Acute Management of Traumatic Bone Defects in the Lower Limb

T. Begue and J.C. Auregan

Abstract

In severe trauma of the lower limb, acute management needs to refer to Damage Control Orthopaedics (DCO). When additional bone, loss is encountered, surgeons face more challenging situations and decision about treatment of the bone loss is difficult. Critical size defects are those exceeding 5 cm and they cannot be treated by conventional bone grafting due to graft resorption and additional procedures needs for complete fusion.

The induced membrane technique, so-called Masquelet technique, is dedicated to treat very huge bone defects up to 25 cm, using a two-stage procedure with a cement spacer insertion for six to eight weeks then filling the chamber created around by autologous cancellous morcelized bone graft.

Ilizarov techniques can be used either by immediate shortening, acute shortening followed by compression-distraction techniques, or bone transport. Advantages and pitfalls include difficulty for shortening over 3 cm, length of external fixation with infection pin sites, docking site non-union, and extrusion of transferred bone due to retraction of soft tissue in the defect.

Free vascularized fibula transfer is the last option for acute reconstruction for traumatic bone loss in case of femoral bone loss with a double-barreled technique or tibial defect over 12 cm.

Tissue engineering will modify solutions by combining mesenchymal stem cells, specific scaffolds, and growth factors such as bone morphogenetic proteins (BMP).

Introduction

In severe trauma of the lower limb, the level of injury of the bone, the soft tissue environment, the presence of arterial damage and duration of ischaemia and nerve injury, in particular plantar nerve disruption, are all parts of the decision of

T. Begue (✉) • J.C. Auregan
Department of Orthopaedic and Trauma Surgery,
Antoine Beclere Hospital,
University of Paris-Sud, Orsay,
157 rue de la Porte de Trivaux,
Clamart 92140, France
e-mail: thierry.begue@abc.aphp.fr

G. Bentley (ed.), *European Instructional Lectures*, European Instructional Lectures 14,
DOI 10.1007/978-3-642-54030-1_7, © EFORT 2014

whether or not to preserve the limb, Different scores have been chosen [1–3] to try to define which limbs must be reconstructed, and those which may need immediate amputation. None of them emphasises the importance of the amount of bone defect. In addition, as scores are difficult in determining what to do, recent authors [1, 4, 5] have emphasized preference for "damage control management" (DCO), not only in polytraumatized patients but, as an extension, in severe multi-tissue injuries of the limbs especially the lower limb. We have based our initial bone treatment management on this Damage Control Orthopaedics method of evaluation and proposals.

In DCO, severe trauma of the lower limb includes any type of fracture. Most often those fractures are open and the severity of the bone lesion is part of the whole injury. The soft tissue lesion is a second critical criterion for complete management of the fracture. In fact, in very severe lower limb injury there is a patchwork of bone lesion from simple fracture to comminuted ones with bone defect, surrounded by a massive destruction of the soft tissue where correct analysis of viable and unviable ones is very difficult to assess. All injuries make management of such trauma quite challenging, and may lead to amputation, non-union or malunion, infection, joint stiffness and poor function [3]. For Meinig [6], management of traumatic bone defect must be done in three consecutive phases which are phase I: initial patient management; phase II: interim management – skeletal fixation and definitive soft tissue coverage; phase III: final bone defect reconstitution. Time schedule of all those procedures are not well defined, and we think that they can be done in a shorter time. In our unit, management of this type of injury, even in a single lesion of the leg, is done using the DCO guidelines. Serial débridement of soft tissue within the first days after the injury is done, and temporary external fixation is the standard of care for the fracture. Such procedures help to remove compromised tissue and avoid any huge bacterial contamination. At the end of the first week after the injury, definitive treatment can be done, with removal of the ExFix, secondary and definitive internal fixation, and soft tissue coverage to resolve all defects.

In some cases, either due to the severity of the initial trauma, or due to secondary dead bone resection, a bone defect can be seen. The extent of the bone defect tends not to be a limiting factor for limb salvage in the lower limb, even if time for complete healing is quite high [6, 7]. Treatment of such bone defects may be difficult when its length is "critical", and different treatment protocols have been proposed such as conventional cancellous bone graft, open-air cancellous Papineau grafting [8], fibula transfer in a non-vascularized or vascularized manner, and bone transport [3, 9].

"Critical-Sized" Bone Defect in the Lower Limb

As critical-sized bone defect is mentioned, one can argue that the definition of such clinical situation is unclear. From animal models, researchers have defined a critical sized bone defect as "the smallest osseous defect in a particular bone and species of animal that will not heal spontaneously during the lifetime of the animal" [10]. From a clinical point of view, critical sized bone defects can be defined as segmental bone losses exceeding 2–2.5 times the diameter of the injured bone [10–12]. So the size is different in the lower limb in the femur and the tibia. We can assume that a segmental bone defect, which is a complete cylindrical defect with no contact between the proximal and the distal fragment can be considered as a critical sized bone defect if the length is of 7–8 cm in the femur, and 5–7 cm in the tibia [7].

As part of the DCO management, this defect must not be considered at the time of early care of the open fracture, but after the serial débridement and bone excision, as the defect may be more important at the end of the first stage after débridement of the fracture site. In our unit, we identify this critical sized defect at time of definitive total care, using clinical and radiological measurements.

All authors agree that critical sized defects in the lower limb will not heal without secondary intervention [13]. As the treatment scheduled may be different on the basis of the results of each

bone in the lower limb, the way to identify a critical sized defect is important. In the femur, numerical X-ray analysis is essential, as the diameter of the bone may be quite different between gender and ethnicity of the patients. Discussion with radiologists will help to evaluate correctly the real size of the defect. CT-scan may be used but is not mandatory, as precise evaluation is not really needed. For Dugan et al. [11], a critical sized defect in the femur can be considered as less as 2.2 cm of bone defect, but they have considered, in their study, only polytraumatized patients which may give more challenges for healing as others bone segments may be involved in the initial trauma. Tibial bone defects are easier to evaluate as the bone is close to the skin, and direct measurement can be done. For Calori et al. [9] a critical sized defect leads to non-union and this can be observed when the defect is over 3 cm whatever is the bone involved. Based on different literature considerations, we can assume that any defect which is over 3 cm must be carefully considered as close to a critical sized defect and a specific treatment protocol in emergency must be added to the fixation device used.

Localisation of the defect is another major point. Diaphyseal defects need, for a correct healing process, to obtain cortical bone at the end of the process. In most cases, both ends of the defect are of Haversian (cortical) bone type, where fusion is hard to obtain. Alternatively, cancellous bone from the metaphysis or the epiphysis is easier to reconstruct and to fuse. In the latter, the main problem is the adjacent joint function after healing has been achieved. Then, the ideal treatment must be able to reconstruct the missing bone while allowing immediate function of the muscles and joints located around the defect. In addition, such clinical situations are associated with soft tissue damage, and its treatment must be included in the operative protocol. As we know, early soft tissue reconstitution aids in the prevention of deep sepsis as well as preparing an environment advantageous for bone grafting [6, 13].

When dealing with critical-sized bone defects, surgeon must consider whether the defect is a cavitary one, where some contact between the fragments ends is still present, even if the surface of contact is very poor, or a segmental one, where a complete cylinder of bone is missing, with a tendency of the soft tissues to fill the defect if it is left without specific treatment.

Based on all the above conditions, the treatment protocol can be considered to have two possibilities:

1. in the acute phase, the surgeon decides to maintain the defect, either segmental or cavitary, and the difficulty is how to do it, and when to treat it? ;
2. in the acute phase, the surgeon decides to remove the defect using acute shortening techniques, and the difficulty is how and when to restore the normal length of the limb? The different options are discussed in the following chapter.

Conventional Cancellous Bone Graft for Treatment of Large Bone Defects

This type of graft is the first to be tried when the surgeon has decided to maintain the bone defect. Autologous bone grafting remains the gold standard in the reconstitution of such defects. Autograft is the only material that provides osteogenic cells (osteocytes, osteoblasts, marrow stem cells), osteoconductive matrix (inorganic mineral), and osteo-inductive molecules (BMP's, transforming growth factor-beta, vascular endothelial growth factor, and others) [6, 14]. All those criteria have made conventional cancellous bone grafting as the "gold standard" against which all others techniques must be shown to produce better results.

With defects of 2 cm or less, traditional anterior iliac crest bone graft is usually sufficient as 5–72 ml can be harvested. Larger defects can still be grafted with iliac crest by multiple harvest sites such as the contralateral site or use of the posterior iliac crests with amounts of 25–90 ml being obtained. In addition, the use of a small acetabular reamer may result in less donor site pain and larger volume of graft.

The most recent development in autologous harvest techniques is the intramedullary canal harvest. A recent review confirms that the use of

the Reamed Irrigator Aspirator [9]. In a single pass, reaming of the femur produces significant amounts of bone graft (25–90 ml) with low rates of complications and post-operative pain. While the rate of complication is lower than that described in conventional iliac crest harvest, iatrogenic femoral fracture has occurred. In addition, studies of RIA harvest material suggest that it is rich in growth factors, viable cells, and morcellized trabecular bone. The RIA harvest can thus be considered biologically equivalent to iliac graft. The bone marrow harvest, however, lacks any structural properties that can be achieved with tri-cortical iliac harvest [6].

There are very few publications about the treatment of critical sized defects by conventional bone graft, either solid or cancellous. In our practice, when this type of graft is used, we have observed a fusion at bone ends, but bone resorption at the most central part of the graft leading to non-union. Partial healing can be noted as the amount of bone defect has been treated, but with additional procedures needed to get complete fusion of the defect. Those results were also reported by Pelissier et al. [15], as this author had bone resorption in 5 of 14 cases (35.7 %), to be compared to a 8.33 % rate with other procedures available. In the same paper, the mean bone defect size was 4.37 cm in the conventional graft group versus 9.58 cm in the other procedure group. We can assume that conventional bone graft is not suitable for critical sized defects.

"Induced-Membrane" (Masquelet) Technique

Maintaining the volume of the defect without filling it as a primary treatment protocol leads to retraction of the soft tissues inside the defect, and the graft bed must be rebuilt at the time of the grafting itself [3]. In 2000 [16], we published an original technique where the defect is filled up, at the initial phase, by a cement spacer. Since then, the procedure is known as the Masquelet technique or the Induced Membrane technique. The initial fracture management is according to the Damage Control Orthopaedic concept [1], with limb alignment and external fixation. In the following days, additional débridements are done with resection of all dead or devitalized tissues, including bone fragments if needed. At the end of the first week, a comprehensive evaluation allows the replacement of the external fixation by an internal, either plate or nail, whist at the same time performing flap coverage of the skin defect if needed. Treatment of the bone defect can be done accordingly.

The induced membrane technique consists of a reconstruction of the segmental or cavitary defect with a cement spacer built with commercially available PMMA-antibiotic beads or surgeon-fabricated PMMA-antibiotic spacers [6]. The technique is easily performed. PMMA cement is prepared, and a tubular or appropriately shaped spacer is fabricated to span the defect and overlap the native bone ends [17]. Overlapping bone ends allow a continuous reconstruction with the non-injured periosteum, which will be of value for the second procedure. Antibiotic cement is utilized as an adjunct to around the bone defect to prevent deep sepsis. The cultivation of an "induced membrane" has clinical and basic science advantages for delaying definitive autologous bone transfer into segmental defects [17, 18]. The global concept is a two-stage procedure dedicated to wide diaphyseal bone defects with the use of a cement spacer placed within the osseous void, in the first phase. In contact with the PMMA cement spacer a pseudosynovial membrane forms. The cement spacer remains in place for 4–8 weeks to allow the membrane to fully develop biochemically and physically.

The second stage is carried out with removal of the spacer by breakage, maintaining the membrane intact, filling the defect by bone grafting within the induced biomembrane [19]. The intramedullary canals must be opened and freshened on either end of the defect, removing the membrane only at this level. This must be done also in cavitary defects to get a close contact between living bone and graft [7]. The pseudomembrane induced by the spacer prevents graft resorption and favours its vascularisation and corticalisation [10].

The role of the membrane in healing has been examined in animal models. Histological and immunochemical analysis has revealed that the membrane is made of a type I collagen-heavy matrix, and fibroblastic cells are the dominant cell type. The inner aspect of the membrane is

epithelial-like and composed of fibroblasts, myofibroblasts, and collagen bundles. This tissue is highly vascularized, and the PMMA spacer causes a mild foreign-body inflammatory response; giant cells and macrophages were discovered on histological evaluation [17, 18, 20]. The membrane contains a high concentration of vascular endothelial growth factor and an angiogenic factor that has been shown to increase the vascularity of the surrounding tissue [18, 20].

Soft-tissue repair, if needed, is performed with a muscle flap during the first stage (spacer insertion) operation. The first role of the spacer is mechanical, as it prevents fibrous tissue invasion of the recipient site. Moreover, since the spacer behaves as a foreign body, absence of infection after 2 months is an excellent indicator of favourable local conditions for bone grafting [10]. The definitive fixation implant should have sufficient mechanical properties to function during the duration of bone reconstitution. Stable fixation is mandatory as biological reconstruction using the induced membrane technique cannot be associated with dynamisation. With early restoration and maintenance of the limb in the anatomical position, patient comfort, rehabilitation, and function are greatly enhanced which is a distinct advantage over distraction osteogenesis [6]. In a recently published experience, 40 patients with an acute bone defect were treated with this technique [21]. Bone defect sizes were from 2 to 10 cm. All patients healed, with a final reconstruction close to a normal bone (Fig. 1). Donegan et al. [19] has used this strategy in five patients treated acutely, with bone union obtained in all cases. All defects were above the critical sized level, either in the femur or in the tibia. Different types of bone substitutes have been used in the Masquelet techniques, as well as bone morphogenetic proteins, demineralized bone matrix, or allograft [7, 10, 15, 19, 20]. All authors agree on the importance of elution of several growth factors, the prevention by the membrane of graft resorption and promotion of revascularization and consolidation of new bone. Excellent clinical results have been reported, with successful reconstruction of segmental bone defects >20 cm [20]. For Taylor et al. [20], if an IM nail is in place, nail removal or exchange is not recommended because of the potential for destabilization. Excellent results have been reported with maintenance of the original IM nail [22].

The main disadvantage of the induced membrane technique is that of a two-stage procedure. Some authors have proposed a similar technique in a one-stage manner using Cylindrical Titanium Mesh Cage (CTMC) and polylactide membranes technique [10]. It is a one-stage procedure that relies in the use of cylindrical hollow mesh implants, consisting of biodegradable polylactide membranes or titanium cages [12, 23]. The cylindrical implant surrounds the segmental defect and is packed with cancellous allograft. The bone cage interface is protected by means of internal or external fixation. Initially reports were of cases which included titanium mesh-allograft reconstructions of large tibial diaphyseal defects, which were protected by intramedullary nailing. Cylindrical polylactide mesh membranes and titanium cages demonstrate marked similarities in the treatment of segmental long-bone defects when applied in combination with bone graft [10]. Biocompatibility of the mesh material (lactide and/or titanium), fenestrated design and ability to enclose bone graft are some of advantageous biological properties of those devices. Moreover, a graft composite consisting of allograft chips mixed with demineralized bone matrix or rhBMP-2 has been successfully used [10].

Acute Shortening, Compression-Distraction and Bone Transport

As an alternative to staged care, fractures with bone loss may be effectively managed with bone transport techniques. Inspired by Ilizarov's philosophy, this can be accomplished by acute shortening of the fractured area and immediate or secondary lengthening of the bone. The advantage of this approach is its inherent simplicity. Nevertheless, different types of shortening have been described [24]. Isolated acute shortening and bone healing is the more simple technique [13]. The goal is to remove completely the defect, ending with both bone ends in contact waiting for fusion. If this is a suitable technique in the upper extremity, this type of management is more controversial in the lower extremity, as any final limb discrepancy will lead to gait disturbance. After bone union,

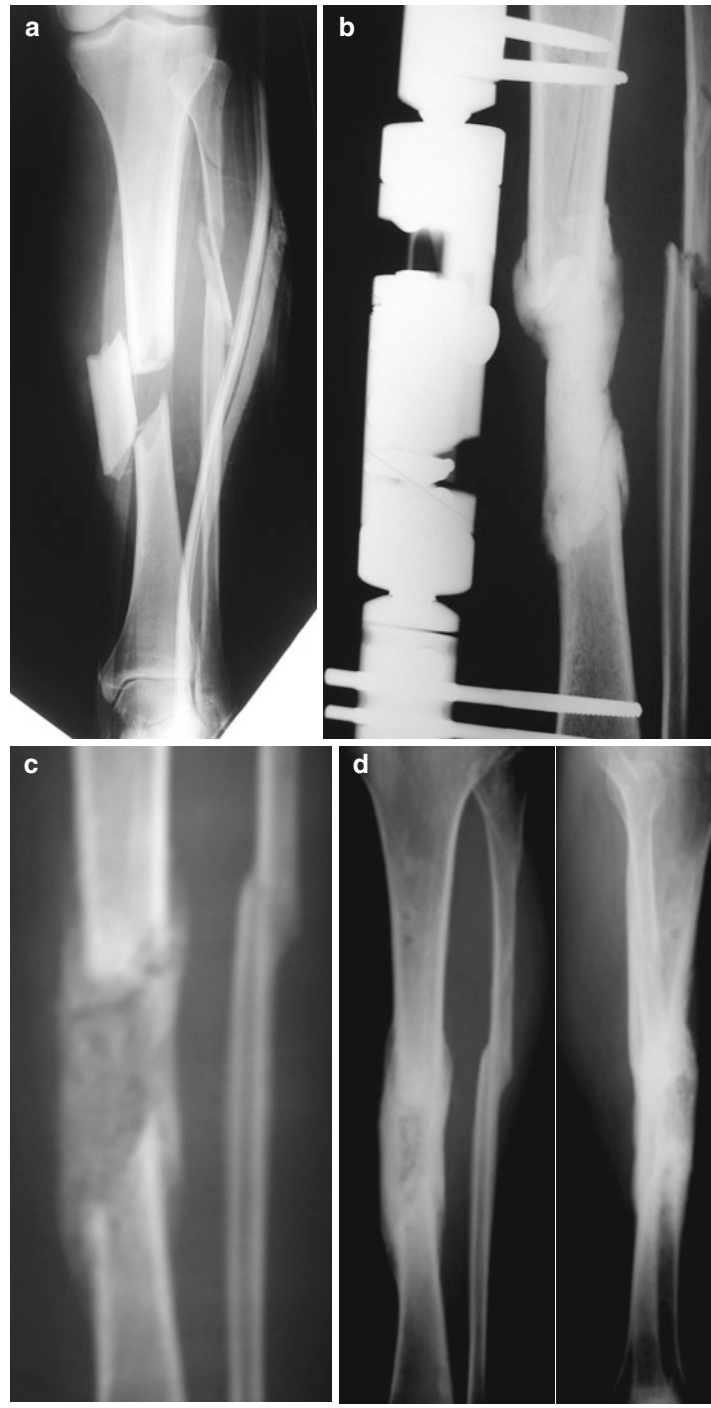

Fig. 1 (**a**) Emergency X-ray of a IIIA open fracture of the tibia. Segmental bone is devitalized outside the skin. (**b**) Segmental reconstruction with a cement spacer overlapping bone ends, and external fixation. (**c**) Autologous cancellous bone graft: appearance after 4 months. (**d**) Final appearance after 3 years

additional techniques will be required for lengthening. The concept of isolated shortening is to create an ideal biomechanical environment to promote union without any need for bone grafting as direct cortical contact encourages primary osseous union [13]. Other techniques include acute shortening with compression-distraction at the fracture site, or acute shortening and progressive lengthening after a corticotomy distant from the fracture and progressive bone transport [24, 25].

All techniques have their own advantages and pitfalls. The main advantage of acute shortening is to cure immediately the bone defect, as bone ends will come into contact. Doing this, in case of associated soft tissue defect, allows direct wsound closure to be done without any additional plastic surgery. This may help in circumstances where plastic surgeons or trained trauma surgeons in flap surgery are not available, i.e. in undeveloped countries, or with mass or war trauma. This technique needs external fixation either with a circular or a monolateral stable frame. Doing this, the duration of hospital stay can be lowered which is of value as it lowers costs and additional co-morbidities. Surgeons can expect fusion when apposition of bone ends is achieved and in a compressive situation. Nevertheless, the high level of "docking site" non-union is high [8, 24, 26, 27]. Pitfalls include a long time of external fixation with a high rate of pin site infections, skin scars, and non-union at the site of distraction. But the main pitfall concerns the amount of acute shortening that vessels, nerves and soft tissue of the lower limb can tolerate. All authors [24, 26] have fixed the maximum length of acute shortening to 3 cm, which is rather limited, and cannot be enough for large bone defects of critical size. For the later, Sen et al. [26] has proposed a gradual shortening at a rate of 2 mm/day with good final results. If acute shortening doesn't need additional surgery in the upper limb, this type of technique in the lower limb leads to a discrepancy needing to be compensated later [24]. Based on clinical results [24, 28], isolated acute shortening can be used in the tibia, but must be excluded in the femur. Immediate contact can be expected for defects lower than 3 cm, but are dependent on the vascularisation of the foot in larger defects. In all cases, partial resection of the fibula is needed, and late lengthening must be considered due to functional consequences.

After acute shortening, leg length discrepancy can be overcome by distraction lengthening at the fracture site at a rate of 1 mm/day after a latency period of 10 days [10, 24], or during the shortening phase through a corticotomy at a proximal or distal level depending on fracture localization, until there is equalization of leg-lengths [25, 26]. In the paper of Sen et al. [26], 24 patients were treated using the shortening-lengthening technique in an acute manner. There were 14 Type IIIA and 10 Type IIIB fractures according to Gustilo classification. The mean defect was of 5 cm (3–8.5).

The author prefers an alternative method to provide solid union. It is to compensate for bone loss by transporting healthy bone to the fracture site, hence bridging the bone defect [26]. This is done by simultaneous corticotomy and lengthening down to equal length. Mean healing time in this series was of 7.5 months [4–11]. Using the healing criteria of Paley and Maar [29], the Index of External fixation was of 1.4 month/cm. The author has reported the incidence of 52 complications which was 2.08 per patient. Different major complications were seen such as equinus deformity, hardware complications, too rapid fusion, limb leg discrepancy, adjacent joint stiffness, mal-union and osteitis.

For Sen et al. [26], these findings support the argument that, when compared with bone transport series and the length of time for external fixation, the treatment period was shortened and the rate of complications and secondary interventions were decreased in patients who underwent simultaneous acute shortening and lengthening. At the same time, according to the results, mal-alignment, such as angulation and translation, were not observed if the shortening-distraction technique was used in the acute post-traumatic period when the plasticity and mobility of the soft-tissue is still present. For Rigal et al. [24], stability of the construct is easier to obtain in a compression-distraction technique when compared to Bone transport. This may explain the lower risk of misalignment that can be observed during the progression of the bone fragment. Needs for additional bone grafting at the docking site are still controversial with this technique [24, 26]. All authors agree that initial debridement and resection of dead bone are mandatory to expect a fusion within segmental bone ends after compression with no complementary procedure.

El-Rosasy [25] experienced this technique in ten acute tibial fractures (seven IIIA and three IIIB Gustilo types), with bone loss ranging from 3.0 to 7.0 cm. The author outlined some technical details for good final results. The amount of bone resection required was decided intra-operatively, so that

the bone limits are apparently healthy bleeding bone ends. Bone ends must be in contact either by wedging one bone end into the other or by a square osteotomy of the bone ends in order to obtain the widest area of contact, and get a stable fracture site. In case of a progressive shortening, bone ends must be cut perpendicular to the anatomical axis. Fixation is done, in this paper [25], with an external fixator. A circular frame similar to the Ilizarov must be chosen when dealing with osteoporotic bone, and if limb lengthening is of more than 5 cm, fixation of the foot was necessary. A monolateral external fixator can be used with good bone quality and short limb lengthening (less than 5 cm). The use of a monolateral fixator simplifies the fixation and is tolerated better by the patients.

All authors emphasize that acute limb shortening with immediate re-lengthening by corticotomy at a healthy level eliminates the problems encountered with bone transport by converting a complicated limb reconstruction into a simpler one, that is a linear limb lengthening. Bi-focal compression-distraction osteogenesis is a safe, reliable, and largely successful method for the acute treatment of open tibial fractures with bone and soft-tissue loss. Further non-operative or operative treatment can correct most complications [26].

The initial use of Ilizarov techniques for treatment of acute bone defects was bone transport without shortening. In such conditions, the defect is maintained, as well as the soft tissue defect when present [30]. The global procedure is well known as distraction osteogenesis. The Ilizarov method is a very satisfactory method for the reconstruction of long-bone defects that are accompanied by soft-tissue deficiency. Nonetheless, surgical experience and patient collaboration are needed for a successful result [10]. As mentioned by El Alfy et al. [30], in such techniques the defect is not removed but maintained as it is after iterative debridement. Soft tissue injuries associated with the bone loss can make reconstruction very difficult and limit the functional outcome. For this author, during distraction osteogenesis, bone and soft tissues are lengthened, giving an opportunity for a spontaneous closure of the soft tissue defects without the need for additional plastic surgery. This is due to the fact that during the distraction, the bone ends carry simultaneously the surrounding soft tissues. This technique was the usual practice in the early 2000s. Paley and Marr [29] reported on 11 fresh fractures treated with distraction osteogenesis including 8 cases with additional soft tissue defects, all treated by soft tissue transport in concert with bone transport. In the paper from Paley and Maar [29], the mean bone loss was of 10.7 cm [2–20]. The Paley criteria were an Index of External Fixation of 2.1 month/cm. In the same paper, the author proposed to modify the Distraction osteogenesis technique in acute bone loss, by doing not only one corticotomy, two different on the same bone, at the proximal and distal metaphysis levels, carrying the bone transport on the two segments. By doing this, the duration of external fixation is lowered and the Index of External Fixation was of 1.2 month/cm. To get the best outcomes, the surgeons must use circular frames that allow correction of mal-alignment, linear transport, and lengthening of the soft tissues when the bone ends are buried under the soft tissue (Fig. 2) [30]. If the bone ends are not well covered, during the bone transport there will be a protrusion of the bone due mainly to the retraction of the soft tissues into the defect. This can be resolved by using cement spacer pieces of cylinder and flap surgery during the initial phase, removing the pieces during the distraction [24]. The problem of management of the soft tissues during the distraction osteogenesis phase is an additional challenge to be taken addressed in these very difficult cases. Even if the distraction osteogenesis technique is of great value, this still-controversial way of management has some limits in acute treatment of bone loss in the lower limb.

The Ilizarov method is a very satisfactory method for the reconstruction of long-bone defects that are accompanied by soft-tissue deficiency. Nonetheless, surgical experience and patient collaboration are needed for a successful result [10]. Although successful bone restoration can be achieved with this modality. Distraction osteogenesis can be protracted, painful, frequently complicated by pin site infections, fluctuates in quality and quantity of the new regenerate, and has healing problems at the docking site with bone transport [12].

Saleh and Rees [31] have compared eight patients managed by bone transport with eight cases of bi-focal compression-distraction osteogenesis in bone loss. The mean duration of treatment was 16

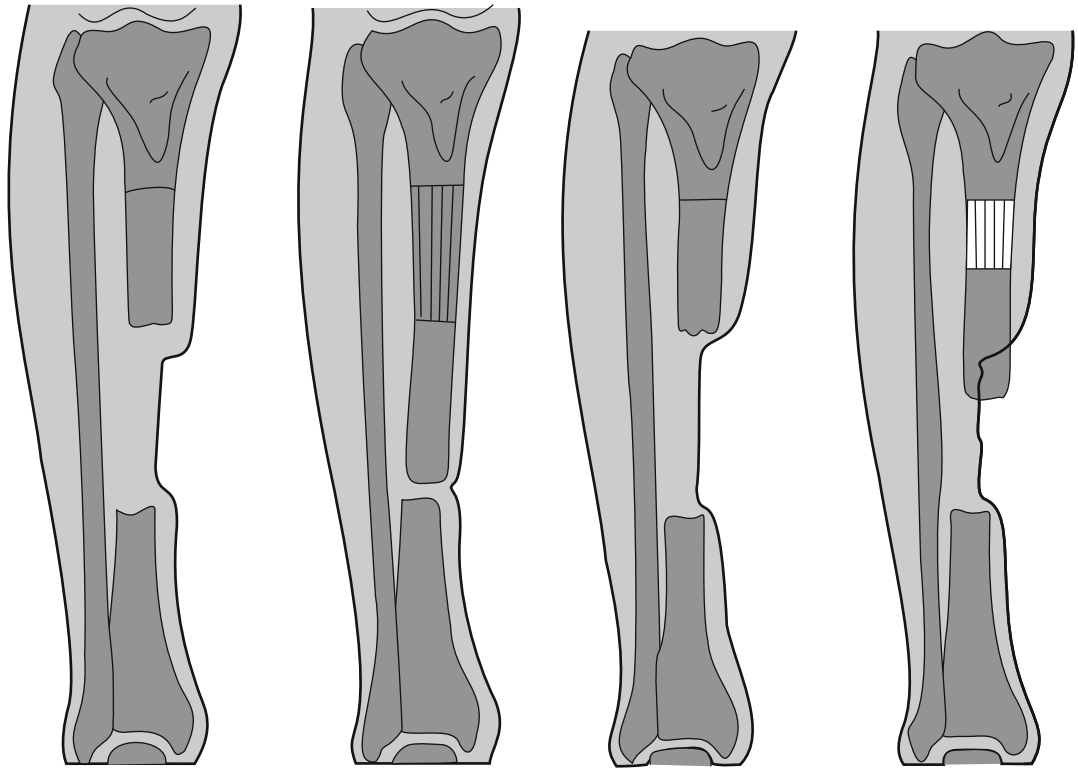

Fig. 2 Difficulty with retraction of soft tissues in the bone defect, and consequences during bone transport. *Left*: progression of soft tissue with the bone transferred with limited retraction of the skin. *Right*: extrusion of bone during bone transport with severe soft tissue retraction in the defect (From El-Alfy et al. [30], Springer Ed)

and 9.8 months, respectively [26]. Complication rates per patient were 1.0 in the compression-distraction group and 2.2 in the bone transport group.

In conclusion, the three approaches that are Acute Shortening, Compression-Distraction, and Distraction Osteogenesis alone, are not mutually exclusive but have their relative indications and difficulties. Distraction osteogenesis therapy is generally more protracted, technically very challenging, and accompanied by high complication rates. However, distraction osteogenesis can be spectacularly successful in the simultaneous management of soft tissue coverage, bone defect, and spatial deformity [6].

Free Vascularized Fibula Transfer

Different types of vascularized bone grafts have been proposed for treatment of bone losses. As accompanying skin paddle or muscle [32] may be harvested at the same time, the free fibula transfer is the most suitable vascularized bone graft for reconstruction of large bone losses in the lower limb. The amount of graft available goes up to 25 cm with a high-density, straight cortical bone with a good vascular pedicle and minimal donor-site morbidity [10]. Of particular interest with the fibula is the ability to fold the graft into two segments, getting a double-barrel graft that can treat large defects in the femur, mainly in the distal metaphyseo-epiphyseal area (Fig. 3). Although the free vascularized fibula has been well documented in the literature for reconstruction for post-tumoral resection in the lower limb, the correct positioning of this type of graft in a post-traumatic situation, especially in an acute management, is still discussed, with very few reports [32–35].

In the 14 cases reported by Pelissier et al. [32] only 2 were done for acute bone loss after trauma, each of them with a large bone defect of 15 cm. The authors have used a composite flap that

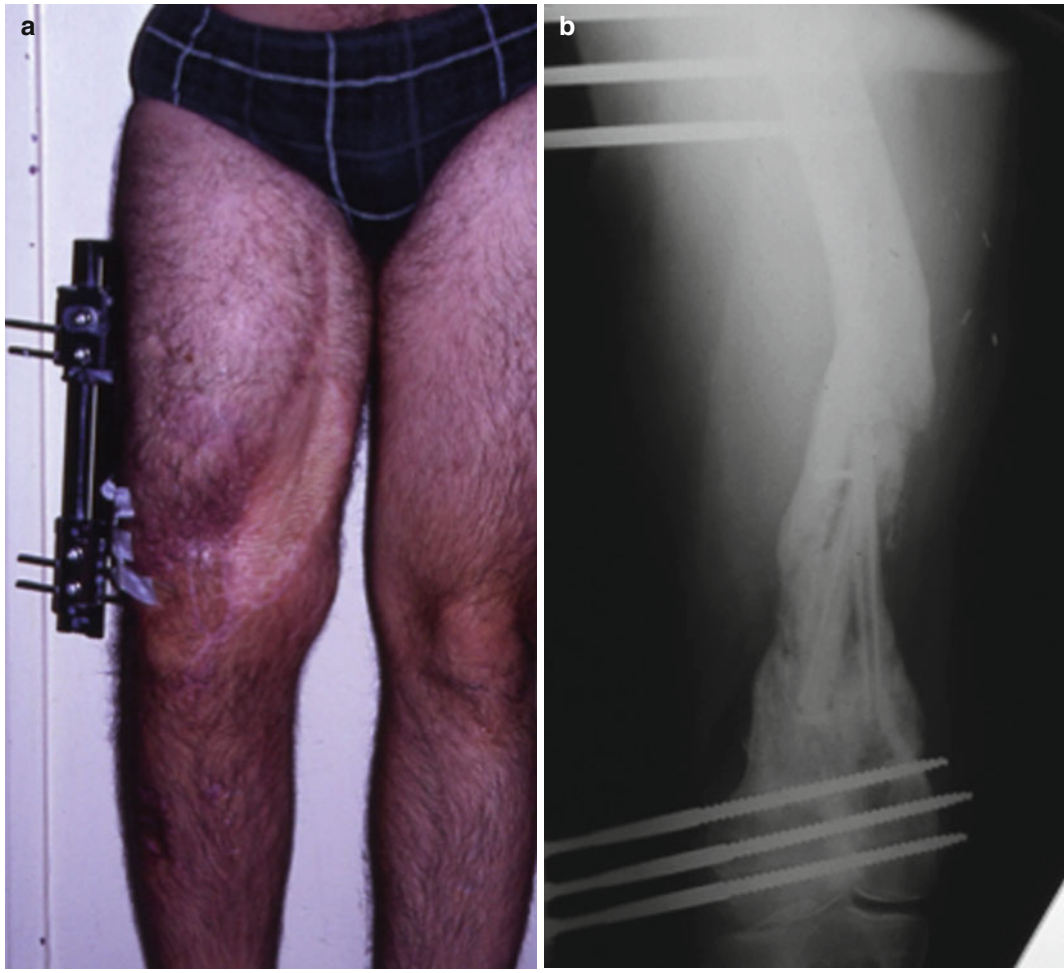

Fig. 3 (**a**) Clinical photograph of femoral defect treated by external fixation and free latissimus dorsi flap on the anterior thigh. (**b**) X-rays with a double-barrelled free fibular transfer for bone reconstruction

includes part of the soleus muscle to restore associated soft tissue defects. This composite flap is intended for extensive defects of the lower limbs involving bone and soft tissues. Bone healing was obtained in 11 months. Free weight-bearing was allowed 17 months after reconstruction [32].

According to Beris et al. [34], controversy regarding bone reconstruction using a free vascularized fibula graft in the acute phase may be linked to the risk of infection in a very technical demanding procedure. Large open fractures are contaminated with bacteria. Trying to get a non-infected bone graft site is the goal of early treatment of such challenging situations. Then, one option is to do the free vascularized fibula transfer within 6–8 weeks after trauma and soft tissue reconstruction. Beris has outlined that this is a difficult procedure due to increased scarring and limited recipient vessels in terms of their quality and location. Immediate one-stage procedure can be done, using composite transfers such as vascularized osteoseptocutaneous or osteomuscular fibula graft, immediately after radical debridement of the lesion site. The advantages of this procedure include simultaneous bone and soft-tissue reconstruction, early bone stability, stimulation of bone union and decreased time for bone healing, prevention of soft-tissue and vessel scarring, and increased rate of infection management [34]. In the author's experience, a one-stage procedure does not add risk of infection but on the contrary, increases the rate for resolving infection.

In a comparative study between free vascularized fibula transfer and bone transport, El Gammal et al. [33] was able to follow 13 free fibula vs 12 Ilizarov cases. Of particular interest are the inclusion criteria as bone defects were at least 6 cm long, none were cavitary defects, and none has involved the knee or ankle joint, so that these cases are exactly those discussed in this chapter. Operative time and blood loss were significantly higher in the free fibula group. External fixation time was longer in the Ilizarov group (10.58 months) vs 6.92 months for the free fibula group. Full weight-bearing time was similar in both groups, and above 9 months. Defect size was found to have the most significant effect on the results. The author recommends using free vascularized fibula for traumatic tibial defects of 12 cm or more, whenever experience is available [33].

A literature review of all cases of free vascularized fibula transfers published for management of acute lower limb trauma is still very unsatisfactory as only 20 papers encountered the previous-mentioned criteria. Among them, there are 11 case reports. This outlines the controversy of using such a demanding procedure in a very challenging situation where the infection rate seems the main drawback. The advantages of free vascularized fibula include maintained graft vascularity and so ability to hypertrophy in response to load [15, 33, 35], and resistance to infection [33, 34]. Its disadvantages are the need for microsurgical skills, possibility of total necrosis due to anastomotic complications, donor site morbidity, and occasional stress fracture [33].

The main drawback of the fibula transfer is the absence of soft-tissue coverage that is almost always needed in acute treatment of traumatic bone loss in the lower limb. The solution is additional plastic surgery such as local skin or myocutaneous flap, cross-leg, free skin myocutaneous flap, or composite flaps with the free fibula [32, 33, 35].

Protection of the vascularized fibula graft is needed during the first year and loading must be gradually increased for remodelling and hypertrophy. Stress fractures are common complications [10]. The type of fixation, associated with free vascularized fibula transfer, is still controversial. It seems that internal fixation raises the rate of stress fractures, so that external fixation with a monoplane frame [10] or circular one [35] must be preferred, as progressive loading and stress application can be achieved using this type of fixation. Large plates create unnecessary stress shielding and retard the hypertrophy of the fibula [35].

The double-barrelled fibula flap is indicated for femoral and proximal tibial reconstruction. For large defects over 12 cm, division of a single fibula will not provide adequate length [34]. The fibula presents the advantages of providing the greatest bony length and an excellent medullar and periosteal blood supply. In addition, its long cylindrical straight shape, mechanical strength, predictable vascular pedicle, and hypertrophy potential are criteria for some authors to use this demanding procedure in bone reconstruction of the lower limb [34].

Conclusions

Acute management of traumatic bone loss is still a very challenging situation even if there are different options available. Comprehensive literature review is rather difficult as all papers mix acute management and late bone reconstruction. The main criteria for decision-making are the bone defect size and the amount of surrounding soft tissue damage.

Small bone defects (less of 5 cm) can be managed using standard methods of fixation with autogenous bone grafting, and there is no evidence of a new or demanding procedure for a quicker or better outcome.

Management of large bone defects (over 5 cm) require specific techniques. Even if post-traumatic femoral defects of up to 15 cm have shown the potential for spontaneous healing after intramedullary nailing [10], large segmental bone defects, especially in the setting of an unfavourable wound environment, suboptimal surgical technique or biomechanical instability are usually characterized by low regeneration potential and will require more specialized surgical management.

The “induced membrane” technique seems to be a method of choice in all cases [7] as it maintains the limb length avoiding leg length discrepancy, allows acute flap surgery for soft tissue reconstruction in the post-traumatic period, gives some opportunity for diagnosis of infection in

those contaminated situations [21], and leads to a combined mechanical and biological favourable environment [19]. In the future, additional techniques of orthobiologics may help to limit the amount of bone graft needed [36, 37]. The main drawback of this technique is that of a two-stage technique needing additional anaesthesia. This situation may be improved by using new implant technologies with Cylindrical Titanium Mesh Cage (CTMC) and polylactide membranes technique [12], or custom-made products such as pre-determined bone segment with collagen-hydroxyapatite scaffold and autogenous platelet-rich plasma [38]. Part of the efficacy of the induced membrane technique is a non-infected and well-vascularized bone graft bed, so that all new techniques should be compared on this basis. In this technique, stability is mandatory, and future studies will help to determine which type of stable fixation is better [22].

Acute shortening, compression-distraction and Ilizarov bone transport must always be considered as they can correct associated deformity and shortening, address small areas of soft tissue defects, and allow immediate mobilization. Their disadvantages are long duration of treatment especially in long defects, pain accompanying the transport, frequency of pin tract infection, and occasional non-union at the docking site [33]. Based on previous published studies, in acute management of lower limb bone loss, it seems that compression-distraction techniques are the most suitable ones for reducing the number of complications. However, management of soft tissue involved in the trauma is still a significant problem with this type of procedure.

For long bone defects over 8–10 cm in length, the free vascularized fibula must be considered even if there is a high risk of septic complications and stress fractures. Exact positioning of this type of graft will be better defined in the future, as it is a very demanding procedure needing a high level of experience and must be limited to some surgical centres able to do it in a multidisciplinary surgical environment [15].

In conclusion, biological pseudomembrane seems to facilitate bone reconstruction. However clinical trials are needed in order for their effectiveness to be confirmed and their place in the armamentarium for the treatment of bone segmental defects to be clarified [10]. Addition of osteogenic proteins (BMP's), and their effect on bone healing and regeneration either in an induced membrane technique [18] or in an Ilizarov technique [39] must be studied more precisely. Such considerations will lead to the possibility of using tissue engineering for acute post-traumatic bone reconstruction, such as osteogenic cells, growth factors, and biomaterial scaffolds. The previously mentioned Masquelet and cylindrical mesh techniques may be the basis for tissue engineering procedures.

References

1. Hildebrand F, Giannoudis P, Kretteck C, Pape HC. Damage control: extremities. Injury. 2004;35(7):678–89.
2. Nahm NJ, Vallier HA. Timing of definitive treatment of femoral shaft fractures in patients with multiple injuries: a systematic review of randomized and non-randomized trials. J Trauma Acute Care Surg. 2012;73(5):1046–63.
3. Watson JT, Anders M, Moed BR. Management strategies for bone loss in tibial shaft fractures. Clin Orthop Relat Res. 1995;315:138–52.
4. Scalea TM, Boswell SA, Scott JD, Mitchell KA, Kramer ME, Pollak AN. External fixation as a bridge to intramedullary nailing for patients with multiple injuries and with femur fractures: damage control orthopedics. J Trauma. 2000;48(4):613–21.
5. Pape HC, Tornetta 3rd P, Tarkin I, Tzioupis C, Sabeson V, Olson SA. Timing of fracture fixation in multitrauma patients: the role of early total care and damage control surgery. J Am Acad Orthop Surg. 2009;17(9):541–9.
6. Meinig R. Management of traumatic bone defects. In: Sanders R, Borrelli JJ, Pape H-C, editors. The poly-traumatized patient with fractures. Berlin/Heidelberg: Springer; 2011. p. 295–303.
7. Masquelet AC, Begue T. The concept of induced membrane for reconstruction of long bone defects. Orthop Clin North Am. 2010;41(1):27–37.
8. Green SA. Skeletal defects. A comparison of bone grafting and bone transport for segmental skeletal defects. Clin Orthop Relat Res. 1994;301:111–17.
9. Calori GM, Phillips M, Jeetle S, Tagliabue L, Giannoudis PV. Classification of non-union: need for a new scoring system? Injury. 2008;39 Suppl 2:S59–63.
10. Lasanianos NG, Kanakaris NK, Giannoudis PV. Current management of long bone large segmental defects. Orthop Trauma. 2010;24(2):149–63.

11. Dugan TR, Hubert MG, Siska PA, Pape HC, Tarkin IS. Open supracondylar femur fractures with bone loss in the polytraumatized patient – Timing is everything! Injury. 2013;44(12):1826–31.
12. Lindsey RW, Gugala Z, Milne E, Sun M, Gannon FH, Latta LL. The efficacy of cylindrical titanium mesh cage for the reconstruction of a critical-size canine segmental femoral diaphyseal defect. J Orthop Res. 2006;24(7):1438–53.
13. Sands S, Siska P, Tarkin I. Reconstructive strategies for skeletal complications in the polytrauma patient. In: Pape H-C, Sanders R, Borrelli JJ, editors. The poly-traumatized patient with fractures. Berlin/Heidelberg: Springer; 2011. p. 333–44.
14. Marino JT, Ziran BH. Use of solid and cancellous autologous bone graft for fractures and nonunions. Orthop Clin North Am. 2010;41(1):15–26; table of contents.
15. Pelissier P, Boireau P, Martin D, Baudet J. Bone reconstruction of the lower extremity: complications and outcomes. Plast Reconstr Surg. 2003;111(7):2223–9.
16. 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(3):346–53.
17. Klaue K, Knothe U, Anton C, Pfluger DH, Stoddart M, Masquelet AC, et al. Bone regeneration in long-bone defects: tissue compartmentalisation? In vivo study on bone defects in sheep. Injury. 2009;40 Suppl 4:S95–102.
18. 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(1):73–9.
19. Donegan DJ, Scolaro J, Matuszewski PE, Mehta S. Staged bone grafting following placement of an antibiotic spacer block for the management of segmental long bone defects. Orthopedics. 2011;34(11):e730–5.
20. Taylor BC, French BG, Fowler TT, Russell J, Poka A. Induced membrane technique for reconstruction to manage bone loss. J Am Acad Orthop Surg. 2012;20(3):142–50.
21. Karger C, Kishi T, Schneider L, Fitoussi F, Masquelet AC. Treatment of posttraumatic bone defects by the induced membrane technique. Orthop Traumatol Surg Res. 2012;98(1):97–102.
22. Apard T, Bigorre N, Cronier P, Duteille F, Bizot P, Massin P. Two-stage reconstruction of post-traumatic segmental tibia bone loss with nailing. Orthop Traumatol Surg Res. 2010;96(5):549–53.
23. Attias N, Lindsey RW. Case reports: management of large segmental tibial defects using a cylindrical mesh cage. Clin Orthop Relat Res. 2006;450:259–66.
24. Rigal S, Merloz P, Le Nen D, Mathevon H, Masquelet AC. Bone transport techniques in posttraumatic bone defects. Orthop Traumatol Surg Res. 2012;98(1):103–8.
25. El-Rosasy MA. Acute shortening and re-lengthening in the management of bone and soft-tissue loss in complicated fractures of the tibia. J Bone Joint Surg Br. 2007;89(1):80–8.
26. Sen C, Kocaoglu M, Eralp L, Gulsen M, Cinar M. Bifocal compression-distraction in the acute treatment of grade III open tibia fractures with bone and soft-tissue loss: a report of 24 cases. J Orthop Trauma. 2004;18(3):150–7.
27. Burkhart KJ, Rommens PM. Intramedullary application of bone morphogenetic protein in the management of a major bone defect after an Ilizarov procedure. J Bone Joint Surg Br. 2008;90(6):806–9.
28. Nho SJ, Helfet DL, Rozbruch SR. Temporary intentional leg shortening and deformation to facilitate wound closure using the Ilizarov/Taylor spatial frame. J Orthop Trauma. 2006;20(6):419–24.
29. Paley D, Maar DC. Ilizarov bone transport treatment for tibial defects. J Orthop Trauma. 2000;14(2):76–85.
30. El-Alfy B, El-Mowafi H, El-Moghazy N. Distraction osteogenesis in management of composite bone and soft tissue defects. Int Orthop. 2010;34(1):115–18.
31. Saleh M, Rees A. Bifocal surgery for deformity and bone loss after lower-limb fractures. Comparison of bone-transport and compression-distraction methods. J Bone Joint Surg Br. 1995;77(3):429–34.
32. Pelissier P, Casoli V, Demiri E, Martin D, Baudet J. Soleus-fibula free transfer in lower limb reconstruction. Plast Reconstr Surg. 2000;105(2):567–73.
33. El-Gammal TA, Shiha AE, El-Deen MA, El-Sayed A, Kotb MM, Addosooki AI, et al. Management of traumatic tibial defects using free vascularized fibula or Ilizarov bone transport: a comparative study. Microsurgery. 2008;28(5):339–46.
34. Beris AE, Lykissas MG, Korompilias AV, Vekris MD, Mitsionis GI, Malizos KN, et al. Vascularized fibula transfer for lower limb reconstruction. Microsurgery. 2011;31(3):205–11.
35. Levin LS. Vascularized fibula graft for the traumatically induced long-bone defect. J Am Acad Orthop Surg. 2006;14(10 Spec No.):175–6.
36. Li LJ, Liu N, Shi JG, Liu Q, Jia LS, Yuan W. Osteogenic scaffolds for bone reconstruction. Biores Open Access. 2012;1(3):137–44.
37. McKee MD. Management of segmental bony defects: the role of osteoconductive orthobiologics. J Am Acad Orthop Surg. 2006;14(10 Spec No.):S163–7.
38. Chang SH, Hsu YM, Wang YJ, Tsao YP, Tung KY, Wang TY. Fabrication of pre-determined shape of bone segment with collagen-hydroxyapatite scaffold and autogenous platelet-rich plasma. J Mater Sci Mater Med. 2009;20(1):23–31.
39. Watson JT. Nonunion with extensive bone loss: reconstruction with Ilizarov techniques and orthobiologics. Oper Tech Orthop. 2008;18(2):95–107.