CLINICAL TECHNIQUE

Transfocal Osteotomy to Treat Shear (Oblique) Non-union of Tibia

Om Lahoti[1], Naveen Abhishetty[2], Mohannad Al-Mukhtar[3]

Abstract

Aseptic non-unions of tibial shaft fractures often need surgical treatment which carry significant socio-economic implications. The causes for non-union include patient co-morbidities, high energy trauma, open fractures and fracture geometry. Oblique fractures are subject to shear forces and, if not adequately neutralised, will fail to unite. Experiments have shown that callus formation is poor in oblique fractures due to local shear stresses. We report a technique of minimally invasive transfocal transverse osteotomy and compression in a hexapod circular fixator, Taylor Spatial Frame (TSF) for 12 patients treated with a shear non-union of tibia between 2010 and 2019. There are four female and eight male patients. The average age is 49 years (range from 26 to 72 years). The fracture pattern was oblique (30–45°) in all cases. Healing of the non-union occurred in 12 cases with one case needed additional treatment with bone marrow aspirate and demineralized bone matrix. The technique of creating a minimally invasive transfocal transverse osteotomy through the oblique non-union of tibia and the use of a hexapod circular fixator to compress the osteotomy is described and adds to the range of treatments available for aseptic non-union of tibia.

Keywords: Aseptic non-union, Biomechanics, Cohort study, Compression force, Fracture geometry, Osteotomy, Shear force, Taylor Spatial Frame, Tibia.

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Introduction

Aseptic non-union after a tibial fracture is a significant complication and causes are multifactorial. Surgical intervention is required often with medical, financial and personal consequences.[1] The incidence of non-union is estimated at 4–8% after intra-medullary nailing of closed fractures of the femur and tibia and is even higher after open fractures, high energy injuries and in smokers.[2] Amongst other factors, fracture morphology influences the biomechanical environment at the fracture site. Oblique fracture geometry subjects the fracture to shear forces which are known to inhibit healing.[3,4] About 30–40% of tibial fractures are oblique.[5] The commonly used fracture fixation techniques–including IM nails, plates and external fixators–do not always neutralise the shear forces adequately and can lead to non-union. Surgical intervention in such cases should aim at neutralising shear forces or modifying the mechanical environment to promote healing or both. In orthopaedic practice, transverse osteotomies are more stable under loading and tend to heal quicker.[4] We use this principle for treating recalcitrant non-union consequent to oblique fractures of the tibia (termed 'shear non-union'). The aim of this study is to report our results of using a minimally invasive, low energy, transverse osteotomy through the shear non-union–the transfocal osteotomy–and applying compression with a hexapod frame in 12 patients.

Materials and Methods

This is a sample obtained from a retrospective review. The indications for using a transfocal osteotomy and compression in a hexapod frame were the diagnosis of an aseptic non-union consequent to an oblique fracture of the tibia. The non-union was diagnosed when there was a failure to see progression in any radiological signs of union or if the callus seen was limited to one cortex at 6 months or later after the fracture. Multiple methods were used to rule out infection: a thorough history of injury, treatment, and postoperative complications, and a clinical examination for local signs of infection. A full blood count (FBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) were obtained in every case and found to be normal in all cases. Bone scans were not obtained unless there was clear clinical suspicion and/or elevated inflammatory markers.

The soft tissue envelops around the non-union was stable but multiple scars were present in most patients either from the primary injury or primary surgical procedures. Two patients had local tissue conditions that caused concern in choosing treatment methods that involved large surgical exposures; one patient had a local fasciocutaneous flap and another had oedema from prolonged use of casts and splints. An important pre-requisite for this technique was that the patient be capable of weight-bearing fully on the affected limb post-surgery.

Informed consent was obtained after a thorough explanation of the risks and benefits of minimally invasive hexapod frame treatment. All patients were shown a model of the frame and met other patients undergoing circular frame treatment. The

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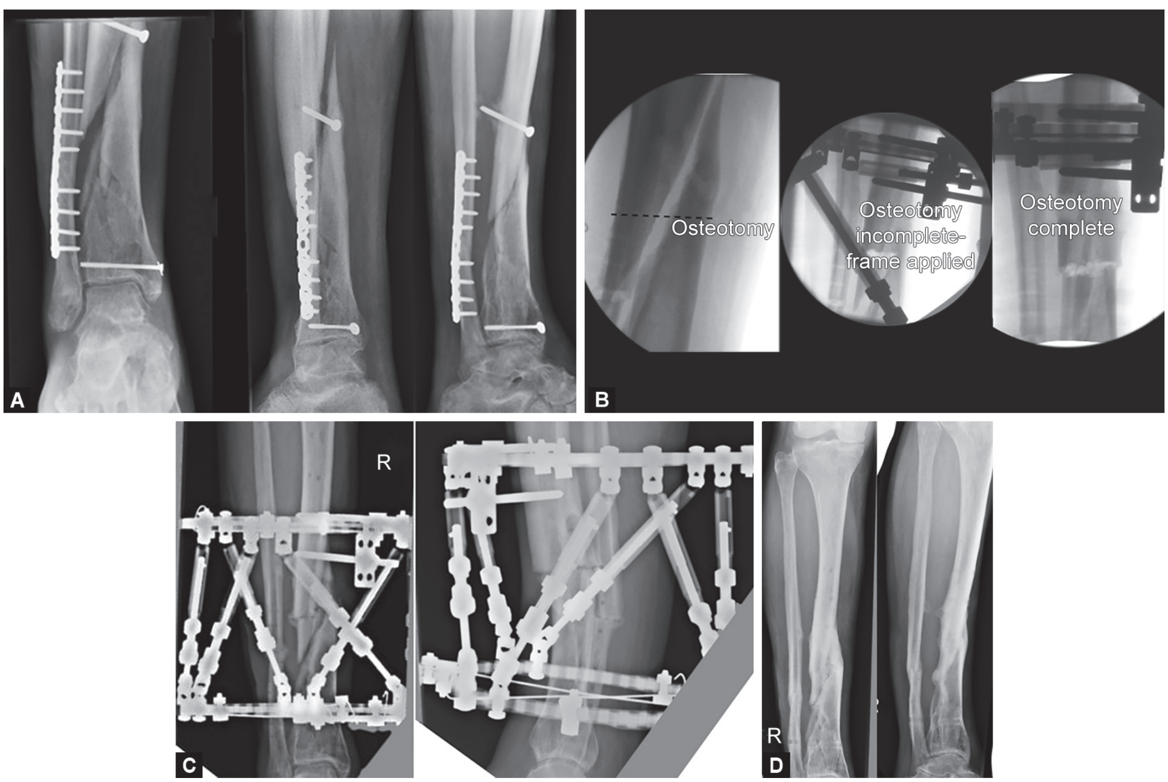
postoperative pin site care regime and instructions on how to manipulate the fixator struts for compression were provided. The importance of full weight-bearing was emphasised.

Surgical Technique

The whole procedure was carried out with minimal soft tissue disruption. Any previous metal work was removed through small incisions. Broken screws were left *in situ* unless at the site of the planned transverse osteotomy. Under an image intensifier, a transverse plane through the non-union is identified and marked with a K-wire or a 2.5 mm drill bit. A tourniquet was inflated now after limb elevation. The osteotomy was carried out through a targeted 2–3 cm incision, with minimal soft tissue stripping, and using the multiple drill holes from a 3.5 or 4 mm drill bit. The drill holes were joined with a sharp osteotome until the osteotomy was 90% complete (Fig. 1). The osteotomy was left incomplete until after a stable frame was in place. This kept the leg stable and prevented displacement of the osteotomy during frame application. A complete fibular osteotomy was then performed through a separate incision. This was placed 3–4 cm distal or proximal to the tibial osteotomy depending on the level of non-union in the tibia. A fibular osteotomy within 6 cm of the ankle joint was avoided to maintain ankle stability. The tourniquet was released after applying a pressure bandage. A two-ring TSF construct was then applied without a tourniquet. This sequence minimised the overall tourniquet time. Frame-mounting parameters were obtained with the help of an image intensifier.[6] The pressure bandage was then removed and the tibial osteotomy completed. In cases of non-union with deformity, a 10–15° malalignment was corrected acutely at this stage. In the presence of concerns over vascular or neurological compromise or if the deformity was large, correction was then done gradually using the TSF software. Postoperatively patients were allowed to weight bear as soon as comfortable and discharged home.

The first review in clinic was at 7–10 days where wounds were checked and the pin site regime demonstrated. In patients without deformity, compression of the osteotomy was initiated at 0.5–1 mm/day and continued until the osteotomy gap closed. It took about 2 weeks to achieve good compression. In those with deformity, gradual correction was commenced and the osteotomy compressed once satisfactory alignment was achieved. Anteroposterior, lateral, and oblique radiographs were obtained at 6-week intervals until callus was seen. The frame was dynamised by unlocking the struts once callus was noted on three cortices. Mild ache was not uncommon when the struts were unlocked for the first time but if the patient reported severe pain, the struts were re-locked and the patient reviewed again after 4–6 weeks to repeat the process. If there was no pain or deformation at the osteotomy site, the patient was encouraged to leave the struts unlocked during the day and continue to bear weight fully and to lock the struts whilst resting and at night. Further X-rays were obtained after 3–4 weeks to confirm the osteotomy had not displaced and



Figs 1A to D: (A) A 55-year-old male patient sustained a lower tibia and fibula fracture. At initial surgery, fibular was fixed and the long oblique tibial fracture was fixed with two screws and a spanning external fixator because of extensive blistering and swelling. The fibular wound broke down due to swelling and needed split skin grafting. The external fixator was removed at 4 months. X-rays at presentation, 6 months after the injury, showed an oblique (shear) non-union. The soft tissues were stable but the limb was oedematous and the ankle stiff; (B) Image intensifier sequence. Osteotomy level identified. Incomplete osteotomy of tibia with frame *in situ*. Osteotomy completed; (C) Progression in frame. Early callus formation seen at 8 weeks; (D) AP and oblique views show full healing of the non-union. Note that the healing has progressed above and below the transverse osteotomy level

Table 1: Details of patients

Patient	*Age/sex*	*Primary fixation*	*Duration of non-union (months)*	*Duration in frame (months)*
1	AM/37/F	Nail x3 Primary reamed nail + 2 exchange nail procedures	28	11 Required BMA** and DBX*** at 8 months
2	DH/37/M	Circular frame for open fracture – 25° varus deformity lower tibia	23	6
3	LB/56/M (Fig. 1)	External fixator + lag screws	10	7
4	KH/42/M	External fixator as definitive treatment	7	6
5	SP/72/F	External fixator, local flap	32	6
6	DC/26/M	Intramedullary nail, lower third tibia, 15° varus	10	6
7	KG/54/F	Plating–lower third tibia, 30° external rotation	15	4
8	AE/54/M	Gunshot wound, external fixation	30	7
9	NH/44/F (Fig. 2)	MIPO*, lower third tibia	7	8
10	MP/63/M	Cast initially, followed ex fix,	32	6
11	MH/32/M	Hexapod	6	8.5 (incl. time in initial hexapod)
12	GD/40/M	Plate fixation of lower tibial fracture	6	9 (incl. time in initial hexapod)

*MIPO, minimally invasive plate osteosynthesis; **BMA, bone morrow aspirate; ***DBX, demineralized bone matrix

the callus satisfactory. At this follow-up, all six struts were removed and the patient was asked to walk around in the clinic for 30 minutes with two rings still *in situ* but without struts. AP, LAT and oblique radiographs were obtained without struts to evaluate healing of osteotomy, and if found to be satisfactory, the rings were removed in clinic under nitrous oxide inhalation. The leg was protected in an Aircast boot for 4–6 weeks. All patients were followed up for a minimum of 1 year post-union. We recorded the functional progress using an lower extremity functional scale (LEFS) questionnaire on a digital tablet linked to our electronic patient records (EPR). Lower extremity functional scale (LEFS) is a patient-reported lower extremity functional assessment tool, developed by Binkley et al.,[7] and has 20 items with scores ranging from zero (extreme difficulty/unable to perform a physical activity) to four (no difficulty). The total score is obtained by adding the responses to 20 questions and a score of 80 indicates no functional difficulty. A change of nine points or more is indicative of clinically meaningful improvement. It is widely used in successfully assessing the outcomes in a range of lower limb musculoskeletal conditions[8] and found to be equivalent to SF-36.[9] Lower extremity functional scale (LEFS) was included as a physical function assessment tool, part of the Integrating Mental and Physical healthcare: Research Training and Services (IMPARTS) initiative at our institute, at initial consultation and at follow-up post-treatment.

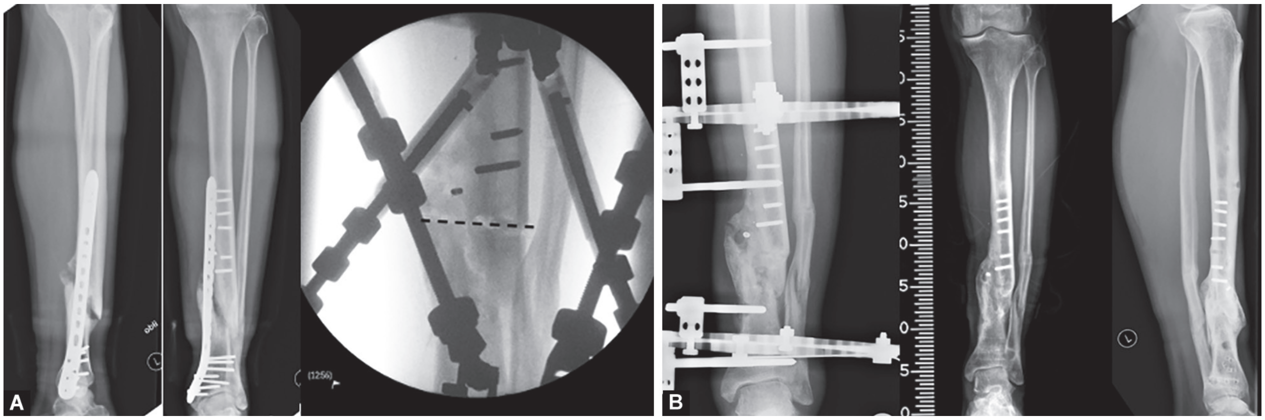
Results

Twelve patients with shear non-union (through an oblique fracture line) of the tibia were treated using this technique between 2010 and 2019. There were four female and eight male patients with an average age of 49 years (ranging from 26 to 72 years). The fracture pattern was oblique (30–45°) in all cases. The primary treatment had included an external fixator in four cases, where soft tissues were significantly compromised from primary injury (but were not open fractures), a reamed intramedullary nail in two cases (in one case there were two exchange nailing procedures before referral), a circular frame in two cases and locked plating in four cases. In cases treated with an external fixator and where the fracture site had not been exposed, the external fixator was removed in out-patients and definitive surgery was carried out after 4–6 weeks; the limb was immobilised in a plaster cast whilst awaiting surgery. The average time between the primary fracture stabilization and the definitive transfocal osteotomy and use of the hexapod circular fixator was 19 months (ranging from 6 to 32 months). The average duration in frame was 201 days (with a minimum of 125 days and maximum of 349 days). Details are in Table 1.

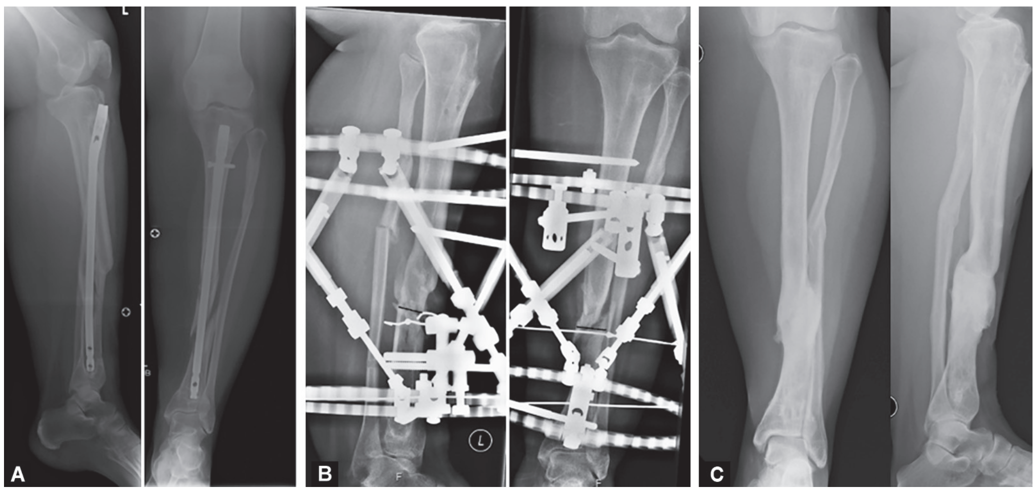
All 12 patients were healed. Eleven patients achieved union without further intervention and only one patient needed supplemental demineralized bone matrix mixed with bone marrow aspirate from the iliac crest at 8 months. This patient had three nailing procedures (one primary and two exchange nailing procedures) and was referred at 28 months post-fracture. The three reaming episodes may have resulted in significant damage to bone biology. Radiologically, this was an atrophic non-union with a 5–7 mm gap across the oblique fracture plane (Fig. 3). The surgical wound of the osteotomy healed well in all patients, and no patient developed infection at the osteotomy site. Six patients developed one episode of superficial pin infection, requiring oral antibiotics for 5 days. There were no pin breakages. Radiologically, it was noted that the transverse osteotomy site healed first before the entire oblique plane non-union beyond the site of transverse osteotomy consolidated (Figs 1D and 2B). The lower extremity functional scale records improved from a pre-operative score average of 40.5 (ranging from 20 to 45) to 70.75 (ranging from 63 to 75) at 6–12 months after the removal of frame. Residual symptoms were difficulties in running and hopping on the injured leg.

Discussion

Non-union remains a problem of trauma surgery even with improved implant technology and better understanding of bone healing. The treatment of non-union uses substantial healthcare



Figs 2A and B: (A) Pre-operative X-rays show an oblique non-union with plate failure. The image intensifier shows the transverse osteotomy and TSF in place; (B) Healing of osteotomy and non-union. Note the healing of entire oblique plane non-union above and below the osteotomy



Figs 3A to C: (A) A case of failed fixation with an intramedullary nail (two prior attempts to heal with exchange nailing with a total of three reaming procedures including the initial nailing) showing a long oblique atrophic non-union; (B) Transfocal osteotomy (black line) and application of the Taylor Spatial Frame; (C) Final result

resources.[1] The incidence of non-union of tibial shaft fractures is 4–8% after intramedullary nailing of closed fractures and even higher in open fractures.[10] Non-union is equally prevalent after plating at 5–12%[11] and is also common after monolateral or, to a lesser degree, circular frames.

Fracture geometry plays an important role in fracture healing and oblique fractures are at risk of delayed or nonunion[3,4] despite the large surface area. About 30–40% of diaphyseal fractures are oblique.[5] Aro et al.[4] studied the healing pattern of transverse and 60° oblique fractures in canine tibiae under similar external fixator constructs and concluded that the oblique fractures lagged by 30 days compared to transverse fractures to reach complete healing. Furthermore, bending stiffness at 60 days and torsional stiffness at 90 days (after sacrificing the animal) were higher in the transverse fracture group. Intra-cortical new bone formation and remodelling were also superior in the transverse group. Augat et al.[12] studied the effects of shear and axial movement on the healing of an experimental transverse osteotomy model in sheep. They used an external fixator in which they could control shear and axial movement independently without changing the overall stability of the construct in each group and the healing outcome was assessed mechanically, radiographically and with histomorphometry. They concluded that the fixation that allows shear movement delays bone healing whereas axial movement promotes healing of diaphyseal fractures. Finite element analysis studies also confirm that longitudinal motion promotes callus formation whereas shear forces inhibit it.[13] In our study, non-union was consequent to an oblique fracture of the tibia in all cases. The fixation devices used in primary treatment had not neutralised the shear forces adequately and contributed to the non-union; in these instances, we refer to a shear non-union.

The ideal treatment for an aseptic non-union remains elusive; there are several different approaches. Exchange nailing is a good option[14,15] in the absence of infection. An oligotrophic or atrophic pattern of non-union and a bone gap of five millimetres or more are associated with failure of the exchange nail procedure (Fig. 3). Plate augmentation of nail and bone grafting is another alternative but involves a large surgical exposure which is not ideal in cases with questionable integrity to the soft tissues. Autologous bone graft harvesting has its own complications and morbidity. Giannoudis et al.[16] have put forward the Diamond Model of Bone Fracture Healing Interactions in which biological as well as mechanical factors are optimised irrespective of the cause of non-union. This approach often involves extensive soft tissue stripping, harvesting autologous graft, and use of expensive bone morphogenetic protein. Success of this approach ranged from one failure out of 64 cases[17] to 20% failure.[18]

In this sample, the soft tissues were considered fragile for various reasons; this included the presence of a local fasciocutaneous flap, split skin grafts, extensive scarring from a gunshot wound and oedema from prolonged immobilization, making extensive surgical exposure a precarious option. The patient was assessed for evidence of infection at the non-union site through clinical examination, inflammatory markers and an SPECT-CT in appropriate cases. Frank or strong suspicion of infection was a contraindication for this procedure.

The non-union was identified through an oblique fracture plane in all cases including one case of a comminuted fracture (case 1 in Table 1) in which all other fragments had united, leaving an oblique plane non-union. The chosen primary fixation methods had failed to neutralise the shear forces across the oblique fracture geometry. Our treatment strategy was to create an optimal biomechanical environment for the non-union to heal which could not have been achieved by the plate or a nail. The local biology was respected by performing osteotomy through a small incision and minimising stripping of soft tissues. The transverse osteotomy through the non-union created a stable mechanical configuration. Application of the circular fixator hexapod (Taylor Spatial Frame) was done to stabilise and compress the osteotomy. This, whilst enabling gradual correction of varus angulation (mal-nonunion) in two cases and malrotation in one patient, also provided a stable construct to allow immediate weight-bearing, thus promoting the axial loading which is beneficial to bone healing.[19] The non-union was not excised or bone graft added at the time of transfocal osteotomy and frame application. One case (Patient 1 in Table 1) where bone biology was significantly damaged from repeated exchange nailings was very slow to heal. Demineralised bone matrix and bone marrow aspirate were then added to enhance local biology and promote union.

The observation that the entire oblique plane above and below the transverse osteotomy healed in all cases (Figs 1 to 3) highlighted the benefits of an improved biomechanical environment. In one case (Fig. 2B), a degree of translation at the osteotomy site was accepted because it offered the best opposition of the transverse osteotomy for compression. Given the circumstances, the fracture was fixed with minor translation using a plate prior to the transfocal osteotomy and there was distortion of local anatomy, we felt the position acceptable. All angular deformities had been corrected to prevent long-term adverse effects on the knee and ankle joints.

We used functional outcome scores of the LEFS and healing of the non-union on radiographs as measures of success. All patients reported an improved LEFS score at 6–12 months post procedure– from a pre-operative average score of 40.5 (ranging from 20 to 45) to an average of 70.75 (ranging from 63 to 75). Radiologically, all tibiae healed with complete bone consolidation across the shear non-union with good coronal and sagittal alignment. A 5–7 mm translation at the osteotomy site was accepted in one case (Fig. 2) because that position afforded good contact across the osteotomy site.

The strengths of this study are that the treatment strategy was based on mechanical and biological principles. The surgical approach respected the local biology and a stable mechanical environment was produced through creating a transverse osteotomy which was then compressed in a hexapod circular fixator. Compression of an oblique non-union in a circular frame does not always achieve satisfactory axial compression, and depending on the direction of obliquity, it can generate shear stresses.[20] A transverse osteotomy neutralised such a risk. Union was achieved in all cases with only one case needed biological augmentation at 8 months (Fig. 3). There were no wound healing problems or infection of the osteotomy in this series. The strategy of a thorough clinical assessment, screening of serum inflammatory markers and radio-isotope bone scans, when indicated, allowed us to rule out infection at the non-union site.

Elliott et al.[21] have presented an elegant, unified theory of bone healing and non-union (BHN Theory) and suggested that mechanical instability is the common cause of non-union. According to this theory, addressing the adverse mechanical and biological environment is the key to achieving successful union. We encountered one case where biology was inadequate even after optimising the mechanical environment and biological augmentation healed the non-union. We believe that this study supports BHN theory.

There are limitations to this study. There is a selection bias because patients were selected based on non-union through an oblique fracture of the tibia and the fragile state of soft tissues. It is retrospective as patients were enrolled only after success with first three patients. There is no control group. There is no similar study in the English language to compare the results of this approach.

Conclusions

The creation of a transverse (transfocal) osteotomy through an oblique non-union of the tibia followed by compression in a circular hexapod fixator is able to produce healing across the entire non-union. The technique, being minimally invasive, is of particular benefit in patients with a fragile soft tissue envelop and adds to the range of treatments available for aseptic non-union of the tibia.

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