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Original Article

Radiological Assessment of Distraction Osteogenesis of Large Bone Defect in Lower Extremity Long Bone: A Descriptive Study

Satish Prasad Barnawal[1], Suresh Gandhi[1], Avinash Rathod[1]
[1]Department of Orthopedics, Jawaharlal Institute of Postgraduate Medical Education and Research, Pondicherry. India.

ABSTRACT
Introduction: Bone defect is difficult to manage. Objective of this study was to assess radiological parameters of distraction osteogenesis of large long bone defects.
Methods: Descriptive study was carried out in department of orthopedics, Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry, India during April 2018-March 2019. Inclusion criteria were bone gap of more than 5cm either in tibia or femur, skeletal maturity, bone defect due to trauma or excision of tumor; and bone transport by either by Ilizarov or linear reconstruction system. Patients with incomplete data, poly-trauma, and brain injury were excluded. A senior orthopedic surgeon performed all surgeries. Well-trained orthopedic surgeons collected data. Outcome variables were bone union, primary bone length, length of bone gap, implants type, duration of apparatus, number of days of distraction, percentage of transport, distraction speed and bone healing index.
Results: Mean age of participants was 33.8 years. All of them were males. Road traffic accident was cause for bone loss in 80 % of cases. Bone union was attained in all patients. Bone loss of up to 15 cm was gained by distraction osteogenesis. Range of bone gap was from 5.38 cm to 15 cm. 6.9 to 17.66 months were required for complete union and removal of fixator. Up to 46 % of bone transport was possible with Ilizarov. Two patients were treated with additional intramedullary nail.
Conclusion: Distraction osteogenesis can achieve union in large bone defect up to 15 cm in tibia and femur. Additional internal fixation with an intramedullary nail can be beneficial.
Key Words: Bone union, distraction osteogenesis, large long bone defect

INTRODUCTION
Bone defect is one of the most challenging problems.[1] It can be due to trauma or malignant or benign bone tumors.[2] A good number of bone loss reconstruction procedures are available for long bones like use of bone auto or allografts, induced membrane technique, or bone transport.[3] Outcome of long bone defects with free allografts or autografts are poor.[4] Minimum invasive fixators such as linear reconstruction system (LRS) and ring fixators help in efficient wound management and bone transport.[5] Since 1940, Ilizarov has been widely used for bone transport of gap non-unions.[6]
Distraction osteogenesis (DO) generates new bone between vascular bone surfaces created by an osteotomy and separated by a controlled gradual distraction.[7] Prime concerns are rigid external fixation, proper alignment and bone transport. It is important to monitor regenerate and maintain joint motion.[8] Concept of DO was established by Codivilla and detailed by Ilizarov.[9] As per Ilizarov, "Living tissue, when subjected to slow steady traction, becomes metabolically activated in both biosynthetic and proliferative pathways.[10]"

Correspondance:
Dr Satish Prasad Barnawal
Department of Orthopedics, Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry, India.
Email: satishprasadbarnawal@gmail.com

Distraction of 0.25 mm carried out 4 times per day produces an excellent regenerate and allows grouping of early mesenchymal growth into parallel bundles of collagen.[11]
We find a good number of cases with large long bone defect in lower limb in our part of world. The objective of this study was to assess radiological parameters of DO of long bone defects by use of either Illizarov or LRS.

METHODS
It was a descriptive study carried out in department of orthopedics, Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER) Pondicherry, India during April 2018 through March 2019. Clinical records of the patients were reviewed. There was only one study arm. The patients were included in the study if there was bone gap of more than 5cm either in tibia or femur, if the physes were closed; bone defect was due to trauma or excision of tumor; and if the transport was performed by Ilizarov or LRS. Patients with incomplete data, poly-trauma, and brain injury were excluded. Further, use of allografts was not part of the study. A total of 10 patients were identified. Owing to incomplete information, five patients were excluded. This case series consists of five patients involving long bone defects in tibia or femur.

All the surgeries were performed by a team lead by a senior orthopedic surgeon. The same surgeon performed all the surgeries. Well-trained orthopedic surgeons collected all the relevant data.

Principle of procedure: Principles of DO is based on superior biologic quality of regenerated bone after corticotomy. [10] Periosteal and medullary blood supplies can be preserved by cutting cortex alone. [11] Latency period lasts 3 to 7 days and is important for neovascularization prior to initiation of distraction. [11] 1 millimeter per day distraction is done. Use of additional intramedullary implants decreases rate of deformities and re-fractures. [12] Collagen bundles mineralize from both corticotomy sites towards center. With time, central region remains fibrous, and permits viscoelastic lengthening. Mineralization initially protects through entire cross section of gap. Finally, solid cylinder of fresh bone changes into cortex and medullary canal. [11] Management protocol: Fracture ends were debrided. Fragments were then reduced and stabilized with pin placement above and below gap. Either Ilizarov fixator or LRS was used preferred at surgeon's decision. In few cases, an intramedullary nail was inserted concomitantly. [13] Infected cases were given antibiotics for six weeks as per cultures sensitivity. Blood counts, ESR and CRP were assessed. Clinical as well as radiological assessment along with blood parameters was observed.

After initial latency period of 5-7 days, distraction was started by well-trained orthopedic surgeon at the rate of 1mm per day divided into 4 settings. Patients and care providers from family members were taught regarding distraction. They followed the same after discharge to home. Pin site and illizarov care was taught to them. They were encouraged to take bath and clean the pin sites with soap and water. Rehabilitation was started from day one of surgery, which included range of movement exercise of adjacent joints and mobilization with walking aids.

Outcome variables: Apart from baseline information, surgical data like operative procedures, latency period, presence of bone union, primary bone length, bone gap, amount of bone transport, implant type, and duration of apparatus were included. Further, number of days of distraction, percentage of transport, distraction speed and bone healing index (BHI) were estimated.

Definition of outcome variables: Distraction speed was calculated as distraction gap in millimeter divided by number of days of distraction. BHI was calculated as the number of days of external fixator apparatus treatment per centimeter length gained. The percentage of lengthening was calculated as gained callus length divided by primary bone length. One of the standard means of evaluating quality of bone regeneration is healing index.[14] Removal of fixator was chosen as a definable end-point, a stage where healing without fracture was predictable.[7] Removing fixator when at least three cortices have regenerated is a sound hypothesis to judge fixator removal.[9]

Table 1: Baseline information of the patients who underwent distraction osteogenesis with external fixator apparatus (n=5)

SN	Patients' ID	Age (Years)	Gender	Bone	Cause	Illizarov Use	LRS Use	Nail Use
1	R1	46	Male	Tibia	RTA	+	-	-
2	C2	22	Male	Femur	*GCT	+	-	+
3	J3	44	Male	Tibia	RTA	+	-	-
4	S4	21	Male	Femur	RTA	-	+	+
5	A5	36	Male	Tibia	RTA	+	-	-

RTA: Road traffic accident; GCT: Giant cell tumor; LRS: Linear Reconstruction System. *The patient had recurrent GCT

RESULTS

The mean age of participants was 33.8 years. A total of five patients were assessed. All of them were males. The baseline information of the patients has been mentioned in Table 1. In present study, there were 3 patients with tibial gap non-union and 2 patients with involvement of femur. Bone loss of up to 15 cm was gained by distraction osteogenesis. Two patients were treated with additional internal fixation with intramedullary nail. Illizarov was used for four cases and LRS was used for a patient. Road traffic accident was the cause for bone loss in 80 % of the cases whereas recurrent giant cell tumor was the etiology for the remaining (Table 1).

Table 2: Radiological parameters of the patients who underwent distraction osteogenesis with external fixator apparatus (n=5).

SN	Parameters	R1	C2	J3	S4	A5
1	Bone Union	+	+	+	+	+
2	Primary length (cm)	32	42	34	42	35
3	Bone gap (cm)	15	14	5.43	15	5.38
4	Number of days of distraction	154	201	94	125	144
5	Duration of fixator (months)	9.2	17.66	11.43	6.9	12.96
6	Distraction speed (mm/day)	1	1	1	1	1
7	Bone healing index (BHI)	18.4	37.8	63.2	13.8	72.3
8	Percentage of transport (%)	46	33.3	16	35.7	15.4

The radiological outcome variables are mentioned in Table 2. Bone union was achieved in all the patients. The range of bone gap was from 5.38 cm to 15 cm. Up to 46 % of bone transport was possible with Ilizarov.

Typical Case example C1: A 46-year-old male presented to our outpatient department with left infected both-bone leg fracture partially treated elsewhere (Figure 1). The tibia was exposed and distal fibula had been plated. He was offered amputation by some other surgeons when referred for vascular graft. He underwent series of surgeries, which included debridement & irrigation, implant exit, Ilizarov application and corticotomy (Figure 2a-f). DO was taught to him and the caretakers. To his surprise, he could walk without walking aids after removal of the implant with the same limb, which was offered amputation.

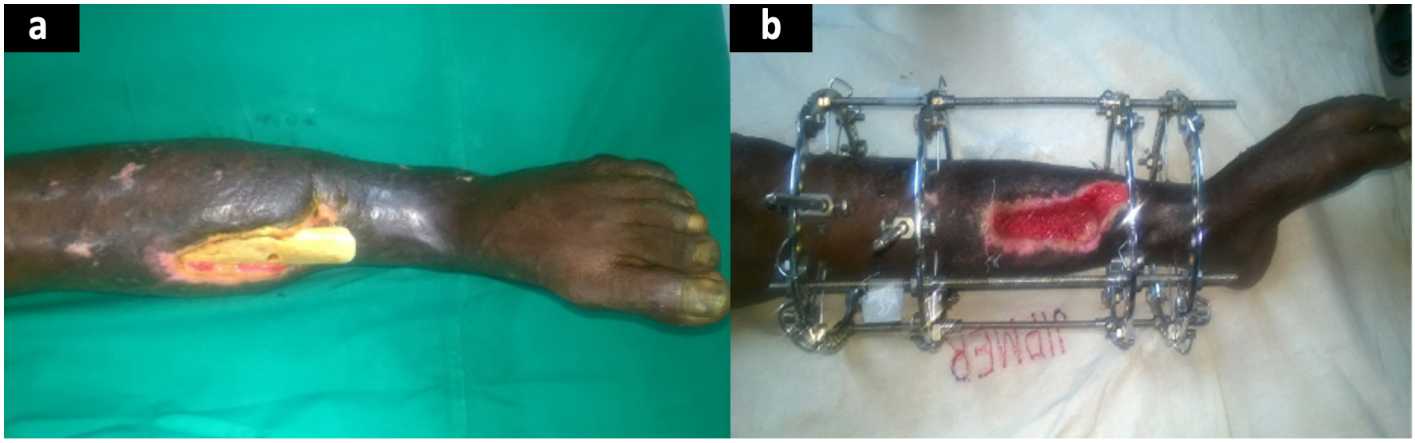

Figure 1: Clinical picture of the typical case. a. exposed bone. b. status of the wound following debridement and Ilizarov application.

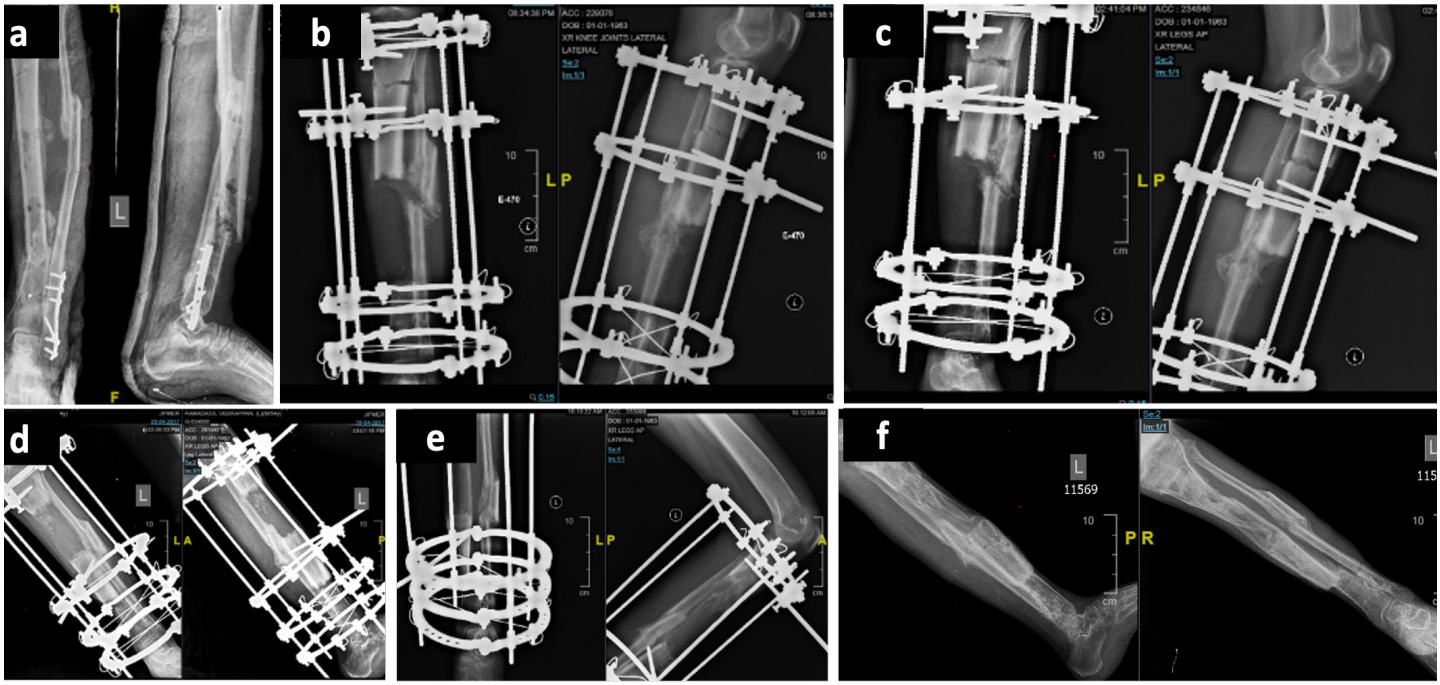

Figure 2: X Ray picture of the typical case. a. status before debridement and Ilizarov fixation. b. Corticotomy and Illizarov external fixator was applied. c. distraction started. d. regenerate formation while he was on distraction phase. e. regenerate was in consolidation phase. f. X Ray showing well-formed regenerate after removal of the Ilizarov.

Typical case example S4:
A 18 year/male presented to our center with alleged history of road traffic crash following which he sustained injury to right thigh. There was 15 cm bone loss in mid-distal one third femur with some butterfly fragments. He under went intramedullary interlocking nailing with linear reconstruction system. Distraction osteogenesis was done and fixator was removed after 6.9 months (Figure 3). Radiological union was achieved for the patient whose details are mentioned in table 2 case S4.

DISCUSSION

In our study, bone union was attained in all patients. The range of bone gap was from 5.38 cm to 15 cm. We observed that 6.9 to 17.66 months were required for complete union and removal of fixator. Up to 46 % of bone transport was possible with Ilizarov.

DO is based on biology of bone regeneration.[13] Bony stability is essential for osteogenesis and is dependent on stability of external frame.[15] Unlike other external fixators, Ilizarov system uses thin transosseous wires that allow stable yet dynamic fixation of the bone fragments.[16] Biomechanical parameters such as wire angle, amount of wire tension and wire material have been defined as improving overall frame stiffness.[16] Hence, improved stiffness can facilitate improved rehabilitation as well as improved patient compliance. These parameters are important for improvement in radiological parameters, most importantly bony union as found in our cases.

Average union time in patients with bone loss is directly related to bone defect.[17] Duration from end of distraction until bony union is called consolidation phase.[15] One disadvantage of DO is the need to wait for a long consolidation phase, which is nearly four times as long as distraction phase in

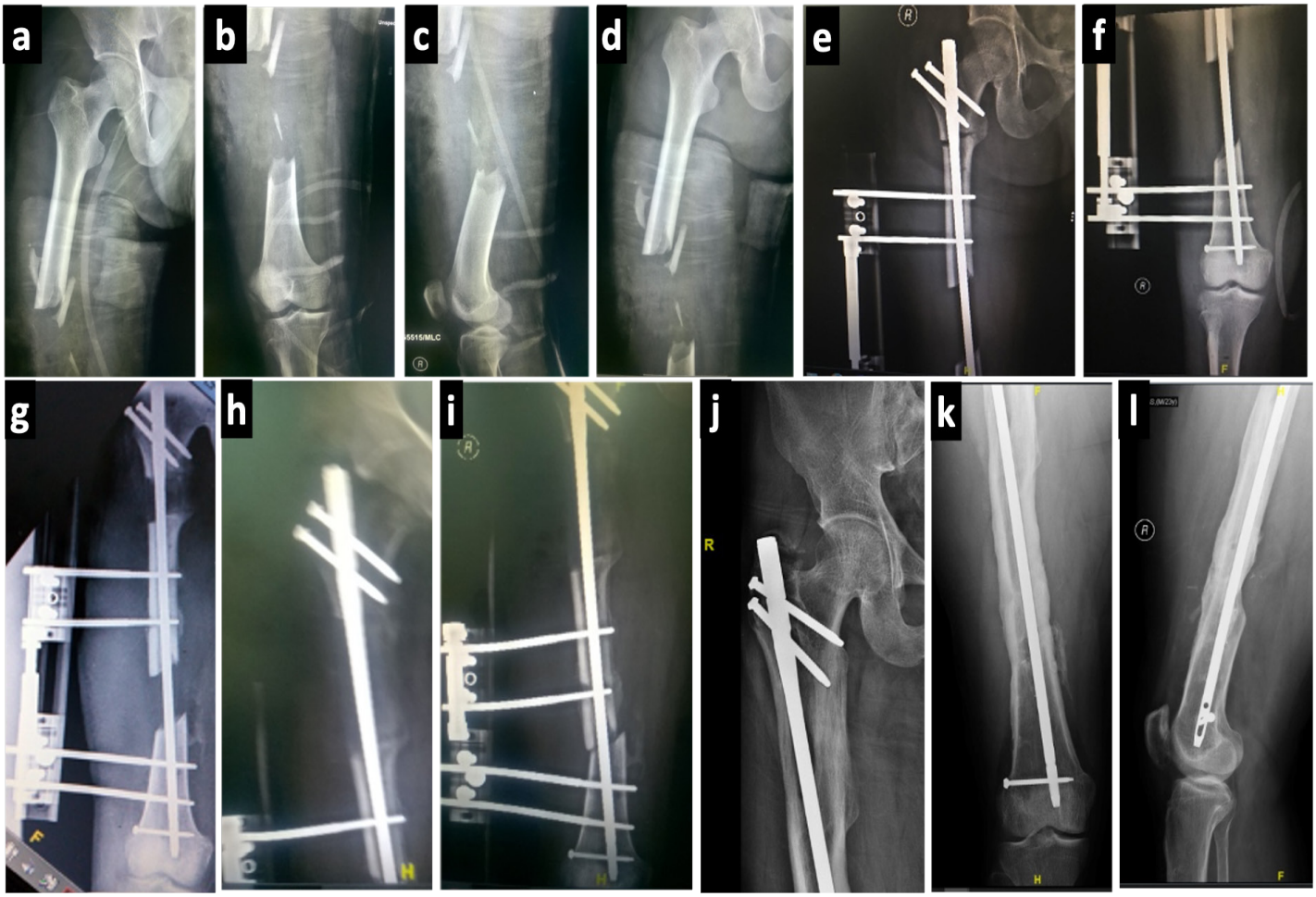

Figure 3: a-d. Anteroposterior and lateral X-Rays of case S4 of right hip with thigh with knee showing mid-distal shaft of femur fracture with bone loss with butterfly fragment. E-f. corticotomy sites. g-i. serial regenerates with docking of distal site. j-l. Anteroposterior and lateral X-Rays of case S4 showing union of mid-distal shaft of femur fracture as well as calcification of regenerate.

adults.[13] External fixation period is important for healing distracted bones as it promotes stability as well as maturation.[2] As per some reports, 9 to 18 months may be necessary to manage tibial defects of 6 to 12 cm.[4] Our study is in line with this. The range of bone gap was from 5.38 cm to 15 cm. We observed that 6.9 to 17.66 months were required to remove the external fixator apparatus. Should the duration of external fixator be too short, limited maturation time can lead to instability of distracted bone, leading to nonunion or re-fracture.[2]

If we look into evidence, there is some meta-analysis, which states Ilizarov as a reasonably good option for treatment of infected nonunion of tibia and femur.[18] There was no compelling evidence that vascularized bone graft produce better outcomes for longer bone grafts.[19] Harvesting vascularized fibular graft is technically difficult and impossible at times.[4] Vascularized graft demands skilled team and a long surgical time; utilizes substantial hospital resources; produces pain at donor site; sacrifices a major vessel of lower extremity and requires immediate postoperative monitoring of circulation to graft. Most importantly, its success is questionable in areas that have severe trauma.[1] Lower extremity is difficult area for grafting due to high relapse rate of infection and trouble in finding appropriate recipient vessels. High incidence of thrombus formation poses additional risk.[20] Infection also plays a role in graft selection. Many a times, two-staged method with delayed grafting is necessary.[21] It is difficult to match to geometry of recipient site. It is undesirable to subject a patient to additional stress if defect can be satisfactorily repaired with other options.[19] Considering all these factors, we didn't opt for bone grafting. It is noteworthy that one of our cases, as described above, was suggested for transtibial amputation by the department that usually performs vascular grafts. However, we could achieve union in all our patients with improved radiological parameters.

Further, use of non-vascularized graft in defects larger than 5 cm is not recommended.[21] In our case series all the patients had defect larger than five cm. Hence, we opted for distraction histogenesis. We could find radiological union in all of our cases as mentioned in table 2.

Intramedullary nail with an Ilizarov external fixator is advantageous as it overcomes shortening, plastic deformation, angular deformity, and fracture of regenerated bone.[22] It reduces time of external fixator. Further, it allows early full weight bearing with decreased chances of joint stiffness.[23] Early removal of external fixator decreases risk of pin-site infection and allows for earlier patient rehabilitation.[22] Deep infection is a major concern of combined intramedullary nailing and external fixation.[13]Fat embolism, deep infection and

breakage of nails and locking screws can occur.[24] Paley suggested avoiding contact between pin of external fixator and intramedullary nail to prevent deep infection.[24] As mentioned in table 2, case S4, we had also used intramedullary nailing for a case of shaft of femur fracture with bone loss. We also observed prevention of deformity and fracture of regenerate. Radiological parameters were better with use of additional nail.

Infected nonunion is associated with deformity, bone loss and persistent fracture site infection. Ilizarov can overcome all associated problems simultaneously.[25] DO can treat osteomyelitis of any length with a less aggressive and more flexible compared to other techniques.[26] Ilizarov technique is less invasive with minimal soft-tissue exposure and blood loss. And the fixation is stable enough to allow early weight bearing.[27] Benign bone tumors, like giant- cell tumors, must be resected in order to provide a safe margin to prevent local recurrence causing a loss of bone stock, which requires reconstruction.[2] DO is a good treatment option in patients with bone defects after resection of a benign bone tumor.[2]Our case R1 and C2 had infected gap non-union of tibia and recurrent giant cell tumor respectively. We also observed the similar benefits radiologically.

Pain, long treatment process, and prolonged external fixation are unavoidable shortcomings.[25] Heavy external fixation apparatus along with psychological issues and soft tissue contractures make its use uncomfortable.[28]

There are few limitations of the present study. First, it was a retrospective study and there was no control arm. Second, the study size was relatively small. We have done radiological assessment alone. Additional clinical information could provide more evidence. Nevertheless, there were some strengths of the study. Same orthopedic surgeon performed all the surgeries. Well-trained orthopedic surgeons collected all the data. Duration of follow up can be taken as additional strength of the study. There is little publication about the topic from our part of world. Distraction osteogenesis by Ilizarov or LRS can achieve union in large bone defect up to 15 centimeters in tibia and femur. Further, additional internal fixation with a nail is beneficial for union and other radiological parameters. Study with larger study size and preferably with randomization would give better understanding of the procedure.

CONCLUSION

Distraction osteogenesis can achieve union in large bone defect up to 15 cm in tibia and femur. Additional internal fixation with an intramedullary nail can be beneficial.

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