A comparative study between bone transport technique using Ilizarov/LRS fixator and induced membrane (Masquelet) technique in management of bone defects in the long bones of lower limb

Govind Kumar Gupta¹, Amit Kumar Majhee¹, Sudha Rani², Shubhendu Shekhar¹, Pancham Prasad¹, Ganesh Chauhan³

¹Department of Orthopaedics, ²Department of Genetics and Genomics, Rajendra Institute of Medical Sciences, Ranchi, Jharkhand, ³Department of Anatomy, Sheikh Bikhari Medical College, Hazaribagh, Jharkhand, India

Abstract

Introduction: In earlier times due to difficulty in managing segmental long bone defects, amputation was the preferred treatment. Nonunion with bone loss of long bones is a challenging problem, requiring serious attention. Post-traumatic segmental bone defects can have severe long-term ill impact on patient’s lives. Reconstruction is more difficult and functional outcome is usually less satisfactory compared to bony outcome. Distraction osteogenesis and induced membrane technique are the techniques that can be used. Aims and Objectives: To find out and compare clinical, radiological, and functional outcome of bone transport technique and induced membrane technique in management of bone defects in the long bones of lower limb. Materials and Methods: A comparative study was conducted on 24 patients (22 males and 2 females) of lower extremity fractures with bone defect more than 3 cm. Patients were divided into two groups according to the method of reconstruction used, that is, either bone transport technique in 12 patients (group A) or masquelet in the other 12 patients (group B). The mean age of the patients was 44 years in group A and was 38 years in group B. Regular follow-up was done with a mean period of follow up of 18.35 ± 5.58 months in group A and 18.25 ± 3.95 months in group B. Result: In group A (bone transport), 67% showed union, 25% showed union with bone graft and 8% showed delayed union. In group B (masquelet), 75% showed union and 25% showed delayed union. Bone transport technique showed excellent result in 58.3% and good in 41.7% while Masquelet technique showed excellent result in 50% and good in 50%. Conclusion: For an orthopaedic surgeon, long bones defects with a substantial loss of bone volume are one of the most challenging bone defects encountered in clinical practice. Induced membrane technique and bone transport both offer successful options for filling of bone defects. Both techniques have their own pros and cons and provide varied option for healing. In our study, both methods have comparable results statistically although induced membrane technique required soft tissue reconstructive procedures.

Keywords: ASAMI score, bone defects, induced membrane technique, Ilizarov fixator, limb reconstruction system, Masquelet technique

Introduction

The incidence of compound fractures with bone loss are increasing due to rising incidence of high velocity trauma and road

How to cite this article: Gupta GK, Majhee AK, Rani S, Shekhar S, Prasad P, Chauhan G. A comparative study between bone transport technique using Ilizarov/LRS fixator and induced membrane (Masquelet) technique in management of bone defects in the long bones of lower limb. J Family Med Prim Care 2022;11:3660-6.
traffic accidents. These injuries are commonly encountered by family physician and primary caregivers. Improper management of fractured bone usually leads to deformity, nonunion, and other complications. It becomes burden to patient, their family members, and also health care providers.

In earlier times due to difficulty in managing segmental long bone defects, amputation was the preferred treatment. Limb salvage has been developed over the last half century.[2,3]

Post traumatic bone defects usually results in severe long-term adverse impact on patient’s lives. Reconstruction is more difficult and functional outcome is usually less satisfactory compared to bony outcome. There is no single technique at present which is reliably successful in the management of large bone defects. In case of significant bone loss, limb salvage surgery is technically very difficult, economically and mentally very challenging for patients and very difficult to predict the success.[4-7]

Bone transport technique is used for the management of very large bone defects. The procedure has a very high complication rate, this technique is very demanding also and patient’s utmost co-operation is required.[8] The Masquelet technique does offer an effective alternative for management of large bone defects.[9,10] It can be safely used in infected areas provided the membrane is formed around the defect to protect and vascularize the bone graft.[11-13]

Aims and Objectives of Study
1. To compare clinical, radiological, and functional outcome between both Ilizarov/LRS bone transport and Masquelet technique in non-union of fractures and traumatic defects of lower extremity long bones by using Association for the Study and Application Methods of Ilizarov (ASAMI) scoring system.
2. To find out the technical requirement, complications of both the techniques in non-union fractures and traumatic defects of long bones.

Materials and Methods
This was a prospective double-blinded study. The study was carried out on 24 patients with lower extremity long bone defect of more than 3 cm, operated at Department of Orthopaedics, Rajendra Institute of Medical Sciences (RIMS), Ranchi, from January 2019 to January 2021. Informed written consent was taken from each patient. Ethical approval was taken from ethical committee, RIMS, Ranchi. The cases were first randomized with lottery method and then classified into two groups. Group A included 12 patients managed by bone transport technique and group B included 12 patients managed by induced membrane (Masquelet) technique.

All the patients were assessed clinically and radiologically and scanogram was done to assess deformity and limb length.
discrepancy. The result was evaluated using the ASAMI Scoring System postoperatively.

**Inclusion criteria**

Patients who gave consent for the procedure, age above 18 years and less than 65 years, comminuted fractures of lower extremity with bone loss, gap nonunion of lower extremity fracture, gap produced after resection of bone tumor, gap non-union tibia/femur complicated with infection.

**Exclusion criteria**

Patients medically unfit for surgery, neurovascular injury.

**Operative procedures**

A. Surgical technique of Ilizarov/LRS bone transport

All devitalized bones were removed, tissue sample taken and sent for culture and sensitivity, soft tissue coverage was done. Fixation was done with external Ilizarov frame. If there was no sign of infection, corticotomy was performed or if active pus discharging or sinus present then this step was delayed for six weeks.

After a delay of around seven days, bone transport was initiated. The rate of transport was 1 mm distraction and 2 mm compression until the docking site showed compression and the calculated defect was compensated. If the docking site showed signs of non-union bone grafting done. New bone formation occurs in this gap as the distraction continues. Once the distraction is stopped, the frame remains attached to allow the new bone to consolidate. This time is usually one month per cm of new bone formed. After this time the frame is removed. Fibular osteotomy was carried out only in cases associated with shortening to manage the large bone defect (more than 6 cm) [Pic 1 and 2].

B) Surgical technique of induced membrane (Masquelet)

The Masquelet technique is a 2-stage reconstruction procedure.

Stage 1 – The first step was active management of infection by repeated debridment, culture, and sensitivity of intra-operative tissue sample. Fracture margins were freshened. All devitalized and infected bone and soft tissues were removed. Then the fragments were aligned and stabilized. The primary stability was provided by an external or internal fixation device. After debridement, the defect was filled with polymethylmethacrylate (PMMA) cement spacer which contained antibiotic mixed with it, to manage dead space and control infection and induction of a membrane that protects against graft resorption and promotes bony ingrowth in the defect. This leads to the formation of induction membrane as a result of foreign body reaction. The bone cement provided additional stability.

Stage 2 - After a period of four to eight weeks, the body’s reaction to PMMA beads or a spacer leaves a bioactive membrane, Masquelet membrane. In the second stage, the bone cement was removed taking care of the membrane. The defect was filled with cancellous or corticocancellous bone graft as per size of the defects [Pic 3, 4 and 5].

Serial follow-up was done for all patients. Clinical, radiological, and functional outcome was assessed using ASAMI score at six months postoperative period.

**Statistical analysis**

Data were analyzed using Statistical Program for Social Science (SPSS) version 20.0, Quantitative data were expressed as mean ± standard deviation (SD), and qualitative data were expressed as frequency and percentage. Independent samples t-test, Chi-square (X2) test, and Probability (P-value) were used.

CTRI/2020/07/026485

**Results**

Minimum age of participant in Group A was found to be 32 years and maximum age of the participant was found to be 60 years with mean value of 43.83 and standard deviation of 9.311. In group B, minimum age was found to be 20 years and maximum age of the participant was found to be 56 years with mean value of 38.08 and standard deviation of 9.802 [Table 1].

In both group A and group B, majority 11 (91.7%) were male and 1 (8.3%) was female [Table 1].

Patients’ postop activities of daily living (ADL) compared in percentage with activities of daily living before trauma. In group A, 2 (16.7%) patients can do up to 50% ADL, 9 (75%) patients can do up to 75% ADL, 1 (8.3%) patient had 100% ADL. In group B, 1 (8.3%) patients can do up to 50% ADL, 7 (58.3%) patients can do up to 75% ADL, 4 (33.3%) patients had 100% ADL [Table 2].

In group A, 11 (91.7%) patients had mild pain at pin sites, 1 (8.3%) patient had moderate pain due to infection at pin site...
which was then controlled by dressing and antibiotics. In group B, 6 (50%) patients had no pain at operative site, 6 (50%) patients had mild pain due to soft tissue contracture [Table 2].

In group A, 4 (33.3%) patients had no dystrophy, 7 (58.3%) patients had mild dystrophy and 1 (8.3%) patient had atrophy due to scar. In group B, 2 (16.7%) patients had no dystrophy, 10 (83.3%) patients had mild dystrophy and no patient had atrophy [Table 3].

Patients were examined in supine position, angle at knee joint in anatomical position measured, then compared with opposite normal knee joint and grouped as knee joint contracture <5 degree and >5 degree. In bone transport technique, all patients had contracture <5 degree. In Masquelet, 11 patients had knee contracture of <5 degree and 1 patient had contracture of >5 degree [Table 3].

Patients were examined in supine position, angle at ankle joint in anatomical position measured, then compared with opposite normal ankle joint. Joint contracture grouped as <5 degree and >5 degree. In bone transport technique, 11 (91.7%) patients had contracture <5 degree, 1 (8.3%) had >5 degree. In Masquelet, 11 (91.7%) patients had ankle joint contracture of <5 degree and 1 (8.3%) patient had contracture of >5 degree [Table 3].

Patients were examined in supine position, angle of knee joint movement measured, then compared with opposite normal knee joint. Loss of knee joint motion grouped as <15 degree and >15 degree. In bone transport technique 11 (91.7%) patient had minimal loss of knee motion <15 degree, 1 (8.3%) had >15 degree loss of movement. In Masquelet, 10 (83.3%) patients had loss of knee joint motion of <15 degree and 2 (16.7%) patients had knee joint motion of >15 degree [Table 4].

Patients were examined in supine position, angle of ankle joint movement measured, then compared with opposite normal ankle joint motion. Loss of ankle joint motion grouped as <15 degree and >15 degree. In bone transport technique, 10 (83.3%) patient had minimal loss of ankle motion <15 degree, 2 (16.7%) had >15 degree. In Masquelet, all patients had loss of ankle joint motion of <15 degree [Table 4].

Patients were examined in supine position and true limb length measured from anterior superior iliac spine to tip of medial malleolus, then compared with opposite normal limb.

In all the patients of group A and group B, LLD is ≤2.5 cm [Table 4].

In bone transport, that is, group A, 11 patients (91.7%) showed no signs of infection whereas in 1 (8.3%) case pin site infection was seen. Whereas in patient of Masquelet technique, that is, group B, all 12 patients wound healing occurred without any signs of infection [Table 5].

### Table 1: Sample characteristics of the study population

| Characteristics | Bone Transport | Induced Membrane |
|-----------------|----------------|------------------|
| Total           | 12             | 12               |
| Gender (male/female) | 11/1          | 11/1             |
| Age (mean±SD)   | 43.83±9.31     | 38.08±9.80       |
| Comminuted fracture tibia with bone loss | 3             | 2                |
| Gap non-union tibia | 1             | 4                |
| Infected malunion | 1             | 0                |
| Infected non-union | 4            | 3                |
| Open segmental fracture tibia | 3             | 3                |
| Bone loss <5 cm | 3              | 1                |
| Bone loss ≥5 cm | 9              | 11               |

### Table 2: Comparison of activity of daily living and pain severity

| Trait                   | Bone transport | Masquelet | Statistics |
|-------------------------|----------------|-----------|------------|
| Activity of daily living|                |           |            |
| Up to 100%              | 1              | 4         | χ²=7.077, P=0.132 |
| Up to 70%               | 9              | 7         | P=0.385   |
| Up to 50%               | 2              | 1         | χ²=1.733, P=0.132 |
| <50%                    | 0              | 0         |            |
| Total                   | 12             | 10        |            |
| Pain severity           |                |           |            |
| No pain                 | 0              | 0         |            |
| Mild pain               | 11             | 6         |            |
| Moderate pain           | 1              | 0         |            |
| Severe pain             | 0              | 0         |            |
| Total                   | 12             | 10        |            |

### Table 3: Comparison of soft tissue condition, knee joint, and ankle joint contracture

| Trait                        | Bone transport | Masquelet | Statistics |
|------------------------------|----------------|-----------|------------|
| Soft tissue condition        |                |           |            |
| No dystrophy                 | 4              | 2         | χ²=6.278, P=0.043 |
| Mild dystrophy               | 7              | 10        |            |
| Atrophy                      | 1              | 0         |            |
| Total                        | 12             | 100       |            |
| Knee joint contracture       |                |           |            |
| <5 degree                    | 12             | 100       |            |
| >5 degree                    | 0              | 0         |             |
| Total                        | 12             | 100       |            |
| Ankle joint contracture      |                |           |            |
| <5 degree                    | 11             | 91.7      | χ²=12.00, P=0.083 |
| >5 degree                    | 1              | 8.3       |            |
| Total                        | 12             | 100       |            |

In bone transport, that is, group A, 8 (66.7%) patients union seen without any bone grafting, 3 (25%) patients union occurred after bone grafting, 1 (8.3%) patient delayed union seen.

Whereas in patient of Masquelet technique, that is, group B all 12 patients received cancellous or corticocancellous bone grafts in second stage. In 9 (75%) patients union seen, 3 (25%)
patients showed delayed union. No cases of nonunion were observed [Table 5].

11 (91.7%) patients do not need coverage in group A, that is, Bone transport technique, whereas as in group B, that is, Masquelet 5 (41.7%) patients do not need any coverage [Table 6].

In bone transport group, 7 showed excellent and 5 showed good result, whereas in Masquelet group 6 showed excellent and 6 showed good functional outcome [Table 6].

**Discussion**

Both techniques induced membrane technique or bone transport technique have its pros and cons. In our study on 12 cases of bone defects managed with bone transport with bone defect ranging from 3 cm to 10 cm with mean 6.25 cm. All cases were operated using unifocal bone transport. In 10 cases, Ilizarov fixator was applied and in 2 cases limb reconstruction system was applied. The radiological union time was 150 days +/- 30 days ranging from 120 to 180 days (4–6 months). The functional outcome of this study according to ASAMI score showed 7 cases excellent, 5 cases good, no average or poor outcome. 11 (91.7%) cases patient did not require wound coverage, 1 (8.3%) patient case in whom operative site was complicated by severe infection and due to debridment bone was exposed, coverage done after infection subsided. In bone transport, that is, group A, among 12 patients 8 (66.7%) patients union seen, 3 (25%) patients union occur after bone grafting, 1 (8.3%) patient delayed union seen. There was no non-union seen. In terms of pain severity at six months according to Stanford pain scale subgrouped as no pain, mild pain, moderate pain, severe pain. In group A, 11 (91.7%) patients have mild pain at pin sites, 1 (8.3%) patient had moderate pain due to infection at pin site which was then controlled by dressing and antibiotics. In group A, 4 (33.3%) patients had no dystrophy, 7 (58.3%) patients had mild dystrophy and 1 (8.3%) patient had atrophy due to scar. In bone transport technique, all patients had knee joint contracture <5 degree. In bone transport technique, 11 (91.7%) patients had ankle joint contracture <5 degree, 1 (8.3%) had >5 degree. In bone transport technique, 11 (91.7%) patients had minimal loss of knee motion <15 degree, 1 (8.3%) had >15 degree. In bone transport technique, 10 (83.3%) patients had minimal loss of ankle motion <15 degree, 2 (16.7%) had >15 degree. In all the patients of group A Limb length discrepancy (LLD) is <2.5 cm.

Overall functional result according to ASAMI score in bone transport group, 7 were excellent, 5 were good result.

In our study, the postoperative complications in bone transport group are as follow:

A. Pin tract infection, most of pin tract infection was grade one except two patient who had grade II and were treated by removal of the infected pin and debridement.

B. Delayed union in four patients who were treated by cancellous bone grafting and compression distraction method.

---

### Table 4: Comparison of loss of knee joint motion, ankle joint motion, and limb length discrepancy

| Trait                           | Bone transport | Masquelet | Statistics |
|---------------------------------|----------------|-----------|------------|
| Loss of knee joint motion       |                |           |            |
| <15 Degree                      | 11             | 10        | $\chi^2$ = 5.455, $P = 0.167$ |
| >15 Degree                      | 1              | 2         |            |
| Total                           | 12             | 12        |            |
| Loss of ankle joint motion      |                |           |            |
| <15 Degree                      | 10             | 12        | $\chi^2$ = 0.197, $P = 1.00$ |
| >15 Degree                      | 2              | 0         |            |
| Total                           | 12             | 12        |            |
| Limb length discrepancy         |                |           |            |
| <2.5 cm                         | 12             | 12        |            |
| >2.5 cm                         | 0              | 0         |            |
| Total                           | 12             | 12        |            |

### Table 5: Comparisons of bone union, infection, and limb deformity

| Trait                        | Bone transport | Masquelet | Statistics |
|------------------------------|----------------|-----------|------------|
| Bone union +/- B.G.          |                |           |            |
| Union-1                      | 8              | 6.67      | $\chi^2$ = 6.668, $P = 0.02$ |
| Union with bone graft        | 3              | 25.0      | 75         |
| Delayed union with bone graft| 1              | 8.3       | 3          | 25         |
| Non union                    | 0              | 0         | 0          |            |
| Total                        | 12             | 100.0     | 12         | 100.0      |
| Infection                    |                |           |            |
| Absent                       | 11             | 91.7      | 12         | 100.0      | $\chi^2$ = 5.455, $P = 0.167$ |
| Present                      | 1              | 8.3       | 0          | 0          |
| Total                        | 12             | 100.0     | 12         | 100.0      |
| Limb deformity               |                |           |            |
| <7 degree                    | 12             | 100.0     | 9          | 75         | $\chi^2$ = 0.197, $P = 1.00$ |
| >7 degree                    | 0              | 0         | 3          | 25         |
| Total                        | 12             | 100.0     | 12         | 100.0      |

### Table 6: Comparison of soft tissue coverage and ASAMI score outcome

| Trait                        | Bone transport | Masquelet | Statistics |
|------------------------------|----------------|-----------|------------|
| Soft tissue coverage         |                |           |            |
| No                           | 11             | 91.7      | 5          | 41.7       | $\chi^2$ = 12, $P = 0.04$ |
| Yes                          | 1              | 8.3       | 7          | 58.3       |
| Total                        | 12             | 100.0     | 12         | 100.0      |
| ASAMI score outcome          |                |           |            |
| Excellent                    | 7              | 58.3      | 6          | 50.0       | $\chi^2$ = 5.60, $P = 0.04$ |
| Good                         | 5              | 41.7      | 6          | 50.0       |
| Total                        | 12             | 100.0     | 12         | 100.0      |

Advantage of bone transport: No need for massive bone grafting, less requirement of complex soft tissue repair procedures, and can correct limb length and deformity, no internal fixation leading to better infection control and easy implant removal.

Disadvantage of bone transport technique: Technically demanding for surgeon, longer time was needed for union in
massive defects, risk of neurovascular damage from wire, and poor patient compliance especially in femur.

In our study on 12 cases of bone defect managed with induced membrane technique (Masquelet) with bone defect ranging from 4 cm to 10 cm with mean 6.58 cm, soft tissue reconstruction was needed in four cases which was done by local and free flaps, three cases required only skin grafting. In two cases, repeat flap was required. In this current study, in all cases we used cancellous iliac bone auto graft to fill the defect. The mean healing time was 150 days +/- 30 days ranging from 120 to 180 days (4–6 months). The functional result of this study according to ASAMI score; 6 cases showed excellent, 6 cases good and no average or poor outcome. In patient undergoing Masquelet technique, that is, group B all 12 patients received cancellous bone grafting in second stage surgery. In 9 (75%) patients union was seen, 3 (25%) patients showed delayed union. In terms of pain severity at six months according to Stanford pain scale. In group B, 6 (50%) patients have no pain at operative site, 6 (50%) patients have mild pain due to soft tissue contracture leading to joint restriction. In group B, 2 (16.7%) patients had no dystrophy, 10 (83.3%) patients had mild dystrophy and no patient had atrophy. In Masquelet, 11 patients had knee contracture of <5 degree and 1 patient had contracture of >5 degree. In Masquelet, 11 (91.7%) patients had ankle joint contracture of <5 degree and 1 (8.3%) patients had contracture of >5 degree. In Masquelet, 10 (83.3%) patients had loss of knee joint motion of <5 degree and 2 (16.7%) patients had knee motion loss of >5 degree. In Masquelet, all patients had loss of ankle joint motion of <15 degree. In all the patients of group B, LLD is <2.5 cm. Overall functional result according to ASAMI score in Masquelet group, 6 (50%) showed excellent and 6 (50%) showed good functional outcome. While the success rate of the technique may appear to be lower than the previous studies because of the need of complex soft tissue reconstruction. The mean healing time was longer than previous study due to the use of cancellous or corticocancellous bone alone without adding growth factor.

The results of the current study are comparable to those done with unifocal bone transport. While the rate of complications and their type (problems, obstacles, and sequelae), were comparable to most of the mentioned study. In our study, the postoperative complications of Masquelet or induced membrane interventions are: Pin tract infection (PTI). In three patients, the bone was initially stabilized with external fixator. Most of PTI was grade one infection, and were treated with antibiotic. Deformity: 3 patients have external rotation and one patients also have equines deformity. LLD: all patients had <2.5 cm. Failure of the technique: union was seen in all cases. In 1 case repeated plastic coverage was required due to infection of the bone cement with skin loss of 2.5 cm x 5 cm. Flap rotation was done eventually after failure of fasciocutaneous flap.

Advantage of induced membrane technique: relatively simpler technique if complex procedures of soft tissue repairs are excluded, less demanding for the patient, and shorter time is need for union in large defect, patient compliance is better.

Disadvantage of induced membrane technique in tibia: Technically demanding for soft tissue coverage, two stage operation, need of massive harvest graft and in massive bone defect when shortening was done but cannot regain the length of bone and significant limb length discrepancy may occur.

Relevance to the practice of primary care physicians
The incidence of fractures with bone loss is increasing day by day and is commonly encountered by primary care providers and family physicians. The management of these complex injuries is very challenging. The peripheral areas of our country lack facilities for proper management of these complex injuries. Improper management of fractured bone usually leads to deformity, nonunion and other complications. It becomes burden to patient, their family members, and also health care providers. This study helps family physician and primary care givers in better understanding about management of fractures with bone defects (gap nonunion). It will also help in better understanding of these injuries by primary care physicians so that patient can be referred to appropriate centers where these injuries can be managed.

Limitations of study
A. Inter-departmental co-ordination
Lack of co-ordination delays the procedures which further alter the outcome.

B. Burden on patient due to repeated operation

Patients had to go through repeated debridements and surgeries throughout the process specially in Masquelet, apart from serial debridements and two-staged surgery patients also had to face number of plastic surgery procedures for wound coverage. These factors were resulting in prolonged hospital stay which further impacted on the physical, psychological, and financial status of the patients and their family.

Conclusion
From an orthopaedic surgeon's point of view, bone defects with a substantial loss of bone volume are one of the most challenging problems encountered in clinical practice. While modern day medicine offers a variety of bone substitute materials, autologous bone graft and other modalities of treatment need to be evaluated. Induced membrane technique and bone transport both offer successful options for filling of bone defects. Both techniques have its own pros and cons and provides varied option for healing. In our study, both methods have comparable results statistically although induced membrane technique required soft tissue reconstructive procedures. Hence, each method should be appropriately evaluated for individual patient and managed accordingly.

Declaration of patient consent
The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other
clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

**Abbreviations**

- ADL: activities of daily living
- LRS: limb reconstruction system
- ASAMI score: Association for the Study and Application of Method of Ilizarov
- LLD: limb length discrepancy

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Watson JT, Anders M, Moed BR. Management strategies for bone loss in tibial shaft fractures. Clin Orthop Relat Res 1995;138–52.
2. Weinberg H, Roth VG, Robin GC, Floman Y. Early fibular bypass procedures (tibiofibular synostosis) for massive bone loss in war injuries. J Trauma 1979;19:177-81.
3. Trivedi A, Rawal D. Prevalence of road traffic accidents and driving practices among young drivers. Health Line 2011;2:72-5.
4. Hertel R, Gerber A, Schlegel U, Cordey J, Ruegsegger P, Rahn BA. Cancellous bone graft for skeletal reconstruction. Muscular versus periosteal bed—preliminary report. Injury 1994;25(Suppl 1):A59–70.
5. Ip WY. Polylactide membranes and sponges in the treatment of segmental defects in rabbit radii. Injury 2002;33(Suppl 2):B66-70.
6. Aronson J. Limb-lengthening, skeletal reconstruction, and bone transport with the Ilizarov method. J Bone Joint Surg Am 1997;79:1243-58.
7. Adam D, Hamel A, Perrot P, Duteille F. Long-term behavior of the vascularized fibular free flap for reconstruction of bony defects in children. Ann Chir Plast Esthet 2020;65:219-27.
8. Giannikas K, Maganaris C, Karski M, Twigg P, Wilkes R, Buckley J. Functional outcome following bone transport reconstruction of distal tibial defects. J Bone Joint Surg Am 2005;87:145-52.
9. Masquelet AC, Fitoussi F, Begue T, Muller GP. Reconstruction of the long bones by the induced membrane and spongy autograft. Ann Chir Plast Esthet 2000;45:346-53.
10. Masquelet AC, Begue T. The concept of induced membrane for reconstruction of long bone defects. Orthop Clin North Am 2010;41:27-37.
11. Pelissier P, Masquelet AC, Bareille R, Pelissier SM, Amedee J. Induced membranes secrete growth factors including vascular and osteoinductive factors and could stimulate bone regeneration. J Orthop Res 2004;22:73-9.
12. Masquelet AC, Kishi T, Benko PE. Very long-term results of post-traumatic bone defect reconstruction by the induced membrane technique. Orthop Traumatol Surg Res 2019;105:159-66.
13. de Boer H. Early research on bone transplantation. In: Aebi M, Regazzoni P, editors. Bone Transplantation. Berlin, Heidelberg: Springer; 1989. Available from: https://doi.org/10.1007/978-3-642-83571-1_2.
14. De Bastiani G, Aldegheri R, Renzi-Brivio L, Trivella G. Limb lengthening by callus distraction (callotasis). J Pediatr Orthop 1987;7:129-34.
15. Morelli I, Drago L, George DA, Gallazzi E, Scarponi S, Romanò CL. Masquelet technique: Myth or reality? A systematic review and meta-analysis. Injury 2016;47:S68-76.
16. Yin P, Ji Q, Li T, Li J, Li Z, Liu J, et al. A Systematic review and meta-analysis of Ilizarov methods in the treatment of infected nonunion ofibia and femur. PLoS One 2015;10:e0141973.
17. Aho OM, Lehenkari P, Ristiniemi J, Lehtonen S, Risteli J, Leskelä HV. The mechanism of action of induced membranes in bone repair. J Bone Joint Surg Am 2013;95:597-604.
18. Lavini F, Dall’Oca C, Bartolozzi P. Bone transport and compression-distraction in the treatment of bone loss of the lower limbs. Injury 2010;41:1191-5.
19. Tiemann AH, Schmidt HG, Braunischweig R, Hofmann GO. Strategies for the analysis of osteitic bone defects at the diaphysis of long bones. Strategies Trauma Limb Reconstr 2009;4:13-8.
20. El-Gammal TA, Shiha AE, El-Deen MA, El-Sayed A, Koth MM, Addosooki AI, et al. Management of traumatic tibial defects using free vascularized fibula or Ilizarov bone transport: A comparative study. Microsurgery 2008;28:339-46.
21. Viateau V, Guillemín G, Calando Y, Logeart D, Oudina K, Sedel L, et al. Induction of a barrier membrane to facilitate reconstruction of massive segmental diaphyseal bone defects: An ovine model. Vet Surg 2006;35:445-52.
22. Rohilla R, Sharma PK, Wadhwani J, Das J, Singh R, Benival D. Prospective randomized comparison of bone transport versus Masquelet technique in infected gap nonunion of tibia. Arch Orthop Trauma Surg 2021. doi: 10.1007/s00402-021-03935-8.