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ORIGINAL ARTICLE

Bone transport techniques in posttraumatic bone defects

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KEYWORDS
Bone transport;
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Summary
Introduction: The treatment of posttraumatic diaphyseal bone defects (BD) calls on a number of techniques including bone transport techniques: isolated shortening, compression-distraction at the fracture site, shortening followed by lengthening in a corticotomy distant from the site and segmental bone transport.
Patients and methods: The multicenter retrospective study combined 38 cases: 22 cases of initial diaphyseal bone defect and 16 cases of secondary diaphyseal BD, sometimes associated with metaphyseal or metaphyseal-epiphyseal BD, involving the humerus, the forearm, the femur and the tibia. These techniques were mainly used on the lower extremity (33 cases), for the most part on the tibia (22 cases) in young men.
Results: Bone healing was acquired in 37 cases out of 38 after a mean 14.9 months (range, 6—62 months). A mean 4.3 secondary interventions were required to obtain final union; most notably, a bone graft was necessary at the docking site for the segmental bone transport procedures.
Discussion: Many reconstruction techniques can be proposed to treat posttraumatic BD. None responds to all situations. Bone transport techniques have their place and their indications. Isolated shortening is intended for bone loss not exceeding 3 cm, notably in the humerus and to a lesser degree in the lower extremity. Shortening associated with lengthening is valuable in the femur and the tibia for bone loss up to 6 cm. Segmental bone transport is the only technique that can treat bone defects associated with shortening in the lower limb.

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For substantial bone loss beyond 10 cm, segmental bone transport is particularly indicated. However, these cases of substantial bone loss tend to be resolved by a hybridization of the procedures. The distraction gap of a bone segment can, for example, be prepared using an induced-membrane technique.
Level of evidence: Level IV. Retrospective study.

Introduction

The major technical options for the reconstruction of traumatic diaphyseal bone loss are traditional bone grafting (in the leg including the intertibiofibular graft and tibialization of the fibula), vascularized bone transport, the induced-membrane technique and bone transport techniques [1—6]. The latter can be categorized as follows:

- isolated shortening, whose limitations will be discussed below (S);
- shortening followed by immediate or deferred lengthening, with a distinction between lengthening by distraction in the nonunion area after a short period of compression (CD) and lengthening in a corticotomy area distant from the fracture site (S + L);
- vertical segmental bone transport (SBT), based on progressive transport of a bone segment after corticotomy.

Apart from isolated shortening, bone transport techniques are founded on the notion of osteogenesis by distraction whose principles were described by Ilizaroz [7] and refined by Cattaneo [8]:

- bone compression and distraction are provided by dynamic external fixation that allows weightbearing on the lower limb;
- distraction distant from the fracture site, performed after corticotomy in the metaphyseal zone, keeping the periosteum and the endosteum intact, thus transporting a bone segment 1 mm per day, in four maneuvers regularly spaced over 24 h.

The French reference series published in 1989 [9] comes from the Association for the Systematic Study of the Ilizarov Method Application in France (Association pour l'étude systématique de l'application de la méthode d'Ilizarov en France [ASAMIF]), which grouped 39 cases of nonunion with bone loss.

The objective of the present study was to analyze the files of patients treated for traumatic bone loss to assess the techniques used and detail their indications.

Patients and methods

This retrospective multicenter study investigated 38 cases extracted from a group of 204 patient files (18%) reviewed in the SoFCOT[1] symposium. The extent of the bone loss was divided into four groups (< 2 cm, 2—5 cm, 5—10 cm and > 10 cm) and classified according to type B of the Catagni classification [10], which breaks down nonunion with bone loss into:

- type B1: the length of the limb segment is preserved;
- type B2: the limb segment is shortened but there is contact between the bone extremities;
- type B3: the bone loss is associated with shortening of the limb segment.

Bone transport techniques have been applied in cases of diaphyseal bone loss, isolated or sometimes associated with metaphyseal or metaphyseal-epiphyseal bone loss, whether they be immediate, contemporaneous with the injury, or secondary in cases of septic nonunion requiring bone resection. The locations were the humerus (four cases), the forearm (one case), the femur (11 cases) and the tibia (22 cases).

The reconstruction techniques used were isolated shortening (S), compression followed by distraction (CD) (Fig. 1), shortening associated with lengthening after corticotomy (S + L) and segmental bone transport (SBT) (Fig. 2).

One patient out of two was treated between 1985 and 1995. The mean age was 24 years (range, 6—65 years), but one patient out of five was less than 16-year-old. Twenty-eight cases out of 38 had experienced a motor vehicle

Figure 1 Osteogenesis in distraction with new bone formation between the two bone extremities that are progressively moved apart.

[1] Report present at the symposium: ''Treatment of posttraumatic diaphyseal bone loss'', 85th annual SoFCOT meeting, Paris, November 2010.

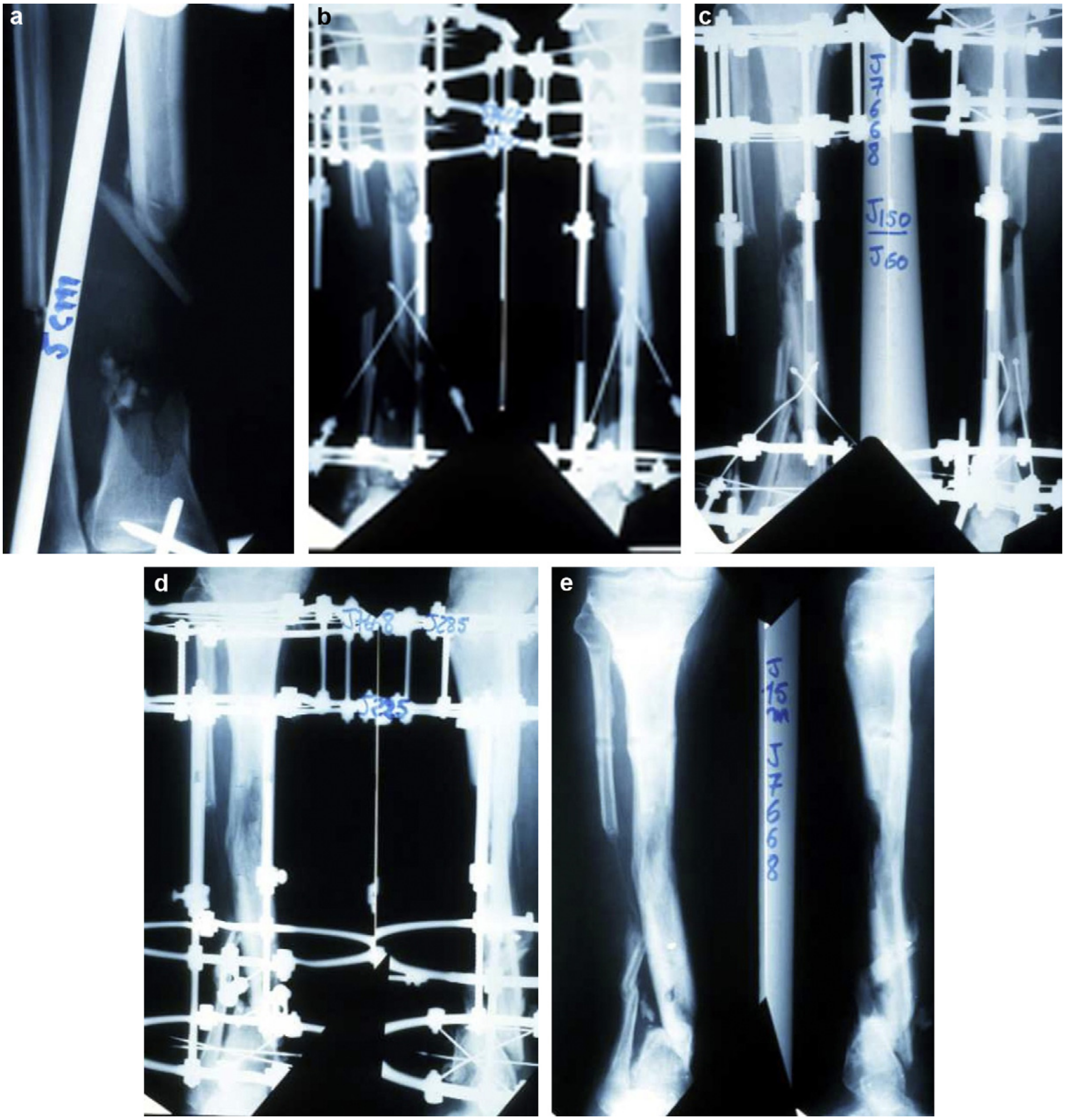

Figure 2 a—e: posttraumatic tibial bone loss. Segmental bone transport (SBT) reconstruction with progression of the bone segment and consolidation acquired (courtesy P. Merloz).

accident and five cases gunshot wounds. Thirty-six fractures were open (11 Cauchoix stage 2 and 25 stage 3). Four vascular lesions required revascularization. For the 14 open fractures with no initial bone loss, infection caused half of the secondary bone loss (8/14). At the time bone loss treatment was initiated, 18 were infected. The bone loss treatment was immediate in 14 cases and delayed in 24 cases, with a mean delay of 12 months (with a mean 6.2 interventions beforehand). Bone loss was mostly located in the middle third of the diaphysis (11 cases) and at the distal diaphyseal-metaphyseal level (nine cases).

Bone transfer techniques were used no matter how extensive the bone loss (Fig. 3). Catagni types B2 and B3 were greater in number and were treated with CD or SBT (Fig. 4). Substantial bone loss was located in the lower limb (Fig. 5). The techniques using osteogenesis in distraction were essentially used in the lower limbs, whereas isolated shortening was used preferentially in the tibia and the humerus (Fig. 6). Shortening of the limb segment was initially present in 74% of the cases.

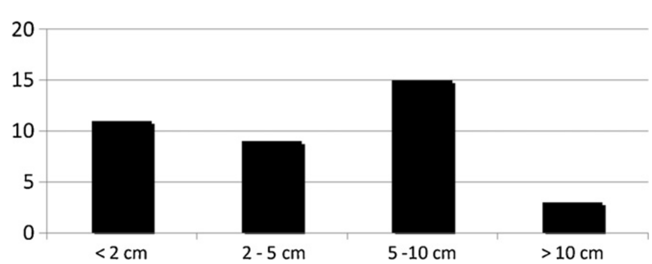

Figure 3 Number of patients treated with bone transport according to the extent of bone defect.

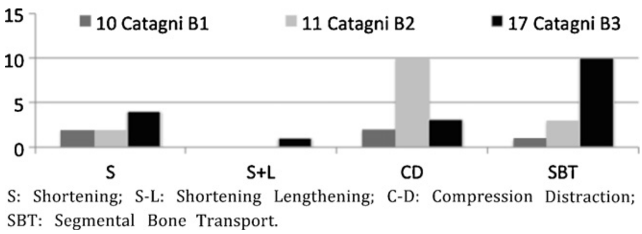

Figure 4 Bone transfer techniques used versus Catagni stage.

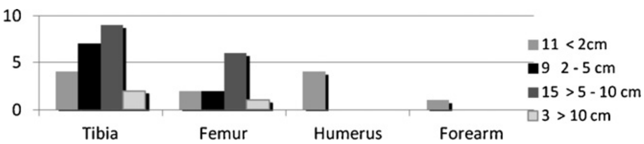

Figure 5 Number of patients in relation to the extent of bone loss versus anatomical location.

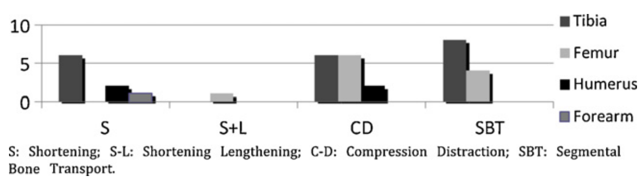

Figure 6 Techniques used in relation to the anatomic location of bone loss.

Results

Consolidation was achieved in 37 out of 38 cases in a mean 14.9 months (range, 6—62 months) (femur, 17.2 months; tibia, 14.3 months; humerus, 11.2 months), identical to the overall series. In one case, after 2.5 years of treatment and nine interventions, several repeated infectious episodes led to amputation at the thigh.

The consolidation index per centimeter of bone loss was 5 months per centimeter at the femur and 3 months at the tibia.

The patients underwent a mean 4.3 secondary interventions (tibia, 5.38; femur, 4.0; humerus, 1.5). Bone grafts at the docking site in the SBT procedures were necessary in half the cases (five intertibiofibular grafts out of ten SBTs, two cancellous bone grafts out of four femoral SBTs).

Seven infectious episodes required complementary debridement. One regenerate fracture and one iterative fracture of the site consolidated after a new stabilization procedure.

Eleven cases of residual shortening were noted, with the mean length being 10 mm. In eight cases, this was a planned choice. However, in three cases, the shortening was subsequent to a partial failure of the technique. Stiffness was frequent: six cases in the knee and nine cases in the ankle. Two cases were the direct consequence of the bone transport technique.

Discussion

The only statistically significant criterion with the symposium's overall series (204 cases of bone defect) was the inclusion period. The preferential recruitment period, from 1985 to 1995, can be explained by the introduction of distraction osteogenesis techniques in France in the mid 1980s. After 1995, other techniques such as the induced-membrane technique, progressively took precedence.

Secondary bone loss is for the most part subsequent to development of sepsis, which explains the delayed management of the bone loss in these cases and the high number of previous interventions, in accordance with the data reported in the literature [11].

The analysis of the series makes it possible to propose a bone transport technique according to the extent and location of the bone loss:

- isolated shortening, stabilized by internal osteosynthesis or external fixator, has its place in bone defect limited to 3 cm, with two preferential indications: the humerus and the tibia. In the lower limb, compensation of the discrepancy is necessary and late lengthening can be discussed secondarily in terms of the functional repercussions. In the humerus, shortening up to 3 cm does not substantially alter the biomechanics of the elbow [12];
- the initial shortening is most valuable when it is associated with a bone distraction technique (S + L) performed in a corticotomy distant from the fracture site [1] (Fig. 1). This nearly immediate shortening with progressive lengthening is a technique to balance with segmental bone transport. Other than a delay in consolidation and therefore maintaining the external fixator for a shorter period of time [2,3], the shortening provides immediate covering for the fracture site. Compression of the site allows its consolidation with no complementary procedure. Transport in distraction after proximal corticotomy prevents the risk of misalignment that can be observed during the progression of the bone fragment in SBT. However, beyond 6 cm of bone loss, telescoping the soft tissues does not lead to shortening with contact between the bone extremities and presents a vascular risk. Finally, in the leg, shortening implies resecting a segment of the fibula.

Catagni types B2 and B3 have been treated with compression-distraction or segmental bone transport. Only these two bone transport techniques can recuperate the bone length, a problem common to types B2 and B3.

The compression-distraction shortening-lengthening technique at the fracture site is intended for limited bone defect that does not exceed 3 cm in the tibia, femur, or humerus. Comparison with the SBT technique shows comparable delays in consolidation, but CD only requires a small number of complementary procedures because the risks of misalignment and absence of consolidation at the contact site are low [3].

SBT is most particularly aimed at Catagni type B3 bone defect because it can fill the bone loss and recuperate shortening [10]. SBT's main indication is substantial bone defect greater than 10 cm in the femur and tibia.

The consolidation index per centimeter, the reference in the literature in the assessment of bone transport techniques, was very high in the symposium series (5 months/cm in the femur, 3 months/cm in the tibia). Because of the strict consolidation criteria retained by the symposium, it is not possible to compare this series with the data reported in the literature, for which the mean index is 2—3 months per centimeter.

At the end of bone transport, SBT frequently requires a secondary autograft to obtain final consolidation at the docking site, which is in agreement with the data reported in the literature [3,13]. This graft is nearly systematic for Songet al. (25/27 cases) [4] to prevent repeated fractures and nonunion. For Paley et al. [5], 6 months of contact are necessary for consolidation. The complementary graft should be conceived as part of the technique and be planned for from the beginning of treatment. This procedure is recommended to reduce the duration of treatment.

Anatomic and functional sequelae, far from being exceptional, are not solely the consequence of the transport techniques, but also the associated preexisting lesions [11]. However, one must be aware that bone transport procedures that rely on the principles of osteogenesis in distraction and most particularly, the SBT technique require extensive experience in these indications, rigor in the treatment process, scrupulous respect of the technical rules and patient cooperation on penalty of abandoning the treatment before it is completed [9,11].

These techniques do not obviate the need for elementary debridement and excision of infected tissues because bone infection is not healed by the simple compression of the fracture site [13,14]. All fixation procedures are acceptable as long as they ensure the indispensable stability. They should control the stresses harmful to osteogenesis (notably torsion) and provide the stresses that are favorable in compression-distraction during loading, while allowing mobilization of the neighboring joints. The monolateral fixator is certainly more comfortable, in particular for the femur, but the circular device is probably more easily adjusted and modified during segmental bone transport (Fig. 2).

Certain requirements should be underscored:

- initial realignment should imperatively be corrected before beginning SBT;
- attentive monitoring of segmental bone transport should prevent risks of misalignment, wire rupture or infection and joint deformities;
- the trophicity of the soft tissues should be maintained and the indication for bone grafting at the point of contact should be entertained.

Composite deformity of the soft tissues and the bone is a difficult problem. For El-Afy et al. [15], prior restoration of the envelope of the soft tissues is an essential step. Even if segmental bone transport can be accompanied by regeneration of the soft tissues, provided that minimal covering of the bone extremity of the transported segment is provided, the notion of reconstruction space must not be ignored. Precarious covering is not compatible with SBT. Providing high-quality covering with a flap before beginning segmental bone transport is a prerequisite, as is using a cement

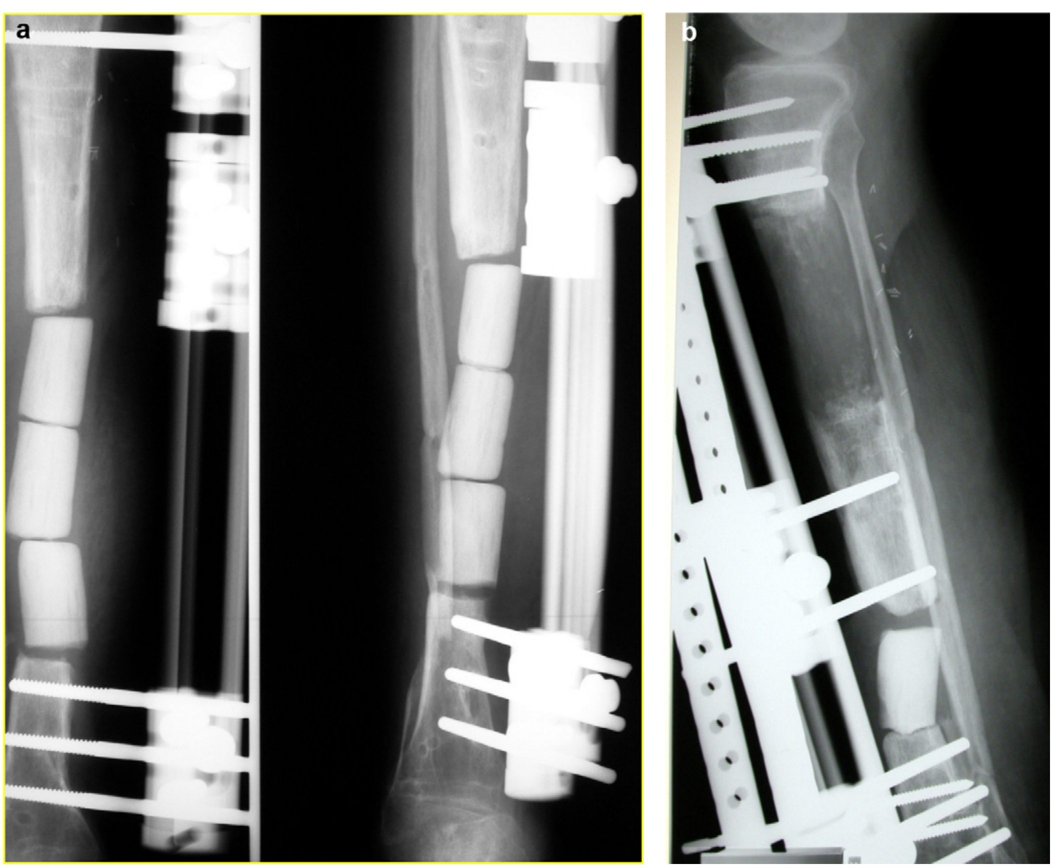

Figure 7 a and b: segmental bone transport within a reconstruction space induce by a segmented cement spacer for progressive ablation adapted to the migration of the transported segment (courtesy P. Tripon).

spacer to manage the transport space [16], even a segmented cement spacer that can be progressively removed [17] (Fig. 7).

Conclusion

The time to consolidation of bone reconstruction obtained using a bone transport technique is comparable to other reconstruction techniques for posttraumatic bone defect. However, no technique is universal. Analysis of this series has made it possible to specify the indications of bone transport techniques. Isolated shortening is designed for bone defect extending up to 3 cm, particularly for the humerus and to a lesser extent, the lower limb. Compression-distraction at the fracture site designed to recuperate shortening is also indicated for bone defect that does not exceed 3 cm. Shortening associated with lengthening distant from the fracture site is most valuable in the femur and tibia for bone defect extending up to 6 cm. Segmental bone transport is the only technique that can treat bone defect associated with shortening in the lower limb. For cases of substantial bone defect, beyond 10 cm, SBT is particularly indicated but should be discussed with other techniques such as vascularized bone transport and induced membrane. In all cases, the possibility of combining several techniques should be discussed. For example, the induction of a transport chamber using the induced-membrane technique can greatly facilitate a segmental bone transport; similarly, the pitfall of delayed consolidation at the end of the transport procedure can be avoided by systematic grafting, applied on the fibula.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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