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Cambridge Protocol for Management of Segmental Bone Loss

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Learning Point of the Article:

A treatment algorithm to guide surgeons in choosing the best lower limb reconstruction options in the sub-acute setting for segmental bone defects considering the skill set and resources of the centre in which one works.

Abstract

Introduction: Segmental long bone defects are some of the most challenging to surgically reconstruct; however, there is no clear guidance on which of the myriad of techniques is superior in a given clinical context. We describe three cases of segmental bone loss presenting to a major trauma center and have use these to develop a treatment algorithm for the sub-acute management of such fractures.

Case Report: Case 1 - Acute shortening and delayed lengthening using lengthening intramedullary (IM) nail to treat diaphyseal non-union of the femur with associated 3 cm shortening. Case 2 - 15 cm traumatic bone loss of femur, failed Masquelet, treated with IM nail, monolateral external-fixation and cable with a mean lengthening rate of 46 days/cm. Case 3 – 12 cm tibial traumatic bone loss, failed Masquelet, treated with fine wire frame with a mean lengthening rate of 49 days/cm.

Conclusion: As our cases illustrate; attempting complicated, definitive management in the acute phase generates complications and necessitates re-intervention. As such, we have developed a treatment algorithm for traumatic segmental bone loss. We recommend waiting 6 weeks and reimaging to check for evidence of spontaneous bone formation before deciding on definitive treatment. First-line treatment for femoral defects <4 cm is acute limb shortening with delayed lengthening using lengthening IM nail. First-line treatment for femoral defects >4 cm is lengthening over nail with monolateral external fixator. First-line treatment of tibial segmental bone defects in our hands is fine wire circular frames which provide excellent scope for soft tissue coverage and deformity correction. Treatment times of over 2 years in a frame are not uncommon and patients must diligently comply with pin sites management and lengthening protocols. This is the first paper providing an algorithm to guide surgeons in choosing the best lower limb reconstruction options in the sub-acute setting; considering the skill set and resources of the center in which one works.

Keywords: Segmental bone loss, distraction osteogenesis, lengthening nail, frame, treatment algorithm

Introduction

Segmental long bone defects are some of the most challenging to surgically reconstruct. Definitions of segmental critical limb defects vary between studies; with common definitions being "a defect 2–2.5 times greater than the diameter of the injured bone" or "a defect in the bone that is too wide for spontaneous regeneration" [1]. The two main techniques for reconstructing segmental bone are the induced membrane technique pioneered by Masquelet, and distraction osteogenesis, introduced by Ilizarov.

Masquelet noted that inserting a polymethylmethacrylate spacer for 6–8 weeks in a segmental cortical bone defect induced the formation of a periosteum-like membrane which provided a better space into which autologous cancellous bone graft could be protected from resorption. This two-stage procedure and variations of it are now commonly referred to as the Masquelet technique. Several modifications of the distraction osteogenesis technique have been described including, bone transport over an intramedullary (IM) nail, bone transport with a plate, and bone transport with a plate and IM lengthening nail there is no consensus on which technique

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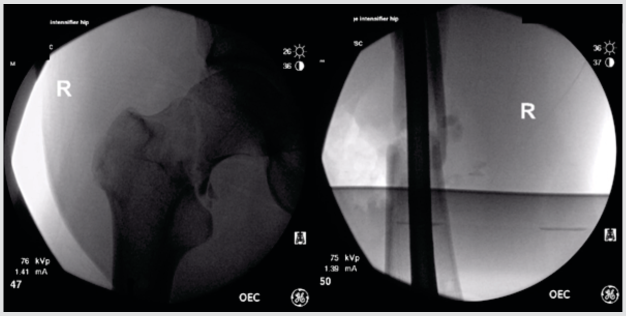

Figure 1: Case 1 initial intraoperative images of 59-year-old man who sustained a right neck of femur fracture and right open femoral fracture treated with IM nail.

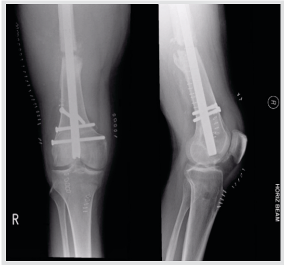

Figure 2: Case 1 anterior posterior and lateral femoral films taken day 7 post-removal of old nail and insertion of PRECICE nail with proximal corticotomy. Compression started to obtain union.

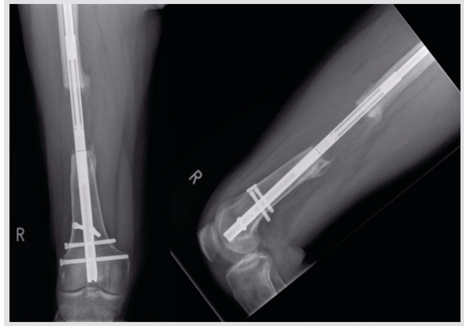

Figure 3: Case 1 - anterior posterior and lateral femoral films taken 4 weeks post-operative when the distraction phase is complete.

to use (Table 1).

We present a case series of traumatic, lower limb, segmental bone defects presenting to a UK major trauma center and describe how we have used these cases to develop a treatment protocol.

Case Report

Case one-

acute shortening and lengthening using lengthening IM nail

A 59-year-old man was referred for non-union right femur at transition between middle and distal third with a 3 cm shortening of the femur 22 months after a significant polytrauma resulting in a right neck of femur fracture and right open femoral fracture treated (at another center) with a dynamic hip screw and IM nail, respectively (Fig. 1). While this is not an example of deliberate acute shortening, the principles are the same. The non-union and leg length discrepancy were treated with a one stage procedure; performing debridement of the non-union up to the bleeding bone; inserting a lengthening IM nail and compressing the fracture by five milometers using a hand-held external remote controller (Fig. 2). Two weeks post-surgery, the fracture was compressed by a further 1 cm at a rate of 1 mm/day. After the compression was complete, the fracture was left for 4 weeks before beginning to distract the previous non-union gap by 1 mm/day in four increments with a re check X-ray within a week to confirm that the regenerate was moving (Fig. 3). The patient was kept touch toe weight bearing for 22 weeks, followed by partial weight bearing for an additional 8 weeks. 24 weeks post-surgery, the patient had gained 78 mm regenerate and was mobilizing pain free without aids (Fig. 4). The mean lengthening index was 21.5 days/cm.

Case two–

12 cm tibial traumatic bone loss treated with fine wire TSF

A 22-year-old female polytrauma patient following a road traffic accident sustained several orthopedic injuries; right femoral shaft fracture; right talar fracture; and medial malleolar fracture; left Lisfranc injury; and left tibia Gustilo-Anderson IIIB fracture treated initially with washout, debridement, and ex-fix application. Thirty-six hours post-injury, the patient was taken to theatre as a joint orthoplastics case for IM nailing and first stage Masquelet technique, followed by free gracilis flap. Fifteen weeks later the patient returned for second stage Masquelet procedure with autologous

Figure 6: Case 3 – anterior posterior film of right femur of 28-year-old male day 1 post-operative following 1st stage of Masquelet (intramedullary nailing of femur with cement spacer).

Figure 4: Case 1 - anterior posterior and lateral femoral films taken 24 weeks post-surgery (20 weeks post-distraction) showing 78 mm of regenerate.

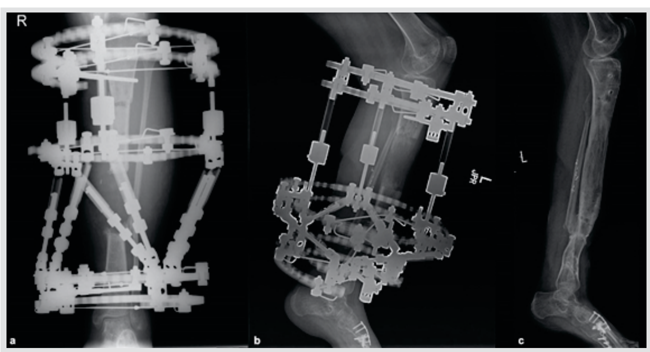

Figure 5: (a) Case 2 – anterior posterior film of right tibia day 1 post-tibial corticotomy and fibular corticotomy and Taylor Spatial Frame placement for 12 cm bone defect. (b) Lateral film of right tibia 19 weeks post-Taylor Spatial Frame placement with lengthening protocol of 0.5 mm/day showing evidence of regenerate formation. (c) Lateral film of right tibia 21 months post-Taylor Spatial Frame placement showing 12 cm of strong regenerate with no evidence of refracture. Patient was mobilizing pain free.

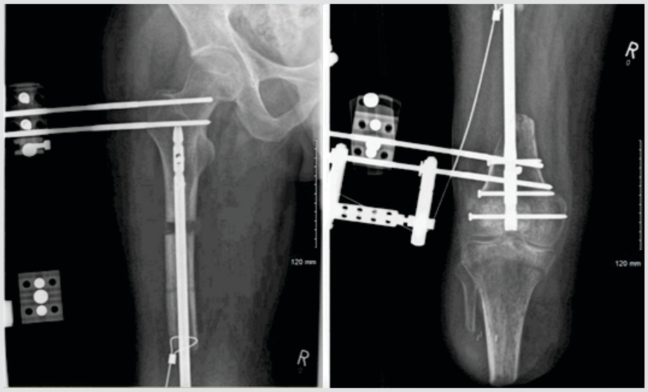

Figure 7: (a) Case 3 – anterior posterior film of proximal right femur taken day 1 proximal corticotomy, IM nail change and Orthofix monorail assembly with cable in proximal fragment of bone to be transported. (b) Case 3 – anterior posterior film of distal right femur taken day 1 post-IM nail insertion with cable and monorail assembly for bone transport. Note cable in proximal fragment of bone pulled submuscularly and extra-articularly to exist wound lateral to the knee; attached to pulley system on monorail.

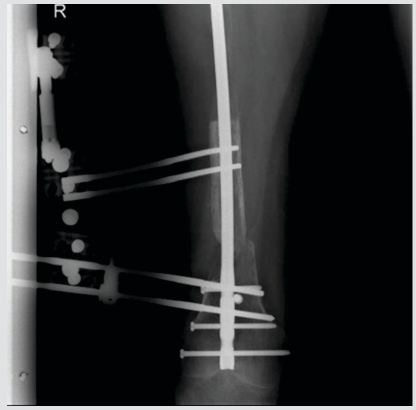

Figure 8: Case 3 – anterior posterior film of distal femur showing transported fragment at docking site 53 weeks after bone transport commenced with ex-fix still in situ.

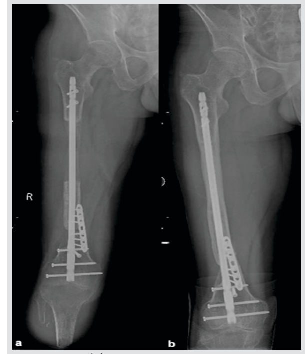

Figure 9: (a) Case 3 – anterior posterior film of femur post removal of ex-fix with seven hole small fragment locking plate applied between regenerate and docking site. (b) Case 3 – anterior posterior film of femur 34 months after bone transport was commenced showing strong regenerate formation.

bone graft which failed 7 weeks later (22 weeks post injury). With a 12 cm tibia bone defect, the patient was finally treated with proximal tibial corticotomy and fibular corticotomy and TSF placement (Fig. 5a). Lengthening was set at 0.5 mm/day for 6 months. Fig. 5b shows patient 19 weeks into lengthening protocol. The frame was removed 14 months post-cessation of lengthening when the regenerate had remodeled completely (Fig. 5c). The mean lengthening rate was 49 days/cm.

Case 3 -

15 cm traumatic bone loss of femur treated with IM nail, monolateral ex-fix, and cable

A 28-year-old man involved in motor cyclist versus road crash sustaining an open right segmental tibial shaft fracture with vascular injury treated with primary below knee amputation due to hemodynamic compromise. He also sustained a Gustilo-Anderson IIIB open right segmental femoral shaft fracture treated initially with debridement and application of external fixation (ex-fix) and vacuum assisted closure VAC dressing. Two days after the initial damage control surgery, the patient returned to theater for first stage of Masquelet and a meshed skin split graft (Fig. 6). Thirty-three weeks post-trauma when second stage Masquelet had failed the patient had IM nail removed and an Orthofix Limb Reconstruction System™ Monorail (Orthofix Limited, Maidenhead, U.K) assembled. Two distal and two proximal HA half pins were inserted under II, with the distal part of proximal fragment identified through old incision and the cable put through the old incision after predrilling with 2.5 mm drill bit. The cable pulled sub-muscularly and extra-articularly to the exist wound lateral to the knee. The low energy corticotomy of the proximal femur was distracted and then compressed using six milimeter conical half pin. Pulleys and clickers were assembled through the cable and threaded rod (Fig. 7). The patient underwent lengthening at a rate of 1 mm/day with three weekly clinic appointments for frame adjustments. Twelve weeks into lengthening the rate were reduced to 0.5 mm/day. The distal fragment reached the docking site after 53 weeks; external fixation index of 31.3 days/cm (Fig. 8). The ex-fix was removed a week later and a seven-hole small fragment locking plate applied to fracture. The patient was made partially weight bearing (Fig. 9a). Twelve weeks post-removal of ex-fix, there was evidence of regenerate the entire 15 cm between corticotomy and docking site. 99 weeks after the ex-fix was applied this regenerate had remodeled completely with a mean lengthening rate of 46 days/cm (Fig. 9b). The regenerate was strong enough to facilitate complete weight bear painlessly with a below knee prosthesis and 2 years later the patient is very pleased with the results of his surgery.

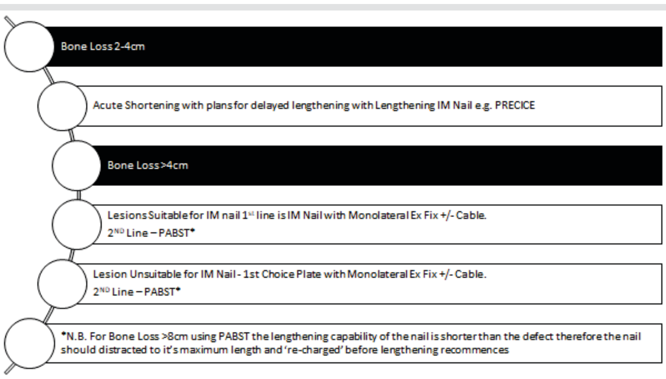

Figure 10: Algorithm for the sub-acute treatment of traumatic segmental bone defects in the femur with no evidence of spontaneous bone regeneration at 6 weeks. PABST: Plate-assisted bone segment transport.

Discussion

As our cases illustrate; attempting complicated, definitive management in the acute phase generates complications and necessitates re-intervention. For traumatic segmental bone loss, we recommend waiting approximately 6 weeks with an X-ray or CT scan at this time to check for evidence of spontaneous bone formation before committing the patient to bone transport or acute shortening-delayed lengthening procedures. Open

Table 1: Summary of bone transport techniques currently in use; their advantages and disadvantages.

Technique	Advantages	Disadvantages
Distraction osteogenesis by Ilizarov method	• Enables simultaneous lengthening and correction of deformity	• Complications related to external fixation
	• Allows for six degrees of freedom bone fragment displacement Allows for six degrees of freedom bone fragment displacement	• Pin tract infections
	• No requirement for autologous bone grafting techniques, eliminating donor site morbidity	• Broken wires requiring re-operation for frame revision
	• Allows the patient to bear weight with an external fixator during treatment	• Joint contractures
	• Effective for treatment of complex infected non-union	• Psychological and physical distress caused by prolonged external fixation time
Bone transport using a monorail fixator over an intramedullary nail	• Interlocking of the transported segment protects the regenerated callous.	• Difficult insertion of half pins (half pins cannot touch the nail)
	• Ex-Fix can be removed once docking has occurred thus reducing external fixation time	• Readjustment of the monorail/nail relation during the transport to adjust the parallelism
	• Increased stability of the intramedullary device reduces the stability required by the external fixator	• High percentage of septic complications
		• Docking site non-union
		• Additional procedure required when docked to keep the fragment in place
		• Joint stiffness
Intramedullary cable bone transport	• Decreases the external-fixator-associated complications	• Permits only gradual weight-bearing during the consolidation period
	• All equipment widely available	• Increased infection rate
	• Improved cosmetic outcome	• Docking site non-union
		• Not applicable to bone defects, excessive rotational deformities, or joint contractures
Plate-assisted bone segment transport	• Fully removes the need for external fixation and the associated complications	• Typically limited to defects up to 8 cm. Need to recharge the nail to go further
	• Improved cosmetic outcome	• Plate bending +/- breakage +/- nail jamming due to 3-point fixation
		• Docking site non-union
		• Increased infection rate with open fractures
Bone transport using a submuscular locking plate and a monorail fixator	• Submuscular position of the plate preserves periosteal and endosteal blood supply	• Increased infection rate
	• Opportunity to additionally compress and stabilize the transported segment at the time of docking using additional locking screws through the plate.	• Docking site non-union
	• Facilitates earlier external fixator removal than bone transport over the nil	• Need for appropriate tissue transfers and other wound coverage to cover metalwork
Acute shortening, acute fracture deformation and gradual lengthening	• Shorter union time	• Increased surgical trauma with concurrent fibula should be shortened at the same time
	• Higher healing rate than bone transport	• Common peroneal nerve and distal branch injuries due to increased pressure on lower leg
	• Requires less frequent bone grafting than bone transport alone	• Mechanical axis deviation
	• Lower rate of complications and better radiographic outcome than bone transport	• Foot drop due to limb shortening and muscle relaxation
		• Limb pain and discomfort

fractures should receive early, appropriate plastic surgery to get soft-tissue coverage before any bony reconstruction attempted.

If repeat imaging within 6 weeks does not show, any evidence of spontaneous bone regeneration bone transport techniques should be initiated. Factors which make spontaneous bone regeneration more likely include younger age, periosteal preservation, associated TBI; and with the presence of infection being a negative factor [2].

For the tibia; initial treatment includes spanning ex-fix, followed closely by soft-tissue cover provided by plastic surgeons. We do not expect any spontaneous bone regeneration. By default, every patient is listed for fine wire circular frame 4 weeks after the soft-tissue cover has been completed. Typical operative protocol includes proximal tibial and fibular corticotomy and Taylor Spatial Frame™ (TSF) (Smith & Nephew, Memphis, TN, USA) assembly (2-1-2) with clickers. Any fine wire circular frame can be used. Our protocol is to commence lengthening on post-operative day 8 at 0.25 mm 4 times daily per clicker with clinic appointments every 2 weeks to facilitate modification of lengthening and deformity correction prescription if necessary and to monitor pin sites. SPATIALFRAME.COM VERSION 5.4 software by Smith and Nephew can be used to preoperatively plan and make ongoing corrections. When the fragment has reached the docking site, that is, when struts cannot be turned by hand, distraction may be stopped. Post-lengthening the frame remains in place until good quality regenerate has formed; we determine this to be when the line between old and new bone begins to blur. There is currently no evidence to guide optimum time or radiological signs of good regenerate formation. Post-frame removal patient can weight bear as comfort allows and one can consider an "aircast" boot for psychological support and to act as a social deterrent.

Femoral treatment option depends on length of defect (Fig. 10).

We recommend acute shortening with delayed lengthening with lengthening IM nail for bone loss between two and four cm. This simple single stage surgery avoids more complex bone transport needed for larger defects. For larger defects greater than four cm it should first be determined if there are any contraindications to the placement of an IM nail including but not limited to those cited by Bernstein et al. [3]. Where the medullary canal that is too small to accommodate a rigid IM nail consider plating or "Plate-assisted Bone Segment Transport" (PABST) technique with IM lengthening nails, for example, PRECICE [4, 5].

While our algorithm does not prescribe a single technique for the treatment of segmental bone loss in the femur, we have made bone transport with fine wire frames the only treatment option for large segmental bone defects in the tibia. The absence of indwelling metal work helps limit the risk of deep infection and fine wire frames allows for transfer of intercalary segments of bone in fractures associated with bone loss while obtaining soft-tissue coverage. Our experience is that for segmental tibial bone loss, the Masquelet technique and IM nails are plagued by failure. Systematic review by McMahon et al. suggested that circular external fixation provides the most satisfactory results, with IM nailing, and open reduction internal fixation having higher rates of infection [6]. The use of ex-fix and bone lengthening with IM nail can have up to 50% complication rate including non-unions [7, 8]. It is not only our experience but also the literature which demonstrates the use of Ilizarov as a "rescue procedure" in the treatment of tibial fractures when other techniques have failed [9, 10, 11, 12]. Systematic review has demonstrated that Ilizarov method of distraction osteogenesis significantly reduced the risk of deep infection in infected osseous lesions (risk ratio 0.14) [13].

It should be noted that treatment times of over 2 years in a frame is not uncommon and patients must diligently comply with pin site management and lengthening protocols. The demand this technique places on patients is illustrated by the voluntary amputation rate of 1.6% (95% CI 0–3.1) in systematic review [13]. This underlines the need for careful patient selection and it should be acknowledged that excellent functional outcomes can also be achieved with primary amputation and prosthesis fitting. There should be a focus on shared decision making when deciding definitive treatment. The 6 week wait that we have now decided to implement in our center before proceeding to definitive management allows the patient more time to be both physiologically and emotionally stabilized to make an informed decision.

With improvements in lengthening IM nails an all internal method of bone transport has been shown to be successful and could provide an alternative to external fixation in certain cases (Fig. 10). The PABST technique using The PRECICE System (NuVasive) has been hailed as combining four procedures in one; IM Nailing; bridge plating; corticotomies; and plating over a nail [4, 5]. The nail moves the intercalary segment while the plate provides fixation for proximal and distal segments and prevents medial drift. PRECICE Standalone bone transport nail has been licensed for the treatment of bone defects up to 10 cm in length. Nails can be pre-distracted to pull the fragment (shortening the nail) if needed. If the lengthening capability of the nail is shorter than the defect, the nail can be exchanged or "re-charged," that is, adapted to more lengthening by temporary fixation of the transport fragment; recompressing the nail, and relocking it in its newly shortened position before commencing the second phase of lengthening [5, 14].

Opinions on the treatment of segmental lower limb fractures does differ across major trauma centers and there is a rationale for conducting a prospective randomized control trial despite the difficulties encountered with consent, blinding, and adherence to protocol requirements in such a setting.

Conclusion

To the best of our knowledge, this is the first paper providing an algorithm to guide surgeons in choosing the best lower limb reconstruction options in the sub-acute setting. Treatment of femoral defects varies based on length of bone lost. Treatment of tibial defects is with TSF. Despite the heterogeneity of massive bone loss injury, this algorithm prescribes enough to guide decision making while also considering the skill set and resources of the center in which one works.

Clinical Message

Traumatic segmental bone loss is a challenge to surgically reconstruct and we recommend delaying definitive treatment for 6 weeks and re-image to check for evidence of spontaneous bone formation. If there is no spontaneous bone formation defects should be treated, according to length. In our hands, first-line treatment for femoral defects <4 cm is acute limb shortening with delayed lengthening using lengthening IM nail. First-line treatment for femoral defects >4 cm is lengthening over nail with monolateral external fixator. Tibial segmental bone defects are treated with fine wire frames though patients should be counseled on the long external fixation times and meticulous pin sit cleaning required to make this treatment a success.

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