Current management of long bone large segmental defects

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Abstract

Large segmental defects of long bones comprise a complex pathology resulting from a variety of aetiologies. Their prolonged, painful and uncertain treatment is usually beset with a range of consequences for the patient, varying from the psychological to the socioeconomic. Trauma, osteomyelitis, bone tumour resections or treatment of congenital deformities are main causes of bone deficiency. Their treatment has been thoroughly studied for the last 35 years and both vascularized bone grafting and distraction osteogenesis with the Ilizarov technique have emerged as gold standards. Novel techniques have arisen during the last 10 years, giving new perspectives to the management of this problem. Intramedullary lengthening devices, bioactive membranes, osteogenic proteins and tissue engineering are the new weapons in the armamentarium of orthopaedic surgeons. This study describes the aforementioned treatment techniques (classic and novel) and elaborates on their indications, advantages/disadvantages and complications. Algorithms for the assessment and treatment of critically size long-bone segmental defects are also proposed.

Keywords bone defects; fixation; fracture healing

Introduction

Bone healing and reconstruction after traumatic or non-traumatic lesions are processes involving a cascade of cellular, humoral, and mechanical events culminating in the reestablishment of bone integrity. Surgical intervention, if needed and undertaken, should facilitate timely recovery and may be categorized depending on the nature of the bone lesions being addressed. When these lesions are long-bone segmental defects of the upper or lower limbs specific considerations shall be taken into account, depending on the cause, the grade of the defect and any existing commorbidities.

High energy trauma, diseases, developmental deformities, revision surgery and resection of tumour or osteomyelitis are the main causes of long-bone defects.[1] Based on several animal studies, critically-sized defects are defined as ‘‘the smallest osseous defect in a particular bone and species of animal that will not heal spontaneously during the lifetime of the animal’’.[2,3] Alternatively they have been defined as segmental bone deficiency of a length exceeding 2–2.5 times the diameter of the affected bone.[4,5] However it is not only the length of the bone defect that may characterize a bone defect as critical, but a number of variables. These variables include location, associated soft tissue and biomechanical problems in the affected limb, age, metabolic and systemic disorders and related co-morbidities that may affect bone healing.[2,5–10] These factors impede the implementation of an overarching classification pattern for long-bone defects, comparable to those existing for fractures in general. Moreover, the complexity of potential co-morbidities (soft-tissue defects, inflammation) and the variety of predisposing causes (developmental, post-traumatic, tumours, osteomyelitis) have not allowed a single surgical technique to become established as the treatment of choice.

For relatively small bone defects with adequate soft-tissue coverage, the bone gap can usually be bridged with conventional cancellous bone grafts or bone substitutes.[11] However, most authors[12,13] do not advocate this technique when the defect exceeds 4–5 cm. Partial resorption of the graft and revascularisation by creeping substitution result in a weakness of the reconstructed segment, predisposing to iterative fractures.[14] Thus, for segmental bone defects larger than 4–5 cm, with or without a soft-tissue defect, the need for more specialized management becomes essential.[15] The two methods that have prevailed lately are vascularized fibular grafting (VFG),[16–19] and distraction osteogenesis or internal bone transport (IBT) with an external fixator (Ilizarov technique).[20–23] Apart from these two well known techniques, several other novel approaches have been examined over the years.

This paper presents the current concepts of management of large, long-bone diaphyseal defects (> 5 cm) and discusses the indications, limitations and complications of each of the commonly used surgical techniques.

Vascularized bone graft

Various donor sites can be used for vascularized bone grafting, such as the iliac crest, ribs or the fibula.[15] The accompanying skin paddles (fibula, rib, ilium) or muscle components (latissimus dorsi and serratus anterior in rib flaps) may be harvested at the same time. Thus, reconstruction of combined soft-tissue and bone defects caused by trauma, tumour ablation, or chronic osteomyelitis, can be provided by this technique.[15] There are also indications for use in smaller defects, where improved blood supply is needed for healing.[24,25] The fibula is generally accepted as the most suitable vascularized bone graft for the reconstruction of composite segmental long-bone defects.[16,26–33] It provides up to 25 cm of high-density, straight cortical bone with a good vascular pedicle and minimal donor-site morbidity.[16,26–32,34] The ability to fold the graft into two or three segments with

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preservation of the vascular pedicle is another advantage of the fibula. This allows for the reconstruction, for example, of massive bone defects in the midshaft of the femur.[18,35–37] However, in some cases when the fibula is not available, the iliac and serratus anterior-rib flaps become useful alternative choices.[38] In contrast to fibula, the iliac crest[31] has an undesirable curvature, limited length (usually less than 10–12 cm), and an unreliable skin paddle that often limits its clinical application.[39] The serratus anterior-rib flap also has an unfavourable curvature and less bone mass with little mineral and, therefore, is seldom used for long-bone reconstruction.[40] Nonetheless, both flaps have been successfully used in lower-extremity reconstruction.[31,38,41,42]

It has been stated[34] that a vascularized fibula graft should be protected during the first year but loading should gradually increase to enhance remodelling and hypertrophy of the graft. Protection is provided by internal or external fixation. Minami et al.[43] advocate the use of external fixator frames which can provide adjustable load-sharing and mechanical alignment of the fibular graft eliminating the chance of stress fracture. In general the vascularized fibular graft technique is a useful procedure for the reconstruction of massive bony defects. The free fibula flap can be used in three major types of reconstructive combinations: vascularized fibula flap combined with an allograft (additional strength provided – useful for tibia defects); vascularized fibula flap as a sole bony replacement (humerus defects); and vascularized double-barrelled fibula (indicated for femoral defects).[44] Postoperative complications can be minimized by meticulous planning of the procedure. Important considerations include the choice of vessels for anastomosis in the recipient, the method of anastomosis (antegrade or retrograde, end-to-end or end-to-side), the use of a vein graft, the type of fixation device and the introduction of the graft without angulation.[43]

Circular frame (Ilizarov) lengthening techniques

Circular frames, with the Ilizarov device as their main representative, have been successfully used to stimulate the healing of long-bone fractures or non-unions.[45–49] Moreover they provide a very good solution to the treatment of long-bone defects of any aetiology and at any site of the body.[22,50–58] External fixator lengthening systems require an understanding of how mechanical forces are used to induce two separate biological processes: distraction osteogenesis and transformational osteogenesis.[58] Distraction osteogenesis is the *de novo* production of bone between corticotomy surfaces undergoing gradual distraction.[58] Histologically, this process strongly resembles intramembranous ossification, as seen in periosteum.[59,60] Transformational osteogenesis is the mechanical stimulation of a pathologic bony interface (e.g. non-union) to regenerate normal bony continuity.[58] Bone transportation involves moving a free segment of living bone, which has been previously corticotomised, to fill intercalary bone defects with vital bone. The trailing end of the transport bone segment maintains continuity with the host bone surface by distraction osteogenesis. The leading end of the transport bone segment fuses to the target bone surface by transformational osteogenesis. The transportation device usually consists of a non-invasive universal system of ring external fixators with tensioned transosseous wires. The small diameter of the transosseous wires contributes to better patient tolerance over the prolonged treatment times required for gradual distraction at 1 mm per day.[58] Because the Ilizarov external fixator is circumferential, bone transportation or distraction osteogenesis can be carried out in either axial or angular directions, or indeed both simultaneously. In fact, the device can be adapted for correction of rotational alignment as well.[58] The use of modern monolateral external fixation with static and dynamic compression capabilities and hydroxyapatite-coated pins is an alternative to the use of circular frames. Monolateral external fixators allow early partial weight bearing and, moreover, both pin track infection and loosening rates are reduced.[61,62] The management of a soft-tissue defect is easier with monolateral external fixation than with a ring fixator, which may impair the harvesting of a local flap.[63]

Treatment time is divided into three consecutive periods: latency, distraction, and consolidation.[64] The latency period is the time from osteotomy until distraction begins, usually seven days. During the distraction period, the apparatus is adjusted by 1 mm per day at a rhythm of 0.25 mm four times a day. This produces a gradually elongating distraction gap (DG) between the bone ends. The distraction phase ends when either the lengthening is completed or terminated because of complications or patient non-compliance. The last, and longest, phase is the consolidation period. During this time, the newly formed bone in the DG is allowed to bridge and corticalize. The apparatus is left in place until the new bone is judged to be strong enough to allow apparatus removal without shortening, bending, buckling, or fracturing the newly formed bone.[64] Full weight-bearing and active range of motion (ROM) exercises, which are important for rapid healing, are permitted if the system has been properly adjusted; however, sometimes they may be difficult to enforce.[58] Factors that may affect the rate of healing include the patient's age, the defect size to be lengthened, and the level or levels of corticotomy.[64] Two levels of corticotomy reduce healing time compared to a one level corticotomy.[53] Healing time may also be reduced by several other modifications, such as pre-grafting the docking site,[65] acute shortening of part or all of the bone defect with gradual re-lengthening and transport over an intramedullary nail.[66] Concerning the soft tissue that surrounds the augmented bone, in a similar process to distraction osteogenesis, distraction histogenesis has been used for skin expansion.[67] Flap coverage also works well[20,68,69] with bone transport under a healthy soft-tissue envelope. Several reports[65,70,71] however, show that synchronous bone and soft-tissue transport can be successful, avoiding the need for a flap. The final choice will depend on the surgeon's preference and availability of plastic surgery expertise. Other factors, such as vascular anatomy and medical co-morbidities, should also be taken into account.[53]

In conclusion, 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's collaboration are needed for a successful result.

