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Role of Masquelet's technique in the induction of membrane and secondary bone grafting in patients of long bone fractures with bone loss

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Abstract
Introduction: Long bone fractures with bone loss are always said to be filled with the complications. They cause severe disability and morbidity. Many methods are there to deal with bone loss in long bones. To tackle all these complications a novel method of bone regeneration called the Masquelet's technique came into the play in recent times.
Aims and Objective: To see the incidence of generation of the induced membrane by Masquelet's technique in long bone fracture with bone loss. To see the radiological union at fracture site in patients treated by Masquelet's technique. To see the infection rate in patients treated with Masquelet's technique. To see the complication in patient's treated with Masquelet's technique.
Material and Methods: 30 patients of segmental bone loss in long bone fractures with different aetiologies were treated using Masquelet technique. All patients undergone two stage procedures as described in Masquelet technique. Stage 1 surgery performed to generate the induced membrane. Through debridement, fixation of fracture and placement of antibiotic PMMA cement are the steps involved in stage 1. In stage 2 the removal of cement, placement of cortico-cancellous bone graft and careful closure of induced membrane was done. Primary fixation changed to definitive fixation using plates and intramedullary nails. Sequential radiographic union along with other complications of procedure was noted on follow-ups.
Results: Overall incidence of generation of induced membrane was 100%. Mean age at presentation was 41.23 years with (SD) standard deviation of 11.464. The male population if the study was 27/30 i.e. 90% while the female proportion was 3/30 i.e.10%. Most common aetiology of segmental bone loss in long bone fracture was roadside accidents i.e. 66.7% which was followed by septic non-union of fractures i.e. 33.3%. Mean time to achieve radiological union at fracture site in our study was 5.87 months with standard deviation of 1.795. Complications in the study were pin track infection, superficial and deep infections, flap necrosis and implant failure.
Conclusion: Overall union was achievable in cases of bone loss in long bone fractures. Masquelet technique gives promising results in bone loss cases upto 8 cm. Patient compliance was better throughout the study as the procedure is simple to understand, easy to apply no special expertise needed. We recommend this technique for bone loss upto 8 cm. However, for larger bone defects we recommend Ilizarov/LRS.

Keywords: Induced membrane technique (IMT), bone loss, Masquelet technique, bone cement

Introduction
Segmental bone loss in compound fractures is another challenge in Orthopaedics apart from the several known complications of these fractures. Compound fractures are more vulnerable to getting infected and becoming more complicated [1]. The degree of the loss of bony tissue, soft tissue, and loss of skin coverage divides the compound fractures into different categories.
For that, in 1976 Gustilo-Anderson classified compound fractures. Later, Gustilo *et al*. 1984 modified this classification further to treat compound fractures [2]. Other classification for open fractures is Oestern and Tscherne Classification which tells the level of damage of soft tissue, involved in fractured limb.
Although many treatment modalities have been in the literature for the management of compound fractures, the question of the best treatment for segmental bone loss in open

fractures has remained unanswered until the emergence of limb salvage procedures.

The increasing use of motor vehicles resulting in high-energy trauma has increased the incidence of compound fractures. The true extent of incidence and the resultant morbidity are unknown as compound fractures are not a reportable disease [3].

Both sexes are equally affected. From the beginning of the amputation era to modern external fixators, the treatment has been evolving over the decades. Although LRS (Limb Reconstruction System) and Ilizarov (distraction osteogenesis) method has been used to manage bone loss, the advantage of one over the other is still debatable [4].

Segmental bone loss of more than 2 cm, is unlikely to progress uneventfully without some kind of intervention [5]. For treatment of bone loss, the concept of primary bone grafting during the debridement and primary fixation of the fracture is advocated [6, 7].

It is beneficial to take care of small segmental bone loss with immediate bone grafting, but as the size of bone loss exceeds 5 cm, the primary bone grafting ends up in the early resorption of the bone graft.

Vascular fibular graft is another technique in which the vascular graft fills the void, and the chances of graft resorption are low, because the graft has its own preserved blood supply [8]. Fibular strut graft act as the bone segment that can fill the bone gap as long as 15 cm or more. Clinical and Microsurgery experience of the Operating Surgeon is the skill that an Orthopaedic Surgeon has to master to achieve the desired length.

The lack of skin coverage leads to bone ischemia at the fracture site, which causes infection and leads to non-union of fracture. Hence, bone defect is required to be covered. Management of compound fracture with segmental bone loss is a multidisciplinary approach [9]. Different methods for wound coverage, for example, free flaps, transpositional flaps, and gastrocnemius flaps are described in the literature.

Another major impediment in the healing process is the infection, which can be superficial to deep-seated infections. A long-lasting inflammation becomes chronic infection and causes non-union. It also impairs bone quality. Thorough debridement, irrigation, and decontamination in an Emergency Room, are done to prevent the infection.

The risk of sepsis in open fractures increases with the severity of fractures. 0%-10% in type 1 fractures, 10%-20% in type 2 fractures and 10%-50% in type 3 fractures [10] Role of local and systemic antibiotics have proven in infection management. Antibiotic- laden PMMA (polymethylmethacrylate) cement beads are proven to decrease the infection rate in open fractures.

Both LRS and Ilizarov fixator work on the principle of distraction osteogenesis. Bone transport with LRS has proven to manage the bone loss by new bone formation. It has been proven for deformity correction also [11]. This technique is applicable to long bones of lower limbs but, has no evidence in bone loss management in long bones of the forearm.

In contrast, Ilizarov has proved its significance in limb lengthening and deformity correction in upper limbs, including the forearm and lower limbs [12]. Low patient compliance and the complex application technique of Ilizarov fixator are the reasons, why LRS outdates Ilizarov [13].

Stage 1 of Masquelet Technique

The first step of the Masquelet technique starts with thorough debridement of the fracture site. Debridement should be aggressive and extensive to remove all the foreign material, devitalized bone, necrotic soft tissue, dirt and other contaminants. In septic non-union cases, the debridement is done till the bleeding edges of the bone are not found (paprika sign). The bone defect created by debridement is thoroughly irrigated and samples for the pus culture-sensitivity are sent for microbiology studies. It will add to the management strategy later on.

The next step is the fixation of the limb. Both internal fixations as well as external fixation, have been advocated in the literature [14]. What fixation method is to be adopted during stage 1 of the surgery, depends upon the aetiology. One thing that is mandatory for the fixation is that it must be rigid or cause minimum disturbance to the fracture site and cement spacer. External fixators are the choice for infective pathologies and internal fixators such as intramedullary nails and plates are the choices for post-traumatic bone loss and tumour resection cases.

This step is followed by the placement of the cement spacer. The spacer is polymethylmethacrylate (PMMA) bone cement which contains antibiotics [15]. Porous structure made by spacer helps in releasing the antibiotics to local environment. Local concentration of antibiotics remains high at bone defect site. It irradicates the infection and keeps the surrounding sterile. Cement application is done in such a way that it covers the bony edges and the whole of the bone gap is bridged with the cement spacer. The choice of antibiotics in the cement is related to the causative organism of infective pathology. A combination of Vancomycin, Gentamycin, and Tobramycin is recommended. Despite the high local concentration of antibiotics in spacer, systemic toxicity is not noted. The exothermic reaction of the cement spacer, when it takes its shape, is harmful to the nearby soft tissue. The chances of thermal necrosis of nearby soft tissue are always there. So, to prevent this, soft tissue handling with wet gauze and continuous irrigation of cement spacer with cold normal saline is advised.

Soft tissue around the bone gap is responsible for the formation of the induced membrane. Hence, the vascularity and integrity of the soft tissue during the stage 1 procedure is of prime concern. Soft tissue handling during this stage also contributes to results later on.

After putting the cement spacer and covering bony edges with cement, all that is needed, is the proper closure of the wound [16]. The closure of wound should not be too tight, it leads to skin necrosis. Wider skin defects are generally taken care of with the help of Plastic Surgeons. The need for skin graft, muscle flap, transpositional flap, and rotation flap are fulfilled with the help of Plastic and Reconstructive Surgeons.

Good coverage and tension-free closure around the bone defect are the prerequisite for the generation of induced membrane. Stage 1 of the Masquelet technique lasts for 4-6 weeks but depending upon the local complications, stage 1 can be revised in resistant cases, where the infection is hard to remove [17]. Skin graft failure / flap necrosis and wound dehiscence are common in this phase.

Implant related complications such as loosening of implant, broken implant and pin track infections are also common. Culture-specific systemic antibiotics are advised in this phase and regular monitoring of the infection markers ESR, CRP (Erythrocyte Sedimentation Rate, C-Reactive Protein) is done.

Stage 2 of the Masquelet Technique

Stage 2 of the Masquelet technique starts after 6-8 weeks of stage 1. Following a detailed physical examination, blood investigations, and thorough inspection of the previous scar, the fracture site was exposed with an incision on the previous scar. The soft tissue dissection is performed and the induced

membrane is opened with a linear incision. Any sign of infection can lead to the revision of stage 1.
After opening the wound, the spacer is removed as a whole or as small pieces. The cavity made by the spacer looks clean, but it is good practice to send the culture swab from the floor of the wound. Bony edges are freshened again till the red paprika sign. It decreases the chances of infection. The next step in this stage is to harvest the graft from the iliac crest. The iliac crest is considered the gold standard for graft harvesting [18]. The anterior and posterior parts of the iliac crest are considered for graft. Fibula could be used as a strut graft in such cases, where a longer length of the segment is required. Another technique to harvest grafts is the reamer irrigator aspirator technique. These methods are helpful in generating a large amount of graft.
Fixation can be revised at the second stage by the decision of the operating surgeon. Now, the surgeon can replace the primary fixator with a definitive one. Sometimes, nailing and plating can replace the external fixators. Definitive fixation should hold the construct in place throughout treatment. Many bone graft expenders are available nowadays to enhance bone growth. These are namely: -

- Bone marrow aspirate concentrates
- Demineralized bone matrix
- Calcium triphosphates

These are commercially available entities except the bone marrow aspirate concentrate. Graft harvesting is followed by graft placement in bone defect and the graft is placed in such a manner that it just bridges the bone defect. Overpacking is not advised by studies as this leads to tight closure of wounds. Careful closure of the wound is done and then systemic antibiotics and post-operative care is given to the wound.

Materials and Methods

The present study was conducted in a prospective randomized manner Between the period of December 2020 to July 2022 in the department of Orthopaedics at Guru Gobind Singh Medical College and Hospital, Faridkot.
A total of 30 cases of segmental bone loss in long bone fractures with different aetiologies, were treated using the Masquelet technique. All patients were initially assessed in the Emergency Department/OPD (Out Patient Department) and then they underwent detailed evaluation of their hemodynamic, radiological examination, limb examination including neurological examination, and other injuries if associated with trauma. Patients were interviewed; their epidemiological, historical, and physical findings were noted.

Inclusion Criteria

1. All patients between 15-60 years of age group.
2. Both sexes
3. Post-traumatic fresh and old open fractures of a long bone with a bone loss equal to or >5 cm.
4. All patients have open fractures up to Gustilo-Anderson type 3B.
5. Infected fractures with exposed dead bone.

Exclusion Criteria

1. Closed fractures.
2. Pathological fractures.
3. Gustilo Anderson type 3C fractures
4. Chronic osteomyelitis of long bones.
5. Tumours of long bones.

Keeping in view, the availability and feasibility of participants a non-random convenient technique was adopted. Hence, consecutively 30 eligible participants were considered for the study.

Observation and Results

Statistical analysis

In our study, all thirty patients of different aetiologies were treated with the Masquelet technique, and observed data were coded and entered into a Microsoft Excel spreadsheet. Analysis was done using SPSS version 20 (IBM SPSS Statistics Inc. Chicago, Illinois, USA) windows software program. Descriptive statistics included the computation of percentages, means, and standard deviations. The following results were obtained.

Discussion

Segmental bone loss due to any aetiology is devastating and can lead to a considerable amount of morbidity and threat to the involved limb. In this scenario, every step of the management of post-traumatic segmental bone loss in long bones is under debate from the need for surgical intervention to the approach of surgical intervention and type of fracture fixation.
The induced membrane technique is a relatively novel method to address bone loss. In this study, we have operated on 30 patients with segmental bone loss using the Masquelet technique. In literature the wide application of the Masquelet technique has been advocated so, we have taken fresh and old post-traumatic segmental bone loss patients and the septic non-unions of long bones with exposed or dead bones.

Demographic variables

Age at presentation

From the study, we mark our finding that the overall mean age of people who underwent treatment under the Masquelet technique is 41 years. Morris *et al*. conducted a similar study in 2017 [19]. The findings of which were according to our study. they marked the mean age as 47 years for the patients suffering from segmental bone loss in long bones following the open fractures. Another similar study conducted by Abdulazim *et al*. in 2019 marked the finding that the mean age of sufferers was 45 years [20]. Our findings are following these too.
In all these studies we can see the most involved age group is the 3rd to 5th decade, which represents the bulk of the working population.

Gender distribution

Analyzing the gender distribution in our study in terms of gender, we see that the gender distribution of bone loss in long bone fractures of various males to females is 27 to 6.
This finding is per the findings by Liu *et al*. which marked the gender distribution of male to female as 7 to 4 [21]. Our findings on gender distribution are also in agreement with that of Siboni *et al*. who recorded it as male to female ratio of 14 to 4 [22].
We understand that the pattern of gender distribution in bone loss cases of long bones of different aetiologies is in a manner due to the active participation of males in mechanical work outside and vehicle usage more than the female population.

Etiology

The most common cause of bone loss in fractures of the long bone in this study is found to be road traffic accidents followed by the septic non-union of the fractures in a ratio of 20:10.
A similar study of 4 cases of bone loss in long bone fractures cases by Giannoudis *et al*. in 2016 reported the cause as 3

roadside accidents and 1 was the infection [23].
Another study by Zoller *et al*. in 2017 on 5 cases of bone loss cases recorded 3 open fractures from roadside accidents and 2 septic non-union cases [24].
Higher incidence of road traffic accidents, when compared to an infected non-union can be attributed to the increased usage of the motor vehicle leading to high energy trauma and while the causes of septic non-union are multifactorial depending upon the nature of the injury and the patient's body response to the antibiotic therapy.

Bone involvement
The most common bone involved in our study was found to be the mid-shaft tibia 26% cases followed by the distal femur 20% cases. Followed by the proximal tibia cases as 16 % cases. Followed by the mid-shaft femur and humerus in 10% of cases.
Masquelet AC *et al*. in 2000 reported a series of 35 patients in which 85% of cases were the tibial segment [25]. Our study is in accordance with that showing the tibial segment being the most commonly involved.

Radiological union achieved in months
We analyzed and observed that in our study the mean time through which the radiological union was achieved was 6 months.
Similar studies in past conducted by Pelissier *et al*. in 2002 also marked the meantime for the radiological union was 9 months which is also in accordance with our study [26].
Ma *et al*. in 2017 also conducted a similar study and marked the meantime for radiological union 6.5 weeks in their study [27]. Our study is in accordance with this.

Follow up period
We analyzed in our study that the mean follow-up period of our patient remained at
9.96 months in which the maximum followed up period was 12 months and the minimum was 9 months.
A study conducted by Sivakumar *et al*. in 2016 marked their followed-up time as up to 12 months [28]. Our study goes with the literature.
Another similar study conducted by Makridis *et al*. in 2014 also marked the mean followed up period as 18 months [29]. Our study also goes with this study.

Bone loss
We observed and marked the mean bone loss in our study as around 6 cm. maximum bone loss we encountered was 8 cm and the minimum was 5 cm. We also found our study in accordance with similar studies conducted by Siboni *et al*. in 2018 and Ronga *et al*. in 2019 which marked the mean bone loss in their studies as 6.1cm and 6-7 cm respectively [22, 23].

Primary fixation at stage 1 surgery
We analyzed our study and marked the external fixator being the most common (76% i.e. 23/30) tool for fixation at stage 1 of surgery. Followed by a nailing system and plating system.
We also observed through literature that a similar study by Pelissier *et al*. in 2002 marked their most common method of fixation at stage 1 as an external fixator [26].
Similarly, the study conducted by Qu *et al*. in 2019 also marked the external fixator as being a common modality of fixation device at stage 1 surgery [31].
However, Sivakumar *et al*. in 2016 used LRS as the mode of fixation in their study [28]. Our study is in accordance with these studies as we have also used LRS in one case.

Definitive fixation at stage 2 surgery
We observed in our study that the most common tool for definitive fixation was the plates in 40% of cases followed by Nails.
In our study 1/30 cases had Ilizarov fixator. Zou *et al*. in 2016 conducted a similar study as marked plating as the common definitive fixation method [32]. Our study is in accordance with that.
We also observed that Siboni *et al*. in 2018 also conducted a similar study also marked plating as the definitive fixation [22]. Our study is following that also

Skin coverage
In our study, we observed and marked that most of our patients had good skin coverage of wounds around 80% of wounds were closed with primary closure while in the remaining cases, we had the wound coverage with help of Flaps.
We observed in the literature Ronga *et al*. in 2019 used flaps for wound coverage [30]. Our study is in accordance with that. We also observed Mathieu *et al*. in 2019 also used the free flap in the study conducted by them for the mean of wound coverage [33]. Our study shows a similar inference to them.

Induction membrane
In our study, we were able to observe the induced membrane commonly. We have observed and marked the induced membrane as 100% in all cases of bone loss in long bone fractures.
We have observed a similar study by Shabir A Dhar *et al*. in 2019 which also marked the induced membrane to be present in all cases when the Masquelet method was applied [34]. Our study is in accordance with them.
We also observed that the study conducted by Largey *et al*. in 2009 in which it was marked that the patients were kept for partial weight bearing for 10 months [35]. Our study is sharing the same inference.
Apart from this another study conducted by Mak *et al*. in 2015 marked the partial weight-bearing period for 12 months which is also in accordance with our study [36]. We have observed that partial weight bearing is helpful to prevent implant failure.
A similar study conducted by Akira hara *et al*. in 2018 marked the restricted range of motion of patients in their study [37]. Our study is in accordance with that.

Conclusion
Overall union was achievable in cases of bone loss in long bone fractures. Masquelet technique gives promising results in bone loss cases upto 8 cm. Patient compliance was better throughout the study as the procedure is simple to understand, easy to apply no special expertise needed. We recommend this technique for bone loss upto 8 cm. However, for larger bone defects we recommend Ilizarov/LRS.

Conflict of Interest
Not available

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Not available

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