Two-stage reconstruction of post-traumatic segmental tibia bone loss with nailing

T. Apard, N. Bigorre, P. Cronier, F. Duteille, P. Bizot, P. Massin

Bone Surgery Department, Angers Teaching Hospital Center, 4, rue Larrey, 49033 cedex Angers, France
Plastic Surgery Department and Burn Unit, Nantes Teaching Hospital Center, 30, boulevard Jean-Monnet, 44093 Nantes cedex 1, France
Orthopaedics and Traumatology Department, Bichat Hospital, Paris, France

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Summary
Introduction: Treatment of lower extremity segmental bone loss is difficult. Masquelet et al. proposed a two-stage technique: first, debridement and filling of bone loss with an acrylic spacer; second, bone reconstruction by filling with cancellous bone in the space left free (following cement removal) inside the so-called self-induced periosteal membrane. In the originally described technique, the fracture site is stabilized by an external fixator, which remains in place throughout the bone healing process, i.e., often longer than 9 months with all the known disadvantages of this type of assembly. Following the principle of two-stage reconstruction, we modified the technique by reconstructing around an intramedullary-locking nail placed in the first stage.

Hypothesis: This technique prevents the mechanical complications related to external fixator use and provides faster resumption of weight-bearing.

Patients and methods: Twelve patients were operated for segmental tibial bone loss greater than 6 cm resulting from injury (four cases) or aseptic necrosis (one case) or septic necrosis (seven cases). All the patients were operated on in an emergency setting and the first stage was performed before the 2nd week. A free muscle flap (ten patients) or a pediculated fasciocutaneous flap (two patients) was necessary during this first step to cover the site and provide good conditions for secondary bone growth. The follow-up was 39.5 months (range, 12–94 months).

Results: Complete weight-bearing was resumed at a mean 4 months. After the second step, all the patients except one had apparently healed (complete weight-bearing with no pain). Five septic complications occurred after the second step, in one case leading to reconstruction failure. Four other patients had infectious complications successfully treated (as of the last follow-up) either by changing the nail in two cases or by prolonged antibiotic therapy in two other cases, with no graft loss.

* Corresponding author.
E-mail address: thomasapard@yahoo.fr (T. Apard).

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Introduction

Reconstruction of extended diaphyseal bone loss in the tibia is difficult and calls on a variety of techniques: external fixation procedures or microsurgical techniques such as ascension of a corticotomized bone fragment with an Ilizarov fixator [1], a free vascularized fibular flap [2,3], or the osteomyocutaneous flap [4]. More recently, Masquelet et al. [5] described a two-stage technique in which bone is added sometime after the initial episode when the debridement and cutaneous healing conditions are satisfactory. This technique allows formation of a self-induced membrane around the acrylic spacer placed during the first stage, after initial debridement. According to its advocates, this self-induced membrane has a double mechanical and biological advantage: it prevents penetration of scar tissue in the bone loss area and it plays an osteoinduction role by producing growth factors (VEGF, TGF-β1) and an osteoinductive factor (BMP-2). This membrane is impermeable and hypervascularized. It prevents bone resorption and favors corticalization of the autograft [6,7].

In this technique, the bone is stabilized by an external fixator until union, with time to weight-bearing longer than 6 months in four cases out of 27 (15%) and secondary fractures (two cases before 3 months and two cases after 2 years) [5]. In addition, the fixator can disturb plastic surgery. Its stability can be compromised, with infectious complications at the pinholes [5]. The lower pins are sometimes very close to the talocrural joint, interfering with rehabilitation. While following the Masquelet technique, we modified the type of bone fixation by using an intramedullary-locking nail for static fixation in the first stage of 12 cases of extended bone loss in the leg. The objective was to achieve bone union while shortening the time required to resume weight-bearing and prevent secondary fractures. The associated question was to determine whether the advantages in terms of stabilization with nailing were associated with increased risk of sepsis.

Material and methods

Twelve patients (ten males and two females), mean age, 41 years (range, 18–74 years), were treated for a crush injury of the leg. Diaphyseal bone loss was a mean 8.7 cm (range, 6–15 cm), resulting directly from injury and debridement in four cases (mean, 8 cm; range, 6–12 cm), resection of necrotic bone for treatment of aseptic nonunion in one case (9 cm), and resection of osteitic bone for treatment of septic nonunion in seven cases (mean, 8 cm; range, 6–15 cm).

Debridement with bone resection was achieved without a tourniquet, with knife excision of the soft tissue and of devascularized, necrotic, or infected bone with a reamer (slow rotation) until reaching bleeding tissue. After diaphyseal washing, the bone was stabilized with a solid or hollow locking nail (Synthes®) for static fixation, with two screws above and two screws below the bone loss after restoration of tibial torsion in accordance with the opposite side. The length was also adjusted based on the opposite side, taking care not to cause lengthening or excessively stretch the soft tissues. The nail diameters ranged from 8 to 14 mm, sometimes requiring reaming to prepare the remaining diaphysis. The nail length was chosen so as to place the distal end as near as possible to the subchondral bone at the talocrural joint. Once stabilization was obtained, the bone loss area was filled with acrylic cement with gentamicin molded around the nail. In cases with substantial bone loss, the cement was applied in several interconnected pieces to facilitate later extraction. The fibula was not fixed.

Impermeable aspiration bandaging was placed and all the patients initially received hyperbaric oxygen therapy while waiting for plastic surgery performed by another surgical team of plastic surgeons a few days later (3–8 days), consisting in a free muscle flap in ten cases and a pedicled muscle flap in two cases.

Systematic antibiotic prophylaxis was administered beginning with debridement, associating beta-lactam and gentamicin administered intravenously for 4 days followed by the association of amoxicillin and clavulanic acid per os for approximately 3 weeks until the flap had healed. Dorsal flexion of the talocrural joint was treated with physical therapy. For the seven cases operated for septic nonunion with resection of osteitic bone, an intravenous vancomycin treatment was initiated and replaced by a double antibiotic therapy adapted to the bacteria found for at least 3 months.

The second stage of bone reconstruction occurred a mean 4 months (range, 2–6 months) after the first stage. One patient had to be reoperated for an infection between the two procedures. The nail was changed and the reconstruction stage took place normally after prolonged intravenous antibiotic therapy. In all cases, bone grafting was decided after complete healing of the soft tissues and normalization of the inflammatory biological constants. After bone harvesting from the two anterosuperior iliac crests (ten cases) or the four crests (two cases) with the posterosuperior crests (for substantial bone loss), the site was initiated at the edge of the flap, incising longitudinally the self-induced membrane to extract the pieces of cement by fragmentation. The cancellous bone grafts were then packed into the cavity bordered by the membrane around the nail. In four cases,
Table 1  Patients.

<table>
<thead>
<tr>
<th>Case</th>
<th>Age</th>
<th>Sex</th>
<th>Gustilo classification</th>
<th>Time from injury to 1st stage</th>
<th>Soft tissue procedures</th>
<th>Weight-bearing after 2nd stage</th>
<th>Postoperative infection</th>
<th>Bone defect (cm)</th>
<th>Follow-up (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>M</td>
<td>Closed</td>
<td>6 days</td>
<td>LMF</td>
<td>4.5</td>
<td>+</td>
<td>15</td>
<td>94</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>F</td>
<td>IIIb</td>
<td>45 days</td>
<td>FMF</td>
<td>4</td>
<td>—</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>M</td>
<td>IIIc</td>
<td>4 months</td>
<td>FMF</td>
<td>7</td>
<td>—</td>
<td>10</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>61</td>
<td>M</td>
<td>IIIc</td>
<td>3 months</td>
<td>FMF</td>
<td>5</td>
<td>—</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
<td>M</td>
<td>II</td>
<td>5 months</td>
<td>LMF</td>
<td>3</td>
<td>+</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>M</td>
<td>IIIb</td>
<td>19 days</td>
<td>FMF</td>
<td>5</td>
<td>—</td>
<td>6</td>
<td>61</td>
</tr>
<tr>
<td>7</td>
<td>38</td>
<td>M</td>
<td>IIIb</td>
<td>6 months</td>
<td>FMF</td>
<td>3</td>
<td>+</td>
<td>5</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>M</td>
<td>IIIb</td>
<td>Emergency</td>
<td>0</td>
<td>3</td>
<td>—</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>32</td>
<td>F</td>
<td>II</td>
<td>1 month</td>
<td>FMF</td>
<td>3</td>
<td>—</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>M</td>
<td>IIIc</td>
<td>2 months</td>
<td>FMF</td>
<td>3</td>
<td>—</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>43</td>
<td>M</td>
<td>IIIa</td>
<td>2 months</td>
<td>FMF</td>
<td>5</td>
<td>+</td>
<td>11</td>
<td>38</td>
</tr>
<tr>
<td>12</td>
<td>24</td>
<td>M</td>
<td>I</td>
<td>5 months</td>
<td>FMF</td>
<td>Failure</td>
<td>+</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Mean</td>
<td>40.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.5</td>
<td>+</td>
<td>15</td>
<td>39.5</td>
</tr>
</tbody>
</table>

LMF: local muscle flap (one case of flexor digitorum muscle and one case of lateral fibularis brevis muscle); FMF: free muscle flap (two cases of anterior serratus, two cases of rectus abdominis muscles and six cases of latissimus dorsi muscle).

Results

Table 1 summarizes the patient data.

The mean follow-up was 39.5 months (range, 12—94 months). Patients resumed weight-bearing a mean 4 months (range, 3—7 months) after the second stage. Bone union was considered acquired at the last follow-up in all cases except for one patient, in whom infection occurred in the weeks following bone grafting. A septic osteonecrosis focus on the fixator pins had not been recognized during debridement. After new debridement, including removal of the grafts, a modified Ilizarov bone transport technique was performed on the nail in place. In another patient, a nail fracture in the 13th month required changing the nail with no new complications at 25 months of follow-up.

In the ten other cases, union was obtained with the nail in place (Fig. 1), despite progression with scattered late infectious complications in four cases. These four cases of osteitis presented no rupture of bone continuity. Two infections that erupted at 8 and 24 months required changing the nail followed by prolonged antibiotic therapy, which apparently allowed healing and union with 1 and 2 years of follow-up in the two cases. Two other infections occurred during the 2nd year after reconstruction and were treated medically, one successfully and the other not, since intermittent fistula

![Figure 1](https://via.placeholder.com/150)

Figure 1  Case no. 3. a: preoperative X-ray (Gustilo IIIc fracture); b: immediate postoperative X-ray; c: debridement of a bone sequestrum covered with ischemic cutaneous tissue in the first stage; d: second stage; e: integration of the graft (6 months after second stage); f: X-ray after removal of the material; g, h: last follow-up at 47 months.
persisted. This last patient now walks with a cane for more than 1 km, at 35 months of follow-up. His precarious health as well as this acceptable functional result have motivated him not to reoperate.

At the last follow-up, the patients walked without pain, with a symmetrical gait angle and an aligned tibia, with no length discrepancy. The talocrural joint showed reduced mobility values compared to the opposite side in six cases, with two cases of painful equinus that were treated with Achilles tendon lengthening. In three patients, the nail was removed to allow cortex thickening, with no resulting deformity or secondary fracture 6, 19, and 43 months after removing the material.

Discussion

The initial series reported by Masquelet et al. [5], which included 27 cases of bone loss in the leg, manifested three types of complication: amputation, infection, and late secondary fracture of the reconstituted segment. Two amputations were necessary because of vascular complications (thrombosis of arterial bypass) or because of associated lesions in the corresponding foot. They therefore do not reflect poorly on the method. However, they underscore the importance of a careful examination of the functionality of the foot before initiating a long surgical program (associated fractures and sensitivity of the corresponding foot). Similarly, in the three cases reported by Pelissier et al. [6], an amputation was necessary because of poor blood supply to the foot. In our series, no amputation was required and the two cases of residual equinus were recuperated by a simple Achilles tendon lengthening procedure. Woon et al. [8] reported an observation of the Masquelet technique on a nail for a tibial bone defect measuring 60 mm at its smallest axis. The authors used a cement with an antibiotic (imipenem for Woon et al. and gentamicin for our study) and postoperative intravenous antibiotic therapy.

Infection is undoubtedly the main complication. Masquelet et al. reported five early recurrences of infection between the two stages: four were treated by repeating debridement and placing a spacer and one case continued to present chronic osteitis. Use of a nail does not seem to cause more severe infectious complications than using the external fixator, but they occur later. Four of the five late infectious complications in our series were controlled either by changing the nail or by prolonged antibiotic therapy, without changing methods. As in Masquelet’s series, one patient remained a carrier of chronic osteitis with acceptable function. Hyperbaric oxygen therapy is a significantly effective adjuvant in cases of crushing injury according to Bouachour et al. [9].

The use of foreign bodies with antibiotic therapy was evaluated for tibial bone loss with sepsis. McKee et al. [10] used a bone substitute with tobramycin for 15 cases of external fixator osteosynthesis. All the patients achieved bone union, but three secondary fractures appeared at 3, 18, and 22 months. Hutson et al. [11] filled the bone loss with gentamicin cement beads and applied the Ilizarov bone transport technique. Alternatively, Masquelet et al. recommended using a spacer without antibiotic and a per os antibiotic prophylaxis limited to 7 days, so that an infection related to insufficient debridement would not be masked. It seems that the quality of the initial debridement, although difficult to quantify, is the main factor of prognosis. Repeated debridement is sometimes necessary; antibiotic therapy should only be considered as additional treatment for complete debridement. It is possible that use of gentamicin cement in our series masked insufficient debridement, which should have been revised earlier, explaining the high rate of late infections, which, more numerous than in the series reported by Masquelet et al. (5), had the disadvantage of causing graft loss in one case, which is not the case of early infections occurring between the two stages. However, the use of the intramedullary nail eliminated all local infections on pins related to poor tolerance of the fixator over the long term.

Stress fractures appeared late and were the third source of complication in this technique. Masquelet et al. report two cases occurring 2 years after reconstruction, before complete corticalization of the reconstructed bone, which requires several years. The intramedullary nail works as a tutor protecting bone reconstruction, but better flexibility of the material (a titanium nail) could favor bone remodeling. The case of nail fracture in our series did not involve a repeated fracture but undoubtedly unrecognized aseptic nonunion, which we were able to treat with new nailing.

Finally, the three patients whose nail was removed have not presented late fracture.

From the mechanical point of view, intramedullary nailing allows earlier weight-bearing and has the advantage of aligning the leg bones. Stabilization therefore seems better than with the external fixator, particularly in cases of substantial bone loss. Filling within the center of the self-induced membrane reduces the quantity of graft material necessary to fill the space left empty by the spacer. However, radiological evaluation of bone union is more difficult because the metal can hide partial continuity.

Use of the locking nail assumes preservation of distal and proximal bone segments long enough to allow good-quality locking. However, the advent of nails with locking holes very close to their ends (Expert, Synthes® nails, used in one patient in this series) should extend this technique’s field of application, without resorting to fixators bridging the adjacent joints.

Conclusion

The self-induced membrane technique with cancellous autograft according to Masquelet et al. [5] is a reliable but long technique, requiring 6 months without weight-bearing in its initial description. It is facilitated by the use of an intramedullary stabilization nail, which can be implanted in the first stage. Infection remains the main complication, occurring in a large number of cases, but its severity seems limited and does not delay treatment nor compromise the result if it is treated early. In this respect, the infections in our series occurred later than in the Masquelet et al. series, perhaps warranting the use of an acrylic spacer without addition of antibiotics so as not to mask any effects of incomplete debridement.
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Conflicts of interest

None.

References