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# A One-wire Method for Anatomic Reduction of Tibial Fractures with Ilizarov Frame

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**Abstract** Traditional external fixator techniques do not always correct minor residual malalignment. We asked whether using a one-wire method that corrects minor malalignment with an olive traction wire placed in the plane of the deformity allowed (1) uniform healing, (2) proper alignment, and (3) adequate reduction of fracture gaps. We retrospectively evaluated 72 patients in whom we used closed tibial fracture reduction using a circular external frame. We identified the plane of the residual deformity after alignment on a traction table using a C-arm. In this plane, the final correction was performed with traction through an olive wire. Satisfactory alignment (less than 3° deviation from normal) was obtained in 68 of the 72 patients (94%), and satisfactory reduction (gaps less than 2 mm) attained in 51 (71%). In no case was the fracture site opened surgically. Four patients underwent additional alignment correction with conical washers outside the operating room but no other efforts were needed to obtain further reduction after the initial surgery. Fractures healed in an average of 20 weeks. We observed no major infections. The Ilizarov frame has been a valuable tool to achieve alignment and anatomic or near anatomic reduction of closed tibial fractures.

**Level of Evidence:** Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

## Introduction

The anatomic reduction of fracture is a goal of internal and external fixation. In contrast to external fixation, open methods for fracture reduction typically violate tissues in such a way as to interfere with the normal biological repair processes. Different methods of closed reduction of tibial fractures with circular external frames have been proposed [3, 9, 12, 13]. Circular frame techniques include adjustments of the frame itself to achieve maximal alignment, or adjustments of the wires or pins. These manipulations can be computer-assisted and performed with oblique bars as with the hexapod system of the Taylor spatial frame. With the traditional Ilizarov device, usually the proximal and the distal ring are placed parallel to articular surfaces, fixation blocks are constructed as separate units and then assembled with straight bars or with universal hinges. Because the bone fragments are usually not in the same position with respect to the plane of the facing rings of the circular blocks, connecting the two blocks with conventional bars can introduce translational and rotational forces that prevent accurate reduction. Hexapod computer-assisted techniques can aid in the reduction. However, we believe the application of any external fixation system should be preceded by manual reduction and the fixator must be placed when the extremity is aligned with a distraction system [9]. These principles of correction are

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well-established and described in the literature [1, 3, 9]. Once the frame is in place, any residual minor malalignment may then be corrected.

We determined whether using a one-wire method that corrects minor malalignment with an olive traction wire placed in the plane of the deformity allowed (1) uniform healing, (2) proper alignment, and (3) adequate reduction of fracture gaps.

## Materials and Methods

We retrospectively reviewed 72 patients with 72 extraarticular closed tibial fractures treated with an Ilizarov circular external fixator (Plustek, Assago, Italy) from August 1995 to July 2006. There were 50 men and 22 women with a mean age 47.6 years (range, 15–77 years). According to AO classifications [10], nine fractures were metaphyseal proximal (4.1A: A2: three patients, A3: six patients), 29 diaphyseal (4.2: A2: four patients, A3: one patient, B1: two patients, B2: two patients, B3: one patient, C1: 10 patients, C2: seven patients, C3: two patients), and 34 metaphyseal distal (4.3A: A1: thirteen patients, A2: twelve patients, A3: nine patients). The minimum clinical and radiological followup was 3 months after frame removal (average, 6 months; range 3–25 months). Seventy-one of 72 patients were followed to the end of treatment. The one patient was lost to followup after moving to another country with a fracture in frame at 2 months without complications.

We first aligned the fractures on a traction table (Fig. 1A), trying to achieve reduction and eliminate rotational and translational displacements and with a light overlengthening. In midshaft fractures, we inserted a sterile traction pin across the calcaneus in a slightly oblique direction (superolateral to inferomedial) in the frontal plane. This maneuver was intended to generate a varus moment when traction was applied to avoid the general tendency of these fractures to malalign in valgus due to tensioning of the interosseous membrane. We placed horizontal reference wires in the distal and proximal metaphysis, and the circular frame was assembled in an orthogonal manner to manipulate the fracture (Fig. 1B–C) [9].

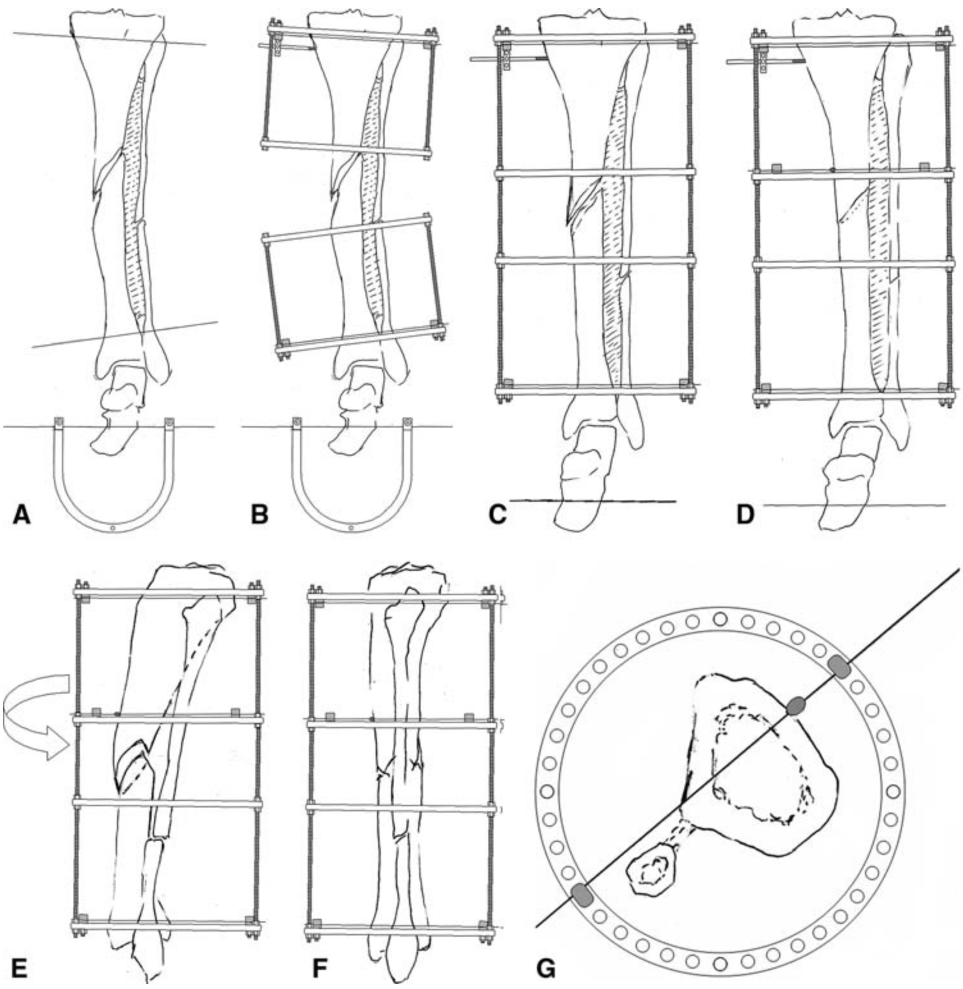

**Fig. 1A–G** (**A**) Reduction sequence in the frontal plane. Good alignment is achieved through correctly positioning the leg on the traction table. (**B**) Two Ilizarov blocks have been attached to the proximal and distal tibia. (**C**) The two Ilizarov blocks have been connected; residual minor malalignment is corrected with an olive wire in the (**D**) AP view and (**E**) axial view. (**F**) Identification of the plane of the residual deformity can be performed rotating the C-arm around the fracture until the deformity disappears; usually this plane is that of the interosseous membrane. (**G**) Illustration shows the final correction.

Reference wires were undertensioned (65 kg) and each associated with one half pin on the same ring, free to rotate on its axis with respect to a Rancho universal cube (Smith & Nephew, Plustek) [8], a multiholed cube that connects 5- or 6-mm external fixator half pins to the rings. As an alternative, the distal reference wire was associated with a second 65-kg tensioned wire in some instances. Once axial rotational and translational deviations have been eliminated, based on trigonometric principles, any residual malalignment is in a single plane. With a C-arm, we rotated the tibia to identify the plane in which the deformity disappears: this plane is the plane of the residual deformity and is the correct plane in which to place the olive wire (Fig. 1D–E). Usually this was the plane of the interosseous membrane. The C-arm was then placed in the orthogonal plane and a correcting force introduced through tensioning of the olive wire. In simple shaft fractures, the corrective force was directed on the proximal segment, and usually the olive wire was placed on the anteromedial tibial cortex due to the frequent valgus tendency of the shaft fractures of the tibia. An opposing olive wire was placed in some cases on the other bone segment to generate a counterforce to avoid overcorrection. Once reduction was achieved and the olive wire blocked on the ring, the fracture distraction was reduced to eliminate overlengthening, the reference wires were tensioned to 130 kg, and the half pins blocked on Rancho cubes (Fig. 1F). The fixation was completed with one more half pin on the proximal ring and wires and half pins on the two rings proximal to the fracture site. In multisegmental fractures, more rings were employed and each deformity level aligned with the same method (Fig. 1G).

Reduction and alignment of the fracture on standard postoperative radiographs were evaluated by the authors. If malalignment was suspected, we obtained long-standing radiographs of both legs with the knees extended and the patellae facing forward.

Pin site infection was diagnosed according to the criteria proposed by Davies et al. [5]. These criteria were: "the pin site was painful, inflamed, and discharging with a either a positive culture or a response to antibiotics in the absence of a positive culture."

We (GL, LB) assessed healing with radiographs focused at the fracture level: from the 60th day after surgery we obtained oblique views in addition to anteroposterior and lateral views to evaluate the uniformity of the callus formation circumferentially. When callus was observed in two or more planes, we asked the patients to open the nuts of one of the four bars at the fracture level and to change daily the level of the dynamization in a clockwise protocol: the purpose was to increase incrementally the mechanical stresses on the different axial quarters of the callus circumference. We based our decision to remove the frame on clinical and radiographic considerations. The presence of callus on the three cortices, documented with standard and oblique radiographs, was the radiographic criterion for frame removal. When three cortices of bone callus were evident on radiographs we instituted a "full open test", usually 4 weeks after initial dynamization. This test consisted of opening all the nuts 3 mm at the level of the junctions of the bars with the rings facing the fracture, then asking the patient to stand on the affected side only. If this test did not produce pain or any movement at the level of the junctions of the bars with the rings, we judged the consolidation mechanically stable enough to remove the frame and the fracture healed.

Based on our experience, we believe the bar-ring connection in a circular frame permits assessment of movements of 1 mm or slightly less. If after 4 weeks of dynamization we observed such persistent movements between rings at the level of a bar-ring connection during the full open test, we presumed the callus was mechanically weak and the bar was subsequently excluded from dynamization.

On final evaluation of the radiographs, we considered alignment within 3° of anatomic as satisfactory. Fracture caps were deemed adequately reduced if less than 2 mm in maximum width.

In one patient with distal tibia extraarticular fracture, we observed a loss of reduction (consolidation in 8° varus) after early frame removal (15 weeks). This patient was excluded from the study because in this particular case the abovementioned strict criteria for removal were not respected.

## Results

Consolidation occurred in all 71 patients. We encountered no major soft tissue complications, deep infections (those requiring débridement), or need for subsequent bone grafting or use of bone substitutes. At least one level of pin site infection occurred in nine patients. In each patient the infection resolved with local antiseptics or antibiotics. The frame was removed after a mean of 20 weeks (range, 10–38 weeks). It was removed after 17 weeks (range, 10–22 weeks) in the proximal fractures, 22 weeks (range, 12–38 weeks) in diaphyseal, and 20 weeks (range, 12–34 weeks) in distal metaphyseal fractures. In the three patients with nonanatomic reduction, the frame was in place for 38, 22, and 26 weeks.

Alignment was within 3° of the mechanical axis in 68 of 72 patients. For patients with proximal tibial fractures (AO 4.1) all nine were within 3° of the mechanical axis. For those in the diaphysis (AO 4.2) 26 of 29 were within 3° and for those in the distal tibia (AO 4.3) 33 of 34 were within

3°. In four of the 72 patients, alignment was between 3° and 6° (proximal tibia none of nine patients; diaphyseal tibia three of 29; distal tibia one of 34). In those four patients, alignment was corrected in the postoperative period with use of conical washers. At last followup we observed no loss of alignment after removing the frame.

Reduction gaps were less than 2 mm in 51 of 72 patients (proximal tibia six of nine patients; diaphyseal 17 of 29; and distal 28 of 34). The gap was between 2 and 5 mm in 18 patients (proximal tibia three of nine patients; diaphyseal 10 of 29; and distal five of 34). The gap was more than 5 mm in three patients (proximal tibia 0 of nine; diaphyseal two of 29; distal one of 34). No correction of nonanatomic reductions was performed in the postoperative period unless associated with malalignment.

## Discussion

Circular external fixation can control the alignment of tibial closed fractures, but an almost anatomic reduction, reducing gaps between fragments, could be useful in accelerating the consolidation process and consequently reducing patient in-frame time. We asked whether a one-wire method that corrects minor malalignment with an olive traction wire placed in the plane of the deformity allowed (1) uniform healing, (2) proper alignment, and (3) adequate reduction of fracture gaps.

One limitation of our study is that we did not obtain a long standing radiograph in all patients to evaluate alignment; only those in whom the malalignment was evident on standard radiographs. In addition, we did not use an independent reviewer of radiographs although we recognize there is some degree of interobserver variability in assessing alignment and fracture gaps. Thus, we may have underestimated the number of patients with minor malalignment. Second, the fracture gap determination method we used, ie, distance between cortices of different segments, is subject to projection error due to overlapping of cortices on different planes. To minimize this bias we used oblique in addition to standard radiographs. Third, we could not ascertain whether anatomic or nonanatomic reduction influenced healing time because the large majority of patients had an anatomic or near anatomic reduction. Fourth, we assessed the uniformity of healing with standard and oblique radiographs, but we adopted no method to quantify the results and did not consider any interobserver variability in interpreting healing. All patients seemingly healed within 20 weeks in the frame; the absence of subsequent loss of correction or refracture after frame removal suggests all fractures ultimately healed. However, while all fractures healed, an assessment of the time of healing could be influenced by the variability in establishing healing so we cannot ensure the healing time we report is accurate. We considered a Tc scan of the healed fractures unethical due to the excessive amount of radiation exposure. Our healing times could also be influenced by the strict removal protocol adopted, which included a periodic increase in mechanical stimulus in the late phases the frame was in place. We have typically maintained the frame for 20 weeks. This period is longer than that reported by other authors using circular external fixation for closed spiral and oblique fractures of distal tibia [6]. However, that series and ours had differing distributions of fractures and that could explain these differences since we had nine AO A3 comminuted fractures in our 34 extraarticular distal tibia fractures, but the other series had a mixed group of extra- and intraarticular fractures without comminution.

Sixty-eight of our 72 patients with closed extraarticular tibia fracture had an angular deformity less than 3° at followup, and all patients had an angular deformity less than 3° at a minimum of 3 months after frame removal. The favorable results of circular external fixation in terms of limb alignment in treatment of tibia fractures have been confirmed by others [6]. We found extrinsic distraction and anatomic ring placement effective for obtaining good axial alignment of the fracture, with subsequent need for only minor corrections.

There are a number of strategies for reducing tibial fractures with circular external fixation. The reduction procedures can require extrinsic or intrinsic distraction, manipulation blocks, universal hinges, and hexapod computer-assisted bars [9, 11, 12]. Data on radiographic results comparing those techniques are, to our knowledge, limited. The hexapod computer-assisted technique has been used in a study on 16 patients, of whom five had displaced tibia fractures [9, 12]. The system resulted in angular deformities less than 5° in four of the five cases. After reduction the authors made measurements of residual displacements between the central axes of the proximal and distal bone fragments on AP and lateral projections. No data about followup after frame removal were presented. The hexapod computer-assisted systems have theoretical advantages with conventional Ilizarov frames with respect to a favorable learning curve, avoidance of time-consuming planning [12], and relatively little dependence on surgeon experience. The hexapod technique, however, has some limitations: the minimal frame height is higher compared to conventional frames, ie, hexapod bars cannot be applied between rings separated by short distances, and the potential for correcting angulation and shortening is accordingly less [11]. The hexapod has more power to correct translational and rotational deformities [11], but deformations of the involved soft tissues, especially with regard to shear stresses during translation [12], must be considered.

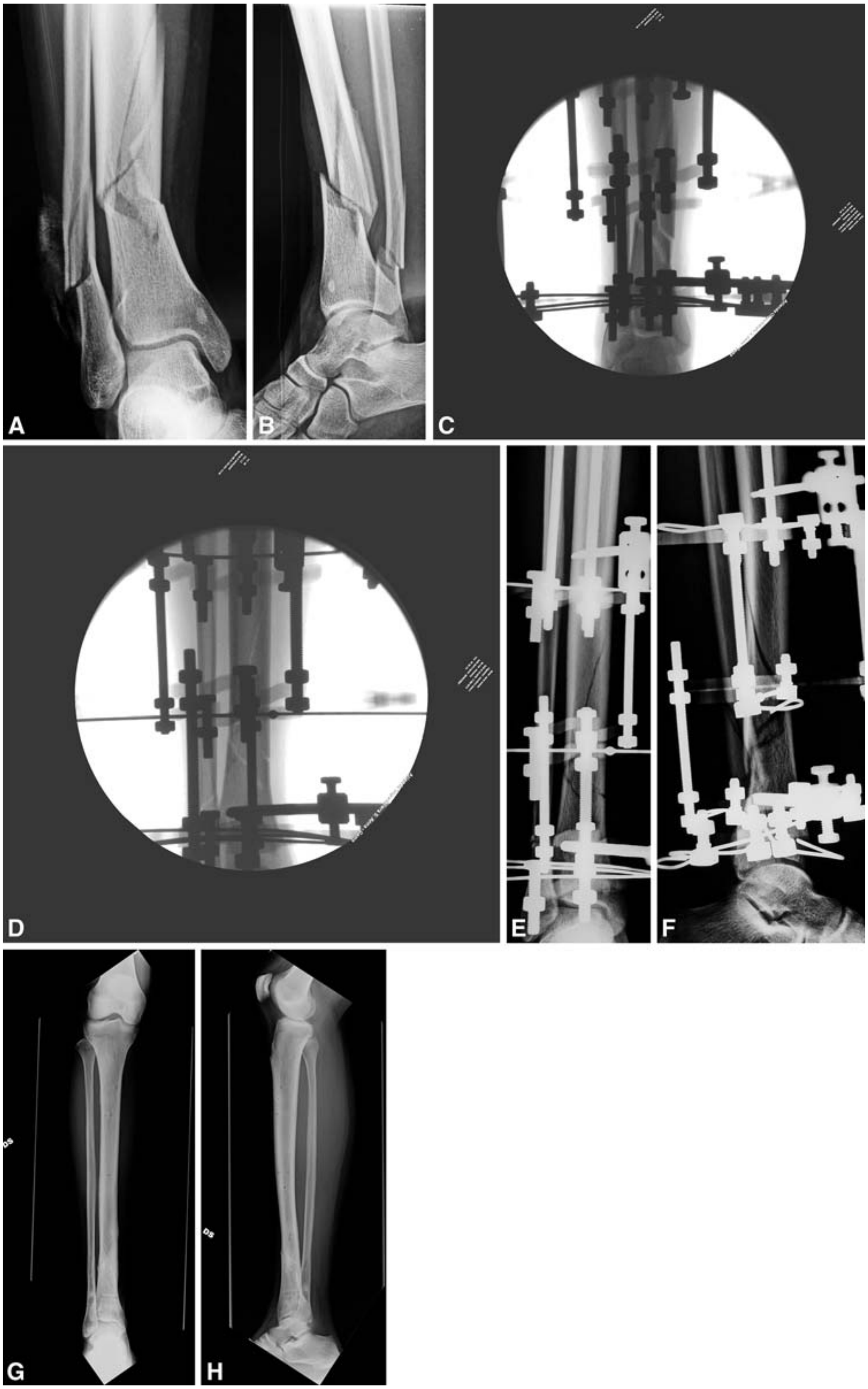

**Fig. 2A–H** The case of this 28-year-old female patient illustrates how distraction angulates a fracture in varus malalignment prior to traction into valgus and how the olive wire reduces the fracture. Paraarticular spiral fracture of distal tibia with two large free fragments. Varus malalignment. (**A**) AP and (**B**) lateral views. (**C**) Intraoperative C-arm control, anteroposterior view. The traction angulates the fractures into a valgus attitude, due to interosseous membrane tensioning. (**D**) Intraoperative C-arm control, anteroposterior view after the "one olive wire" maneuver. The fracture is reduced. Postoperative radiographs in (**E**) anteroposterior view confirm intraoperative reduction and in (**F**) lateral view show some limit of reduction of the inferior apex of the posteromedial fragment could be attributable to soft tissue interposition. Same patient is shown (**G**) 1 month after frame removal after in frame time of 22 weeks. (**H**) The lateral view is shown.

The importance of anatomical placement of proximal and distal fixation rings has been emphasized [9, 13]. If those rings are not placed anatomically, ie, parallel to articular surfaces, hinges or hexapod bars can allow reduction, but the rings are not aligned on the tibial axis, with subsequent axial compression and distraction that could interfere with the late phase of callus healing [4].

Postreduction fracture gaps seem to influence healing. A gap over 3 mm has been associated with risk of nonunion in 162 patients following intramedullary nailing of closed or grade I open fractures of the tibia [7]. The three patients in our study with fracture gaps over 5 mm had a period in-frame longer than the average, and one of them had the longest in-frame time (38 weeks), but no conclusion can be drawn from these limited numbers.

Many Ilizarov techniques have been proposed for these adjustments, and include hinges, olive wires, arch wire, half pin rotation or pulling and traction techniques [9]. In contrast to the number and complexity of these reduction maneuvers, little variation in the direction of displacement of fragments are usually observed. In a study of 192 spiral fractures of the shaft of the tibia [2], the proximal tibial fragment is reportedly always medial and anterior to the distal and an increased space between the proximal tibia fragment and the shaft of the fibula in the plane of the interosseous membrane has been documented. These data are in complete concordance with our findings. We found in the great majority of cases tensioning of the interosseous membrane related to the extrinsic or intrinsic distraction and led to a valgus malalignment (Fig. 2A–D). Interosseous membrane does not lie on a frontal plane, but in an oblique plane due to the posterolateral location of the fibula. The ligamentotaxis, in the particular case of this anatomic structure, does not produce complete alignment. As distraction progresses, the membrane does not elongate and a deformity on the plane of the interosseous membrane is produced.

If the plane of the residual deformity is not properly identified, however, any correction can generate a new deformity. Once this plane has been identified, deciding which of these techniques to employ is dependent on surgeon experience and on the limits of the technique. Arch wire techniques to correct deformities utilize the translational force generated when a wire is bent when connected to the ring and then tightened; the force generated pulls the bone in a direction that is perpendicular to the concavity of the bent wire. Arch wire techniques, however, do not allow corrections laying entirely in the frontal plane: the arch must be in the sagittal plane to drive the correcting force in the frontal plane, but this position of the wire is unsafe for anatomical considerations. For similar reasons, olive wire techniques cannot be employed in corrections limited to the sagittal plane because the olive wire generates correction forces that have the same direction of the pulled olive wire. However, minor misalignments after distraction usually are in the oblique plane of the interosseous membrane and can be resolved with both olive wire and arch tensioning wire techniques. We prefer the olive wire technique because at the end of the correction, the wire can be blocked on the ring on the olive side and then fully tensioned to 130 kg. This cannot be accomplished with arch wire techniques, in which the tension of the wire must be related to the magnitude of the correction. Therefore, with arch wire techniques the correcting wire is usually under less tension than that required for optimal stabilization. If left in site, it can produce soft tissue irritation and osteolysis. We prefer not to use half pins near the fracture site, so we did not employ half pins for corrections.

The various techniques of reduction can generate compressive or distractive forces on bone that can provoke osteolysis around wires or half pins. With our technique, the two reference wires at the end of the procedure are tensioned at 130 kg in a position slightly different from the one in which they were introduced. In this situation, the tensioning process results in some amount of those undesired forces on bone. We did not, however, observe any early loosening of those wires, and we think that those forces could be of little concern with minor corrections.

We are aware that the “one olive wire” maneuver is just a step in the reduction process, but we found it effective (Fig. 2E–H). Other methods of reduction can be employed with success in a similar way, and probably the key to complete reduction is identification of the residual deformity plane. We found this plane in the great majority of tibial fractures to be that of the interosseous membrane. Our aim was to develop a simple method for complete reduction of closed tibial fractures with conventional Ilizarov techniques. To obtain the maximum biological response from the fracture site we believe it important not only to respect the surrounding tissues, but also to limit the distance needed for bridging the callus and to pass through the fracture with a controlled and axially correct mechanical stimulus. If a circular external fixation achieves these goals, it can play a larger role in the treatment of closed tibial fractures.

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