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Continuous external compression with a dynamic axial fixator in the treatment of tibial nonunions: a single-center experience

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ABSTRACT

Background: Tibial nonunion remains a therapeutic challenge for orthopedic surgeons, particularly when associated with poor soft-tissue condition, bone defects, infection, or deformity. Continuous external compression with a dynamic axial fixator offers a biological and mechanical solution without the need for bone grafting. We report our single-center experience using this method.

Methods: We retrospectively reviewed 20 patients (mean age 39 years) with tibial nonunions treated between 2012 and 2017. The mean time from injury to treatment was 21.6 months. Eight cases were septic and received culture-specific antibiotics; no debridement was performed. One case with a 4 cm defect underwent corticotomy and bone transport, while the remaining patients were managed with acute compression only. Outcomes were evaluated clinically and radiographically using the Association for the Study and Application of Methods of Ilizarov (ASAMI) criteria.

Results: Bone union was achieved in all patients (100%). The mean time to union was 3.5 months. Nineteen patients were treated with compression alone, and one with lengthening followed by compression. No bone grafting was required. Bone results were excellent in 17 cases and good in 3. Functional results were excellent in 12 and good in 8. No poor outcomes were recorded. The main complication was pin-tract infection (20%).

Conclusions: Continuous external compression with a dynamic axial fixator is an effective method for the treatment of tibial nonunions, both septic and aseptic, and can achieve union without bone grafting even in the presence of bone loss.

Keywords: Tibial non-union, External fixation, Continuous compression, Dynamic axial fixator, Bone healing

INTRODUCTION

A "non-union" is defined by the persistence of an inter-fragmentary mobility and is proved that the treatment initially instituted will not lead to the consolidation of the fracture.[1]

The failure of union of the tibial fractures constitutes a disabling late complication. Evidenced by a rate of tibial non-union between 2.5 and 6,95% according to the literature, making the leg one of the frequent sites of non-consolidation of long bones.[2,3] It is not only a failure of two bony segments to unite but at the same time, it is also a treatment challenge for the orthopaedic surgeon, who has to take multiple factors into consideration such as different treatment modalities, deformity correction, treatment of infection and rapid rehabilitation of the patient.[4] The controversy surrounding the treatment of tibial non-union is still alive. Defenders of open treatment advocate decortication, compression plate and bone graft to be able to correct anatomical deformation, obtain absolute stability and stimulate osteogenesis. Conversely, closed treatment recommends locked nailing or the external fixator to decrease the septic risk and to avoid problems of precarious skin conditions. Since 2011, we apply an original surgical technique by using a monolateral dynamic external axial fixator in compression, for the treatment of non-union and post-traumatic bone loss of long bones and in particular those of the tibia. The technique is simple and can be rapidly applied with minimal equipment, without bone grafting and avoids the maximum the opening site of the non-union site.

The aim of this study was to evaluate the effectiveness of a monolateral dynamic axial external fixator using continuous compression in the treatment of tibial nonunions, and to assess the clinical and radiological outcomes in both septic and aseptic cases in a single-center experience.

METHODS

This was a prospective single-center study conducted at Habib Bourguiba University Hosptail of Sfax - Tunisia between March 2012 and November 2017.

Patient selection

All consecutive patients presenting with tibial nonunion during the study period were included. Tibial nonunion was defined as the persistence of interfragmentary mobility with absence of progressive radiological healing. Patients with congenital pseudarthrosis of the tibia were excluded.

A total of 20 patients were included in the study.

The initial opening defined according to the Cauchoix and Duparc classification.[5]

Sampling technique

A consecutive sampling method was used, including all eligible patients treated during the study period.

Surgical procedure

All procedures were performed or supervised by the senior author (SS). Under general or spinal anesthesia, patients were positioned supine on a radiolucent table. When present, previous hardware was removed using a minimally invasive technique.

No systematic debridement or bone grafting was performed. A monolateral dynamic axial external fixator (rail fixator) was applied in all cases. Acute compression at the nonunion site was performed in 19 patients. In one patient presenting with a bone defect of 4 cm, a bifocal technique combining corticotomy with bone transport and compression at the nonunion site was used.

In a stiff non-union with deformity, osteclasis was done to obtain alignment prior to compression because the rail fixator must be applied only with reduced bone. Fibular osteotomy was done every time when it opposes the tibial compression. Injectable antibiotics were started empirically in an infected non-union. Antibiotics were modified according to the culture and sensitivity results. The treatment was continued until the erythrocyte sedimentation rate and C-reactive protein level had returned to normal. In an aseptic non-union, all patients received cephazolin intravenously before the inflation of the tourniquet and this was repeated after 12 hours, and no further antibiotics were given. Patients were discharged from hospital on the second postoperative day after a thorough explanation of pin-tract care and mobilisation exercises. Partial weight bearing was started in immediate postoperative. In the monofocal method, initially maximal compression was done at the non-union site to stimulate the tissue towards osteogenesis. Also, acute compression at the corticotomy site in treatment of non-union with bone loss was started initially for seven days to stimulate the osteogenesis at the corticotomy site, and then distraction can be initiate at the first outpatient department visit. Distraction was done at the rate of 1 mm per day. A follow-up was performed by the senior author or a member of his team. The patients were followed up in the clinic every 3 or 4 weeks and physical and radiographic examinations were performed to detect and treat common problems and complications. The pin-tract infection was checked at each visit and treated accordingly. The pin-tract complications were categorized into four types as described by Marsh et al.[6] Type A pin-tract complications were those which resolved with increased local care or oral antibiotics or after planned removal of the fixator. Type B pin-tract problems necessitated operative intervention for change of a pin site. Type C pin-tract problems resulted in fixator removal before successful consolidation. Type D resulted in chronic osteomyelitis. The radiological control allows detecting the secondary necrosis and the resorption of the banks which do not constitute problems in our surgical technique as long as the diastasis is recoverable by a secondary compression in ambulatory. When the bridging callus had appeared radiologically and clinical signs had disappeared, dynamisation of the fixator was started to hasten bone healing. Once consolidation was achieved, the fixator was removed in outpatient consultation.

Outcome assessment

Main outcome measures include functional and radiological outcomes assessed using the Association for the Study and Application of Methods of Ilizarov (ASAMI) criteria.[7] Bone results were evaluated by 4 criteria: union, infection, deformity and limb-length discrepancy. Functional results were evaluated by 5 criteria: active, limp, minimum stiffness (knee or ankle joint), reflex sympathetic dystrophy and pain (Table 1).

Statistical analysis

Data were analyzed using descriptive statistics. Continuous variables were expressed as mean and range, while categorical variables were presented as frequencies and percentages.

Table 1: Association for the Study and Application of the Method of Ilizarov scoring system (ASAMI).[7]

Category and result	Description	Score
Bone results		
Excellent	Union, no infection, deformity <7°, limb-length discrepancy <2.5 cm	50
Good	Union + any two of the following: absence of infection, deformity <7°, limb-length discrepancy <2.5 cm	7
Fair	Union + only one of the following: absence of infection, deformity <7°, limb-length discrepancy <2.5 cm	2
Poor	Nonunion/re-fracture/union + infection + deformity >7° + limb-length discrepancy >2.5 cm	1
Functional results		
Excellent	Active, no limp, minimum stiffness (loss of <15° knee extension/ <15° ankle dorsiflexion), no RSD, insignificant pain	45
Good	Active, with one or two of the following: limp, stiffness, RSD, significant pain	10
Fair	Active, with three or all of the following: limp, stiffness, RSD, significant pain	3
Poor	Inactive (unable to return to daily activities because of injury)	2
Failure	Amputation	0

RESULTS

Demographic characteristics

A total of 20 patients were included in this study. The mean age was 39 years (range: 19–70 years). The majority of patients were male (90%), and 60% were chronic smokers. Road traffic accidents were the most common cause of injury (75%), followed by domestic and occupational accidents. The most frequent location of nonunion was the distal third of the tibia (45%) (Figure 1).

The initial diagnosis was closed fracture in 05 patients and open fracture in 15 patients (09 type II, and 06 type III fractures according to the Cauchoix and Duparc classification).[5] Average duration to injury was 21.6 months (range 07-106 months). The primary treatment received for fracture included closed reduction and cast application in 02 cases, intramedullary nailing in one cases, external fixator in 15 cases and plating in one cases. The non-unions were classified into hypertrophic, oligotrophic and atrophic non-unions, based on the X-ray obtained prior to the operative procedure. There were 08 hypertrophic, 07 oligotrophic and 05 atrophic non-unions.

The non-unions were also classified into infected and aseptic in which infected non-unions accounted for 08 cases. The conditions of the soft tissue at the time of application of our surgical technique was precarious in 08 cases.[8]

Clinical outcomes

All patients came for regular follow-up. The mean follow-up time was 25, 7 months (03–69 months). Union was achieved in all patients (100%).

One case was treated with the bifocal method (Figure 2) and 19 cases were treated with the monofocal method.

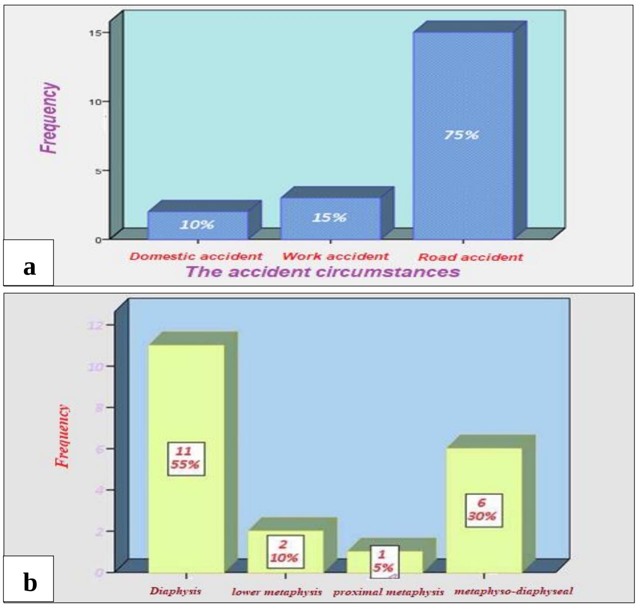

Figure 1: Demographic characteristics (a) circumstances of initial trauma, and (b) anatomical distribution of non-union.

Figure 2: A clinical case treated with the bifocal method after tibial corticotomy.

The average time for union was 3.5 months (range 1–5 months), 2.87 months for hypertrophic forms, 4 months for oligotrophic forms and 3.8 months for atrophic forms. The infected non-union took longer time to unite, taking an average of 5 months as compared to aseptic non-union which united in 3.33 months (Table 2).

Table 2: Mean time to consolidation.

Parameter	Number	Average time
Septic pseudarthrosis		
Without bone loss	04	3.5 months
With bone loss	04	04 months
Total	08	3.75 months
Aseptic pseudarthrosis		
Without bone loss	07	2.7 months
With bone loss	05	4.2 months
Total	12	3.33 months

In the case treated with the bifocal method, the average length gain was 4 cm and the mean duration of the treatment was 7 months. No bone grafting was required at the non-union site for all cases. We studied 13 cases of axial deviations that were corrected (Table 3).

Table 3: Correction of axial deviations.

Bone deformities	Num-ber	Average value before the surgery	Average value after the surgery
Recurvatum	01	12°	05°
Recurvatum-valgus	05	10°-9.5°	3.6°-4°
Recurvatum-varus	02	15°-7.5°	6°-3.5°
Flexum-valgus	01	5°-5°	<5°
Flexum-varus	04	13.5°-13°	1.5°-1.25°

The correction was intraoperative in all cases. 9 patients had insignificant limb shortening with an average value of 1.22 cm.

Functional and radiological outcomes

The end results were assessed by the ASAMI criteria. The bone results were excellent in 17 cases, good three cases, and no fair neither poor result were noticed. The functional results were excellent in 12 cases, and good in eight cases. The most common complication in this series was pin-tract infections. A total of 4 patients got infected out of the 20 cases that were treated (20%). In this series, 3 patients had type A, and one had type C pin-tract infection. There was no case of type D pin-tract infection. Ankle stiffness joint was encountered in three cases (one case is due to a loss of substance circumferential muscle of the anterior and posterior tibialis at the initial injury, the other two cases were due to a prolonged immobilization with bypass of the tibio-talar joint by the initial treatment of the fracture). The smoking character did not significant influence in the consolidation deadlines using our surgical technique which is well illustrated in the figure 11 by a condensation in the interval from 03 to 04 months irrespective of the septic, aseptic or smoker, no-smoker tobacco.

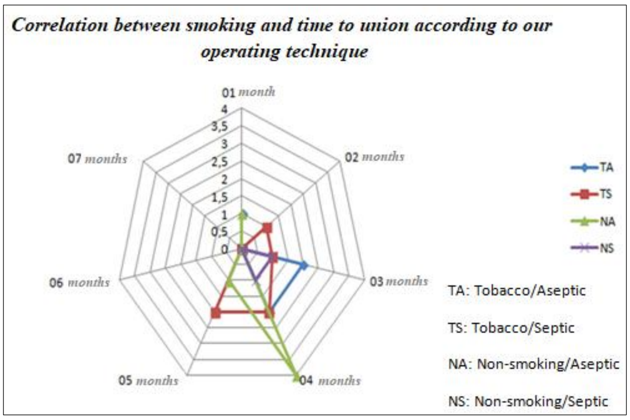

Figure 3: Impact of smoking on bone healing with our surgical technique.

DISCUSSION

Treatment of non-unions is a challenge, not only because of the varied anatomic and pathologic problems encountered, but because of the increasing number of treatment's alternatives available. The first dynamic axial fixator was designed in 1977 by De Bastiani to allow the axial forces in the external setting to be released at a suitable time during the healing process, thus transferring progressive loading to the fractured site.[9] The Dynamic Axial fixator can be applied percutaneously and provide the necessary compression and stability, without disturbing the non-union site.[10] Bone grafting is not necessary. Continuous compression is the principle adopted in our surgical procedure for the tibial non-union.

Fibular osteotomy is not systematic; it depends on the possibility of compression of the non-union site and the degree of angular correction to be made. The line of osteotomy must be oblique and should be done, whenever possible, at a different level but not far from the site of non-union.[1,11,12]

Compression plates offer static compression, inhibit the formation of the periosteal callus and promotes endostelal formation. The stresses induced by this material at the non-union site may be sufficient to induce consolidation in case of hypertrophic nonunion. In contrast to the dynamic axial fixator, external fixation stimulates the endosteal and periosteal callus. Also, the elasticity of the dynamic fixator pins, and the dynamic compression it offers, allow micro-movements at the non-union site stimulating osteogenesis. Using a compression plate is the only technique allowing a good stabilization of the tibial non-unions, while performing a bone graft is essential for consolidation.[13-16] However, in this type of treatment, bone graft seems to play a crucial role particularly in cases of atrophic non-union or significant bone defect. Wiss et al reported that bone grafts were used in all patients who had a non-union that was considered atrophic.[15] The rate of septic complications of the use of compression plating varies from 7.4% to 13% according to the literature.[17] The consolidation rate as well as its delay and the septic complications using compression plating varies according to the series as shown in Table 4.

The use of centromedullary nail fixation will find its place in hypertrophic non-unions without significant alignment disorder.[18-21] The major risk of these treatments is the contamination of the whole bone in case of infected non-unions or when placing a nail after an external fixator, which limits their use.[22,23] The tibial non-union treated by centromedullary nail consolidate with a rate varying from 85 to 100% according to the studies as displayed in Table 5.[17]

Table 4: Comparative results of the treatment of tibial non-unions by compression plate according to the authors.

Author	Consolidation rate (%)	Bone grafting	Average healing times (days)	Rate of septic complications (%)	Duration of hospitalization (days)	Weight bearing
Piriou et al[13]	94	+	108	6		After consolidation
Wiss et al[15]	92	+	210	8		After 02 months
Muller[16]	85	+	-	-	25	-
Rosen[14]	94	+	240	6		After consolidation
Our series	100	-	109	20	2	Immediate post-operative

Table 5: Result of the treatment of tibial non-unions by intramedullary interlocking nailing.

Author	Consolidation rate (%)	Average healing times (months)	Bone grafting (%)
Levin et al[19]	85	-	8.3
Christensen[18]	100	-	2.9
Rosson et al[20]	92	09	
Sledge et al[21]	96	07	19.6
Our series	100	3.5	0

The Ilizarov external fixator should allow stable fixation, possible correction of the reduction and compression of the non-union site.[24,25] Ilizarov external fixator preserves the periosteum vascularization. Its design is based on the dynamic stimulation of the non-union site and the bone distraction that result in a stimulation of the repair process sufficient to cure the infection and ensure consolidation. Our surgical technique is based only on compression. Ilizarov technique is associated with a significant rate of complications including stiffness, iterative fractures after removal of the fixator, nerve damage (the external popliteal nerve and paresis of the dorsal extensor muscles of the foot) and the very bulky material. The literature reports a 27.4% risk of infection on pins.[26] Akthar et al in their study of treatment of 45 tibial non-unions treated by Ilizarov reported a rate of infection on pins of 35.6% and ankle stiffness of 20%, rates similar to the data in the literature.[19,27] Dendrinos et al reported a series of 28 tibial non-unions.[17] Bone graft was applied in 11% of cases and the consolidation rate was 87% in an average time of 06 months. Paley et al, reported a study of 25 tibial non-union, in which consolidation was achieved in 96% of cases with an average duration of 13.6 months.[25] For our study the consolidation was obtained in an average time of 3.5 months for all cases and for all types of non-unions, without any bone graft.

We adopted the principle of compression by external fixation inspired by Ilizarov data on the confrontation of the edges of the non-union, crushing of the interposing tissues, creation of micro fractures, local necrosis of the interposed fibro-cartilaginous tissues, which replaces debridement and open decortication used in several other techniques, inflammation and thus an influx of polynuclear cells, and osteoclasts followed by osteoblasts, thus initiating osteogenesis.[28,29] A histological study made on tibial non-union in a rabbit, was carried out in our research laboratory, studied the initial appearance of non-union and the effect of compression on the various elements of bone consolidation. Histological sections were stained with hematoxylin-eosin stain and masson-trichrome stain. The histological study confirms the centrifugal character of bone healing by the effect of compression on the non-union site (Figure 4). Indeed, consolidation begins at the compression point and spreads to the periphery to result in a globular bone callus.[5]

Our own surgical technique for the treatment of the non-unions of long bones and particularly of tibial non-unions is an original technique whose literature is poor. The authors using the dynamic axial fixator, recommended it mainly for the purpose of stabilizing a classic cure of non-union more than a final treatment of constituted pseudarthrosis. This technique was first described in 1984 by De Bastini about 29 aseptic and septic non-unions of the tibia associated in 28% of cases with bone graft.[9] The consolidation rate was 94%, within a period of 5.6 months. Pin site infection was noted in 2.6% of cases. Hashmi and Saleh, reported in their series of 110 long bone segments with fracture non-union, among which 60 tibial cases, treated by mono-lateral external fixation.[30] Bone grafting was applied for 71 cases. The consolidation rate was 90%, within a period of 12.6 months.

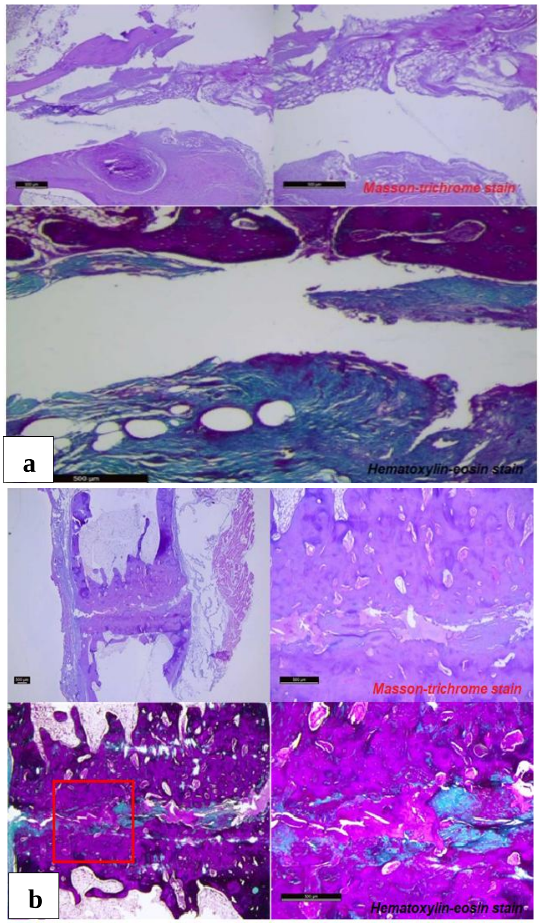

Figure 4: Histological appearance of tibial non-union in a rabbit, (a) non-union before compression, and (b) appearance of the callus after compression with dynamic axial fixator (blue, dark blue: nuclei; red: osteoides; green: mineralized bone, collagen type 1; orange red: cytoplasms).

Compared to the literature, monoplane external fixator in compression as shown as our surgical technique allowed a minimal unilateral exposure at the non-union site, minimal surgical trauma to the soft tissue. In fact, the opening of the non-union site is only necessary for removal of material or a bone sequester, to restore alignment or for excision of a fistula. Furthermore, this technique permitted an easy application of the fixator, consecutively minimal blood loss, a short operating time, and avoided bone grafting and vascular-nerve complications.[31] It also reduces the duration of hospitalization while obtaining very satisfactory anatomical and functional results, regardless of the non-union's type. The study showed that the use of an external compression fixation in the treatment of tibial non-unions allowed their consolidation without opening the site and without bone graft under the conditions of a clear understanding of the principles rules of the surgical technique and regular clinical and radiological follow-up of the patient.

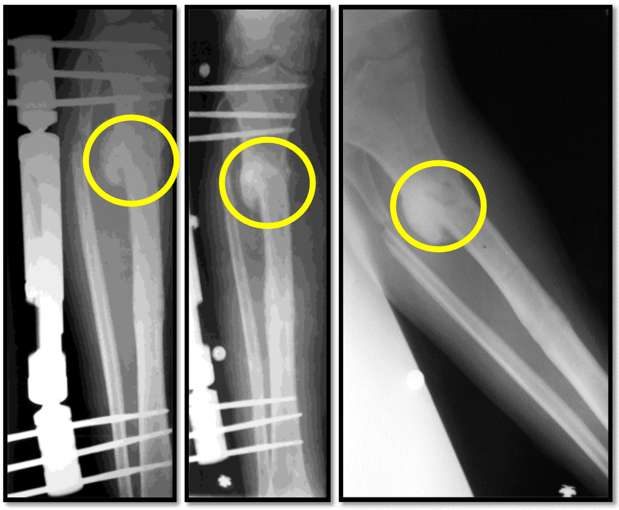

Figure 5: Globular bone callus.

Limitations

This study has several limitations. First, the small sample size limits the generalizability of the results. Second, the retrospective design may introduce selection and information bias. Third, the absence of a control group does not allow direct comparison with other treatment modalities. In addition, this is a single-center study, which may limit the external validity of the findings. Despite these limitations, the study provides valuable insights into the effectiveness of continuous compression using a dynamic axial external fixator in the treatment of tibial nonunions.

CONCLUSION

The monoplane external fixator is a light assembly, small in size, well tolerated by patients. It gives a better rigidity, allows immediate weight-bearing, and offers a great ease to its installation and ablation. Acute compression was shown to allow the necrosis of the interposition tissues and the bone contact associated with a stable fixation. These conditions could be maintained throughout the treatment by the possibility of secondary compression during follow-up. The only limit to this technique is sepsis on pins.

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