ILIZAROV COMPRESSION OSTEOGENESIS FOR TIBIAL NON-UNION: OUR EXPERIENCE

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ABSTRACT

The objective was to evaluate functional outcome and complication of Ilizarov compression osteogenesis done for non-unions and infected non-unions. This study is chosen as non-union and infected non-union tibia is common and difficult to treat.

METHODS

This study of Ilizarov for non-union tibia was done between 1999 – 2014 at Gandhi Medical College and Hospital, Hyderabad; following Grade IIIa and IIIb open tibial fractures, with or without soft tissue loss. The study group consisted 43 patients between 20 to 70 yrs.

RESULTS

Out of 43 cases in study group, atrophic non-union accounted for two thirds of cases, infected non-union one third of cases. Union rate is 97%.

CONCLUSION

Non-union tibia is common in young males due to road traffic accidents. It is always a challenge for an orthopaedic surgeon to treat this subcutaneous bone. Ilizarov osteogenesis is a better method in these cases as they are compounded by deformity, bone loss, infection and soft tissue atrophy and we can control many variables as and when required during the followup period without much damage to soft tissue.

KEYWORDS

Tibia non-union, Ilizarov.

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INTRODUCTION: Management of non-union of tibia is always a challenge for orthopaedic surgeons as it is a subcutaneous bone. The problem of union is compounded by the presence of infection, bone loss, disuse osteoporosis, and soft tissue atrophy and neurovascular damage. Complex problems consist of non-union, deformity, leg-length discrepancy and infection. The bone ends may be atrophic or there may be chronic osteomyelitis.(1)

In cases of non-union tibia, it is usually very difficult to obtain union due to coexisting problems of deformity, infection; and leg-length discrepancy are often not primarily addressed. In more complex cases with atrophic bone ends, gap non-union, substance defects, chronic osteomyelitis or a combination of these; amputation may be the eventual outcome despite current techniques of internal fixation, bone grafting, and electrical stimulation.(2) Ilizarov ring external fixation has gained popularity as a multifactorial approach to the management of tibial non-unions. By giving an external handle on the intercalary bone segments, external fixation offers the opportunity to change the position and even the length of the two bone segments as well as to control and change the biomechanical environment of the non-union site to enhance and control neo-osteogenesis.(3,4)

Ilizarov apparatus is axially elastic and the weight-bearing forces are directly applied to the bone ends, it helps in maintaining the weight-bearing function of the extremity. Rigid fixation systems, such as plates and traditional external fixators that bypass the non-union, have been replaced by the axially elastic system of Ilizarov. Stable fixation with tensioned fixation wires and axial telescoping mobility helps in increasing limb vascularity, formation of a reparative callus at the non-union site.(3,4)

Hence, this study was undertaken to treat the non-unions of fractures of tibial shaft by using Ilizarov ring fixator to analyse the results in terms of union, residual deformity, limb length discrepancy and the residual stiffness and deformity of adjacent joints.

MATERIALS AND METHODS: The study group includes 43 cases of tibial non-unions treated by Ilizarov method. They are prospectively and retrospectively studied. In all these cases, previously other modality of treatment has been tried here or elsewhere.

Pseudoarthrosis (Fracture with nonunion) of the tibia is classified based on the clinical and radiographic findings, according to classification of Catagni for pseudoarthrosis (fracture with nonunion) Paley D et al.(5,6)

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Patient Selection: Nonunion of a tibial fracture.

Parameters:

1. Length of the bone loss between the proximal and distal tibial segments in centimetres.
2. Mobility of the fragments.
3. Deformity.
4. Bony defect.
5. Shortening.

Length of Bone Loss	Type
< 1 cm	A
>= 1 cm	B

Length of Bone Loss	Mobility	Deformity	Type
< 1 cm	Lax (Mobile)	NA	A1
< 1 cm	Non-mobile	none	A2-1
< 1 cm	Non-mobile	present	A2-2

Length of Bone Loss	Bony Defect	Shortening	Type
>= 1 cm	Present	None	B1
>= 1 cm	None	Present	B2
>= 1 cm	Present	Present	B3

Ref: Catagni MA.[5] Paley D, Catagni MA, et al.[6]

Two thirds of cases have gap non-union more than 2 cm and up to 7 cm which are included in group B. Serial roentgenograms were often studied pre and postoperatively. The group includes 38 men and 5 women, age ranging from 20 years to 70 years with mean age of 39.9. The aetiology of pseudoarthrosis in gap non-union was Gr IIIa or Gr IIIb open fractures[7] and in stiff non-union was inadequate immobilisation, the level of pseudoarthrosis was mostly diaphyseal in our cases. Duration of non-union ranged from 9 months to 48 months, with mean duration of 14.6 months before Ilizarov treatment.

Out of 43 cases, 16 cases are classified as atrophic non-union based on radiograph appearance alone. 13 cases were classified as stiff non-union based on clinical and roentgenographic findings, another 9 cases were originally infected and actively draining with atrophic bone ends and with gap, they are classified as infected lax non-union. The remaining 5 cases are infected stiff non-union, actively discharging with minimal mobility and sclerosed bone ends. The mean bone defect was 3.69 cm, with range up to 2-7 cm. The bone loss of type B1 was quite common. Among 25 cases of lax atrophic types, i.e. 14 cases of B1 type, and rest 6 cases are type B2, and 5 cases are of B3 type.

Procedure: A preoperatively planned Ilizarov construct was autoclaved and used. A proximal reference wire is fixed to proximal tibia parallel to the knee joint line, which is attached to proximal ring. Distal reference wire is fixed to distal tibia parallel to ankle joint and is fixed to the distal ring. Middle rings are planned depending on level of non-union and bone transport. If the fibula is intact, resection of fibula was done between non-union and corticotomy to help in bone transport.

Type A non-unions are managed by simple compression osteogenesis. In Type B depending on gap or shortening are managed with corticotomy and bone transport, corticotomy, a low energy osteotomy preserving periosteum and medullary blood vessels is planned. A vertical incision is made on periosteum and corticotomy was done and checked under C-arm image intensifier. Distraction was started after a latency of 7-10 days at frequency of 0.5 mm twice a day.

Cases with shortening of 3 cm or less, simultaneous compression was done by acute shortening at nonunion site, followed by distraction at corticotomy site, keeping a watch on distal pulses. In cases where shortening is more than 3 cm, the bone defect is shortened at nonunion site consecutively, at pace of 2 mm/day postoperatively.

Systemic antibiotics were given for 3 days and changed according to culture sensitivity when required. Pin tract cleaning was done daily.

Patient was encouraged quadriceps exercises and (ROM) range of movement exercises for knee and ROM exercises for ankle. Partial weight-bearing was allowed on second day when pain was less. Foot frame was attached for correction of associated equinus. Full weight-bearing was allowed at completion of distraction. As patients are mobilised early there was no need for thrombo-prophylaxis. Dynamisation with telescopic rods was done at the time of consolidation.

In atrophic type of non-union where gap was more, consecutive compression, distraction and osteosynthesis method was followed in which distraction at corticotomy and bone transport was done and later compression was achieved at non-union site.

In infected lax atrophic non-union, the non-union site is debrided. The ends freshened and where there is little shortening, simultaneous distraction, compression osteosynthesis (Bifocal) method is followed. We followed this method in 9 cases.

In 18 cases of stiff non-union and infected stiff non-union, we followed monofocal distraction, compression osteosynthesis (accordion technique) after partial fibulectomy and freshening of non-union site. In synovial pseudoarthrosis, compression for 2-3 weeks creates stability and crushes fibrous and fibrocartilaginous tissue, stability of fixation is a must for ossification of pseudogrowth zone.

OBSERVATION AND RESULTS: Over the past 15 years, we have been treating tibial non-unions by Ilizarov method. The study group includes 43 cases of tibial non-unions treated by this Ilizarov method. Few of the cases were treated here or elsewhere by other modalities of treatment like external fixator, AK plaster cast, plating and IM nailing. One third of our patients had infected non-unions.

We classified according to Paley D et al, 16 cases as stiff hypertrophic non-union, 13 cases lax atrophic non-union, 9 cases infected lax non-union and 5 cases as infected stiff non-union.[5,6]

6 patients were treated by simple A/K cast, and other cases had previous multiple operations before this definite procedure (Ilizarov). The average duration of non-union is 14.6 months ranging from 9 months to 48 months. The mean bone defect is 3.69 cm, average bone defect in atrophic non-union was 4.25 cm and in infected atrophic non-union 2.77 cm.

Union rate was 97%. In one patient, there was doubt regarding the status of union. The non-union site was opened and found callus on three sides of non-union. One side there was gap, which was grafted.

Atrophic non-unions were treated by consecutive compression, distraction osteogenesis. The average duration of treatment was 10.92 months. In one case during transportation of bone there was angulation of 20 posteriorly and was corrected by using appropriate hinges, 4 weeks after the bone fragment is transported.

Infected atrophic non-unions were treated by debridement[8] and simultaneous compression distraction osteosynthesis. In most cases, an average bone defect was 2.77 cm and the duration of union at fracture sire was 7.42 months. In one patient, fracture united well in 7 months, but the wound initially healed well but at the end of 7 months, there was sudden flare-up of infection and gaping (2 cm X 2 cm) of wound. We investigated this patient for reasons of infection, no definitive cause found. Daily saline dressing was done, later the wound healed well.

In stiff non-union and infected non-union, we debrided and excised the bone ends and monofocal compression distraction was done. The average duration of union in stiff non-union was 5 months and in infected non-union was 5.3 months.

Complications:

- Complications were noted using Paley's classification.[9]
- Minor which did not require additional surgery.
- Major listed as obstacles resolved by additional procedure.
- Major listed as sequelae or true complications.

Problems (Minor Complications):

Gr1-Gr2 soft tissue inflammation and infection	13
Translation/angulation of regenerate (during distraction)	3
Delayed maturation of regenerate (during distraction)	1
Transient knee flexion deformity	1
Transient loss of ankle movement	2

Obstacles (Major Complications and Solutions):

Pin-tract infection (Exchange of pin and wire)	2
Re infection (Irrigation and debridement)	2
Equinus deformity (Tendo-Achilles lengthening)	0
Frame failure (modification of frame)	2
Premature consolidation (recorticotomy)	1

Sequelae (True Complications):

Limb length discrepancy >2.5 cm	1
Loss of knee, ankle ROM> 20^0	2
Knee contracture>5^0	1
Mal-alignment >5^0	1
Infection (chronic osteomyelitis)	0
Total	
All complications.	

Pain was the main complaint subsided with oral analgesia

Pin site problems are divided into three categories by Paley Grade 1: soft tissue inflammation, Grade 2: soft tissue infection, Grade 3: bone infection. Increasing pain due to dermal irritation, pain during distraction if distraction more than 4 cm. None of our patients had neurovascular damage, compartment syndrome.

In one patient fracture united well in 7 months, but the wound initially healed well but at the end of 7 months there was sudden flare-up of infection and gaping (2cm X 2cm) of wound. We investigated this patient for reasons of infection, no definitive cause found. Daily saline dressing was done, later the wound healed well.

In one case of stiff non-union, which was treated initially by A/K cast due to filariasis of leg, there was no union even after 9 months. This particular case is treated by fibulectomy, non-union site was not opened, accordion technique was used to distract the site of fibrous union, once it was distracted we could find displacement of bone fragment so before compression we realigned the bone using olive wires and we could achieve good alignment and early union in three months.

DISCUSSION: Non-union of tibia is most commonly observed complication in long bone fractures. Not only the integrity and weight-bearing capacity of tibia is important but also its length and alignment plays a vital role in gait and in function of knee and ankle.

Treatment of tibia non-union with other modalities of treatment with bone grafts or microvascular osseous transfers, Papineau technique required long time for hypertrophy of bone for weight-bearing, significant surgical exposure by invasive procedures.[10][11] Though the joint motion is started early, the fixation may not be sufficient to allow early weight-bearing. Problem of union is compounded by infection, bone loss and disuse osteoporosis often persists or increases in the presence of an implant.

Distraction osteogenesis first introduced by GA Ilizarov, later popularised by surgeons in the west, has revolutionised management of tibial defects. The Ilizarov method is a comprehensive approach to all aspects of tibial non-union that simultaneously addresses deformity, shortening, defects, infection, articular and limb function.[8] Deformity is corrected by reorientation and realignment of extremity gap is corrected by acute shortening and lengthening of bone at other level. This method is only a semi-invasive one where periosteal and endosteal integrity is well maintained when compared with the more invasive methods.

This study includes followup of 43 patients of difficult non-unions over a period of 14 years. The average chronicity was 14.6 months, with almost all the patients having previous treatment, out of them one third cases were chronically infected and 62.7% were atrophic non-unions. Bone defects, ranged from 2 cm to 7 cm in these patients.

Most studies of tibial non-union reported in the literature have assessed only the presence or absence of bony union. Healing times averaged 6-8 months ranging up to 16 months. Unfortunately, most of these authors did not report on residual shortening and angulation. In a few series that have commented on this the incidence of shortening that is less than 2 cm, is quite high. The above study groups have used closed bone grafting, open reduction and internal fixation, with or without bone grafting.

The series most comparable to our study is that of Goldstrohng et al.[6][7] who treated 39 cases of bone defects and/or shortening, with lengthening and bone grafting procedures. Most of the patients had numerous hospitalisations with many earlier surgical procedures for non-unions. Of these lengthened greater than 5 cm, only 61% healed. Resumption of full weight-bearing took 49 weeks on average.

Compared with conventional therapies, the present study, in most cases achieved superior results. The treatment time, which averaged 5.15 months in monofocal and 7.42 months in bifocal treatment is as seen in most of other studies. It is apparent from this study that monofocal treatment is not indicated for atrophic pseudoarthrosis tissue towards osteogenesis. Only in these cases, compression followed by controlled mechanical distraction leads to distraction osteogenesis. This applies to hypertrophic or normotrophic non-unions. The average healing time with this procedure was only 5 months.

Greatest advantage of this method is the ability of the patient to be ambulatory and bear weight as soon as possible. We consider this as an essential principle of this method with socioeconomic and psychological benefits, but also has biologic importance. The functional loading on the extremity helps to prevent and treat the disuse osteoporosis and soft tissue dystrophy.[12] Most of our patients retained ankle and knee range of movements, compared with pre-operative measurements. One theoretical disadvantage of transfixation of muscles by percutaneous pins was not a problem in our series.

Aaronovich Et al. from Ilizarov's institution reported on 170 patients treated with Ilizarov method for tibial bony defects. The chronicity of non-union was 5-10 years. 64 had chronic osteomyelitis. Excellent results comprising union, no infection, no leg-length discrepancy, and no deformity were achieved in 68.9% of patients. 28.7% had fair result only because of persistent limb length discrepancy greater than 3 cm and 2.4% were considered poor results because of persistence of osteomyelitis.[13]

In series of 25 patients treated for tibial non-union by Dror Paley et al,[6] the patients age ranged from 9 years to 62 years with 22 atrophic and 3 hypertrophic non-unions reported. 19 had limb length discrepancy of 2-11 cm and 13 had deformity. 6 patients had bone defects with no shortening (with fibula intact). Length was re-established by distraction of percutaneous corticotomy or through compression and subsequent distraction of pseudoarthrosis site.

In his series, distraction osteogenesis resulting from both process obviated the need for bare graft in every case. The deformity was corrected by means of hinges on the apparatus. Infection was treated by radical resection of the necrotic bone and internal lengthening to regenerate the excised bone. Union was achieved in all cases. The mean time to union was 13.6 months. The bone results were excellent in 18 cases.[6]

In our series of 43 patients treated for tibial non-union, the patient's age ranged from 20 years to 70 years, with 16 cases of atrophic non-union and 13 cases are stiff non-union, 9 cases are infected lax non-union, 5 cases are infected stiff non-union. 11 patients had limb length discrepancy of 2-7 cm and 14 patients had defects with no shortening. Length is re-established by distraction of percutaneous corticotomy. The mean time of the union in atrophic non-union was 10.92 months and in infected atrophic non-union is 7.42 months. The mean time of union in stiff non-union was 5 months and in infected non-union was 5.3 months. Our results are comparable with those of Dror Paley et al. And Aaronovich et al.[6,13]

CONCLUSIONS: Ilizarov apparatus comprises a modular ring fixator, which works on axially elastic weight-bearing forces acting directly on bone ends, maintaining the weight-bearing function of the extremity. The micromotion at fracture site due to axial dynamisation can accelerate fracture healing. These stresses at fracture site are advantageous to formation of callus and fracture healing.

Non-union, bone defects, limb shortening and deformity can be addressed simultaneously with Ilizarov apparatus. Bone defects were closed from within by Ilizarov method. Transport technique of sliding bone fragment internally, reducing distraction osteogenesis, until the defect is bridged. The deformity was corrected by means of hinges and apparatus, infection was treated by radical resection of necrotic bone and length was achieved with corticotomy and segment transport.

In our study, we have used 1 cm posteromedial vertical incision to expose the posteromedial border of tibia at corticotomy site through this incision. Corticotome is hammered to cut posterior cortex of tibia which helped us in easy corticotomy and breaking the corticotomy site in toto. This is in addition to routine anterior incision and corticotomy.

We haven't had any significant complications with Ilizarov method. Most common complication was superficial pin-tract infection, which were treated with proper pin care. Pain, during treatment was encountered but it was never a severe one, and with analgesics adequate pain control was achieved. There was no deep pin-tract osteomyelitis, no incidences of neurovascular injury, no incidence of compartmental syndrome.

Acceptance of ring fixator with multiple pins and complex structure was good, might be because of the chronicity of the fracture and earlier failed treatments. Many of our patients were ambulatory, seen moving in the wards, initially with axillary crutches and later without any crutches. Most of the patients were happy with the successful progression of treatment, which was shown to them by closure of gaps and lengthening of bone at corticotomy site. Severely injured limbs with soft tissue, bone and skin loss, were saved of amputation after being treated with flap cover and Ilizarov method.

With the current knowledge of Ilizarov compression and distraction osteogenesis, the regeneration of the bone and lengthening of the bone is reproducible, there is no longer a need to preserve infected or atrophic, eburnated bone at non-union site. In our study, we have excised infected, eburnated and atrophic sites and freshening the bone ends were done to gain early union during compression. The Ilizarov procedure addresses all the problems simultaneously and often is a good solution to infected and infected gap non-unions. All the patients could be mobilised and made to walk and bear weight after Ilizarov frame once the postoperative pain permitted them. Even in older patients with osteoporotic or osteopenic bone, adequate purchase in bone with tensioned wires made them walk with full weight-bearing.

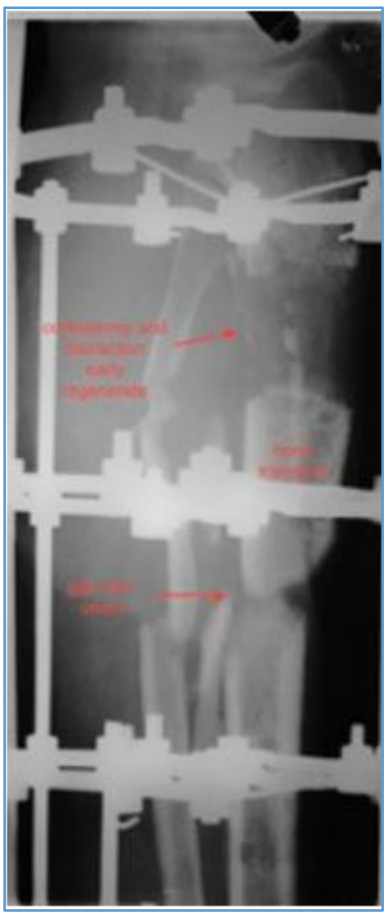
CASE NUMBER 1: A male patient sustained grade III compound fracture following road traffic accident applying external fixator and rotation flap. Wound healed after 3 months, fixator removal done. PTB applied for 6 weeks, resulted in gap non-union of both bones of right leg with shortening of 7 cm in leg component.

On examination, deformity of (Rt) leg, abnormal mobility was present with shortening of 7 cm, knee range of movement 70^0-80^0, ankle was stiff with possible range of movement 10^0 in sagittal plane. X-ray showed gap non-union of (Rt) leg upper and middle third.

Procedure adopted was freshening of non-union site, partial fibulectomy followed by application of Ilizarov ring fixator. Corticotomy was done at upper tibial metaphysis.

Post-operatively Distraction started on 6^{th} postop day, suture removal done on 10^{th} day. Compression started after 3 days at 2 mm per day consecutive compression distraction osteogenesis. Distraction continued regularly followed with appropriate check x-rays every 3 weeks and at 6 weeks followup regenerate at distraction site is seen, at 12 weeks followup callus well formed at distraction site, bony regenerate 7 cm, knee and ankle movements were improved. Result was excellent.

Bone Transport:



Regenerate Well Formed:

Regenerate Consolidating and Completed Bone Transport:

Followup X-Ray AP view:

Followup X-Ray Lateral View:

Clinical Photographs During Followup:

CASE NUMBER 2: A male patient aged 60 years sustained closed comminuted fracture both bones middle and lower third junction, left leg, following road traffic accident 9 months back. Patient had pain and was unable to use (Lt) leg since 9 months. Patient was treated conservatively by applying above-knee cast and later with PTB as patient had elephantiasis involving left lower limb with gross lymphoedema. The fracture ended up with non-union even after prolonged immobilisation.

On examination, abnormal mobility was present without any shortening. Knee flexion 80^0-90^0, ankle movements 30^0 in sagittal plane. X-Ray shows displaced fracture of both bones, left leg, middle and lower 1/3rd, and no callus was evident.

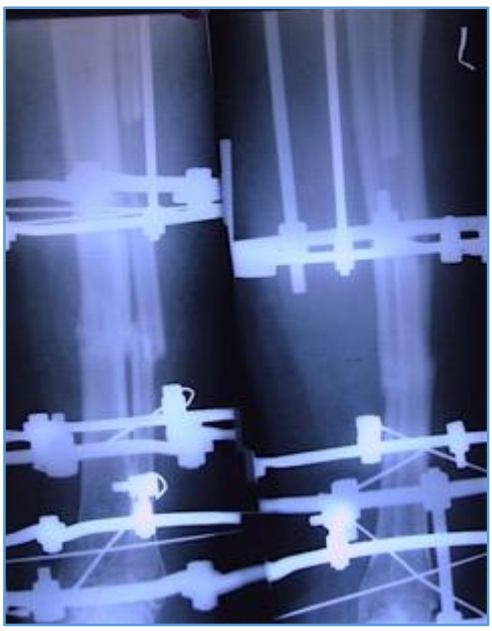
Procedure was partial fibulectomy followed by Ilizarov ring fixator, without opening the non-union site. Post-operatively on 10th day continuous compression and distraction was done. Anterolateral displacement of the fracture was corrected.

Patient was followed regularly with check x-rays. At 6 weeks followup, callus formation at non-union site is satisfactory following compression. At 3 months followup, union was sound, no shortening no gap, ankle and knee movements within normal limits. Patient was allowed full weight-bearing with frame in-situ with dynamisation. Fixator was removed after the non-union healed well 5 months postop and the result was good.

Pre-operative:

Post-operative:

United x-ray before removal of fixator:



CASE NUMBER 3: A 38-year-old male sustained compound fracture in his right leg following road traffic accident one and half year back, latter massaged by quack. He presented to us as infected non-union with discharging sinus.

On examination, there is an actively discharging sinus over medial aspect of middle one third of right leg, no organism grown on pus culture. There is deformity and shortening of 2 cm. Knee flexion is possible up to 100^0. X-ray findings are non-union both bones right leg middle third. Procedure: After partial fibulectomy, non-union site is opened, small sequestrates are removed, atrophic ends are trimmed adding shortening to the preoperative shortening. Ilizarov ring fixator applied, proximal corticotomy was done. Postoperative active mobilisation of knee was done. Consecutive distraction and compression was done. Patient was allowed partial weight-bearing from 2 days onwards. Patient was followed regularly with check x-rays at 6-week intervals. Regenerate calcifying at corticotomy site and on 3 months followup, callus progressing at non-union site. At 4 months followup, callus is consolidating, union is in progress and at 6 months, followup union is sound.

Pre-operative: Infected non-union fracture - united consolidated regeneration.

REFERENCES

1. Dendrinos GK, Kontos S, Lyritsis E. Use of the Ilizarov technique for treatment of non-union of the tibia associated with infection. J Bone Joint Surg Am 1995;77(6):835-846.
2. Patil S, Montgomery R. Management of complex tibial and femoral non-unions using Ilizarov technique and its cost implications. J Bone Joint Surg Br 2006;88(7):928-932.

3. Fleming B, Paley D, Kristiansen T, et al. A biomechanical analysis of Ilizarov external fixator. Clin Orthop Relat Res 1989;241:95–105.
4. Ilizarov GA, Makushin, VD, Kuftiryev M, et al. Recovery of posttraumatic bony defects of the tibia by the lengthening of a bony defects of the tibia by the lengthening of a bony fragment. Thesis, jublee of Practical Medial Sciences, Conference Book, Kurgan, USSR 1973:p. 161.
5. Catagni MA. Classificazione e trattamento delle pseudoartrosi di gamba con perdita di sostanza. In proceedings of the 1st national Congress for the applications of the method of Ilizarov to the tibia. Florence, Italy 1986:87-90.
6. Paley D, Catagni MA, Argnani F, et al. Ilizarov treatment of tibial nonunions with bone loss. Clin Orthop Relat Res 1989;241:146–165.
7. Papineau LJ, Alfageme A, Dolcouit JP, et al. Chronic osteomyelitis: open excision and grafting after saucerization. Int Orthop 1979;3(3):165-176.
8. McKee MD, Yoo D, Schemitsch EH. Health status after Ilizarov re-construction of post-traumatic lower-limb deformity. J Bone Joint Surg Br 1998;80(2):360-364.
9. Panjabi MM, White AA, Wolff JW. A biomechanical comparison of the effects of constant and cyclic compression of fracture healing in long bones. Acta Orthop Scand 1979;50(6 Pt 1):653-661.
10. Madhusudhan TR, Ramesh B, Manjunath K, et al. Outcomes of Ilizarov ring fixation in recalcitrant infected tibial non-unions - a prospective study. J Trauma Manag Outcomes 2008;2(1):6.
11. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty- ve open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 1976;58(4):453-458.
12. Maurizio C. Operative principles of Ilizarov by ASAMI group. Classification and treatment of nonunion. Baltimore, Maryland, USA: Williams and Wilkins 1991;190–198.
13. Aaronovich AM, Shylachoy VI, Pyevski SA, et al. Rehabilitation by Ilizarov technique pf patients with boney defects of the tibia complicated by chronic osteomyelitis. In experimental theoretical and clinical aspects of transosseous osteosynthesis developed at the KNIEKOT. 2nd International Conference Abstracts, Kurgan, USSR, September 3-5, 1986:p.74.