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Abstract:

Temporary Intentional Leg Shortening and Deformation to Facilitate Wound Closure Using the Ilizarov Taylor Spatial Frame

ABSTRACT

Infected tibial nonunions with bone loss pose an extremely challenging problem for the orthopedic surgeon. A comprehensive approach that addresses the infection, the bone quality, and the overlying soft tissue integrity must be considered for a successful outcome. Acute shortening with an Ilizarov frame has been shown to be helpful in the treatment of open tibia fractures with bone and soft tissue loss simultaneously. Cases in which the soft tissue defect considerably exceeds bone loss may require Ilizarov frame with concomitant soft tissue procedure, however, there are a number of potential difficulties with vascularized pedicle flaps and free tissue flaps including anastomotic complications, partial flap necrosis, and flap failure. The technique described in this report involves acute shortening and temporary bony deformation with the Ilizarov apparatus to facilitate wound closure and does not require a concomitant soft tissue reconstructive procedure. Once the wound is healed, osseous deformity and length are gradually corrected by distraction osteogenesis with the Ilizarov / Taylor Spatial frame (TSF).

KEYWORDS

Ilizarov, Taylor Spatial frame, nonunion, acute shortening, deformity correction, wound closure.

INTRODUCTION

The Ilizarov method has been described alone or in combination with soft tissue reconstruction for the management of open tibia fractures, limb shortening, deformity, joint contractures, and infections. Shortening with bifocal compression-distraction has been successfully used in the treatment of open tibia fractures with either primary wound closure or delayed primary wound closure.[1] Bone defects of less than 3cm can be acutely shortened, and defects of greater than 3cm can be gradually shortened.[1] Bifocal compression-distraction not only leads to solid osseous union but also corrects limb length discrepancy, deformity, and joint contractures, and infection throughout the treatment period. Additionally, the absence of internal fixation is potentially safer in the setting of active or history of infection.

Cases in which the soft tissue defect considerably exceeds bone loss may require Ilizarov frame with a concomitant soft tissue procedure. There are potential difficulties with vascularized pedicle flaps and free tissue flaps including anastomotic complications, partial flap necrosis, and flap failure. Additionally, the soft tissue wounds may require multiple surgical procedures which lead to increased hospitalization, morbidity, and overall costs.

In the present article, the authors present the technique of acute shortening and intentional temporary bony deformation to facilitate wound closure, thereby avoiding a soft tissue flap, and two illustrative cases. With the leg stabilized in the Ilizarov /TSF (Smith & Nephew, Inc., Memphis, TN), the wound was allowed to completely heal in the deformed position. The deformed leg was gradually corrected until anatomic reduction of the bony fragments was achieved, and through a second tibial osteotomy, the leg was lengthened to correct the leg length discrepancy (LLD). The TSF is an evolution of the Ilizarov Frame that allows simultaneous correction of length, angulation, translation, and rotation about a virtual axis[2] which proved to be useful in these cases. With the TSF, a crooked frame mounted on a deformed bone can be used to gradually correct the leg deformity.[2]

SURGICAL TECHNIQUE

Surgery is usually performed under regional anesthesia. Preoperative antibiotics are withheld until after intraoperative cultures are obtained. Bony edges are debrided with the goal of removing all dead bone. The bony edges are cut flat and perpendicular to the axis of the tibia with a power saw cooled with saline. An equal sized segment of the fibula must be removed at about the same level. The soft-tissue wound is debrided with the goal of removing nonviable tissue and contouring the edges to enable wound closure. For example, an elliptical shaped incision closes well with shortening. It is important to avoid leaving bone exposed to avoid dessication of the bone. Next, a circular ring is applied orthogonal to each bone segment with wires and half-pins (Figure 1A, B).

Pulses and capillary refill are checked for comparison. One ring is chosen to be the *reference ring* (Figure2). The *origin* is a point chosen on the edge of one bone segment at the defect site. A *corresponding point* (CP) on the other bone segment is chosen with the goal of reducing the CP to the origin. *Mounting parameters* define the location of the origin relative to the reference ring. Mounting parameters are defined by the spatial relationship between the center of the reference ring and the origin in the coronal, sagittal, and axial planes. This defines a virtual hinge around which the deformity correction will occur. Next, the acute shortening and deformation is performed to optimize wound closure. The rings are stabilized in this deformed position with 6 TSF strut connections (Figure 1C). Care is taken avoid loss of pulses which would suggest kinking of the arteries. If this were to occur, then one would have to settle for less shortening and deformity even if the wound edges were pulled apart. In this case, one could gradually increase the deformity to help close the wound.

After the wound heals, a gradual correction of the deformity is performed with adjustment of the TSF struts. Compression at the nonunion follows once there is good contact and no deformity (Figure 1D).

A bifocal approach can be used to avoid limb shortening. With this approach, a tibial osteotomy for lengthening is performed outside the zone of injury. Gradual lengthening at a second level is performed by adding another circular ring and using the principles of distraction osteogenesis (Figure1E).[1,2]

CASE REPORTS

Case 1

A twenty year old man was involved in a motor vehicle accident sustaining an open right tibia and fibula fracture. He was initially evaluated and treated at an outside hospital with an external fixator of the tibia and multiple irrigation and debridements of the open wound. Two weeks after the initial procedure, the external fixator was removed and an intramedullary tibia nail was placed. The patient was discharged without antibiotic therapy.

Five months after the original injury, the patient presented to our Orthopaedic Trauma Service with persistent purulent draining sinus at the junction of the middle and distal third of the tibia with surrounding erythema. The neurovascular exam of the right lower extremity was unremarkable. Plain radiographs demonstrated a fracture of the distal third of the tibia and fibula and intramedullary rod with proximal and distal interlocking screws. The patient underwent removal of right intramedullary tibia nail, irrigation and debridement of the draining sinus tract of the right tibia, application of temporary external fixation, and Epigard to cover the 2cm x 2 cm x 2.5cm skin defect (Figure 3). A vacuum assisted dressing (VAC, Kinetic Concept, Inc., San Antonio, TX) was applied over the open wound and changed every 48 to 72 hours. The patient was then internally referred for management with Ilizarov method.

One week into current hospitalization, the patient was taken back to the operating room for reconstruction of the soft tissue and bone defects. The Synthes external fixator was removed. Vertical extension of the open pretibial wound was preformed to provide exposure of the tibia. The tibia was noted to have irregular bone edges and notable bone defect. The oscillating saw cooled with normal saline irrigation was used to resect bone until viable bone tissue was evident and to flatten edges with transverse orientation and the total defect space was four centimeters. Multiple intraoperative cultures were obtained from the proximal and distal segments. The wound was copiously irrigated with pulsed lavage solution. At this juncture of the case, the decision was to perform acute shortening with the Ilizarov/ TSF to address the bone defect and open wound. The wound edges were debrided to back until areas of punctuate bleeding was visualized. A five centimeter lateral skin incision was created to expose the fibula. After subperiosteal dissection of the fibula, a four centimeter segment was resected at the same level of the tibial defect. The wound was irrigated and subsequently closed. Prior to the acute shortening maneuver, the patient had a 1+ dorsalis pedis pulse and 2+ dorsalis pedis pulse with a warm foot. The tibia was acutely shortened and deformed into recurvatum to allow optimal release of tension of the wound, and as a result, primary closure of the wound was possible. A two-ring construct with the Ilizarov / TSF (Smith & Nephew, Inc., Memphis, TN) was applied. The proximal reference 180mm ring was placed in the middle tibia and fixed with a tensioned wire and two half pins. The distal 180mm ring was placed in the distal tibia with two tensioned wires and a half pin. The virtual hinge, or origin, is established as a point in space relative to the reference ring. The origin point was the end of the proximal fragment, and the center of the reference ring was 8mm lateral, 37mm posterior, and 105mm proximal to the origin. These mounting parameter measurements were done in the operating room. Deformity parameters were obtained from the final fluoroscopic images and found to be 4mm of medial and 10mm of posterior translation of the distal fragment, and 20 degrees of recurvatum deformity (Figure 4). Again, the pulses were assessed and found to be stable from prior to acute shortening maneuver.

Intraoperative cultures grew staphylococcus aureus and he received intravenous cefazolin for 6 weeks. The wound was healed and sutures were removed at 3 weeks at which time the correction of deformity was begun. This occurred gradually over 40 days and was followed by axial compression at the nonunion site for one month. An osteotomy of the proximal tibia for lengthening was performed 5 weeks after the last surgery. Gradual lengthening of 60 mm was accomplished (Figure 5). The frame was removed 6 months after the proximal tibia osteotomy (bone healing index of 6 months/ cm) and 7 months after the excision of sequestrum.

At 6 months following frame removal (Figure 6), he had knee motion of 0^0-130^0 and ankle motion of 20^0 dorsiflexion and 40^0 plantarflexion. He has no deformity, equal leg lengths, and no pain. He has a normal gait and does not use any assistance. There has been no recurrence of infection.

Case 2

A thirty year old smoker with a past medical history significant for complex seizures controlled on Topamax was involved in a head-on motor vehicle collision and sustained a Gustilo-Anderson[3] Grade 3B open tibia and fibula fracture. He was initially evaluated at an outside hospital and underwent irrigation and debridement and application of spanning external fixator. Three days later, the patient was taken back to the operating room for irrigation and debridement and rotational gastrocnemius flap with split thickness skin grafting to close the medial wound. Two weeks later, there was suppurative material noted below the skin graft at the mid portion of the wound, and the graft appeared to have approximately 50% loss, worsened from 15% loss one week earlier. The patient was place on oral cephalexin, but the wound continued to drain. He was readmitted and underwent repeat incision and drainage and placement of VAC dressing over the wound. Intraoperative wound and bone cultures were obtained and grew Staphylococcus Aureus and Enterococcus. Two months later, the patient underwent repeat irrigation and debridement of the wound and elevation of a faciocutaneous flap with overlying split thickness skin graft to cover the open wound. Two months after the faciocutanous flap, the patient developed an infection and soft tissue loss and underwent another irrigation and debridement. Intraoperative cultures were grew methicillan resistant Staphylococcus auerus and Enterococcus, and a six week intravenous Vancomycin regimen was begun. The patient presented to our Orthopaedic Trauma Service for management of limb length discrepancy and persistent drainage from the soft tissue wound.

On physical examination, the patient was unable to bear weight on the right lower extremity with roughly 1 inch shortening compared to the contralateral limb. There was an external fixator frame on the right tibia with a 2.5cm x 2cm x 4cm open wound with drainage over the anterior aspect of the middle third of the tibia. A moderate amount of edema of the right foot was appreciated. Patient has 2+ dorsalis pedis pulse and 0 posterior tibialis pulse, and his sensation was minimally diminished throughout but likely secondary to soft tissue swelling. Motor strength was 4 out of 5 tibialis anterior, extensor hallucis longus, and gastrocnemius and soleus muscles. Active range of motion of the right knee was -10 degrees of extension to 90 degrees of flexion. Active range of motion of the right tibiotalar joint was neutral to 20 degrees of plantarflexion.

Radiographic evaluation demonstrated right lower extremity length of 79.5 cm versus left lower extremity of 82.1cm on 51 inch erect lower extremity x-rays. The 2.6cm discrepancy was consistent with clinical examination. The lateral x-ray demonstrated 11 degree procurvatum deformity at the middle third of the tibia. A comminuted proximal middle third tibia fracture with a lateral butterfly fragment was appreciated with partial healing of the butterfly to the distal fragment. Otherwise no healing was apparent between other fracture fragments. The patient was instructed to discontinue the intravenous Vancomycin for 6 weeks in order to obtain reliable intraoperative cultures.

Eight months after the initial accident, the patient was taken to the operating room and the right lower extremity was prepped and draped in standard sterile fashion. The plastic surgeon raised the fasciocutaneous flap at the proximal middle third of the tibia to provide exposure of the fracture site. An area of the flap encompassing the sinus tract was excised. The tibia appeared to be necrotic with surrounding areas of purulent material. Multiple intraoperative cultures were sent for culture and gram stain. Once the bone was exposed, the oscillating saw cooled with normal saline was used to resect the proximal and distal fragments back to viable bone, and the total defect measured 4cm. The proximal tibial margin was healthy with bleeding bone. The area was copiously irrigated with pulsatile lavage, and Osteoset beads with Vancomycin and Tobramycin were placed in the area of the bone defect. This was chosen for local antibiotic delivery and to avoid the need for flap re-elevation and bead removal.

The sinus tract excision created an open wound that was not amenable to primary wound closure. With the leg in neutral position, the flap experienced a considerable amount of tension with attempted closure. When the leg was manipulated into varus and recurvatum deformity, the flap wound was reapproximated without tension. The surgeon decided that the wound could be primarily closed with acute shortening. A four centimeter incision was created over the distal fibula, and an oscillating saw was used to excise two centimeters of the distal fibula proximal to the syndesmosis.

The tourniquet was deflated to confirm bleeding bone at the margins of the resection. The proximal tibia flap was closed with the leg in varus and recurvatum with the assistance of a plastic surgeon. Pulses did not change with the acute shortening and deformation. The Ilizarov/ TSF was applied, and the reference ring was a 205mm two-third ring placed at the proximal tibial metaphysis. The ring was stabilized with anterolateral and anteromedial half pins and two tensioned wires. Mounting parameters were established. The center of the reference ring was in line with the origin on the AP radiograph, 40mm posterior to the origin, and 55mm proximal to the origin.

Two 180mm rings connected with 150mm rods were placed on the distal tibial segment. The distal ring was fixed with a transverse tension wire, a tibia-fibula wire, and an anterolateral half pin. The middle ring was fixed with a tensioned wire and two 6mm hydroxyapetite coated half pins. TSF struts were placed between the reference ring and two distal rings. The dorsalis pedis and posterior tibial pulses were noted to be stable after the shortening was performed. Intravenous Vancomycin and Ceftazidime were administered for 6 weeks for growth of methicillin resistant staphylococcus aureus (MRSA) and pseudomonas aureginosa from the intraoperative cultures. The wound was healed and sutures were removed after one month.

Gradual correction of 27^{0} varus, 5^{0} apex posterior, 5 mm posterior translation was completed in 2 weeks. This was followed by 2 weeks of slow compression at the nonunion site.

The patient was taken back to the operating room 2 months after the initial surgery for an osteotomy of the distal tibia. Gradual lengthening of 53 mm was accomplished at a rate of 0.75 mm per day. He is now walking full weight bearing, knee motion is 0^{0}-130^{0}, and ankle is 0^{0}-20^{0} plantar flexion. He is now 8 months after excision and 7 months after osteotomy of the tibia for lengthening. He has no significant LLD or deformity. Bony healing has progressed well, and frame removal is scheduled in 6 weeks.

DISCUSSION

Posttraumatic osteomyelitis is a serious complication of open and closed tibia fractures adversely affecting prognosis and increasing the risk for loss of limb.[3, 4] Meticulous debridement with wide excision of the involved bone and accompanying soft tissue is critical in the surgical management of osteomyelitis. The elimination of infected bone and necrotic tissue and improvement of the local blood supply are essential to adequately treat chronic osteomyelitis.[5, 6] Once the necrotic infected tissue has been removed, the remaining osseous and soft tissue defects require stabilization with soft tissue closure or coverage. When soft tissue reconstruction is required with pedicled or free flaps, studies have reported 89% success as a single procedure[7] and greater 91% and 96% as a staged procedure.[1, 8, 9] If, however, flap coverage can be avoided, this is preferable. In addition, there are patients who are not suitable candidates for local or free flaps.

The Ilizarov technique alone or in combination with soft tissue reconstructive procedures is thought to be able to treat segmental bone defects, soft tissue loss, and osteomyelitis.

Depending on the size of bone loss, single or double bone transport with Ilizarov frame has been shown to be a reliable method to treat segmental bone loss and authors have reported between 75% to 100% success.[1,10-17] The lack of soft tissue coverage may further complicate the problem, and early soft tissue coverage has been shown to decrease local infection rates, decrease time to union, and improve strength of osseous union.[18,19] Use of the Ilizarov apparatus with soft tissue reconstruction has been shown to be effective without compromising the vascularized tissue flaps.[20]

Acute shortening with an Ilizarov frame has been shown to treat open tibia fractures with bone and soft tissue loss simultaneously[21,22]. Sen et al.[1] has recently reported 23 of 24 patients with good or excellent functional outcomes, and all 24 patients demonstrated good or excellent bone assessment according to the classification system described by Paley.[23] Patients treated with acute shortening were thought to require fewer operative procedures, have fewer complications, and have decreased hospitalization times and costs.

There have been two published reports of combining bone shortening and angulation for the treatment of bone and soft tissue loss.[24,25] Bundgaard and Christensen[24] described a single case of bone loss in the tibia of 9cm and fibula of 3 cm with soft tissue defect measuring 10 x 15 cm over the anterior and lateral compartments infected with staphylococcus aureus. The patient underwent irrigation and debridement of devitalized tissue and application of external fixator. An Ilizarov external fixator was applied and the bone defect was acutely shortened by 3 cm. Then, gradual anterior angulation at a rate of 4 degrees per day and compression at a rate of 2 mm per day was done until the proximal and distal ends of the open wound were in contact. On day 27, the proximal tibial osteotomy was performed and bone transport started seven days later at a rate of 1 mm per day. The deformity at the nonunion was corrected beginning on day 47.

By day 51, the deformity was corrected and compression was started at a rate of 1 mm per day for seven days. The tibia reached its original length after 90 days of distraction and 125 days after the application of the Ilizarov frame. The Ilizarov frame was removed after one year and the external fixation index[24] was calculated to be 40 days per cm. The authors report that the described technique allows the treatment of the bone defect by distraction osteogenesis and the soft tissue and muscle defect by distraction histiogenesis.[24]

Lerner et al.[25] reported on the use of acute shortening with Illizarov frame to treat severe bone and soft tissue loss. All twelve patients had Gusilo-Andersen type IIIB open fractures with a mean Mangled Extemity Score of 6.7 (range, 4 to 7) and mean bone loss of 7.9 cm (range, 2.5 to 22 cm). All patients underwent acute bone shortening, and three patients additionally underwent anterior angulation of 50 to 60 degrees at the fracture site to minimize the bone and soft tissue defect. Of these three patients, one required a local flap with overlying skin graft and two patients received skin grafts. The authors waited three weeks until the wounds healed and then gradually corrected the malalignment over a period of three additional weeks.

The surgical technique of shortening with angular deformity has been described in the acute setting.[24, 25] The current report of two cases illustrates acute shortening with intentional temporary deformation in the setting of chronic infected nonunion with persistent overlying deep wound infection obviating the need for further soft-tissue reconstruction. In the cases presented in this report, acute shortening alone was not enough to enable wound closure. With implementation of additional deformity, the wound edges were able to be reapproximated without tension. As the wound healed, the Ilizarov/ TSF was adjusted to correct bone length and deformity. The ability of TSF to correct complex deformity is particularly useful in these situations. The *rings first method* [2]of TSF use allows independent application of orthogonal rings to each segment and then the optimal deformation is performed. Six universal struts are used to connect these 2 rings. The subsequent deformity correction is accomplished with adjustment of these six struts.

Infected nonunions with bone loss pose an extremely challenging problem for the orthopedic surgeon. A comprehensive approach that addresses the infection, the bone quality, and the overlying soft tissue integrity must be considered for a successful outcome.[24] Temporary intentional shortening and bony deformation with the Ilizarov / TSF is a technique that may be implemented for a bone and soft tissue defect. This can avert the need for a complex soft-tissue reconstruction procedure.

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REFERENCES

1. **Sen, C.; Kocaoglu, M.; Eralp, L. et al.:** Bifocal compression-distraction in the acute treatment of grade III open tibia fractures with bone and soft-tissue loss: a report of 24 cases. *J Orthop Trauma,* 18(3): 150-7, 2004.

2. **Rozbruch, S. R.; Helfet, D. L.; and Blyakher, A.:** Distraction of hypertrophic nonunion of tibia with deformity using Ilizarov/Taylor Spatial Frame. Report of two cases. *Arch Orthop Trauma Surg,* 122(5): 295-8, 2002.

3. **Gustilo, R. B., and Anderson, J. T.:** Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am,* 58(4): 453-8, 1976.

4. **Tulner, S. A.; Schaap, G. R.; Strackee, S. D. et al.:** Long-term results of multiple-stage treatment for posttraumatic osteomyelitis of the tibia. *J Trauma,* 56(3): 633-42, 2004.

5. **Arnold, P. G.; Yugueros, P.; and Hanssen, A. D.:** Muscle flaps in osteomyelitis of the lower extremity: a 20-year account. *Plast Reconstr Surg,* 104(1): 107-10, 1999.

6. **Ring, D.; Jupiter, J. B.; Gan, B. S. et al.:** Infected nonunion of the tibia. *Clin Orthop,* (369): 302-11, 1999.

7. **Anthony, J. P.; Mathes, S. J.; and Alpert, B. S.:** The muscle flap in the treatment of chronic lower extremity osteomyelitis: results in patients over 5 years after treatment. *Plast Reconstr Surg,* 88(2): 311-8, 1991.

8. **Gayle, L. B.; Lineaweaver, W. C.; Oliva, A. et al.:** Treatment of chronic osteomyelitis of the lower extremities with debridement and microvascular muscle transfer. *Clin Plast Surg,* 19(4): 895-903, 1992.

9. **Patzakis, M. J.; Abdollahi, K.; Sherman, R. et al.:** Treatment of chronic osteomyelitis with muscle flaps. *Orthop Clin North Am,* 24(3): 505-9, 1993.

10. **Cattaneo, R.; Catagni, M.; and Johnson, E. E.:** The treatment of infected nonunions and segmental defects of the tibia by the methods of Ilizarov. *Clin Orthop,* (280): 143-52, 1992.

11. **Cierny, G., 3rd, and Zorn, K. E.:** Segmental tibial defects. Comparing conventional and Ilizarov methodologies. *Clin Orthop,* (301): 118-23, 1994.

12. **Green, S. A.; Jackson, J. M.; Wall, D. M. et al.:** Management of segmental defects by the Ilizarov intercalary bone transport method. *Clin Orthop,* (280): 136-42, 1992.

13. **Marsh, J. L.; Prokuski, L.; and Biermann, J. S.:** Chronic infected tibial nonunions with bone loss. Conventional techniques versus bone transport. *Clin Orthop,* (301): 139-46, 1994.

14. **Paley, D., and Maar, D. C.:** Ilizarov bone transport treatment for tibial defects. *J Orthop Trauma,* 14(2): 76-85, 2000.

15. **Polyzois, D.; Papachristou, G.; Kotsiopoulos, K. et al.:** Treatment of tibial and femoral bone loss by distraction osteogenesis. Experience in 28 infected and 14 clean cases. *Acta Orthop Scand Suppl,* 275: 84-8, 1997.

16. **Saleh, M., and Rees, A.:** Bifocal surgery for deformity and bone loss after lower-limb fractures. Comparison of bone-transport and compression-distraction methods. *J Bone Joint Surg Br,* 77(3): 429-34, 1995.

17. **Song, H. R.; Cho, S. H.; Koo, K. H. et al.:** Tibial bone defects treated by internal bone transport using the Ilizarov method. *Int Orthop,* 22(5): 293-7, 1998.

18. **Byrd, H. S.; Cierny, G., 3rd; and Tebbetts, J. B.:** The management of open tibial fractures with associated soft-tissue loss: external pin fixation with early flap coverage. *Plast Reconstr Surg,* 68(1): 73-82, 1981.

19. **Godina, M.:** Early microsurgical reconstruction of complex trauma of the extremities. *Plast Reconstr Surg,* 78(3): 285-92, 1986.

20. **Lowenberg, D. W.; Feibel, R. J.; Louie, K. W. et al.:** Combined muscle flap and Ilizarov reconstruction for bone and soft tissue defects. *Clin Orthop,* (332): 37-51, 1996.

21. **Feldman, D. S.; Shin, S. S.; Madan, S. et al.:** Correction of tibial malunion and nonunion with six-axis analysis deformity correction using the Taylor Spatial Frame. *J Orthop Trauma,* 17(8): 549-54, 2003.

22. **Sluga, M.; Pfeiffer, M.; Kotz, R. et al.:** Lower limb deformities in children: two-stage correction using the Taylor spatial frame. *J Pediatr Orthop B,* 12(2): 123-8, 2003.

23. **Paley, D.; Catagni, M. A.; Argnani, F. et al.:** Ilizarov treatment of tibial nonunions with bone loss. *Clin Orthop,* (241): 146-65, 1989.

24. **Bundgaard, K. G., and Christensen, K. S.:** Tibial bone loss and soft-tissue defect treated simultaneously with Ilizarov-technique - A case report. *Acta Orthop Scand,* 71(5): 534-536, 2000.

25. **Lerner, A.; Fodor, L.; Soudry, M. et al.:** Acute shortening: modular treatment modality for severe combined bone and soft tissue loss of the extremities. *J Trauma,* 57(3): 603-8, 2004.

FIGURE LEGENDS

Figure 1. Schematic illustration of the stages of the procedure. A. Bone and soft-tissue defect. B. Debridement of bony edges and application of rings orthogonal to each bone segment. C. Acute shortening and bony deformation to enable wound closure. D. Gradual correction of the deformity and compression at the nonunion site after wound healing. E. After addition of proximal ring and tibial osteotomy for lengthening.

Figure 2. Taylor Spatial Frame concept and language. A. Measurement of translation deformity parameters. B. Measurement of angulation deformity parameters. C. Measurement of mounting parameters. D. Structure at risk relative to origin. E. Before correction. F. After correction.

Figure 3. Pre-operative Clinical and Radiographic Evaluation. A. Front view of leg demonstrating open wound over anterior aspect of leg. B. AP radiograph of nonunion.

Figure 4. One month after application of TSF. A. Front view of leg demonstrating primary closure of wound. B. Side view of leg shows recurvatum deformity. C. Lateral radiograph demonstrates 20 degrees of recurvatum deformity and posterior translation of the distal fragment. This deformity and shortening helped re-approximate the wound edges and averted the need for a flap.

Figure 5. Four months after application of the second level of the TSF showing correction of distal deformity and proximal tibial lengthening. A. Front view of leg with well healed wound. B. Side view of leg with normal alignment. C. AP radiograph without coronal plane deformity.

D, Lateral view without sagittal plane deformity. Radiographs show good alignment, contact at the nonunion site, and proximal tibial lengthening.

Figure 6. Six months after removal of the Ilizarov/ TSF. A. AP radiograph demonstrating excellent coronal plane alignment and bony union. B. Lateral radiograph with excellent sagittal plane alignment and bony union. C. Front view of legs showing equal leg lengths and the absence of deformity. D. Close-up view showing well healed wound.

* Unblinded Title Page

Temporary Intentional Leg Shortening and Deformation to Facilitate Wound Closure Using the Ilizarov Taylor Spatial Frame

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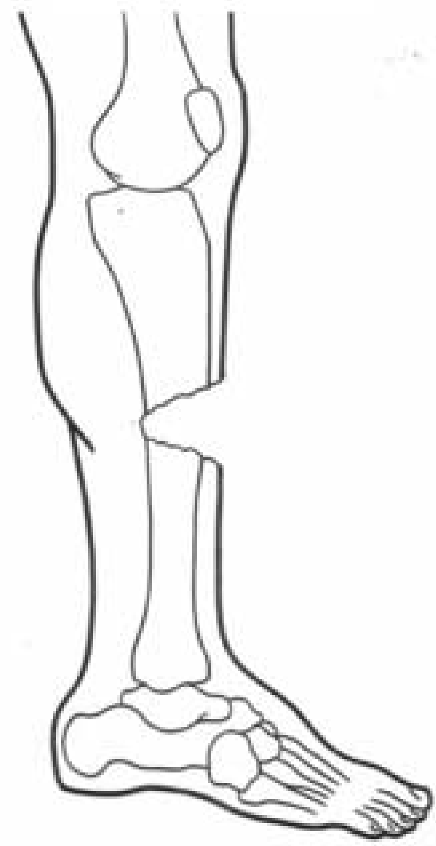

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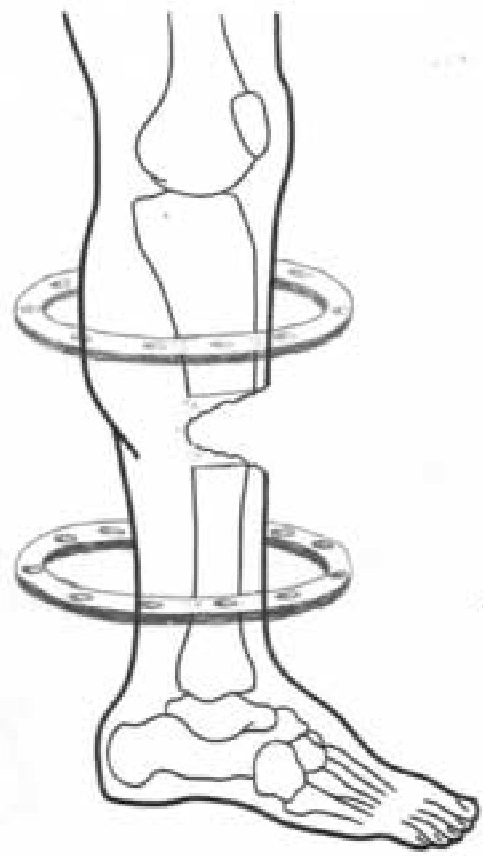

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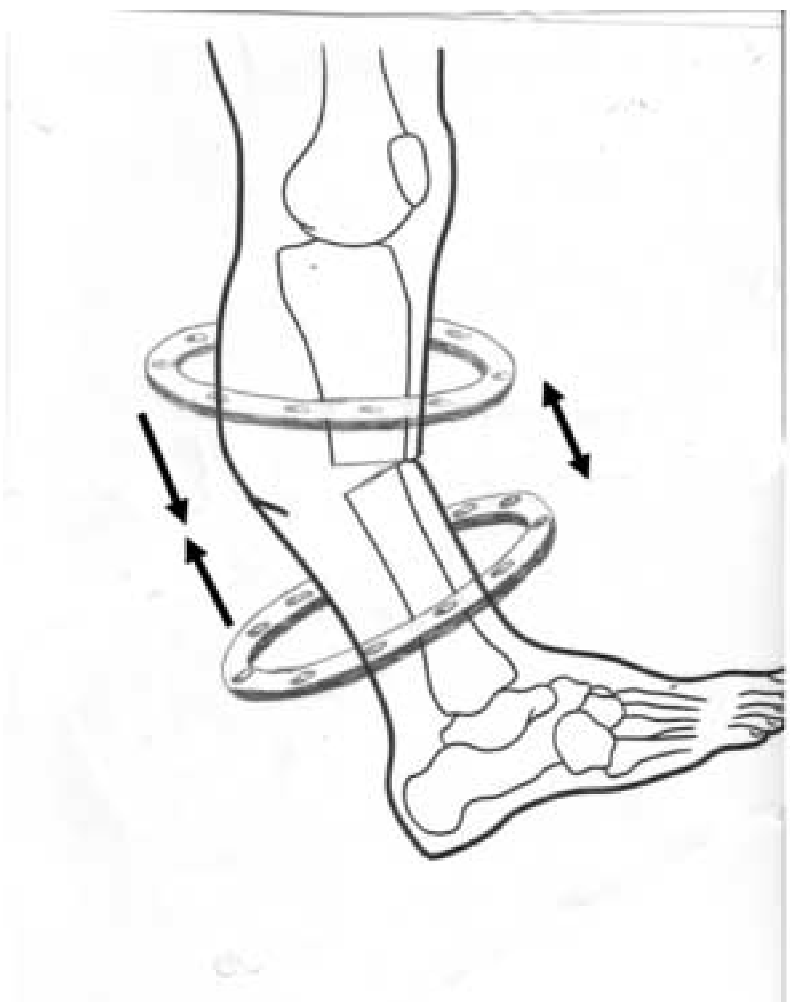

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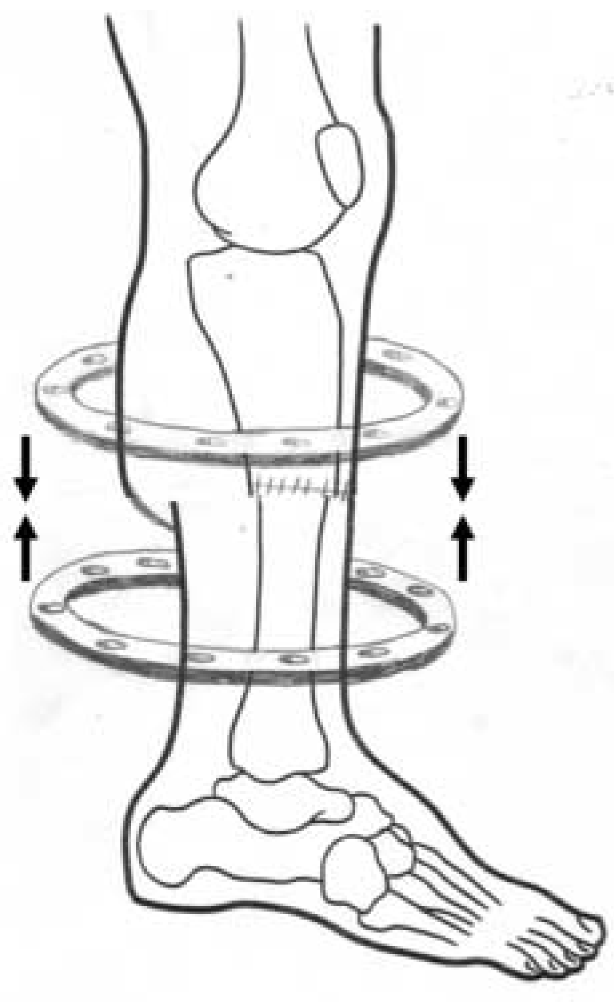

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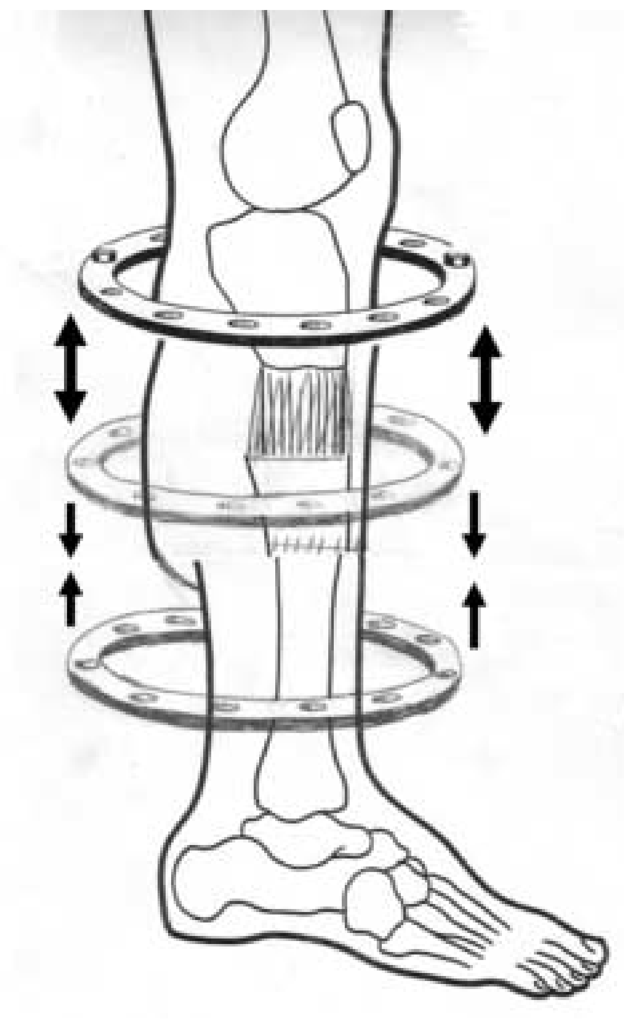

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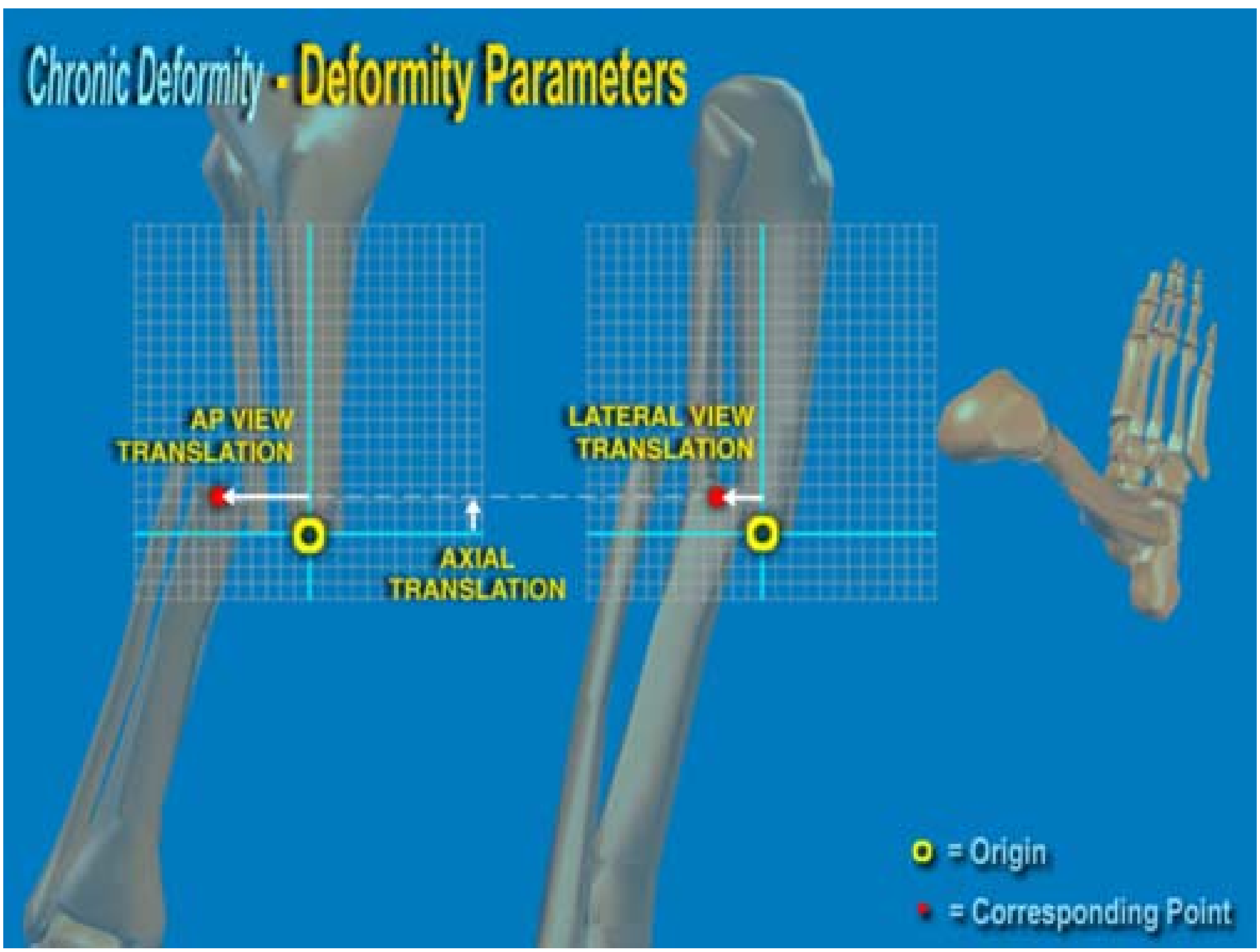

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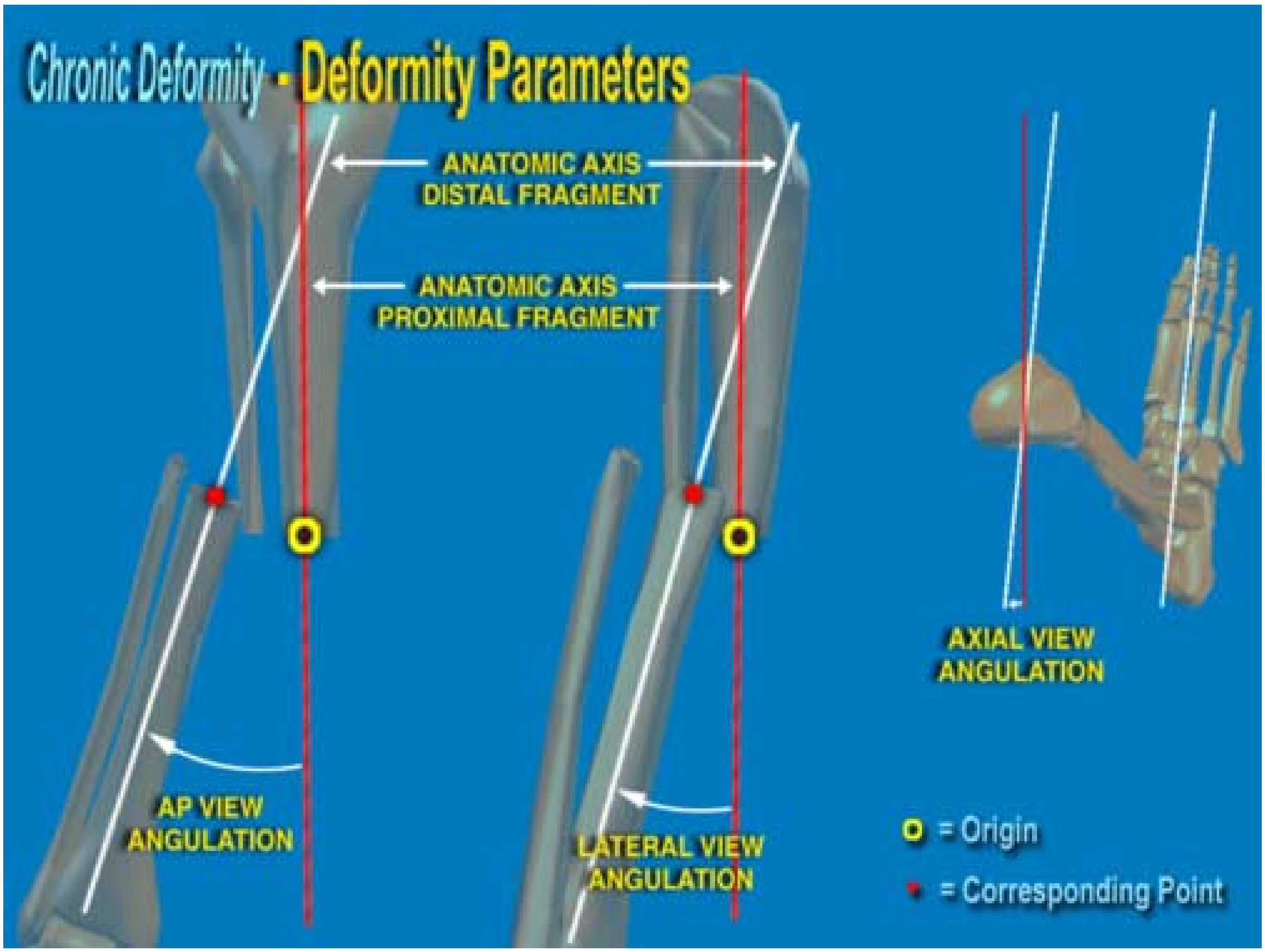

Figure 2C
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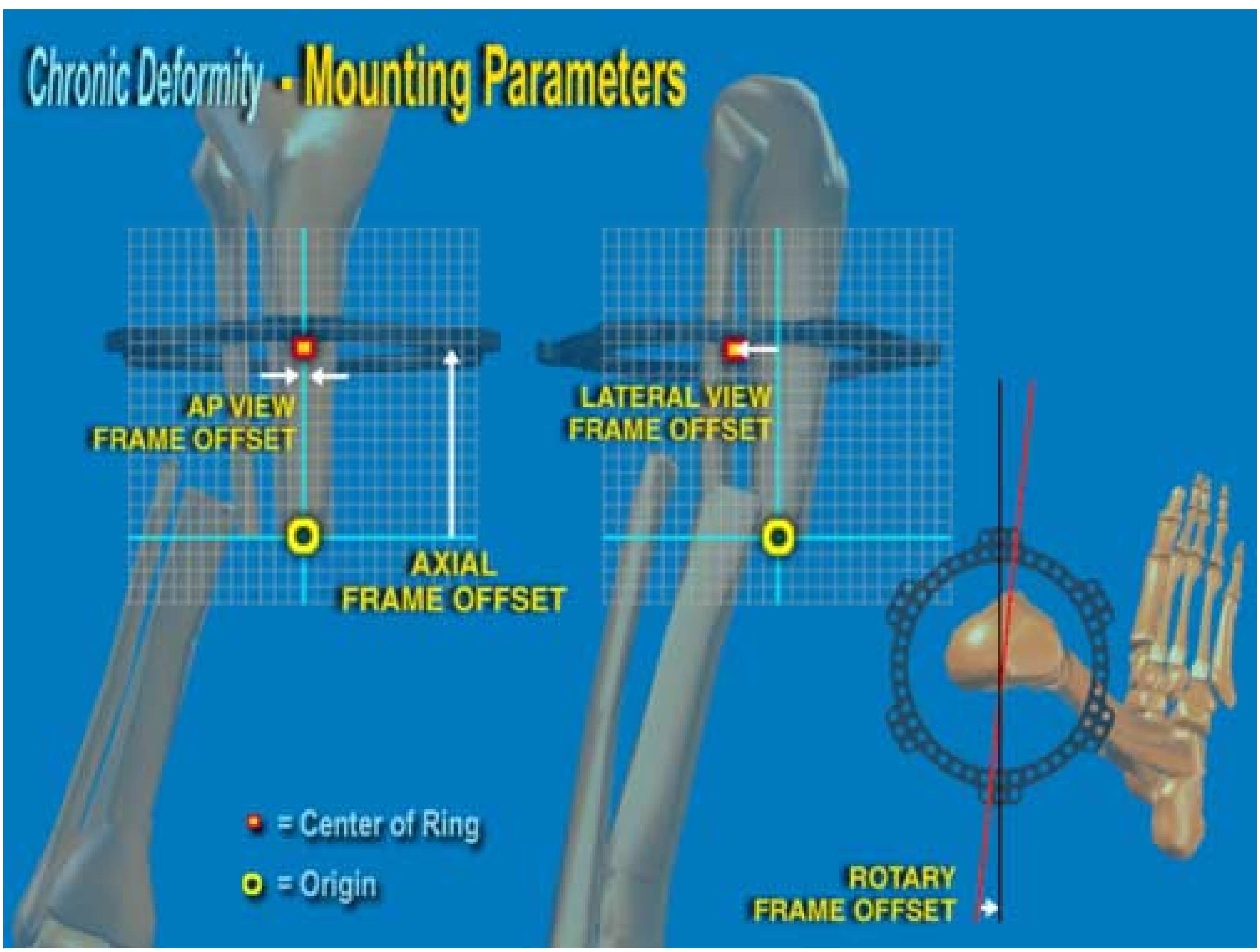

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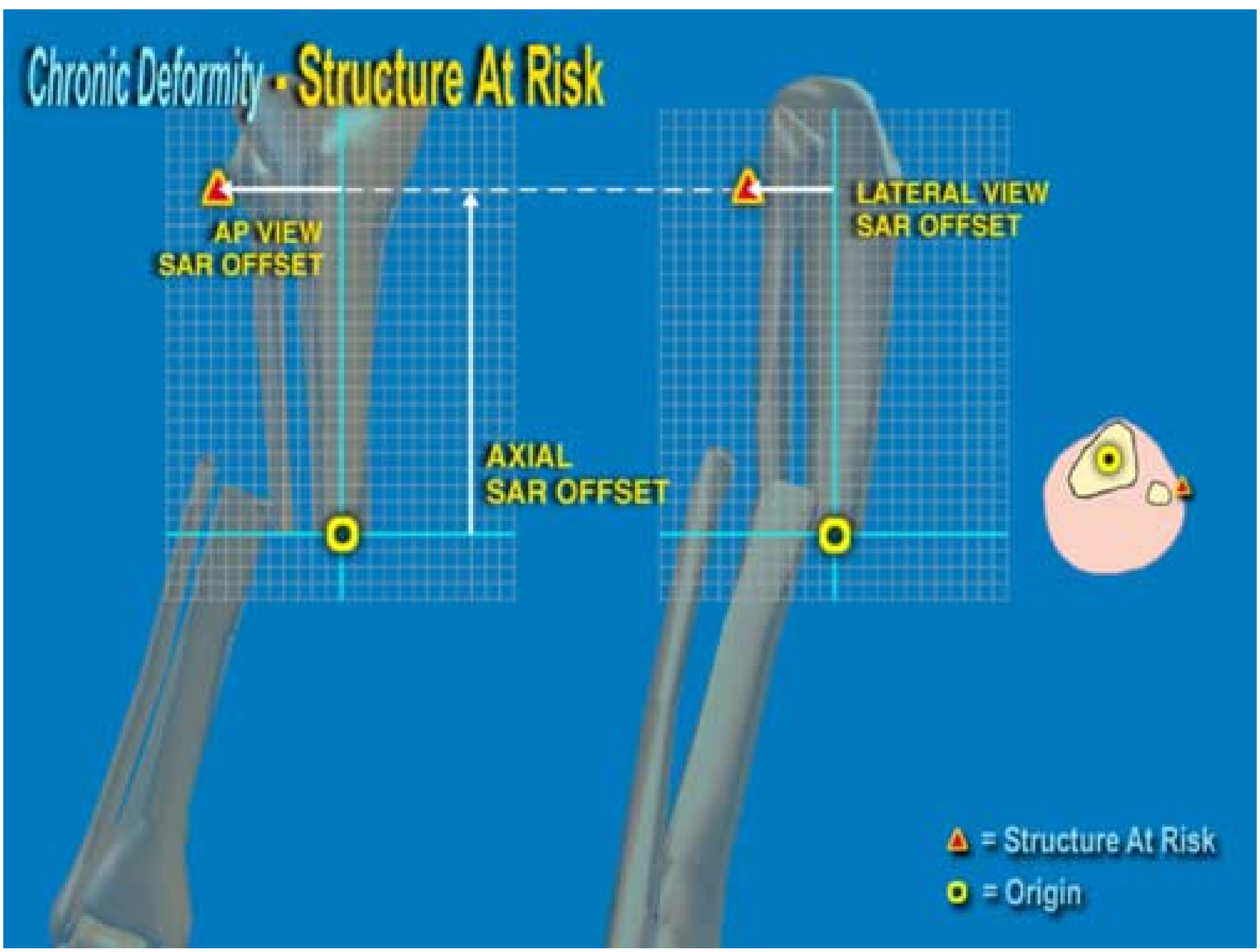

Figure 2E

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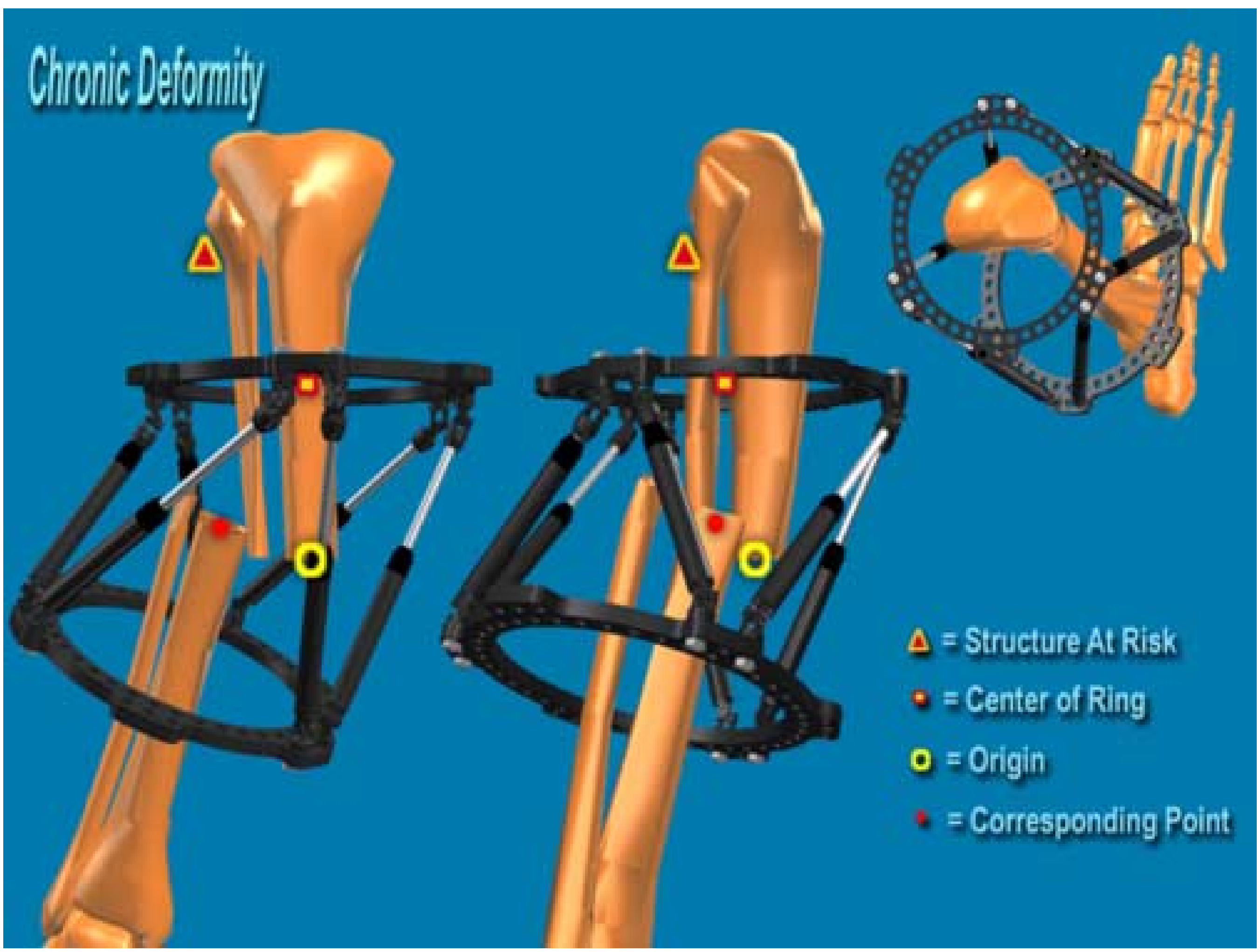

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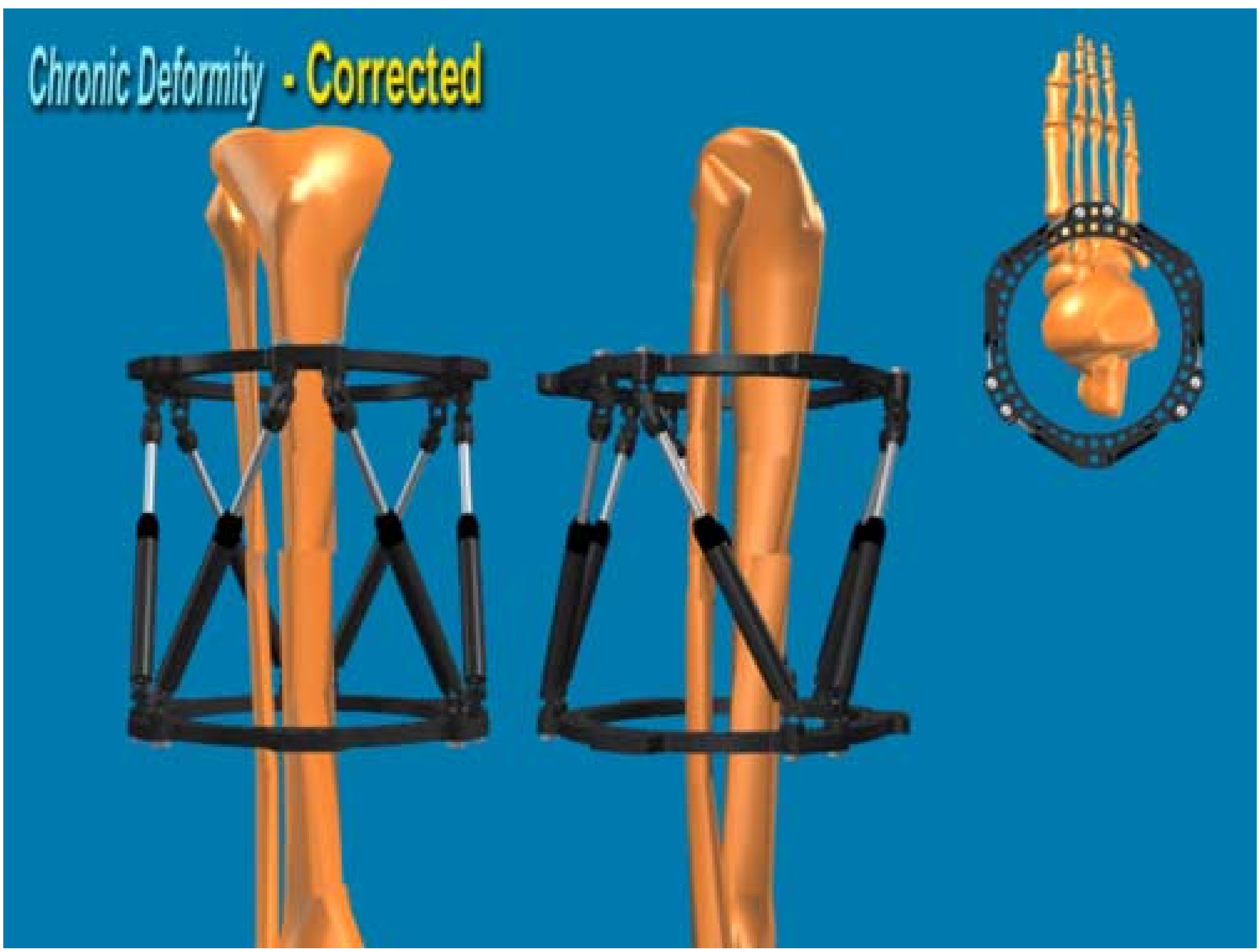

Figure 3A
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Figure 3B
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Figure 4A

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Figure 4B

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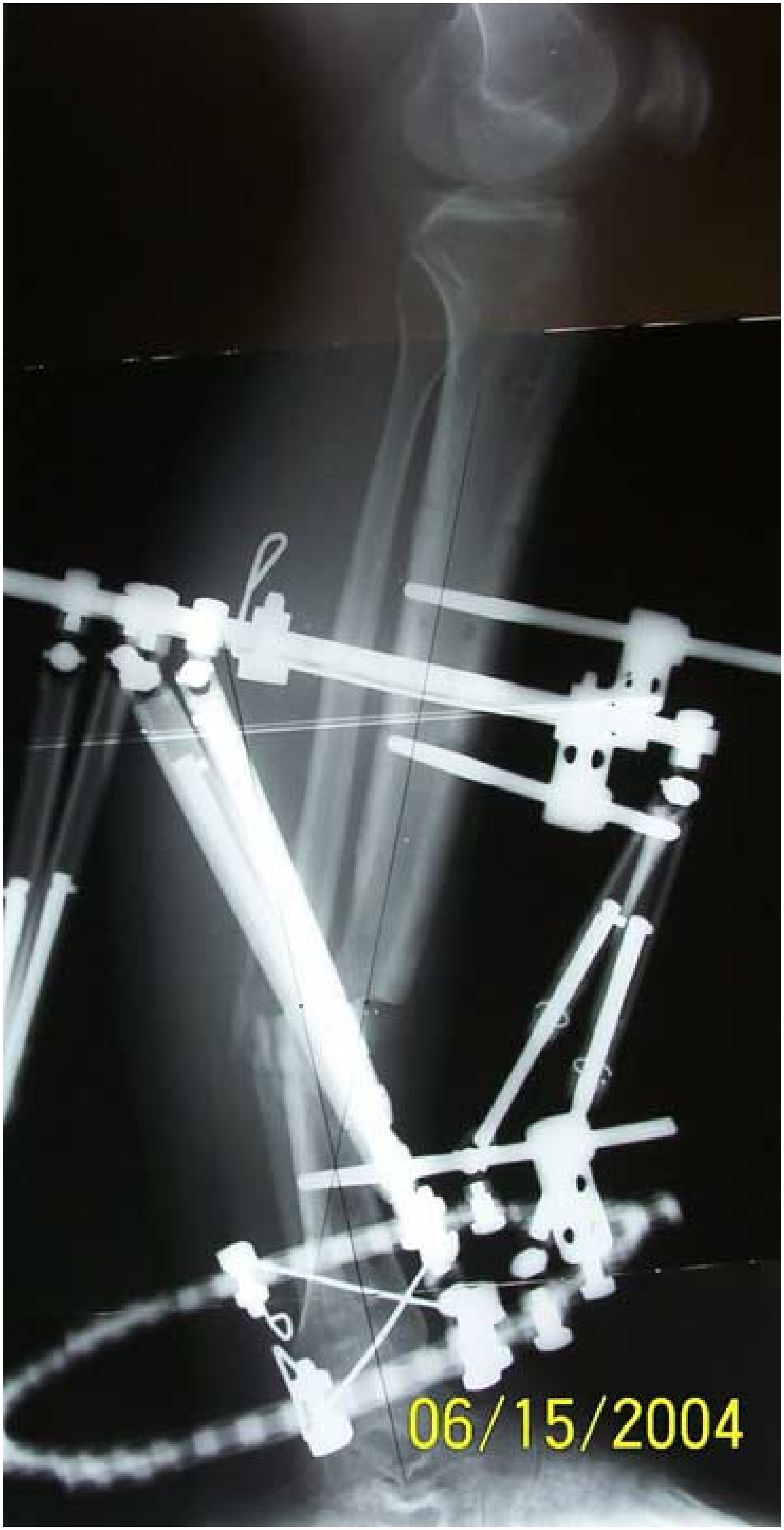

Figure 5A
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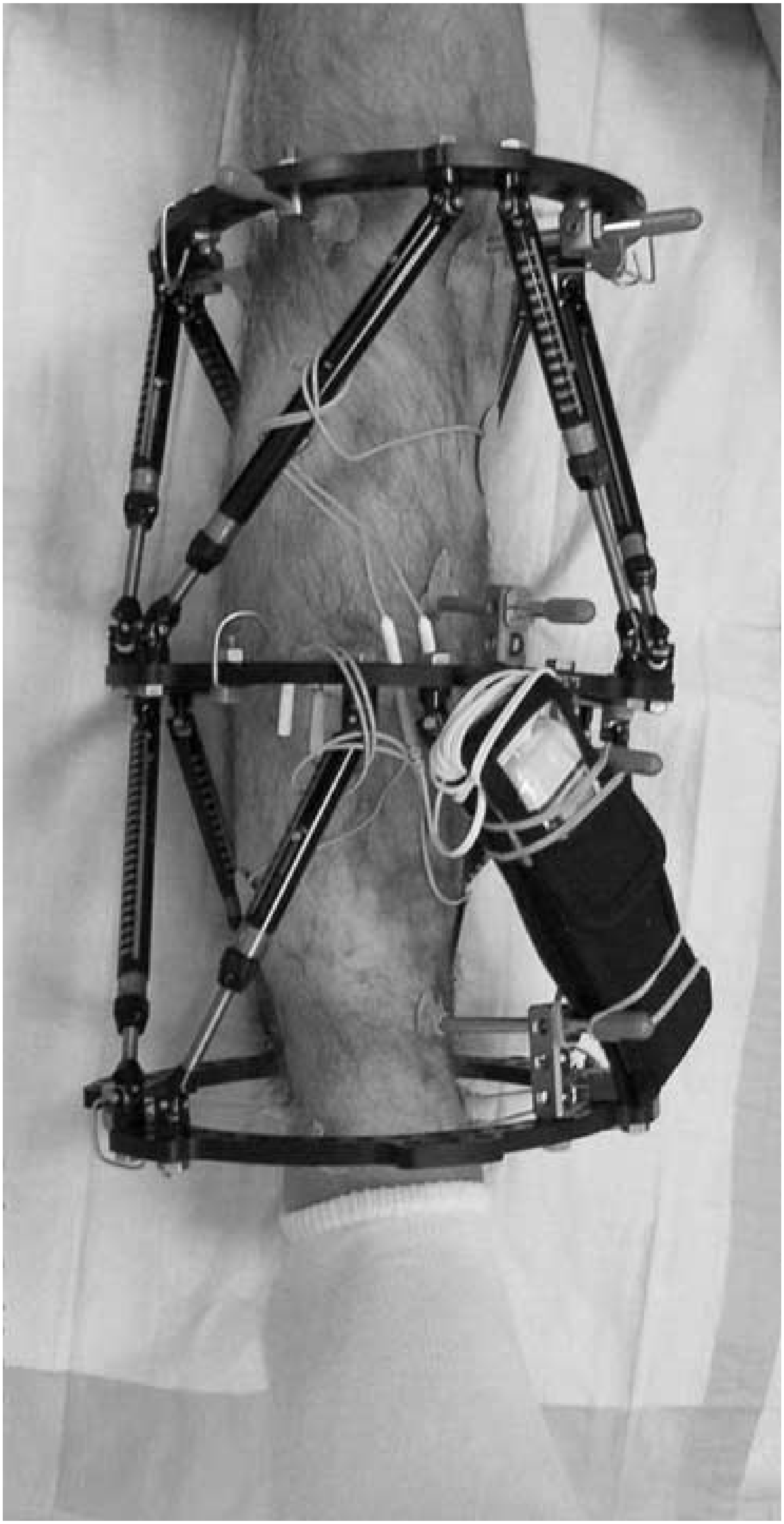

Figure 5B

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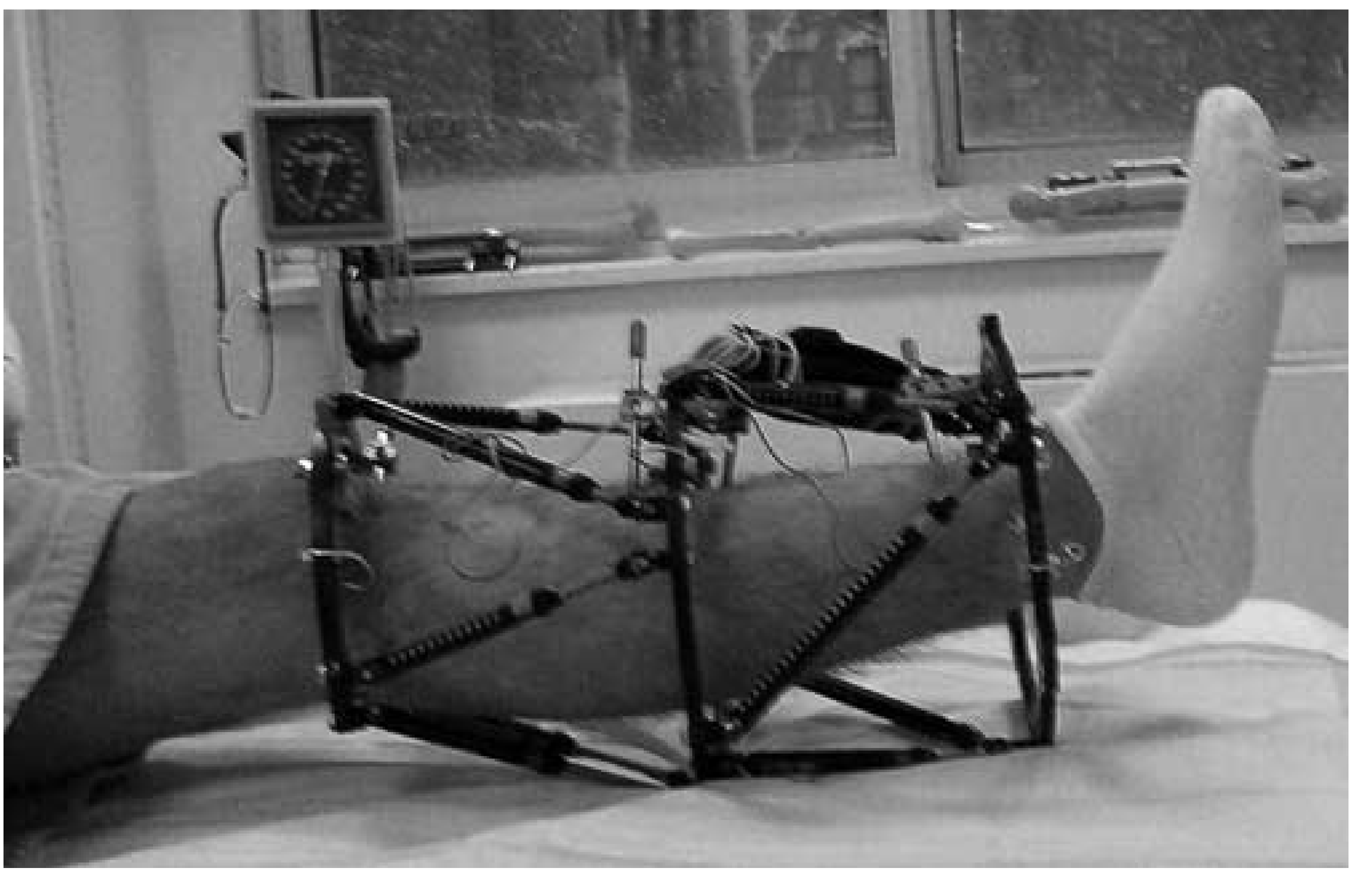

Figure 5C

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Figure 5D

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Figure 6A
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Figure 6B
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Figure 6C
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Figure 6D
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