Journal of Orthopaedic Trauma Publish Ahead of Print
DOI: 10.1097/BOT.0000000000000923

Title: "Open Supracondylar-Intercondylar Fractures of the Femur. Treatment with Taylor Spatial Frame".

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Conflict of interest statement: None of the authors received benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript. The Current study was approved by Ethical Board Review of Niguarda's Hospital, Milan, Italy .

Acknowledgements:

The authors thank Dori Kelly, MA, for professional medical editing.

The authors thank Jayanta Gupta and Christopher Dodoo, for statistical evaluation.

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ABSTRACT

Objectives: Evaluate the Taylor spatial frame (TSF) for primary and definitive fixation of open supracondylar-intracondylar femoral (SIF) fractures.

Design: Retrospective.

Setting: Level I trauma center.

Patients: Subset of 20 SIF open fractures treated with TSF extracted from a consecutive series of 80 SIF fractures treated between 2007 and 2013.

Intervention: Eighteen (90%) fractures underwent definitive fixation with the TSF; 2 were treated primarily within 24 hours of injury. Mean time interval between primary treatment and secondary TSF was 5 days.

Main Outcome Measurements: Clinical and radiological.

Results: Complete union was obtained in 17 (85%) fractures without additional surgery at an average of 33 weeks. Three nonunions and 1 malunion occurred. No deep infection occurred. Results based on Association for the Study and Application of the Method of Ilizarov criteria: 37% excellent, and 63% good for bone outcomes; 5% excellent, 58% good, and 37% fair for functional outcomes. Neer knee scores were 21% excellent, 68% good, and 11% fair. The mechanical lateral distal femoral angle and anatomic posterior distal femoral angle values were within normal range in 80% and 90% of patients, respectively. Abnormal mechanical axis deviation was observed in 4 (20%) cases (2 had associated tibia fractures).

Conclusions: Primary and definitive fixation with the TSF are effective. Advantages include continuity of device until union, reduced risk of infection, early mobilization, restoration of primary

defect caused by bone loss, easy and accurate application, convertibility and versatility, and improved union rate and range of motion for SIF open fractures.

Key Words: multiple trauma, femur, open fracture, Taylor spatial frame.

Level of Evidence: Therapeutic Level IV.

INTRODUCTION

Fractures of the distal femur present considerable management challenges.[1-3] Severe soft-tissue damage, comminution, fracture extension to the knee joint, and injury to the extensor mechanism lead to unsatisfactory results in many cases.[4] Although locked plate fixation has significantly improved the clinical results of internal osteosynthesis in open lesions, and is currently the preferred method of treatment, outcomes could be less predictable in the presence of comorbidities or with the use of stainless steel plates.[5-6] A Two-stage protocol of damage control orthopaedics with external fixation and then definitive fixation is becoming the standard management at many trauma centers.[7] External fixation has been used in the treatment of high-energy fractures, usually multi-fragmentary fractures with soft-tissue injuries.[8] The Taylor spatial frame (TSF) (Smith & Nephew, Memphis, TN) is a modern multiplanar external hexapod frame consisting of rings connected with 6 telescopic struts.[9−12] Our purpose was to determine the clinical effectiveness of the TSF in definitive external fixation of patients with open supracondylar-intracondylar femoral (SIF) fractures.

PATIENTS AND METHODS

This study was approved by our hospital's ethical review board. A nonrandomized retrospective consecutive series of 80 supracondylar-intracondylar femoral fractures were treated surgically at first author's institution between March 2007 and December 2013 (Table, Supplemental Digital Content 1, http://links.lww.com/JOT/A9). Of these fractures, 25 were open. All patients suffering from an open femur fracture were brought to the operating theatre within the first 24 hours for immediate skeletal fixation and radical soft tissue and bone debridement. Skeletal fixation was achieved through a temporary spanning external fixator with a later conversion to definitive fracture reduction and TSF external fixation as a second stage procedure in twenty cases (20/25). In only two cases (2/25) TSF was initially applied as a first stabilizer. In three patients (3/25) with an open fracture we performed a later conversion to internal fixation with a less invasive stabilization system plate (LISS) due to limited fracture exposition and minor soft tissue damage (Gustilo and Anderson, type I). The indication for TSF external fixation as definitive treatment was the presence of more extended soft tissue damage with open fracture (Gustilo and Anderson, type II and type III). Of the fifty-five closed fractures, thirty-one closed cases with an high degree of comminution or in polytraumatized patients received immediate damage control with temporary external fixation, and 24 cases were treated initially with skeletal traction. All 55 closed fractures were managed subsequently with internal osteosynthesis 51 LISS plates, 2 locking compression plates (LCP), 1 dynamic compression plate (DCP), 1 retrograde nail). Two fractures were excluded from the case series (one young patient with open growth plates, another patient because a significant delay in conversion to definitive fixation due to vascular and soft tissue problems, resulted in a large misaligned callus incorporating the vascular graft). Consequently the present study included a series of 20 SIF fractures treated with the TSF (Table, Supplemental Digital Content 2, http://links.lww.com/JOT/A10). The study population included 16 male and 4 female patients

(mean age, 37 years; age range,17–72 years). Fractures were classified according to the OTA/AO, Gustilo and Anderson, and Fraser systems for grading fractures.[13-15] Successful vascular repair was achieved in 3 patients with Gustilo and Anderson type IIIC. The mean ISS was 23 (range, scores of 16–66).[16] TSF conversion as second stage procedure was performed after a mean of 5 days after presentation (range, 1-10 days). At the time of the second procedure, active infection had been documented in eight patients. Soft tissue debridement was associated to TSF secondary treatment in all cases. Four patients had ipsilateral patella fractures. Additional soft-tissue injuries included rupture of the quadriceps and patellar tendons.

Imaging included plain radiography and computed tomography were used to identify the severity of the fracture and to determine the surgical approach to the condylar fragments.

Thirteen fractures underwent open reduction of the condylar joint surface,twelve through a limited-lateral approach, with 3 of these extended with a tibial tubercle osteotomy. One patient underwent a medial approach to address medial condylar comminution. The condylar fragments were reconstructed with a combination of screws, pins, and olive wires (Fig. 1). However, in 8 (40%) fractures, reduction was best achieved with the aid of femoral skeletal traction placed at the proximal tibia. For 6 (30%) femoral fractures with segmental defects, distraction osteogenesis was performed to restore bone length by segmental bone transport (n = 4) or bifocal shortening and lengthening (n = 2).

Mechanical axis deviation (MAD), mechanical lateral distal femoral angle (mLDFA), and anatomic posterior distal femoral angle (aPDFA) were measured on the last follow-up radiographs.[17]External fixation time (EFT) was calculated. Functional and anatomic statuses at follow-up were evaluated based on Association for the Study and Application of the Method of Ilizarov (ASAMI) criteria described by Paley and Maar[18] (Table, Supplemental Digital Content 3,

http://links.lww.com/JOT/A11) and the Neer knee score.[10,12,18−21] Complications encountered intraoperatively and during postoperative treatment were recorded.[22,23]

Surgical Technique

Surgery was performed with the patient in a supine position on a radiolucent table. The initial steps were reduction and stabilization of the condylar fragments, which can be aided by a Schanz pin (as a “joystick”). Manual pressure with a large mallet is occasionally necessary to push on a distal fragment. Skeletal traction was applied to the proximal tibia for comminuted fractures. The hybrid advanced technique presented by Catagni et al was used in all cases.[24] This configuration, in which a better frame stability is achieved extending the frame with a proximal arch at the subtrochanteric level and associating half pins to conventional wires, had been adapted to TSF (Figure, Supplemental Digital Content 4, http://links.lww.com/JOT/A12). A temporary knee-spanning construct with the addition of tibial rings improved joint protection and allowed early weight bearing. Articulated distraction using 2 hinges aligned with the joint allowed for early knee movement. The tibial rings were removed 8 to 12 weeks later. For femoral fractures with bone loss, distraction osteogenesis was used to fill the bone gap and restore normal limb length. Two half-pins were attached to an intermediate ring for the bone transport segment, and a corticotomy was performed in the proximal shaft; after a 7- to 14-day latency period, distraction started at 1 mm per day. Iliac crest bone grafting (ICBG) was done after docking. In some cases, it was better to shorten the bone defect at the fracture site to achieve bony contact more quickly. Physical therapy consisting of assisted range of motion (ROM) of the knee with strengthening and partial weight bearing on crutches started immediately after surgery. Frame removal was performed as an outpatient procedure.

Statistical Methods

Continuous variables were described using mean, standard deviation (SD), and range of the observations. Categorical variables were described using frequencies and proportions (Table, Supplemental Digital Content 5, http://links.lww.com/JOT/A13).

RESULTS

Patients were followed for a mean of 26 months (range, 18–48 months) after injury. Seventeen (85%) of 20 fractures healed with initial fixation. In six patients with significant bone loss two lengthening and shortening procedures and 4 transports were planned as accessories procedures and part of the initial fixation. Mean time to union was 33 weeks (range, 19–70 weeks), excluding cases of unexpected secondary surgery to promote bone healing or to solve a complication before bony union (Table, Supplemental Digital Content 6, http://links.lww.com/JOT/A14). Acute shortening and re-lengthening were performed in 2 cases of femoral fractures with bone loss (7.8, and 4 cm), and mean time to healing was 42 weeks (Figs. 2–5). Bone transport procedures were performed on 4 femoral fractures because of large bone defects. Mean bone transport lengthening was 6.8 cm (range, 4–8.4 cm); mean EFT was 45 weeks. Eight (40%) fractures had ICBG. Limited knee flexion was observed in most patients; however, full extension was achieved in all cases. Mean range of flexion at final follow-up was 95 degrees (range, 50–130 degrees). Six patients had <90 degrees of flexion. Reference values utilized, accordingly to Paley for MAD, mLDFA and aPDFA are reported in Supplemental Digital Content 6(http://links.lww.com/JOT/A14).[17] MAD is the perpendicular distance from the mechanical axis line to the center of the knee joint line. After final consolidation 16 (80%) patients MAD determination fell inside of normal limits. Of the four patients with MAD deviation, two (cases 9, and 20) had minor deviations in part secondary to associated tibia fractures, one (case 3) had a minor deviation with a valgus femoral alignment less than 5 degrees

and one (case 17) major deviation was judged as a malunion. The mLDFA and aPDFA measured values were within normal range in 16 (80%) and 18 (90%) patients, respectively.

Functional and Bone Results

Results based on ASAMI criteria at final follow-up were 37% excellent, and 63% good for bone outcomes and 5% excellent, 58% good, and 37% fair for functional outcomes. The mean Neer knee score was 78.8 (range, 64–92) points. The scores were 21% excellent, 68% good, and 11% fair. Eighty percent of the patients returned to their pre-injury work activities (Table, Supplemental Digital Content 7, http://links.lww.com/JOT/A15).

Complications

The incidences of nonunion (3 cases) and malunion (1 case) were 15% and 5%, respectively. Nonunions were treated with a locking plate and ICBG (cases 1, 14, and 18). A patient (case 17) with OTA/AO type 33C3 (Gustilo and Anderson, type IIIB) femoral fracture had malunion (18 degrees of varus deformity) with a 2-cm limb-length discrepancy (LLD) because of lost alignment after frame removal; the femoral deformity was corrected with a new TSF.

An additional operation, Judet quadricepsplasty, was required for 5 patients (cases 3, 9, 14, 16, and 20) to treat limited knee flexion. One patient refused surgery. Acceptable LLD (<2.5 cm) occurred in two patients (cases 1, and 17). Seven patients developed pin tract site infection.

DISCUSSION

Optimal timing and type of definitive stabilization for open SIF fracture remains a controversial issue.[1−8,10,12,25] Retrograde femoral nailing, open reduction, and fixation using plates and screws are most commonly used.[26−28] Open SIF fracture adds to the complexity of the injury an increased risk of infection. Treatment options for open distal femoral fractures included acute

internal fixation with applications of antibiotic beads and staged spanning external fixation followed by internal fixation with plates and screws, retrograde femoral nailing or conversion to second stage circular external fixator (CEF) as an alternative option.[7,10,12,21,26,28,29]

In the present study, in which definitive external fixation had been the method of choice for open SIF, bone union was achieved in 17/20 cases (85%) and the three nonunions (15%) were successfully treated with revision locking plates and ICBG, so, at the end of treatment, all patients healed with no septic sequelae.

In a systematic review, Henderson et al[30] observed differences in complications rates between 10 published studies treating distal femur fractures with locked plates. Nonunion ranged from 0-17%, delayed union 0-15% and plate failure 0 to 20%. Results of treatment of open SIF fractures with internal fixation reported in the literature are variable. Ricci et al[31] reported a cohort of 335 cases of distal femoral fractures treated with internal fixation. All patients were reviewed for nonunion, deep infection, and implant failure. The cohort included 110 (33%) open fractures. The overall rate of nonunion was 19%, rate of nonunion for open fractures was 37%, and rate of nonunion for closed fractures was 10%. The overall deep infection rate was 5% (7% in open fractures, 4% in closed fractures). Implant failure in open fractures was 12% at any location and 9% proximal compared with 5% at any location and 4% proximal in the closed fracture group. The study indicates that diabetes, open fractures, increased body mass index , smoking, and short plate length were identified risk factors for nonunion and implant failure.

Dugan et al[29] presented a report of 15 patients with open distal femoral fractures treated with a staged protocol of internal fixation and antibiotic beads and subsequent autogenous bone grafting and medial plating. The union rate was 100%, knee stiffness reported in several cases, and no cases of deep infection was encountered in the study. Kolb et al[26] published series of 50 cases of distal femoral fractures, including 5 with open fractures. The deep infection rate was 1%; the nonunion rate was 6%. The single patient with an open IIIC fracture experienced knee stiffness that

required quadricepsplasty. Kregor et al[32] presented a report of 66 patients with distal femoral fractures treated with the LISS plate. The nonunion rate was 5%; the deep infection rate was 3%. No details regarding open versus closed fractures were provided.

Vallier and Immler[33] reported a 71-case series of distal femoral fractures treated with 95 degree angled blade plate versus locking condylar plates. The study included 15 patients with open fractures. The overall complication rates were 6% deep infection, 7% malunion, and 10% nonunion. No clear distinction was made between open and closed fractures. Rodriguez et al[6] reported a retrospective review of 283 distal femoral fractures treated with lateral locked plating. Forty-one (14%) fractures were surgically treated for nonunion. Open fracture, obesity, diabetes, and use of stainless steel plate were reported to be independent risk factors for nonunion.

Few articles in the literature describe use of the Ilizarov technique as a definitive treatment of SIF fracture.[1,8,10,12,21,34] Cavusoglu et al,[35] Arazi et al,[36] and Kumar et al[37] treated 6, 4, and 20 open SIF fractures, respectively, with Ilizarov fixators. Ramesh et al[38] reported radiographic union in 13 C3 fractures managed by autogenous nonvascular fibular strut graft, corticocancellous bone graft, and Ilizarov fixator.

Hutson and Zych[39] reported treating 12 (75%) of 16 open C3 fractures with tensioned wire circular fixation and limited open reduction. Five (31%) patients underwent quadricepsplasty to improve knee motion. Fourteen (87%) fractures had alignment with less than 10° of angulation, two fractures required angular correction for a valgus and recurvatum deformity. Cole et al[28] treated 5 SIF fractures with retrograde nail insertion with an average ROM of 0 to 90 degrees. Sanders et al[40] reported an average ROM of 79 degrees in 5 C3.3 fractures treated with double plating. Loss of motion has been observed in studies of external fixation of the femur. Marsh et al[41] and Hutson and Zych[39] reported average ROM of 62 and 92 degrees, respectively. The patients in our series had a mean range of flexion of 95 degrees (range, 50–130 degrees). Motion improved to flexion after frame removal.

Our findings are consistent with those reported in the literature, and it is our opinion that patients with severe comminution and bone loss, disruption of the quadriceps tendon and muscle, and ipsilateral tibial injuries experience less recovery of knee function. In the current literature, the incidences of pin site infection range from 32% to 80%, with an average 4% being associated with chronic osteomyelitis.[12,21,36,41−43] In the present study, 7 (35%) cases developed pin site infections that were treated with orally administered antibiotics and 1 half-pin removal. We encountered no cases of osteitis. The rate of reoperation in our study was 30%, with a change of the fixation method or fixation device necessary for 3 fractures. This result is like the 30% and 29% rates of reoperation reported by Hutson and Zych[39] and Arazi et al[36] and worse than the rates reported by Kumar et al[37], Ramesh et al[38], and Cavusoglu et al[35] of 0%, 8%, and 20%, respectively, before union was achieved.

The major reasons for secondary procedures after index surgery are nonunion, deep infection, malunion, posttraumatic knee stiffness, and implant failure. The reasons for secondary procedures after index surgery in the present study were nonunion (3 of 20 cases) treated with plating and bone grafting, malunion (1 of 20 cases) treated with reapplication of the TSF to realign the mechanical axis, and quadricepsplasty (5 of 20 cases). Three patients with knee stiffness had floating knee injury. Our study showed a functional Neer knee score of 89% excellent and good; this is better than the results achieved by Kolb et al[26] (80%) and Schandelmaier et al[44] (74%) in 2 trials that used a minimally invasive plating technique. The mean Neer knee score in the present study was 78.8 points (range, 64–92 points), whereas Kolb et al[26] and Schandelmaier et al[44] reported 80 points (range, 60–100 points) and 73.9 points (range, 38–88 points), respectively. No rotational deformity occurred in our study; Zehntner et al[45] reported rotational deformity in 30% of the cases, Krettek et al[46] reported 29% with rotation of 15 degrees, Schandelmaier et al[44] reported 7.5% with rotation >20 degrees, and Grass et al[47] reported a rotational deformity rate of 3.7%.

In the present study, femoral angular deformities in the frontal plane occurred in 2 cases; only 1 (5%) of 20 patients had varus deformity >5 degrees, which was caused by the early removal of the fixator (case 17).

Hutson and Zych[39] reported 38% recurvatum, 94% valgus, and 12.5% procurvatum deformities <12 degrees after treatment for 16 C3 distal femoral fractures.

In this study, the ability to align the fracture with the TSF after the initial frame application greatly improved the angular alignment of the fracture compared to the Ilizarov fixator.

In the present study, no loss of reduction or implant failure occurred, whereas Smith et al[48] noted loss of reduction and implant failure of 19.3% and 5.5%, respectively, in the LISS group. The higher incidence of LLD in the series presented by Kumar et al[37] (40% of cases had 4 cm of shortening and another 40% had 1.5 cm) was because of acute shortening to approximate the bone ends where bone loss existed or to achieve wound closure. Arazi et al[36] found relevant shortening (4 cm) of the femur in 40% and <2.5 cm in 36% of cases, and Marsh et al[41] reported a 16% rate of malunion.

Few data are available in the literature regarding the use of TSF as definitive treatment of acute femoral fractures. Our results with TSF, in a subset of SIF fractures with extended soft tissue damage and frequent bacterial contamination of the fracture compared favorably with those reported for internal osteosynthesis, in terms of bone consolidation, axis alignment and functional outcome. The TSF method has been less technically demanding than the traditional Ilizarov tensioned wire fixator.

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FIGURE LEGENDS

FIGURE 1. Images of a patient with multiple traumatic injuries (ISS = 20), including a type 33C3 grade II femoral fracture (case 12). Five days after the damage control orthopaedics procedure was performed, the patient was returned to the operating room for definitive treatment with accurate anatomic reduction of the intraarticular fracture by using open reduction and internal fixation with screws, olive wires and a TSF. A, Radiographs obtained after the conversion procedure show

condylar osteosynthesis with restoration of the articular surface and the TSF device in place with 6 struts.

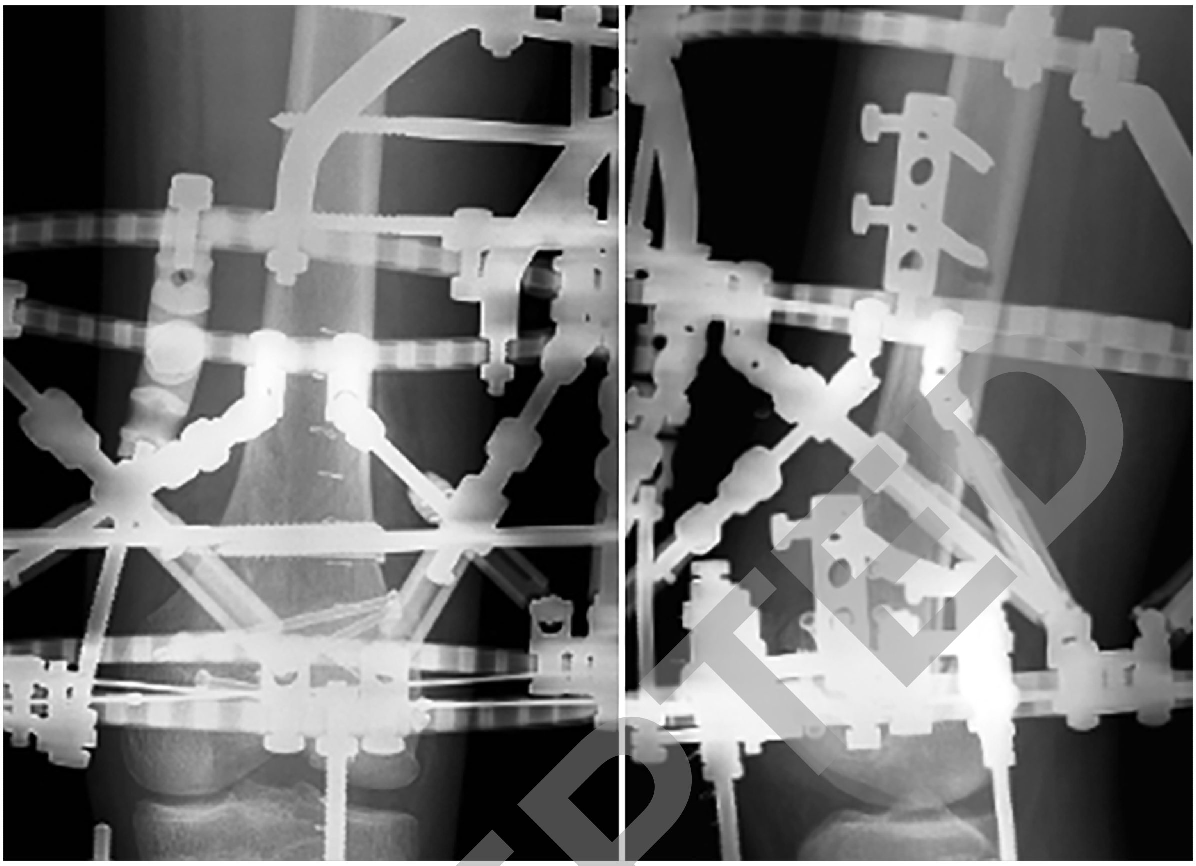
FIGURE 2. Images of a 25-year-old woman (case 20) with an OTA/AO type 33C3 (GIIIA) femoral fracture with supracondylar bone defect and ipsilateral OTA/AO type 42B3 (Fraser type IIB) tibial fracture. A, Clinical photograph of the patient with a knee-spanning external fixator (KTSF) as damage control orthopaedics. B and C, Preoperative radiographs of the displaced right supracondylar femoral and distal tibial fractures stabilized with a KTSF. D, Computed tomograms of the condylar fracture of the femur in coronal planes.

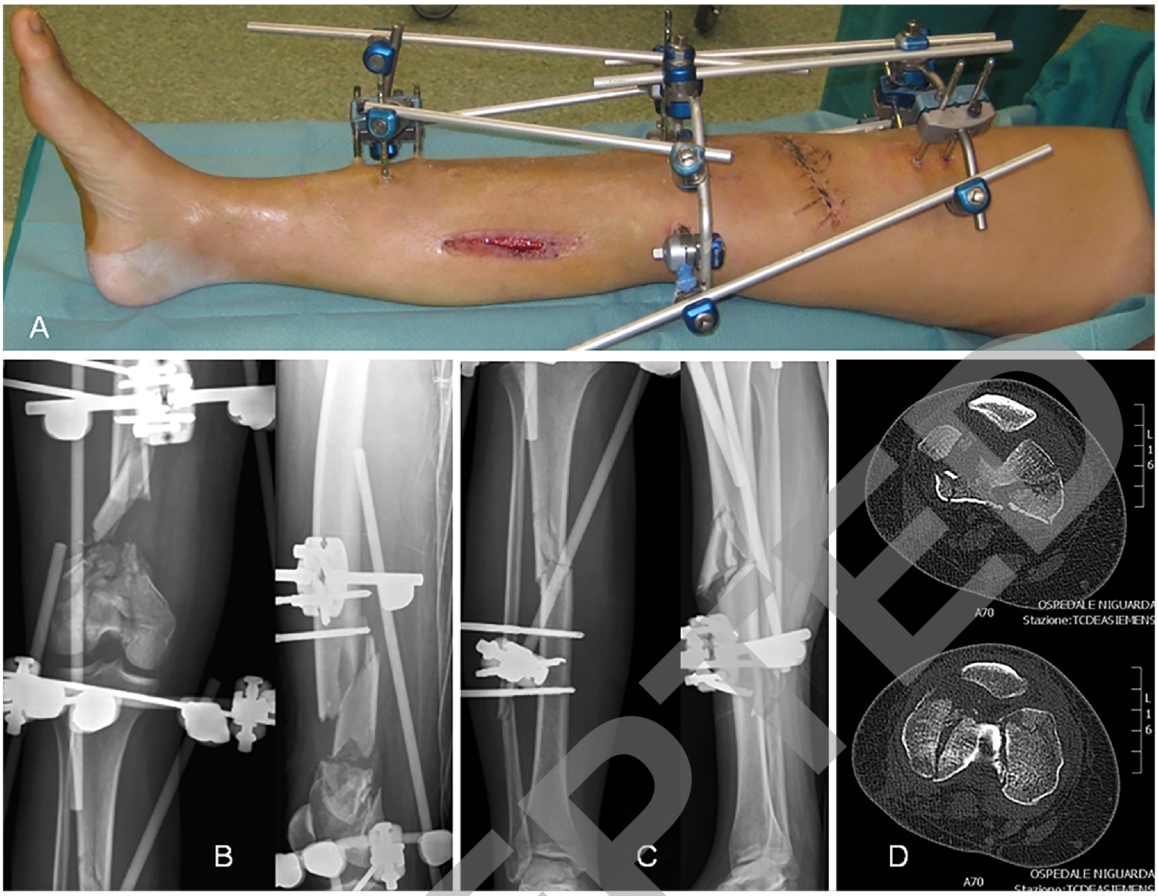
FIGURE 3. Images of the same patient shown in Figure 3 after application of the TSF. A, Clinical photograph of the patient with a multilevel hexapod frame in the femur; tibial extension of the frame across the knee allows stable mounting. B and C, Radiographs, obtained after the conversion procedure, of condylar osteosynthesis with restoration of the articular surface and the TSF device in place with 6 struts achieving acute shortening of the femur with good coronal and sagittal plane alignment. A percutaneous osteotomy was created for distraction lengthening (starting 7 days after surgery).

FIGURE 4. Images of the same patient shown in Figures 3 and 4 present a standing front view 3 months after frame application. A, Orthoroentgenogram obtained with the pelvis leveled and patellae forward indicates accurate distal femoral fracture realignment with correct mechanical axis without LLD. B, Clinical photograph of the patient with femoral TSF in place and tibial extension

of the frame across the knee. C, Anteroposterior and lateral view radiographs of the limb obtained 9 months after frame application.

FIGURE 5. Clinical follow-up images, obtained 18 months after frame removal, of the same patient shown in Figures 3 through 5. Good clinical outcomes were achieved in the femur and tibia. EFT was 38 weeks. Femoral lengthening was 78 mm. Bony and functional ASAMI outcomes were good. Neer knee score was 83 at final follow-up.

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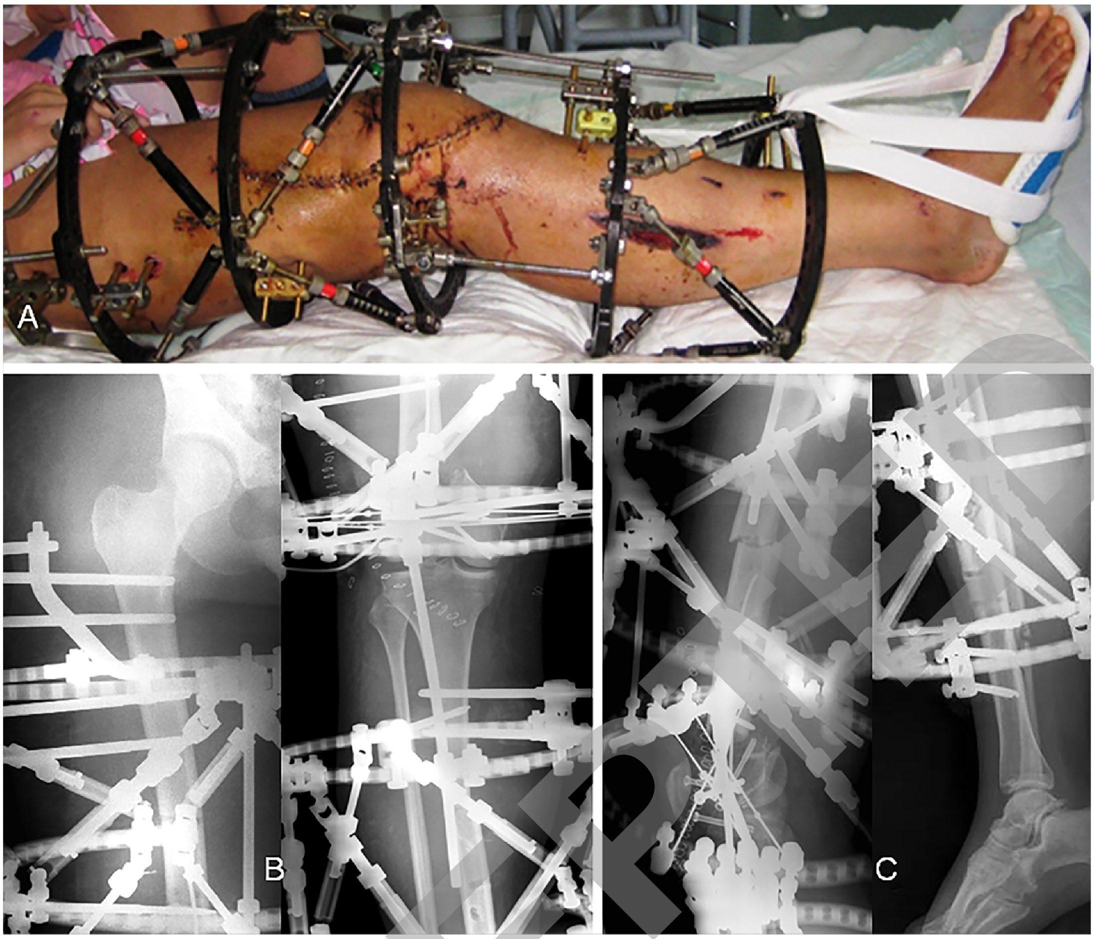
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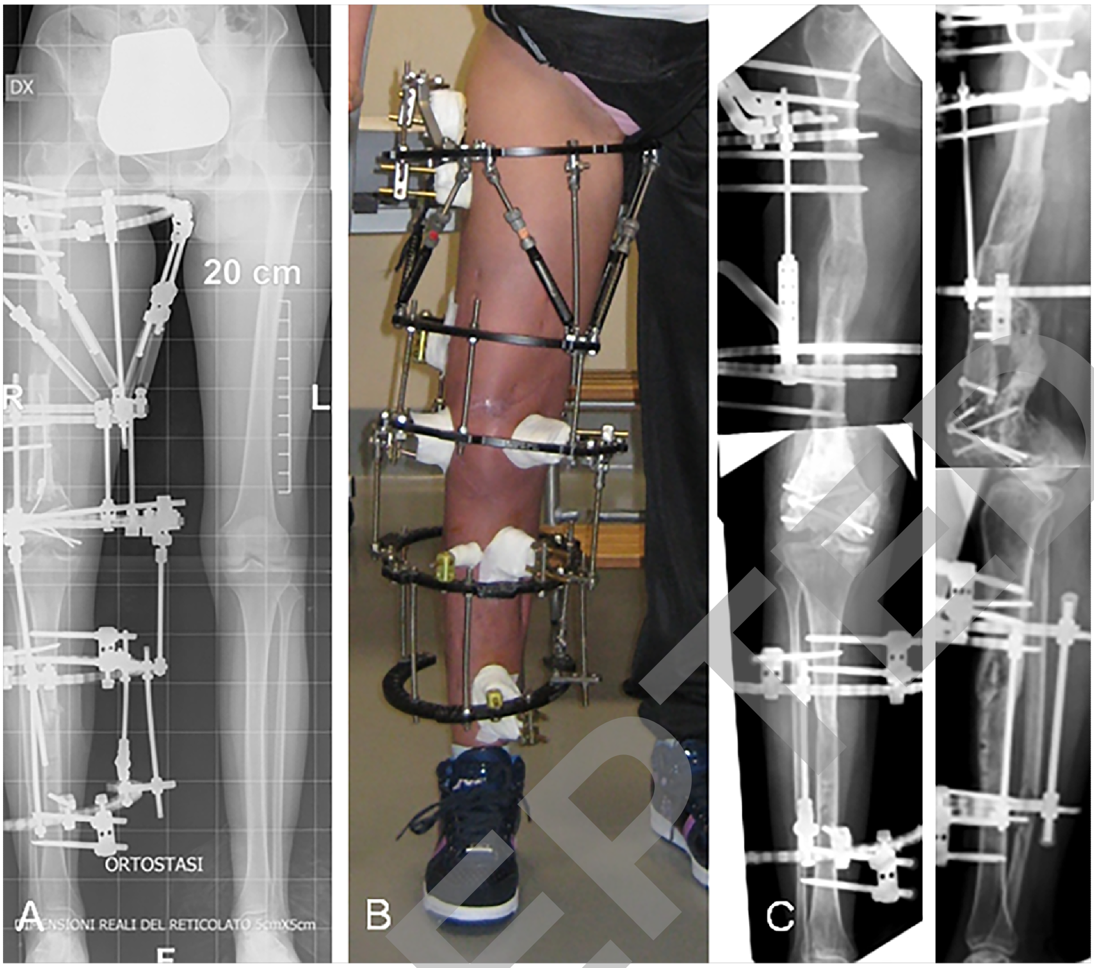
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