REVIEW ARTICLE

The management of fractures with bone loss

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Historically, because of the problems involved in initial limb salvage and the subsequent difficulty of reconstructing large skeletal defects many fractures with significant bone loss were treated by primary amputation. Modern techniques of fracture stabilisation and soft-tissue reconstruction mean that many more severely injured limbs with bone defects can now be salvaged in the acute phase of treatment. However, the problems involved in subsequently bridging or regenerating areas of skeletal loss with viable bone while maintaining limb length and alignment commensurate with satisfactory function, remain a substantial challenge.

Attempting limb reconstruction in the presence of significant bone loss usually involves surgery which is technically difficult, time-consuming, physically and psychologically demanding for the patient, and with no guarantee of a satisfactory outcome. The function of the salvaged limb may be disappointing due to residual pain, joint stiffness and neurovascular deficit. The patient may require a secondary amputation due to refractory infection or non-union. Thus, the correct initial decision as to whether to embark upon limb reconstruction or to perform a primary amputation is important, but difficult. Unfortunately, the relative rarity of these injuries and the considerable variation in their configuration dictate that prescriptive management based on established protocol is not possible. A flexible and individualised approach to treatment is required. In this review, we consider the assessment of these injuries with an overview of the current options available for treatment, and provide guidelines for their management.

Classification of skeletal defects

Bone loss may occur from extrusion of fragments at the time of injury or during debridement of an open fracture when devitalised segments of bone are removed, thereby creating a defect. In most European populations and in areas where blunt trauma predominates, most skeletal defects are created at the time of debridement, but in areas where penetrating trauma from gun or blast injuries are more frequent, extrusion of bone fragments can occur at the time of injury. Systems for classification of open fractures do take some account of bone loss,[1-3] but due to the large number of factors which determine the severity and outcome of these injuries none of the existing schemes are entirely satisfactory. However, it is customary to describe bone loss by its anatomical location in the bone as being diaphyseal, metaphyseal or articular. The extent of the defect can be considered in terms of the length of bone involved and whether the defect comprises partial or segmental circumferential loss. Segmental defects of greater than 2 cm are unlikely to heal spontaneously following skeletal stabilisation alone. Those involving more than 50% of the circumference can heal spontaneously but often require additional treatment to restore normal volume and strength. Articular defects are rare. Their treatment depends on the stability and extent of the defect and the capacity of the remaining joint surface to articulate normally with acceptable loads. In the case of the tibial plateau, defects of more than 3 cm of the joint surface and 1 cm in depth are considered to be an indication for allografting.[4]

Although these considerations are important, other factors also influence the prognosis. Bone loss in certain anatomical locations has a more favourable prognosis due to better blood supply and corresponding osteogenic potential. The degree of soft-tissue injury will have a substantial influence on the subsequent rate of healing. The age of the patient, the presence of chronic disease (e.g. diabetes mellitus), use of medications, alcohol consumption and tobacco usage may alter the potential of bone defects to heal. The way in which the fracture is treated will have a substantial influence on the local mechanical and biological environment, which in turn will influence the quantity and quality of the osteogenic response.

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Table I. Techniques currently available for the management of bone loss. Suitability by the anatomical location and the size of the defect

	Location	Defect size
Principal surgical technique		
IM nailing	Femur, tibia, humerus	Up to 6 cm
Plating	Humerus, forearm, lower limb metaphyseal	Up to 6 cm
Uniaxial/hybrid external fixation	Lower limb metaphyseal, humerus	> 6 cm
Circular external fixation	Upper limb, lower limb, diaphyseal or metaphyseal	> 6 cm
Free fibular graft	Tibia, humerus, forearm	6 to 10 cm
Allograft	Femur	> 6 cm
Articular allograft	Knee, elbow, hand	> 20% joint surface
Tibial synostosis	Tibia	Any diaphyseal defect
Adjunctive treatment		
Autogenous bone graft	Any location	Widely used for defects up to 6 cm in length or > 50% circumferential
Osteogenic agents	Any location	Not generally available for use at present
Osteoinductive agents (BMP etc)	Diaphyseal/metaphyseal defects, upper and lower limb	Any size, but needs structural support – carrier or allograft
Osteoconductive agents (Calcium phosphate cements etc)	Contained metaphyseal defects, upper and lower limb	< 10 cm
Bone shortening and lengthening	Mainly tibia and femur with soft-tissue problems	> 6 cm
Bone transport	Mainly tibia and femur with soft-tissue problems	> 6 cm

Epidemiology

Significant bone loss is seen in only a small minority of all fractures, although it occurs in a higher proportion of open fractures. In a prospective audit of admissions to the Edinburgh Orthopaedic Trauma Unit between 1988 and 1998, fractures with bone loss accounted for 0.4% of all fractures in patients admitted to hospital, but was encountered in 11.4% of open fractures. The majority of these fractures were Gustilo grade[1-3] IIIB injuries, with a smaller number which were Gustilo grade[1-3] IIIC.

Due to the high-energy injury which produces most open fractures with skeletal defects, the injury tends predominantly to affect males, many of whom have multiple injuries. A smaller proportion of middle-aged and elderly suffer these injuries. In Edinburgh, the mean age of patients admitted with fractures with bone loss was 37 years and 71% of these patients were male.

The most common site of bone loss after fracture is the tibia, because of its subcutaneous position which predisposes it to open fracture and extrusion of bone. Open fractures of the upper limb and axial skeleton are less common and bone loss is seldom encountered in these locations. In Edinburgh, 68% of all fractures with bone loss were in the tibia and 22% in the femur, with the remainder occurring sporadically at other sites.

The diaphysis is the most common site of involvement. When bone is lost from the metaphyseal or articular areas, the injury is often devastating because of the high degree of energy transfer at the time of the injury. In the Edinburgh Trauma Unit, 69% of all fractures with bone loss were in the diaphysis, with the remainder having either loss of metaphyseal bone or the articular surface, or both.

Management

Initial assessment and decision making. The majority of these patients present as an emergency with an open fracture. A careful clinical assessment of the vascular and neurological status of the limb is required. The first decision is to determine whether limb salvage should be attempted. Poor prognostic signs for limb salvage are a major soft-tissue injury, an ischaemic time in excess of six hours, the presence of significant neurological deficit, especially of the tibial nerve, and other major organ injuries.[5,6] There are a number of scores[7] (the mangled extremity severity score (MESS); the limb salvage index (LSI); the predictive salvage index (PSI); the nerve injury, ischaemia, soft-tissue injury, skeletal injury, shock, and the age of patient score (NISSSA); and the Hannover fracture scale-97 (HFS-97) devised to assist the surgeon in making the decision as to whether to opt for salvage or amputation in patients with this type of injury. In general these scores increase in magnitude with the degree of severity of the injury. However, a recent multicentre prospective evaluation[7] was not able to validate the clinical usefulness of any of the lower-extremity injury-severity scores. Low scores were found to be useful in predicting the potential for limb salvage but high scores were not good predictors of amputation. It was concluded that scores at or above the amputation threshold had to be interpreted with caution. The final decision to opt for salvage must be based on consideration of the general status of the patient and the local injury to the limb. In patients with serious soft-tissue, vascular or neurological problems the opinion of other relevant specialists must be sought.

Once a decision is made to proceed with salvage, debridement and stabilisation will be required. The debridement itself is usually responsible for creating or extending the bone defect, as devitalised or contaminated bone is excised from the wound. The majority of defects will be clearly seen at the time of debridement so the surgeon will have a clear idea of the extent of the problem. Plain radiographs will give adequate information about the extent of bone loss in most cases. CT scans or MRI are most useful in evaluating articular defects, but may be of limited value if there are metal implants adjacent to the joint. Films

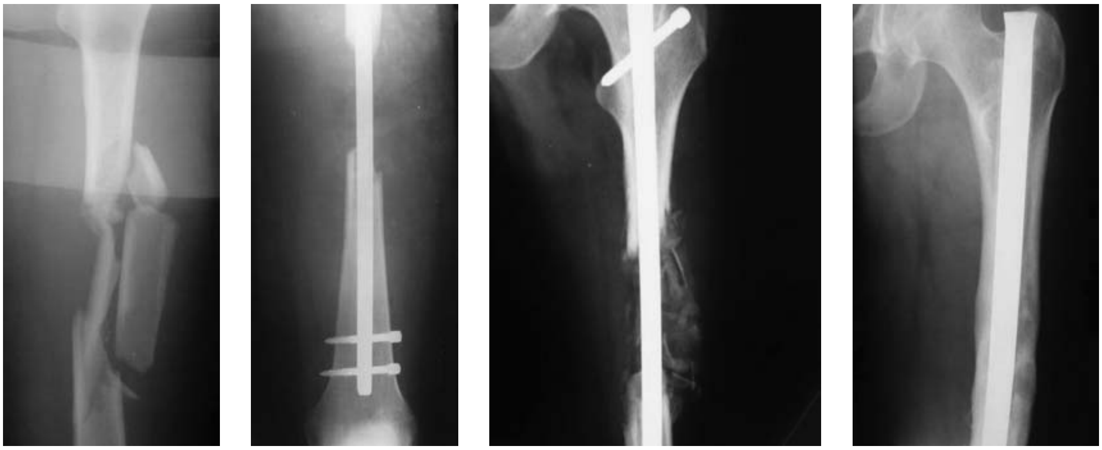

Fig. 1a Fig. 1b Fig. 1c Fig. 1d

Radiographs showing a) open diaphyseal fracture of the femur with comminution, b) following debridement and intramedullary nailing, c) bone grafting and d) union.

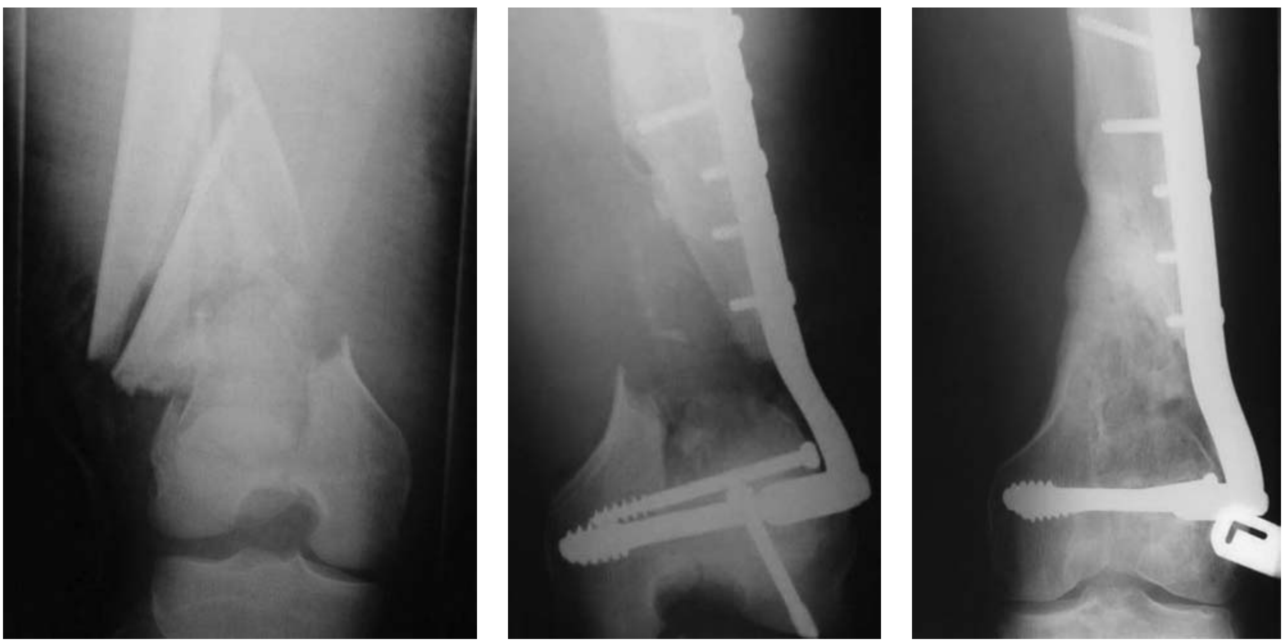

Fig. 2a Fig. 2b Fig. 2c

Radiographs showing a) comminuted open metaphyseal fracture, b) fixation with dynamic condylar screw and plate and c) union which occurred without the need for bone grafting.

measuring leg length will be of value in patients who have undergone shortening as part of the initial treatment, in order to plan subsequent lengthening.

Options for surgical management. The main aims of treatment are skeletal stabilisation, restoration of length and alignment, and preservation of optimum function. Modern orthopaedic techniques offer a bewildering selection of options for treatment. There is rarely a perfect solution; most options for treatment have drawbacks as well as advantages (Table I). Because these cases are uncommon there are no large comparative clinical studies on which to make an informed choice. However, the available literature is sufficient to draw general conclusions and make specific recommendations for management. The initial choice of skeletal stabilisation is particularly important as it will influence subsequent treatment. The following options may all be considered.

Operative techniques

Intramedullary nailing. Interlocking nails have become the treatment of choice for managing open diaphyseal fractures

Table II. Skeletal fixation with bone loss: the advantages and disadvantages

Advantages	Disadvantages
Intramedullary nails	
Stable fixation	Not applicable for all metaphyseal fractures
Can bridge long defects	Not suitable for use in the forearm
Can be inserted with minimally invasive surgery	High complication rate when used in the humerus
Low rates of malunion	Not suitable alone for defects > 6 cm
Shortening and lengthening can be accomplished relatively easily	
Can be used in conjunction with external fixation to lengthen bone	
Allow easy access to soft tissues for bone grafting/flap cover	
Plates	
Versatile method of treating upper/lower limb metaphyseal fractures	Poor results in tibial and femoral diaphyseal fractures
Good treatment for forearm/humeral diaphyseal fractures	Standard plating technique requires extensive dissection
Minimally invasive plate designs now available	Plate failure may occur in situations where prolonged union times are expected
	Does not easily allow shortening and lengthening
	Cannot easily be used in conjunction with external fixation
	Not suitable alone for defects > 6 cm
External fixation	
Versatile method of treatment	Cumbersome, poor patient acceptance
Can be used on upper/lower limb for metaphyseal/diaphyseal fractures	Frame may have to left on for prolonged periods
Can be used to shorten or lengthen bone	Pin-track infection
Bone transport possible	Risk of septic arthritis when used close to a joint, especially the knee
Can be used to compress the fracture site to stimulate healing	
Correction of angular or rotational deformity possible	Not ideal on the femur or humerus
Long defects (> 6 cm) can be treated	
Free fibular transfer	
Versatile, can be used in upper/lower limb, metaphysis or diaphysis	Lengthy, technically demanding procedure
Defects up to 20 cm can be bridged	Risk of failure of the vascular anastomosis
May avoid the need for complex fixation	Prolonged protected weight-bearing required
	Nonunion at graft junctions not uncommon
	Risk of refracture

of the femur and tibia (Fig. 1). In patients with diaphyseal bone loss, nails have some particular advantages (Table II). They confer excellent stability and allow restoration of length and alignment. The soft tissues can be readily accessed for further wound debridement and soft-tissue cover, and joints can be mobilised readily. Lengthening over a nail is an option in the femur or tibia and may be a useful method of dealing with a long defect. Nails are not the choice when distraction osteogenesis or free tissue transfer is being considered to fill the defect, unless an intramedullary lengthener is being considered for subsequent distraction osteogenesis.

At the time of intramedullary nailing the correct bone length may be difficult to judge. Pre-operative measurement of the contralateral limb clinically or on radiographs can provide an approximate guide to the length required. In general, the preferred approach in open fractures with bone loss treated by nailing is early soft-tissue cover, dealing with the defect at a later stage as a planned procedure.

Nailing in conjunction with bone loss has some limitations. In the metaphyseal defects of the lower limb, there may not be adequate distal bone to allow stable fixation with a nail. In the upper limb, there are limited options for fixation in the forearm. In the humerus, the medullary canal becomes narrow and flat at the lower end, which may limit the possibility of achieving satisfactory stability with a nail in the presence of bone loss.

Plates. Plating is technically difficult in situations with bone loss. Extensive exposure may be required, particularly if there is a segmental defect to bridge (Table II). It may be particularly difficult to judge the correct length and rotational alignment. The presence of segmental defects will compromise the stability of plate fixation. Plating is biomechanically unfavourable in the presence of a defect due to cantilever loading. New designs of plates, such as locking compression plates and minimally invasive systems, are now available[8] and may have an advantage over conventional plates. However, there is no adequate data to indicate whether these plates have any particular advantage in the presence of bone loss.

There are other drawbacks when using plates in conjunction with bone loss. Lengthening of the bone is feasible with a nail but is much more difficult when a plate has been used for fixation. A plate spanning a segmental defect will prevent use of distraction osteogenesis or segmental bone transport. Therefore, plates are seldom the treatment of choice in diaphyseal fractures with bone loss, but they continue to be useful for metaphyseal and articular defects where other methods of fixation may not be as readily applied (Fig. 2).

External fixation. External fixation is a versatile method of treating fractures with bone loss and may be deployed in almost any location (Table II). Modern frames have a number of advantages. Circular frames such as the Ilizarov are useful with extensive defects, particularly if distraction

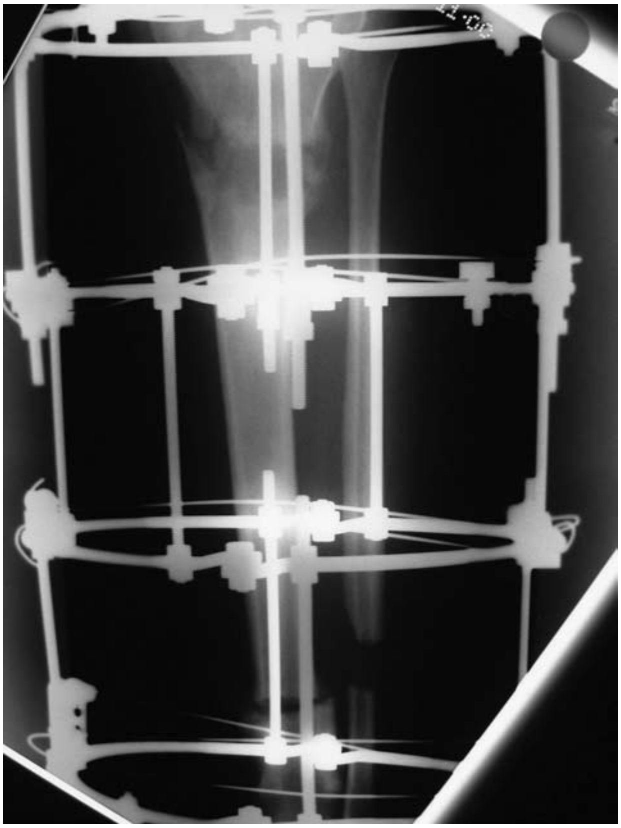

Fig. 3a

Fig. 3b

Figure 3a – Bone transport in the tibia being carried out using a circular frame. Figure 3b – Long leg radiograph showing outcome after union.

osteogenesis is being planned, or if there is an additional deformity requiring correction. Shortening of the bone can be used to facilitate closure of soft tissue defects,[9] with the frame being subsequently used to restore length (Fig. 3). External fixators can be used in the lower limb in conjunction with intramedullary nailing for bone transport. Frames have the advantage that they can be used in any location and in peri-articular defects with short juxta-articular segments. Depending on the design of the frame they can be used to lengthen and transport bone, and correct deformity.

As with other methods, external fixation has specific drawbacks. It may not be possible to remove the frame for many months and pin-track infections may require medical or surgical treatment. This is particularly the case in the femur and humerus. Fine-wire fixators applied too close to joints, particularly the knee, can result in septic arthritis.[10] In the lower limb, the unilateral frames designed for fixation of fractures are not strong enough to maintain alignment in the presence of a segmental defect, resulting in an increased risk of malunion. Compliance with frames when they are in place for long periods can be a problem.

Allograft. Allografts can be considered in some situations. They have been used in conjunction with bone morphogenetic protein (BMP) in nonunion with bone deficiency in the femur.[11] Loss of a major articular component of a joint surface following trauma is fortunately rare, but in younger patients fresh allograft replacement of the joint surface may be considered as an alternative to arthroplasty.

Bone substitutes and growth factors. There is increasing interest in the use of osteogenic and osteoinductive materials for stimulating bone formation. Clinical experience with these materials is limited, particularly in the presence of bone loss. In a trial of bone graft or osteogenic protein-1 (BMP-7) in nonunion in the tibia the success of the two methods was similar.[12] In another randomised trial of open fractures of the shaft of the tibia, patients treated with a BMP-2 implant healed significantly more rapidly than those in the control group.[13] There are many animal studies showing that various BMPs with carrier materials may be useful in stimulating bone formation. However, as yet, there is no osteogenic or osteoinductive material of proven clinical value for the treatment of significant post-traumatic bone loss in humans. Extensive research is currently being carried out investigating suitable carrier materials which will deliver growth factors at the appropriate time and dose to stimulate bone formation.[14]

Osteoconductive materials such as calcium phosphate cement have been used to fill small bone defects following

Fig. 4a

Fig. 4b

Radiographs showing result at two years of minimal internal fixation and calcium phosphate cement used to treat a tibial plateau fracture.

fractures, notably in the distal radius, the proximal humerus, the tibial plateau (Fig. 4) and the calcaneum.[15-19] However, these materials are only suitable for use in relatively small contained metaphyseal defects since they have poor resistance to torsional, shear or bending stresses. These physical limitations and the absence of any osteoinductivity or osteogenicity render them unsuitable for use in the presence of extensive bone loss.

Free fibular grafts. These have been used to bridge diaphyseal defects.[20-24] With the advent of better techniques of lengthening and bone transport, this procedure is used less frequently. However, the graft can be used to bridge defects of up to 20 cm (Table II). The bone is vascularised and therefore remains viable. It is an autogenous graft with structural strength.

The disadvantages include the complex nature of the surgical procedure with the risk of failure of the vascular anastomosis. The graft may fail to unite to the host bone either proximally or distally. There is usually a mismatch in size when used in the lower limb to bridge femoral or tibial defects and the graft may fracture. Prolonged partial weight-bearing may be required to minimise the incidence of this complication. It has limited application for metaphyseal defects due to constraints in shape. Precise restoration of length may be difficult to achieve. A recent comparison of this method with bone transport in the femur indicated that superior results were obtained with the latter method.[24] However the technique remains useful for treatment of segmental defects in the upper limb. A vascularised fibular graft may be used in the forearm. Function can be surprisingly good, but this option is generally reserved for major bone loss. An alternative is the creation of a one-bone forearm.[25] This can be accomplished by medial translocation of the radius to place it in continuity with the ulna.

Tibial synostosis. Creation of a proximal and distal tibiofibular synostosis, fibula pro tibia, may be used to manage diaphyseal defects of the tibia.[26-28] It is another procedure that has been largely superseded by more modern techniques but has the advantage that it can be used for a large defect without the need for sophisticated skeletal fixation or complex procedures for soft-tissue cover. It may be useful where modern facilities are not available. It has drawbacks in that a fracture may occur and nonunion at either end is a risk. Furthermore, the fibula may not hypertrophy adequately, in which case there is persistent pain.

Amputation. Although amputation is seldom regarded as a palatable option by either patient or surgeon, it may be a wise choice in some situations. The indications for amputation have already been discussed. However, in the largest study to evaluate factors influencing the decision to carry out amputation of a lower limb, the degree of bone loss was not a significant factor.[29] The severity of the soft-tissue injury and the absence of plantar sensation were the most important considerations.

Other general factors need to be taken into account.[30] Some patients may be poor candidates to undergo a prolonged reconstructive procedure involving limb lengthening or bone transport for social or medical reasons. Elderly patients or patients with other risk factors such as smoking, alcohol abuse, steroid treatment, diabetes and occlusive arterial disease, may be better advised to accept amputation rather than risk a prolonged attempt at limb reconstruction with multiple surgical interventions and a high rate of complication. The available evidence suggests that in patients with severe limb injury the functional outcome and the chance of returning to work is no different with amputation or limb salvage.[30]

Specific problems

The majority of defects encountered can be treated with conventional methods of fixation augmented by bone grafting. Larger defects need consideration of bone transport techniques. An algorithm summarising a suggested plan for management is given in Figure 5.

Diaphyseal defects

Internal fixation. There is a reasonable amount of information in the published literature on which to base a choice of treatment for diaphyseal defects in the lower limb. Femoral defects of up to 15 cm can heal spontaneously after intramedullary nailing and patients with loss of bone up to this magnitude can be observed up to 20 weeks before further intervention is indicated.[31,32] In general the best choice of fixation for most of these fractures is a locked intramedullary nail. Autogenous bone grafting will usually be successful in obtaining union in cases where spontaneous healing does not occur.

Defects of the tibia have a less favourable prognosis. Loss of less than 50% of the circumference or of a segment of less than 2 cm in length may heal spontaneously or with exchange nailing.[33] Larger defects usually require further intervention. Bone grafting of deficiencies of up 6 cm can be successful after nailing. If the defect is larger alternative treatments should be considered.[34]

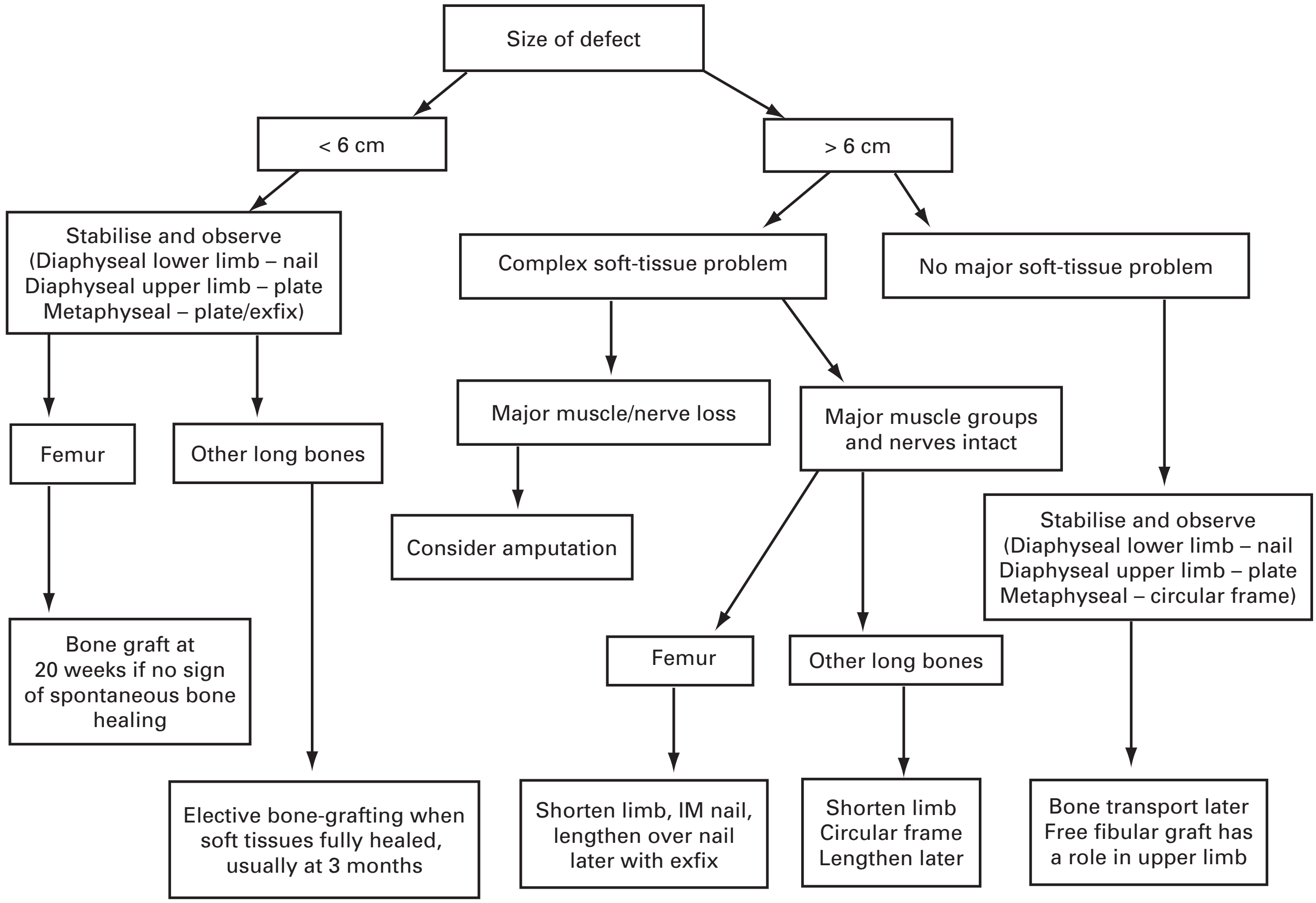

Fig. 5

Algorithm for management of bone loss.

There is little information as to the extent of management of diaphyseal bone loss in the upper limb. However, the available evidence indicates that 6 cm is probably the upper limit which can be addressed by autogenous bone grafting. Plating is the current treatment of choice for fractures of the shaft of the humerus and of the forearm. However with significant segmental defects intramedullary nailing may have to be considered, particularly in the humerus where there are locking nails available. In open fractures, bone grafting may be carried out early if there are no problems with soft-tissue cover. If there is extensive contamination or a severe soft-tissue injury, delayed reconstruction of the defect is preferable.

Bone shortening and staged reconstruction. For defects in excess of 6 cm, one option is to shorten the bone at the time of the initial surgery, apply a circular frame and create a corticotomy through a healthy area of bone away from the zone of injury. The bone can then be lengthened at the same time as obtaining bony union. This procedure should be considered if the associated soft-tissue defect is shorter than that of the bone. Shortening the leg will reduce the size of the soft-tissue defect and may avoid the need for a free flap.[35] Later, one stage lengthening followed by plating or nailing is possible,[36,37] but the length regained by this method is limited, with an average of 4 cm, and despite supplementary bone graft being used, nonunion and delayed union are significant risks. In the upper limb, shortening of 2 to 4 cm may be tolerated without significant functional impairment, obviating the need for subsequent lengthening.

Lengthening can be accomplished over the nail after union by carrying out a closed intramedullary osteotomy and applying a uniaxial fixator.[38-40] The disadvantage of this approach is the risk of deep infection developing as a consequence of pin-track infection. More recently intramedullary nails have been developed with lengthening capacity which should overcome many of the disadvantages of combining intramedullary nails with external fixation. In the tibia, it is rarely possible to carry out closed intramedullary osteotomy, bone regeneration is less certain and the risk of infection is probably greater. Bone shortening and subsequent lengthening is associated with a lower complication rate than bone transport techniques.[41-44]

Bone transport. The use of a frame to carry out callotasis or bone transport to bridge a defect is an alternative to shortening for longer defects. Circular frames are now more popular than uniaxial devices since they confer greater stability and there is more flexibility in the configuration of the frame. There is also more scope for correcting rotational or angular malalignment which may occur during the course of treatment.

Vascularised free fibular grafts. For defects in excess of 6 cm, external fixation and bone transport can be used in the upper limb. However, the use of osteoseptocutaneous free fibular grafts has been associated with excellent functional and cosmetic results. The size of the fibula is also more appropriate for use in the arm. When an injury to the forearm is deemed unsalvageable, the creation of a one-bone forearm remains an option.[25]

Metaphyseal defects. Plating and bone grafting are the mainstay of treatment for metaphyseal fractures with bone loss. The prognosis is generally better in the femur than in the tibia and even large defects can be observed initially since some will heal spontaneously. For more significant defects of up to 6 cm plating and bone grafting can be considered as an elective procedure. Intramedullary nailing can be used in the femur and tibia if there is sufficient distal metaphysis to engage a locking nail. For longer defects, the same options exist as for diaphyseal deficiencies. The treatment of choice in the tibia is probably a circular frame with bone transport or elective shortening at the time of application of the frame, with subsequent lengthening.

Articular defects. Post-traumatic articular defects are fortunately uncommon but a large loss of joint surface presents a considerable problem in management. Small defects can probably be ignored if there is no instability of the joint. Larger defects will require consideration of the use of an allograft or an arthroplasty. For small joints in the hand or foot where articular loss and damage may be encountered in open injuries, fusion is a good option in most cases.

Fresh articular allografts following trauma have mainly been described in the knee, usually for fractures of the tibial plateau.[4,45-49] Allografts were considered for use with defects of more than 3 cm in diameter and 1 cm deep. Their survivorship has been reported to be 95% at five years, 80% at ten years and 65% at 20 years. Failure is more common in patients over 50 years, in the presence of malalignment of the limb and of damage to the adjacent articular surface of the femur. Experience with articular allografts elsewhere has been limited but they have been used in the elbow for unreconstructable fractures of the distal humerus[49] and for metacarpophalangeal defects[50] following trauma. The indications for allografts are limited to younger patients with significant defects.

Arthroplasty can be considered as a more readily available alternative for most situations involving articular defects. Arthroplasty is available for most joints and is indicated in older patients. For some joints, such as the ankle, wrist and interphalangeal joints, fusion is a reasonable alternative.

Conclusion

Bone loss is a relatively uncommon problem encountered in the treatment of open fractures and usually occurs in the femur and tibia. Bone loss in the upper limb and of articular surfaces is rare. Numerous techniques are now available. The majority of defects are small and can be managed with standard methods of fixation and autogenous bone grafting. Larger defects with complex soft-tissue problems can be managed by shortening and fixation with later lengthening. New intramedullary lengthening nails may have a role to play. If there are no major problems with soft tissues, fixation and later bone transport can be considered. Circular frames are particularly useful for more complex problems. Free fibular grafts now have a more limited role but are still useful in the upper limb. In the future bone morphogenetic proteins in an appropriate carrier may prove useful. Restoration of satisfactory limb function is the main aim and if there is extensive soft-tissue damage, amputation may be preferable.

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