Systematic Approach to the Management of Post-traumatic Segmental Diaphyseal Long Bone Defects: Treatment Algorithm and Comprehensive Classification System

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ABSTRACT
Background: Bone defects remain challenging to manage. The wide array of treatment options is a testament to the fact that no single strategy works in every patient. This is more complex if consideration is given to the status of the host and the soft tissues. The choice of treatment should be based on specific patient requirements after taking all variables into account.

Materials and Methods: We present a comprehensive classification system and treatment algorithm to assist with decision-making in management. All potential treatment modalities including amputation are discussed with their relevant pearls and pitfalls.

Conclusion: The proposed classification system may potentially assist with communication, enable patient stratification for assigning the most appropriate treatment modality and guide reporting of treatment outcomes.

Keywords: Bone defect, Bone transport, Masquelet technique.

Strategies in Trauma and Limb Reconstruction (2020): 10.5005/jp-journals-10080-1466

INTRODUCTION
Reconstruction of segmental long bone defects involves a significant investment of time and resources for both the patient and the surgeon. Patient counseling is mandatory before embarking on the reconstructive journey as any lapse by either surgeon or patient may fail treatment. The patient should be motivated for the reconstruction; choosing the right candidate for reconstruction or amputation is the most important decision the surgeon makes at the onset of treatment. If the decision to reconstruct the limb has been made, all modifiable risk factors should be identified and addressed appropriately. Optimising the patient before surgery is of utmost importance as every effort should be made to maximise the odds of success.

A critical-sized defect is dependent upon many variables including age and host status, anatomic location as well as the state of the surrounding soft tissues. By definition, a critical-sized bone defect is one which will not heal if left untreated. The landmark SPRINT Trial defined a critical-sized defect as one involving >50% of the cortical diameter of the tibia and >1 cm in length. In over 1,200 patients only 37 fulfilled these criteria.¹ Sanders et al. evaluated patients with a “critical-sized defect”, according to the SPRINT definition, and found that tibial diaphyseal defects of >1 cm and >50% cortical circumference healed without additional surgery in up to 47% of cases.² The first definition of a critical-sized defect was therefore not as “critical”. Patients with these defects did have, when compared with an overall cohort of tibial fractures, a higher rate of reoperation and worse patient-reported outcomes.² Keating et al. described defects >2 cm in length were unlikely to heal spontaneously and that defects with >50% circumferential bone loss—although might heal—often require additional treatment to restore normal bone volume and strength.³

Bone defects can be the result of trauma, infection or malignancy. Traumatic bone defects have been a subject of relative academic neglect despite the immense reconstruction challenges they pose. Most classification systems for open fractures do not take bone loss into account.⁴ The Paley/Catagni non-union classification, consider bone loss if a fracture gap of >20 mm exists.⁵ According to this classification, all non-unions with bone loss (type B) are considered lax or mobile and further divided into two main groups namely without (type B1) or with (type B2) limb shortening. Solomin and Slango published a comprehensive bone defect classification based on the alphabetic Muller-AO long bone fracture system.⁶ This system categorises segmental defects as type C, subdivided into defects with associated shortening (C-1), defects without shortening (C-2) and subtotal defects (C-3). An inherent drawback of both systems is that the size of the diaphyseal defect is not taken into account which is a critical factor in considering different management options.

A myriad of treatment options has been described for the management of bone defects depending on site and size. A clear, systematic and well-defined approach to managing post-traumatic...
bone defects based on a comprehensive classification system is thus required. This narrative review represents the management protocol followed in the limb reconstruction unit of a tertiary level hospital. A systematic approach and algorithmic protocol along with a novel classification system for managing post-traumatic bone defects are discussed.

**Classification System**

An ideal classification system should take all known determinant variables into account, prognosticate the injury, characterise distinctive treatment groups and the accompanying reconstructive processes and allow for accurate communication amongst surgeons. To fulfil these prerequisites, we considered three main categories for patients with segmental bone defects. These included the size of the bony defects, the ability to reconstruct the soft tissue envelope and general host status (Table 1). We classified these variables:

**Bony Defect**
- Type I: Defects <20 mm.
- Type II: Defects between 20 mm and 60 mm.
- Type III: Defects between 60 mm and 120 mm.
- Type IV: Defects >120 mm.

**Soft Tissue**
- Type alpha: No soft tissue deficit. No soft tissue reconstruction is required.
- Type beta: Soft tissue defect present or requires soft tissue reconstruction.
- Type gamma: Unable to reconstruct soft tissue defect.

**Host Type (Modified McPherson)**
- Type A: Good immune system and delivery.
- Type B: Compromised locally (BL) or systemically (BS).
- Type C: Requires no treatment; minimal disability; treatment worse than the disease; not a surgical candidate.

These three variables are conceptually considered in reverse sequence when contemplating limb reconstruction; host optimisation followed by soft tissue reconstruction and then followed by bony reconstruction.

**Host Type**

The importance of host optimisation during limb reconstruction surgery cannot be emphasised enough. The host status serves as the primary indicator of the patient’s ability to affect the healing of bone and soft tissues, as well as their ability to launch an effective immune response against infection. The McPherson system—derived from the Cierny and Mader classification—divides patients into three classes, based on the number of comorbid conditions. Patients with no compromising factors are grouped as type A, while type B patients have fewer than three compromising factors. Type C patients have three or more compromising factors with or without one of the following conditions: an absolute neutrophil count <1000; a CD4 count <100; intravenous drug abuse; chronic active infection of another site; or dysplasia or a neoplasm of the immune system. Although the McPherson system was developed for the planning of second stage revision arthroplasty for patients with infection after total hip replacement, this system has been used in decision-making in many other orthopedic sub-specialties and may suit limb reconstruction surgery as well. Bowen and Widmaier, e.g., investigated the incidence of infection following open fractures in patients classified according to the McPherson system. They found that type B hosts were 2.86 times, and type C hosts were 5.72 times more likely to develop an infection following open fractures than type A hosts. In using this classification, similar findings might apply to the reconstruction of post-traumatic bone defects.

All potentially modifiable risk factors should be identified and addressed before surgery is undertaken and continued during the reconstructive process. We have modified the McPherson criteria for limb reconstruction surgery (Table 2). Ameliorating modifiable risk factors in type B hosts attempts to improve the outcomes to approach the results seen in type A hosts. Cessation of smoking, tight glycaemic control and dietary supplementation, e.g., take precedence over elective limb reconstruction surgery.

**Soft Tissue**

Plastic surgeons form an integral part of the limb reconstruction team. Early input from a plastic surgeon is important so that an effective treatment course can be planned without jeopardising future interventions by either team. The “reconstructive ladder”, introduced in 1982, serves as the conceptual framework that allows plastic surgeons to decide on the appropriate reconstructive modality for any given defect. The simplest method which would achieve closure is often used. Gottlieb and Krieger introduced the “reconstructive elevator” which, although still representing increasing levels of complexity, encourages the surgeon to ascend directly to the appropriate level of reconstruction. Several variations of the reconstructive ladder haven been published but the principles remain unchanged (Fig. 1).

We divide soft tissue defects into three categories:
- The alpha soft tissue envelope has no current or potential future soft tissue deficit. No additional soft tissue reconstruction is required before or following bony reconstructive procedures. The beta group presents with a soft tissue defect or the bony reconstructive procedures will result in a soft tissue defect. In these cases, the soft tissue envelope will need augmentation to support the underlying bony reconstruction, are procedures higher up on the reconstructive ladder, including random flaps, axial flaps and free flaps, are usually considered (Fig. 2). Gamma defects on the other hand not amenable to reconstructive surgery (Fig. 3).

Negative-pressure wound therapy (NPWT), also known as vacuum-assisted closure (VAC), was initially viewed as a revolution in wound management to the extent a new reconstructive ladder incorporating NPWT was proposed. Purported advantages of NPWT included an increased rate of granulation tissue formation, decreased periwound oedema, decreased time to wound closure, less frequent dressing changes, control of bacterial proliferation and potential financial advantages. Recent literature has, however, cautioned against the indiscriminate use of NPWT; the WOLLF randomised control trial found no difference in fracture-related infection rates in the management of Gustilo-Anderson II and III open fractures of the lower limb, while Liu et al. reported that NPWT did not allow delays beyond 72 hours in definitive flap coverage of traumatic soft tissue defects. The weight of evidence suggests that NPWT does not alter the need for definitive soft tissue reconstruction and should be reserved for temporary wound management.

Once the host is optimised and the soft tissues have been reconstructed, management should be directed towards the bone
defect. Soft tissue healing takes precedence, with clean alpha
wounds addressed at the same time as the bone defect potentially,
however, beta wounds often require a staged approach. Some
management strategies would, however, allow simultaneous

Table 1: Bone defect classification

| Surgical options (in order of preference) | Bone defect type | Host category |
|-------------------------------------------|------------------|---------------|
| Soft tissue defect type                    |                  |               |
| α Primary bone grafting with internal fixation | Acute and gradual shortening and lengthening with ilizarov fixator-trifocal or Masquelet with primary internal fixation or fibula graft in a child or upper limb defects | A |
| β Acute shortening/flap for wound management or Masquelet-induced membrane technique | Bone transport through the induced membrane or Masquelet-induced membrane technique | B |
| γ Convert a γ to β/α wound, bony stabilisation with ex-fix | Consider amputation, especially in C host | B |

Fig. 1: Soft tissue reconstruction ladder

Table 2: Local and systemic risk factors

| Systemic risk factors | Local risk factors |
|-----------------------|--------------------|
| 1 Age >80 years       | Active infection   |
| 2 Low vitamin D levels| Multiple previous incisions with extensive scarring |
| 3 Thyroid and parathyroid disorders | Compound grade III fractures with soft tissue loss |
| 4 Hypogonadism        | Osteoporosis with T score <−2.5 |
| 5 Diabetes            | Prior local irradiation |
| 6 Smoking             | Vascular insufficiency |
| 7 Long-term (>3 months) NSAIDs use | |
| 8 Malnutrition        | |
| 9 Immunosuppressive medication | |
| 10 Alcoholism         | |
| 11 Malignancy         | |
| 12 Renal failure requiring dialysis | |
| 13 Systemic inflammatory disease | |
| 14 Systemic immune compromise | |
| 15 Hepatic insufficiency | |

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Strategies in Trauma and Limb Reconstruction, Volume 15 Issue 2 (May–August 2020)

There are four potential strategies to downgrade the soft-tissue defect category:

- Acute or gradual limb shortening: beta to alpha.
- Deformity-assisted wound closure: beta to alpha.
- Open bone transport: gamma to alpha.
- Negative-pressure wound therapy: gamma to beta to alpha.

It is important to note that NPWT is not a substitute for adequate debridement in gamma defects. Although retrospective studies have reported that NPWT can reduce the requirement for flap coverage, most of these series reported high deep infection rates.

**Bone Defect Reconstruction Algorithm**

The options for managing bone defects include acute shortening, synthetic or autogenous bone graft, Masquelet-induced membrane technique, gradual shortening with or without gradual lengthening, bone transport, posterolateral grafting or fibula bypass grafting, vascularised fibula graft, patient-specific custom-made titanium trusses and amputation. Each patient is individualised to the most appropriate reconstruction process although the algorithmic process to decision-making can assist in this. The chosen reconstructive strategy should be cost-effective, allow early functional rehabilitation, provide durable long-term results, have an acceptable risk-benefit ratio and take local expertise and resources into account.

**Type I Defect (<20 mm)**

Management of type I defect is relatively simple. Intramedullary nail fixation with subsequent autogenous bone grafting where spontaneous healing does not occur has been advocated, even in larger bone defects. Where stability might be compromised with the use of intramedullary fixation, additional strategies might be considered. These include acute shortening and the Masquelet-induced membrane technique. Shortening is the simplest way to address bone defects and may aid in downgrading soft tissue defects from beta to alpha wounds (Fig. 4). Femoral and tibial shortening of up to 20 mm without subsequent lengthening is well tolerated. If acute shortening and gradual lengthening are planned the tibia can be shortened by 10% of its original length and the femur by 20% of its original length without any complications. In the upper limb, the humerus may be shortened up to 20% of its original length without functional impairment. Distal vascularity should always be confirmed after acute shortening as kinking of the neurovascular structures may occur if the shortening is excessive.

Another option for managing type I defects is either single-stage cancellous bone grafting or a two-stage induced membrane technique as described by Masquelet. These are preferred over shortening when the segmental bone loss is part of a larger volume bone loss, such that apposition of bone ends would not allow restoration of bone stock although the fracture might heal.

**Key points on shortening**

- The easiest way to deal with a bone defect.
- Better tolerated in the upper limb.
- May help to downgrade the soft-tissue defect category.
- Be conscious of arterial, venous, and lymphatic patency.

**Type II Defect (20–60 mm)**

As shortening of >20 mm is poorly tolerated, especially in the lower limb, the preferred option for type II defects is autogenous bone grafting as part of a two-stage procedure as described by Masquelet. The Masquelet procedure entails placement of
a physician-directed temporary cement spacer followed by a secondary grafting procedure. Placing the cement spacer gives time for the soft tissues to heal, maintains the length and space of the defect and can act as a local antibiotic carrier. While placing the cement spacer it is recommended to extend the cement over the normal cortices on either side of the defect, so that the membrane can form across the defect extending over the normal bone (Fig. 6). This increases the graft and host bone surface area of contact at the ends and thus increases the chances of the graft bridging across the defect.

The induced membrane which forms around the cement acts as a mechanical barrier and compartmentalises the graft, thus protecting it from resorption and fibrous ingrowth.\textsuperscript{35,36} Cuthbert et al. in the histological analysis of the induced membrane found it to be a thick, vascularised structure that resembles periosteum with a cellular composition and molecular profile facilitating large defect repair.\textsuperscript{37,38} The term “induced-periosteum” was coined and cited as a powerful example of in situ tissue engineering.\textsuperscript{38} Apart from assistive mechanical properties, the induced membrane is biologically active and produces bone morphogenetic protein 2 (BMP2), transforming growth factor-beta (TGFβ), vascular endothelial growth factor (VEGF), von Willebrand factor (vWF), interleukin 6 (IL-6) and interleukin 8 (IL-8).\textsuperscript{39} Aho et al. experimentally showed the biological potential of the induced membrane to be at its highest around 4 weeks following implantation of the cement spacer and therefore suggest this to be the optimal time to perform the second stage surgery.\textsuperscript{40} Multiple authors, including Masquelet himself, have reported their results of performing the second stage between 6 and 8 weeks after the first stage.\textsuperscript{34,41–46}

Choice of Fixation in Masquelet
This is dependent upon many factors and the fixation construct may be changed at the second stage. Patients with beta and gamma wounds are frequently stabilised with simple half pin circular or monolateral external fixators. Alpha wounds, however, allow for a more liberal selection of fixation devices and internal fixation may be chosen if the wound condition is optimal at the time of primary surgery.

The initial half-pin fixator can be changed to either an Ilizarov all-wire circular external fixation construct or an internal fixation device at the time of the second stage surgery. Intramedullary nails are preferred for diaphyseal defects, whereas extramedullary plates are considered for metaphyseal defects where intramedullary nails might not offer adequate stability. Morwood et al. in a review of 121 patients who underwent internal fixation using the Masquelet technique for femoral and tibial bone defects found that patients treated with intramedullary nails had a faster time to union, fewer grafting procedures and fewer reoperations than those treated with plates, although these differences were more pronounced in femoral defects than tibial defects.\textsuperscript{47} The authors speculated that the superior results seen with intramedullary fixation could be due to the establishment of a medullary canal around the nail and the overall favourable load-sharing mechanics.\textsuperscript{47} The choice of implant...
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Bone Grafting Options in Masquelet

Iliac crest bone graft (ICBG) is the gold standard as far as grafting options are concerned. Multiple strategies have been considered to expand the volume of harvested ICBG to an amount required to fill the induced membrane chamber, including the use of xenograft, bone marrow aspirate, bone morphogenic proteins, platelet-rich plasma, demineralised bone matrix, beta tricalcium phosphate-based composite ceramics and the addition of umbilical cord-derived mesenchymal stem cells.48–52

Recently, reamer irrigator aspirator (RIA) harvested intramedullary endosteal graft is gaining popularity53–55 (Fig. 7). RIA graft offers some advantages over conventional ICBG. One of the biggest shortcomings of the ICBG is its limited volume and significant donor site morbidity. In a randomised study, Dawson et al. reported that the average amount of graft harvested using RIA was around 37.7 mL (range 5–90 mL) when compared with 20.7 mL (range 5–60 mL) harvested from the anterior iliac crest.56 RIA has also shown to have similar if not superior biological potential when compared with ICBG. Sagi et al. did a comparative analysis of qualitative and quantitative differences between bone graft obtained from the medullary canal (with a reamer/irrigator/aspirator) and the iliac crest of the same patient. They found that transcriptional analysis of the RIA samples had greater levels of expression of genes associated with vascular, skeletal and hematopoietic tissues. Additionally, stem cell markers and growth factors that act early in the osteogenic cascade were more abundant in the RIA samples compared with the iliac crest samples.57

One potential concern with the use of RIA is the increased amount of blood loss associated with the procedure. Marchand et al. retrospectively reviewed blood loss, postoperative transfusion rate, volume of graft harvested and major complications in 108 patients who underwent bone graft harvesting from RIA or ICBG. The average estimated blood loss was 674 mL (100–2000 mL) in the RIA cohort compared with 255 mL (50–1000 mL) in the ICBG cohort. Twenty-seven patients (44%) required blood transfusion after RIA, whereas 10 patients (21%) required blood transfusion after ICBG.58 There was no significant difference between groups regarding age, gender, medical comorbidities or major postoperative complications.

To minimize blood loss in RIA, it is recommended not to overream the medullary canal by >1.5 mm and to turn the suction portal off when the reamer is not moving forward. Other complications reported with the use of RIA include eccentric reaming, cortical perforations, fractures and heterotrophic ossification.59

Key points in the Masquelet-induced membrane technique:

- Extend cement across normal bone cortices at the ends.
- Second stage preferably at between 4 weeks and 8 weeks.
- Consider using RIA, synthes harvested bone graft.
- The medullary canal should be opened on both sides of the defect during the second stage.
- Have a low threshold for flap coverage, as recipient bed vascularity is important.
- Use a load-sharing implant for stabilisation (IM nail or lizarov).
- Close the membrane over the graft to maintain its mechanical advantages.

Other options for type II defects include acute or gradual shortening followed by gradual lengthening from osteotomy at a distant level. This strategy has entailed the use of circular external fixators traditionally but recent advances in intramedullary lengthening devices have introduced this solution for lengthening following iatrogenic limb shortening. In a retrospective review comparing bone transport with acute shortening then lengthening for segmental bone defects, Tetsworth et al. concluded that acute shortening then lengthening demonstrated a lower rate of complications and a slightly better radiographic outcome.28

Bone transport should be preferred over Masquelet especially in type B hosts as the results are more predictable60–62 (Fig. 8). A recent experimental study by Seebach et al. showed that implantation of mesenchymal stem cells in the Masquelet technique aggravates a simultaneous bone infection by *Staphylococcus aureus*. This was attributed to the powerful immunomodulatory effects of mesenchymal stem cells resulting in the increased attraction of macrophages, osteoclasts and regulation of pro- and anti-inflammatory mediators.63 The increased number of interventions required for the Masquelet technique should also be kept in mind. The French Group reported an average of 6 interventions to achieve union.60

Posterolateral or Inter-tibiofibular Bone Grafting

Posterolateral bone grafting can specifically be considered for tibial defects and was first described by Harmon in 1945.64 This approach utilises the fact that the posterolateral aspect of tibia is usually spared from soft tissue trauma and is covered by relatively well-vascularised muscle tissue, which in turn makes graft incorporation easier and safer. It also utilises the concept of a cross union between tibia and fibula in case of segmental defects. Foster et al. retrospectively reviewed 59 patients with distal two-thirds tibial fractures treated with posterolateral bone grafting.55 Twenty-three patients had bone defects >20 mm, including defects up to 54 mm. Seventeen (76%) of the 23 patients with bone gaps achieved union. However, of the nine patients with defects >40 mm, only five (56%) achieved union with a single bone graft. Similar results were also reported by Ryzewicz et al. in their 20 patients treated with posterolateral bone grafting. The success rates reported were dependent upon the defect size with union rates of 85% for defects <20 mm, 67% for defects between 20 and 40 mm and 50% for defects >40–60 mm.66 Posterolateral bone grafting could thus be considered for a select group of patients with non-infected tibial defects <40 mm in length, with the soft tissue defect not involving the posterolateral aspect of the leg.

Fig. 7: Reamer irrigator aspirator graft harvested from femoral medullary canal
Type III Defect (60–120 mm)

Any defect >60 mm is considered a massive defect and demand specific limb reconstruction skills. For these defects, vascularised fibular grafts and trifocal bone transport may be useful. In a recent retrospective study, Catagni et al. concluded that trifocal transport can significantly reduce the treatment time, the number of additional surgical procedures and true complications compared to bifocal transport in the treatment of long segmental tibial bone defects. Other options for managing type III defects include the induced membrane technique as described by Masquelet and free fibula graft (in upper limb and children). Since type III defects require a massive amount of graft for the Masquelet technique, synthetic grafts can be mixed with BM aspirate and RIA or ICBG to increase the graft volume. However, the ratio of the synthetic graft to autograft should not exceed 3:1.

Despite the recent popularity of the induced membrane technique, bone transport remains the authors’ preferred modality for type III bone defect (Fig. 9). This is because of more predictable outcomes and fewer surgical interventions with bone transport when compared with the induced membrane technique. Another drawback of the Masquelet technique is the inability to lengthen a short limb. The French group reported a mean length discrepancy of 35 mm in their 84 patients.

There is little direct evidence comparing distraction osteogenesis against the Masquelet technique for bone defects, but some indirect evidence can be found after comparing the systematic reviews for each modality. Morelli et al. conducted a systematic review of the Masquelet technique involving 427 adults. Complications were high (49.6%) amongst all studies, occurring in 15–100% of patients and the ultimate union rate after revision surgeries were 89.7%. There was a failure of one of the steps (persistence of infections or non-unions) in 18% of patients with a subsequent requirement for further surgery in 26.7%. In Masquelet’s own series, there was an overall 45% complication rate, with a 29% failure rate (9 patients) and 13% refraction rate. Aurégan et al. in their systematic review of the Masquelet technique in 69 children, observed an overall complication rate of 42%. The mean bone union rate after a single IMT was 58%, which improved to 87% after revision surgeries. The main complications noted were non-union (23%), graft resorption and fracture (9% for each).

Yin et al. conducted a systematic review of the Ilizarov method in the treatment of infected non-unions of the tibia and femur. In a total of 590 patients spanned over 24 studies, the average bone union rate was 97.26% in all included studies. The mean bone defect was 65–67 mm in patients with infected tibial non-unions and 80 mm in patients with infected femoral non-unions. The rate of refraction was 4%, malunion 7%, deep infectious recurrence 5% and knee stiffness 12%. The rate of superficial pin site infection...
varied between 10 and 100%, with the mean external fixation time 10.69 months and the mean external fixation index 1.70 months/cm in the patients. In another review of bone transport for treatment of critical-sized tibial bone defects, Aktuglu et al. observed good outcomes in over 619 patients spanned over 27 studies. The mean bone union rate was 100% for 15 studies and 95.8% for the remaining 11 studies. Bone grafting at the docking site was frequently necessary after bone transport was completed. The mean bone defect was 65 mm and the mean external fixation time was 10.75 (range 2.5–23.2) months. The most common complication was pin site infection seen in 46.6% and joint stiffness in 25%.

Some studies have highlighted the unpredictable outcome of the Masquelet technique, and reported high failure rates, especially in terms of recurrence of infection. The largest case series including 84 patients reported that weight-bearing was delayed until union had been achieved at a mean of 17.4 months. This prolonged period of restricted weight-bearing has inherent drawbacks that should be considered when choosing a treatment method. Unless randomised trials are comparing different treatment modalities, it is difficult to ascertain the clear supremacy of any one modality. However, after a thorough review of the literature, it does seem that bone transport provides a more predictable outcome and should be preferred especially in type B hosts. Bone transport over a nail and trifocal transports shorten external fixation time but significantly add to the complexity of the procedure and should be performed by limb reconstruction specialists.

**Type IV Defect (>120 mm)**

Options for such massive defects include bone transport, vascularised fibula graft, Masquelet-induced membrane technique, titanium mesh cage with bone graft and amputation.

One advantage of the Masquelet technique in type IV defects is that the time of graft consolidation is theoretically independent of the defect size. Mühlhäusser et al., however, identified an increased risk of treatment failure for defects exceeding 80 cc in volume. Karger et al. and Morris et al. both reported unpredictable outcomes in defects >40 mm. To improve the mechanical properties of the construct and reduce the restricted weight-bearing time, the use of a custom made 3D printed cylindrical titanium mesh cage filled with bone graft has been proposed.

Bone transport can be an option, however, the time required for such massive transports can be problematic. Tri- and quadrifocal transports as well as bone transport followed by internal fixation are potential strategies to minimize the external fixation time when choosing bone transport as the treatment modality.

Bone transport through induced membrane is another option in such massive defects. The advantages of such a management strategy include optimum dead space management with an antibiotic-loaded cement spacer and the creation of a pathway for bone transport with added biological and mechanical benefits of the induced membrane.

The initial enthusiasm of vascularised fibular grafts has waned due to the high incidence of graft fracture and the prolonged period of protected weight-bearing while awaiting graft hypertrophy. A fracture rate of over 30% is documented in the literature. The fact that the procedure requires special expertise of microvascular surgery has also led to the procedure not being widely popular. Donor site morbidity is another concern with many reports of muscle weakness, foot pain and valgus ankle deformity. The whole fibula can be harvested along with its peroneal vascular pedicle except the proximal and distal 5–7 cm. It can be fashioned into a double barrel construct to allow for more volumetric reconstruction of bone stock. This decreases the re-fracture rate and the time of protected weight-bearing. Another advantage of the vascularised fibular graft is the ability to include skin, fascia and muscle to add a soft-tissue cover to any reconstruction.

Amputation should be considered as a treatment option rather than a failure to propose viable treatment, especially for type IV defects in C hosts. With the advent of modern prosthetics, the functional abilities of amputees have increased significantly. An amputation may lead to better function than a poorly salvaged limb at the end of a long financially, emotionally and time-consuming journey of reconstruction. The decision to recommend amputation should be made early to help in maximising the benefits. Busse et al. compared, in a systematic review and meta-analysis of observational studies, the functional outcomes of complex limb salvage or early amputation for severe lower-limb injuries. They concluded that functional outcomes amongst patients who present with leg-threatening injuries were not significantly different, at least up to 7 years, whether they are managed with limb salvage or primary amputation. They stressed the need to optimise triage decisions to avoid failed limb salvage.

**Conclusion**

Traumatic bone defects pose unique challenges in management and an individualised approach is essential. There is a myriad of factors affecting the treatment outcome and these should be kept in mind while choosing the most suitable treatment modality for each patient. A classification system lays the foundation for prognosticating the injury, facilitates communication amongst surgeons and enables treatment guidelines. An algorithmic approach based on this classification system helps in rational decision-making but cannot be dogmatic.

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