important to recognize the early signs and symptoms. The patient will usually be experiencing significant discomfort, although this is not always the case. If identified early, the first signs are hyperesthesia and pain. This pain may be reflected pain (e.g., dorsal ankle region for deep peroneal nerve). This is followed by hy-
Figs. 8A–8C. Drawings of the tibia and the fixator. (A) Once the valgus deviation has occurred, it can be corrected by the application of hinges. (B) Compression of the lateral side or distraction of the medial side will lead to tibial realignment. (C) In longer lengthenings, the application of an olive wire can be used to pull out the deformity. (Reprinted with permission from Catagni, M., and Villa, A.: Lengthening of the Tibia by the Ilizarov Method (Bulletin 3, ASAMI), Milan, Medi Surgical Video, 1988.)

Pseudesthesia, then by decreased muscle strength, and finally by paralysis. If treated early, paralysis should never occur. The treatment should emphasize increased physiotherapy and especially functional loading and weight bearing of the limb. The rate of distraction should be decreased or even stopped completely. There is usually no harm in stopping the distraction for several days to a week. The only problem that may arise is premature consolidation in bones such as the femur or the fibula. Distraction should then be restarted at a slower rate, 0.25 mm to 0.5 mm less than before. In the event of motor weakness or paralysis, the limb should be shortened to try to recover the situation. With the Ilizarov technique, one cause of distraction nerve injury is related to tenting of a nerve over a wire that previously was not disturbing the nerve (Fig. 11).

If a nerve injury occurs and particularly if it is pin related, decompression of the nerve at the level of its entrapment, such as at the fibular neck for the peroneal nerve, is a consideration. The rationale for this is to release the entrapment of the nerve, thus effectively lengthening the nerve and preventing tension from being exerted on that nerve until the extra slack from the release is taken up by the lengthening. The present author considers all intraoperative nerve injuries as true complications whether they recover during treatment or not.

On the other hand, distraction-related nerve dysfunction that recovers during treatment is considered a problem only. If a nerve is decompressed prophylactically, it is an obstacle. If any residual dysfunction remains at the end of treatment, it is considered a true complication.
FIGS. 9A AND 9B. For procurvatum deformity of the proximal tibia, the apparatus can be modified (A) so that the wire dropped off the ring is connected to a half ring that (B) can then be gradually pushed posteriorly to derotate the proximal fragment. (Reprinted with permission from Catagni, M., and Villa, A.: Lengthening of the Tibia by the Ilizarov Method (Bulletin 3, ASAMI). Milan, Medi Surgical Video, 1988.)

**VASCULAR INJURY**

Vascular injury may be related to the surgery or to the distraction. Damage to an artery or vein may result from a pin at the time of surgery. This rarely leads to problems because of the small diameter of the wires used. If the problem is recognized at the time of surgery, the wire should be removed and pressure applied to tamponade any bleeding. A rare complication that can result from perforation of both an artery and a vein simultaneously is an arteriovenous fistula. The proximity of a pin to a pulsating artery can result in late erosion with pseudoaneurysm formation.

Direct vascular damage can also result from the osteotome while performing the tibial corticotomy or the fibular osteotomy. The former usually leads to arterial injury while the latter usually involves venous injury. Displacement of these osteotomies may also be the cause of vascular damage. In all of these cases, simple compression will usually resolve the problem. Occasionally, a hematoma will form and may lead to a compartment syndrome. If this is recognized during surgery, prophylactic fasciotomy should be
ried out on the involved compartments. It is important to measure compartment pressures because stretch pain may be unreliable due to the presence of pins in the muscle compartment, leading to a false-positive examination. It is very unusual to get a compartment syndrome because of the subperiosteal nature of the tibial corticotomy.

As with any orthopedic procedure, deep-vein thrombosis is always possible, although in the present author’s experience, it has been very rare. It is difficult to recognize in light of the tendency toward edema of the limb postoperatively. The author knows of one case of fatal pulmonary embolism due to an acute manipulation of the tendo Achillis under anesthesia, and one case has been reported of a fatal embolism syndrome due to acute shortening after lengthening.7

Hypertension is a manifestation of distraction on the arteries.19,22 It is usually caused by too rapid a distraction or by excessive distraction. In the author’s experience, the latter may be seen more commonly in patients whose muscle-to-bone length is normal (constitutional short stature) rather than redundant, as in most limb-length discrepancies and achondroplasia.

Edema is a common problem during lengthening, particularly if the patient is active and walks a lot. It takes several months after removal of the apparatus until the edema finally disappears.

Any intraoperative vascular injuries as well as acute delayed pin-related vascular injuries are considered true complications. Similarly, deep-vein thrombosis, pulmonary embolism, and compartment syndrome are true complications. Hypertension and edema are considered problems.

PREMATURe CONSOLIDATION

This problem is most commonly diagnosed as a failure of the osteotomy to open after the initiation of distraction. The author believes that, in the majority of cases, the problem is an incomplete osteotomy rather

Fig. 10. Valgus deformity of the right tibia following a 7-cm double-level lengthening. The total treatment time was three months.

performed. If it is recognized postoperatively, clinical examination and pressure measurements should be performed to confirm the diagnosis. Urgent fasciotomy is car-
FIGS. 11A AND 11B. (A) An Ilizarov wire is shown (arrow) between the branches of the peroneal nerve (p). The deep peroneal nerve is tented over the wire. The superficial peroneal nerve is free of the wire. This patient developed a deep peroneal palsy. (B) The deep peroneal nerve became tented over the wire after distraction but showed no evidence of injury immediately following surgery. This patient’s earliest symptoms were referred pain in the first web space of her foot one month after the onset of lengthening. The wire was removed with subsequent resolution of the nerve palsy.

than premature consolidation. Premature consolidation, when it does occur, is usually due to an excessive latency period, allowing significant callus healing to block the distraction of the osteotomy. The wires can be seen to bow, with their convex sides facing each other on opposite sides of the osteotomy (Fig. 12). This problem also occurs during lengthening and is manifested as seizing up and failing to progress. This is most commonly seen in the femur, the fibula, and in conditions such as Ollier’s Disease.

Continued distraction can be carried out until the consolidated bridge of bone ruptures. The patient must be warned that this will be sudden, unexpected, and painful and that they may hear and/or feel a crack or a pop. To relieve their pain, they must back up the distraction by the number of millimeters of distraction that have been applied since the time the bone consolidated. If this is not done, a large diastasis may be created, predisposing to delayed or nonunion.

Alternatively, the patient may be taken to the operating room and under a brief general anesthetic have a closed rotational osteoclasis attempted. If this, too, is unsuccessful, then a repeat percutaneous corticotomy is performed. Attention should be paid to the possible massive bleeding that may result from cutting through regenerate bone. The use of a tourniquet is recommended.

Premature consolidation, if treated non-operatively, is considered a problem; if it is treated operatively, it is considered an obstacle. It is a true complication only if it causes the surgeon to quit lengthening prematurely.

DELAYED CONSOLIDATION

Delayed consolidation may be caused by a variety of factors. These can be divided into
technical factors and patient factors. The technical factors to consider are traumatic corticotomy, initial diastasis, instability, and too rapid distraction. The patient factors are infection, malnutrition, and metabolic.

To minimize the risk for delayed consolidation, the corticotomy should try to minimize the damage to the endosteum and periosteum. Translation of the osteotomy should be avoided. Frame instability will usually lead to delay in maturation of the regenerate new bone rather than delay in its initial formation. Instability should be suspected if the trabeculae seem to wander across the distraction gap rather than being all parallel and longitudinally oriented (Fig. 13). Proper tension in the wires should be checked and the construct should be biomechanically sound.

Patients who are malnourished may not be good candidates for this type of treatment. Patients with hypophosphatemic rickets are slow to form regenerate new bone (Fig. 14). Infection should be suspected when the cause of delay in regeneration cannot be explained by any other means.

Delay in regeneration is diagnosed by the delayed onset of regenerate new bone on plain roentgenograms. When it occurs after regenerate bone has already formed, it is manifested as a widening of the interzone between the proximal and distal trabeculae. Since it is difficult to see the regenerate new bone under these conditions, the author has resorted to ultrasound in the early phases of regenerate bone formation. The ultrasound will detect new bone formation as early as two weeks after the onset of distraction. This is extremely predictive for delayed consolidation (Fig. 15).

If delayed consolidation occurs, it should

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Fig. 12. Premature consolidation of the tibia. A double-level lengthening of the tibia is shown with premature consolidation of the proximal corticotomy. The distal corticotomy is shown to be lengthening appropriately. The latency period in this boy was 14 days. Early callus union can already be seen lateral to the proximal corticotomy. The wires are bowing, indicating the distraction being applied to the proximal corticotomy (arrowheads). With continued distraction, the corticotomy suddenly gave way three weeks after distraction began. This was followed by immediate pain. The distraction was backed up 1 mm for each day of distraction. Distraction was then begun anew the following day.
On occasion, there have been cystic changes within the regenerate bone on ultrasound. When this occurs, it is difficult to recover the situation, so bone grafting may be necessary (Fig. 16). Allo- or autograft can be considered to fill the distraction gap according to the methods of Wasserstein or Wagner, respectively.

In adults, the final maturation of the new bone with sufficient neocorticalization to allow removal of the apparatus takes a significant amount of time (Fig. 17). On several occasions, this has been due to loosening of the apparatus within the bone. If this happens, the apparatus can be removed if the bone is thought to be sufficiently strong that it will not shorten in a cast brace. Alternatively, new pins can be inserted and the old ones removed. Delayed consolidation treated nonoperatively is a problem. If treated by the addition of more pins, it would be considered an obstacle. If treated by bone grafting, it would be a true complication.

**PIN-SITE PROBLEMS**

Pin-tract problems are related to pin–skin motion, the amount of soft tissue between skin and bone, and the diameter of the pin used. Maintaining adequate wire tension is important in order to minimize the pin–skin and pin–bone motion. Applying pressure to the skin stabilized to the pin is another useful method. This can be accomplished by using gauze compressed by rubber stoppers or by using cubicle foam sponges pushed down with plastic clips, which is the author’s preference. The foam sponge also acts as a barrier between the air and the skin. Antiseptic or antibiotics can be applied to the sponge.

Pin-tract problems always develop from outside to inside. They start with soft-tissue inflammation, leading to soft-tissue infection and finally to bone infection. Based on this, the author has developed a simple classification for pin-tract problems. Grade 1: soft-tissue inflammation; Grade 2: soft-tissue infection; and Grade 3: bone infection. Since

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**Fig. 13.** Poor bone consolidation due to instability and too rapid distraction. Note the wandering nature of the trabeculae. Under stable conditions the trabeculae are all parallel. The interzone between the trabeculae is wide and irregular. This type of distraction gap needs to be recompressed and then redistracted in order to avoid delayed consolidation (accordion maneuver).
FIGS. 14A AND 14B. Lengthening and correction of deformities through two levels in a five-year-old boy with hypophosphatemic rickets. (A) There is a paucity of new bone formation seen in the two distraction gaps on this lateral roentgenogram of the femur. (B) In order to stimulate the distraction gaps to consolidate, recompression of both gaps was performed. This led to rapid consolidation at both levels as shown on the AP and lateral roentgenograms of the femur.

Grade 3 is the only serious infection if the problem is headed off at Grade 1 or Grade 2, it will not lead to a bone infection.

For Grade 1 pin tracts, the modalities used are incorporating local antiseptic or antibiotic and ensuring proper wire tension. Once there is soft-tissue infection present, defined as the drainage of purulent material from the pin site, the site may be injected with an antibiotic solution of 100 mg/mL of cefazolin. This is injected radially around the pin site from within the tract. This will melt away the pin-tract infection within 24 hours in most cases. The drawback is that it is a rather painful technique. It is preferable to use oral antibiotics quite liberally at the slightest hint of a Grade 2 pin-tract infection. A one-week course will resolve almost any pin-tract infection.

Recalcitrant infections, infections around wires that pass through joints, and cellulitis around a pin site are treated by removal of the offending wire. If the wire is important for structural stability, it will need to be replaced. For this reason, the present author usually inserts an additional wire so that one could be removed.

Pin-tract infections treated by local measures, antibiotics, or even pin removal are considered problems. If the addition of a new
FIGS. 15A - 15C: (A) This malunion of the tibia with shortening was treated by a corticotomy followed by acute correction of the lateral translation deformity of the tibia through the level of the old malunion. Unfortunately, the diastasis between the bone ends at the time of surgery went unrecognized. (B) Longitudinal ultrasound scan of distraction gap. The proximal tibia is seen as the black hypoechic region on the left, while the distal tibia is seen as the black hypoechic region on the right. The distraction gap is the striated region between these two black regions. New bone formation appears as white hyperechic regions. There is bridging bone formation seen posteriorly but minimal to no bone formation seen throughout most of the distraction gap. There are a few trabeculae seen at the edge of the cortical ends. Most of the interposing region is seen as gray, indicating lack of new bone formation. (C) After several cycles of compression followed by distraction, the interposing region was stimulated to consolidate. Notice the snow storm appearance of new bone formation throughout the distraction gap. Longitudinal trabeculae are now seen bridging between the proximal and distal bone ends.
Figs. 15A–15C. (A) This malunion of the tibia with shortening was treated by a corticotomy followed by acute correction of the lateral translation deformity of the tibia through the level of the old malunion. Unfortunately, the diastasis between the bone ends at the time of surgery went unrecognized. (B) Longitudinal ultrasound scan of distraction gap. The proximal tibia is seen as the black hypoechoic region on the left, while the distal tibia is seen as the black hypoechoic region on the right. The distraction gap is the striated region between these two black regions. New bone formation appears as white hyperechoic regions. There is bridging bone formation seen posteriorly but minimal to no bone formation seen throughout most of the distraction gap. There are a few trabeculae seen at the edge of the cortical ends. Most of the interposing region is seen as gray, indicating lack of new bone formation. (C) After several cycles of compression followed by distraction, the interposing region was stimulated to consolidate. Notice the snow storm appearance of new bone formation throughout the distraction gap. Longitudinal trabeculae are now seen bridging between the proximal and distal bone ends.
FIGS. 16A AND 16B. (A) Longitudinal ultrasound scan of a distraction gap in the proximal tibia. The black regions on either side are the cortical ends. The black region delineated by four x's is a large fluid-filled cyst in the distraction gap. Its dimensions are indicated below as 20.5 mm x 30.1 mm. (B) Despite recompression and distraction, no new bone formation was achieved, necessitating bone grafting of the distraction gap. This 3 cm of lengthening took 44 weeks to consolidate. Note the difference in the appearance of graft bone consolidation with its trabeculae oriented in all directions, as compared to the organized parallel new bone formation of distraction osteogenesis.

If a pin is required, it is considered an obstacle. Any true bone infection is considered a complication.

REFRACTURE

Refracture occurs after removal of the apparatus and, therefore, is always a true complication. It may be seen as gradual axial deviation of the bone due to incomplete healing (Fig. 17), as a complete fracture, or as buckling of the bone with some loss in length (Fig. 18). Refracture can best be avoided by careful analysis of the regenerate bone in the distraction gap prior to removal of the apparatus. This bone should have an even consistency with evidence of neocorticalization and opacity similar to its surrounding bone. A favorite saying is, “It is better to remove the apparatus one month too late than one minute too early.”

Refracture should be treated with either a cast or reapplication of the apparatus, depending on the particular case.

Osteoporotic stress fractures of the bone may occur through a normal level. This is due to marked osteoporosis that may develop due to lack of weight bearing, the hypertrophic response to distraction, pain, and reflex sympathetic dystrophy.

All refractures are considered true complications. Those leading only to a buckle fracture (Fig. 18) and loss of less than 1 cm of length or less than 5° of angulation are considered minor. Those leading to greater than 1 cm length loss or greater than 5° angulation are considered major.

JOINT STIFFNESS

Joint stiffness is also a late complication. This occurs due to persistent muscle contractions and is a stiffness of the muscle origin. It is best prevented during the distraction period by active or passive muscle stretching. Once joint stiffness is established, it is best treated by manipulation and offloading.
Figs. 17A and 17B. (A) Lateral roentgenogram of distal femur following double-level lengthening of the femur in this 40-year-old man. The proximal distraction gap consolidated without difficulty while loosening of the wires within the bone led to instability of fixation of the distal femur and poor consolidation of the distal distraction gap. This resulted in pain and instability. The apparatus was removed and the patient was placed into a hip spica. (B) Poor compliance with failure of the patient to return for scheduled follow-up evaluation resulted in a procurvatum malunion of the femur.

Joint due to the increased pressure on the joint surface during lengthening. The latter is a theoretical consideration but is a concern for the long term since no one yet knows what the effect of this temporary increased pressure on articular cartilage will be.

If a joint is suspected of being a high risk for residual stiffness and the apparatus is still on, the apparatus can be extended across the joint if it is not already, and the joint can be distracted 5 mm. The apparatus can then be used to mobilize the joint prior to its removal.

All joint stiffness is considered a true complication; the severity of the complication depends on the functional limitation created. Obviously, 15° loss of knee extension and ankle dorsiflexion is much more serious than a 15° loss of knee flexion and ankle plantarflexion.

OTHER PROBLEMS

Pain is the most common complaint during limb lengthening. Surgical pain may be quite intense the first few days postoperation. Contraction of any muscle transfixed by pins is initially painful but resolves within a week or two. The amount of pain obviously increases with the number of osteotomies. Therefore, a double-level lengthening of the tibia that involves a total of four osteotomies (fibula and tibia) may be very painful the first day. It is easy to misinterpret this as a compartment syndrome in one’s first double-level tibial lengthening and to perform fasciotomies.

During the distraction phase of lengthening, a chronic dull aching pain is often experienced. This varies from patient to patient. It is more common with longer lengthenings and especially with double-level lengthenings. It is more common with fixation and splinting of the joints above and below the lengthening segment. The probable cause is most likely the stretching of the muscles and nerves. The pain, while present at all times, is usually only noticed at night and during physiotherapy and walking. While the pa-
Fig. 18. Bilateral AP roentgenograms of distal tibia following lengthening and correction of supramalleolar deformities. The apparatus was removed prematurely and resulted in a buckle fracture of the left tibial distraction gap. Note how on the right tibial distraction gap there is insufficient new corticalization to allow unprotected weight bearing. This resulted in a 1-cm loss of tibial length.

tient is occupied during the day, the pain is not noticed very much. However, at night without other outside sensory input, the pain is quite intense and frequently interferes with the patient’s sleep. The author recommends that the patient go to sleep while listening to music. For pain, the author prescribes acetaminophen with codeine derivatives and avoids oxycodone derivatives due to their increased tendency to produce dependency in susceptible individuals. The author also prescribes sleeping medication if necessary. Splinting the knee in extension at night leads to increased difficulties with sleep. With the use of the Dynasplint, this has been lessened as compared to the splints that did not allow knee flexion. When the degree of pain is not well tolerated by the patient, the rate of lengthening should be decreased by 0.25 mm at a time. This is usually enough to decrease the pain. It is also a good idea to stop lengthening for one day every three to four weeks.

Another common symptom is loss of appetite and weight. This resolves after the distraction period is over. Depression also occurs in some patients but responds well to the temporary use of antidepressants. The pain, loss of appetite, and depression during lengthening usually resolve spontaneously one week after stopping the distraction.

MATERIALS AND METHODS

Forty-six patients two to 54 years of age were treated by the Ilizarov method of limb lengthen-
ing with or without simultaneous correction of deformity. A total of 60 limb segments were lengthened: 40 tibiae, 12 femurs, four radii, one humerus, and three feet. Twelve were in adults and 48 were in children. The indications for lengthening are listed in Table 1. The minimum follow-up period was six months; the maximum follow-up period was two years.

RESULTS

The lengthenings ranged from 1 to 16 cm, with a mean of 5.6 cm. There was a significant difference in the healing time between children (defined as under the age of 20 years) and adults. The other variables that significantly affected the lengthening index (total treatment time per centimeter of lengthening, usually expressed as months per centimeter), were single- versus double-level lengthening and the treatment of coexisting deformity. Children with single-level lengthening and no deformity had an index of 0.97 mo/cm; children with a deformity had an index of 1.2 mo/cm. Children with a double-level lengthening and no deformity had an index of 0.57 mo/cm, and with a deformity, 0.9 mo/cm. Adults with a single-level lengthening had an index of 1.7 mo/cm; and with a double-level lengthening, 1.1 mo/cm.

There were 35 problems that needed to be resolved in the outpatient clinic during the treatment: 20 pin infections (13 patients), ten axial deviations, two premature consolidations, two delayed consolidations, and one knee subluxation. There were 11 obstacles during lengthening that required surgical intervention: two pin infections, one pin cut out, two axial deviations, one premature consolidation, two incomplete corticotomies, two incorrect constructs, and one bone cyst.

There were a total of 28 true complications, of which 17 were considered minor and of little significance. The minor complications were three axial deviations (<5°), three contractures (recovered), four sensory nerve injuries (recovered), a length loss of 1 cm in three, two delayed consolidations, one pseudocompartment syndrome, and one hematoma. Nine complications were considered major complications, of which only three affected the achievement of the original goals. The major true complications were one reflex sympathetic dystrophy, one equinus, one nonunion, two late bowing, and four motor palsy. Of the true complications, seven were a direct result of surgical injury intraoperatively: three motor nerve injuries, three sensory nerve injuries, and one hematoma.

Of all these problems, obstacles, and complications, the only significant residual were one bowing of the distal femur of 25° in the plane of motion of the knee, one recurrent varus deformity of the tibia, and one nonunion of an ankle arthrodesis lengthening. All three cases were adults. The mistake in all three cases was premature removal of the apparatus with inadequate postremoval protec-

<table>
<thead>
<tr>
<th>Indication</th>
<th>No. Cases</th>
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<tbody>
<tr>
<td>Arthrogryposis</td>
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<tr>
<td>Blount's disease</td>
<td>1</td>
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<tr>
<td>Club foot</td>
<td>3</td>
</tr>
<tr>
<td>Congenital pseudarthrosis</td>
<td>6</td>
</tr>
<tr>
<td>Congenital short femur</td>
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<tr>
<td>Congenital short tibia</td>
<td>5</td>
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<tr>
<td>Dysplasias</td>
<td></td>
</tr>
<tr>
<td>Achondroplasia</td>
<td>1</td>
</tr>
<tr>
<td>Chondroectodermal dysplasia</td>
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<tr>
<td>Hypochondroplasia</td>
<td>1</td>
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<tr>
<td>Metaphyseal dysplasia</td>
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<tr>
<td>Mesomelic dwarfism</td>
<td>1</td>
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<tr>
<td>Growth arrest</td>
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<tr>
<td>Postinfectious</td>
<td>2</td>
</tr>
<tr>
<td>Posttraumatic</td>
<td>5</td>
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<tr>
<td>Madelung's</td>
<td>1</td>
</tr>
<tr>
<td>Meningococcemia</td>
<td>1</td>
</tr>
<tr>
<td>Nonunion</td>
<td>2</td>
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<tr>
<td>Ollier's</td>
<td>3</td>
</tr>
<tr>
<td>Perthes'</td>
<td>1</td>
</tr>
<tr>
<td>Polio</td>
<td>2</td>
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<tr>
<td>Posttraumatic</td>
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<tr>
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<tr>
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<td>Streeter's</td>
<td>1</td>
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<tr>
<td>Thalassemia</td>
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tion. In all three cases the apparatus had loosened and no longer controlled the bone ends. Instead of reinserting new wires for stabilization, the apparatus was removed, and a plaster cast was applied for a short period of time. Had the wires been reinserted and tensioned, better fixation would have been achieved, allowing better maturation of the regenerated bone.

The only true nonunion in this series resulted from a simultaneous lengthening of a proximal tibial corticotomy and a tibiotar arthrodesis site. Both produced excellent bone, but too early removal of the apparatus resulted in a nonunion of the tibiotar arthrodesis. It is probably better to avoid lengthening through an arthrodesis site. All but one of the other patients healed by distraction osteogenesis consolidation. One patient mistakenly distracted at 4 mm instead of four 0.25-mm/day and developed a bone cyst that had to be bone grafted. This consolidated without difficulty.

Residual stiffness of joints is the only complication that was not well assessed in this study. Most patients had fully recovered their range of motion at the knee and almost fully recovered their range of motion at the ankle at the time of review, frequently with a residual 5°–10° loss of dorsiflexion and complete return of plantar flexion. Longer follow-up study is necessary to give a complete assessment of this late complication. The other minor or major complications resolved spontaneously, while one equinus contracture had a tendo Achilles lengthening. For example, the peroneal tendon and knee contractures recovered with physiotherapy.

Delayed consolidations were all treated by plaster casts and functional braces. The motor and sensory nerve injuries completely resolved spontaneously. In one peroneal nerve injury from a wire at the start of an extensive limb lengthening, a prophylactic decompression of the peroneal nerve at the fibular neck was performed to allow the lengthening to proceed without applying early tension on the traumatized nerve. This nerve went on to recovery of the tibialis anterior and extensor digitorum muscles and partial recovery of the extensor hallucis longus. In the same patient, at the distal end of that nerve, the sensory branch to the first web space had been speared by a wire and was explored and severed during the attempt at removal of the wire. This caused no significant sensory deficit or neuroma to the patient. The only reflex sympathetic dystrophy occurred after a still-unexplainable radial nerve palsy that occurred during correction of a Madelung's deformity. This, too, spontaneously resolved. There were no true compartment syndromes diagnosed in this series. However, in the first patient the author operated on, displacement of the tibia during corticotomy led to probable laceration of a branch of the anterior tibial artery and a hematoma in the anterior compartment of the leg. This was recognized intraoperatively, and a prophylactic fasciotomy was performed. In the first double-level tibial lengthening in this series, severe postoperative pain in the leg was misdiagnosed as a compartment syndrome due to erroneous compartment pressure measurements. It was clear at the time of fasciotomy that no compartment syndrome existed. In both of these cases, the skin of the fasciotomy incisions was closed secondarily two weeks after decompression without skin grafting. In three patients, buckle fractures occurred after removal of the apparatus, leading to 5–10 mm loss of length. No true refractures other than the buckle and late bowing cases were seen. The original goals of treatment were achieved in 57 of 60 limb segments. Complete patient satisfaction was achieved in 45 of 48 patients, and partial satisfaction was achieved in the remaining three. All three were adult patients.

DISCUSSION

This study has attempted to analyze the difficulties that arise from limb lengthening by the Ilizarov method. Problems that arose during lengthening that were resolved by op-
REFERENCES


