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Reconstruction of large diaphyseal bone defect by simplified bone transport over nail technique: A 7-case series∗

F. Ferchaud*, L. Rony, F. Ducellier, P. Cronier, V. Steiger, L. Hubert, the Orthopedics and Traumatology Society of Western France (SOO)

Service de chirurgie orthopédique, CHU Angers, 4, rue Larrey, 49100 Angers, France

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A B S T R A C T

Reconstruction of large diaphyseal bone defect is complex and the complications rate is high. This study aimed to assess a simplified technique of segmental bone transport by monorail external fixator over an intramedullary nail. A prospective study included 7 patients: 2 femoral and 5 tibial defects. Mean age was 31 years (range: 16–61 years). Mean follow-up was 62 months (range: 46–84 months). Defects were post-traumatic, with a mean length of 7.2 cm (range: 4 to 9.5 cm). For 3 patients, reconstruction followed primary failure. In 4 cases, a covering flap was necessary. Transport used an external fixator guided by an intramedullary nail, at a rate of 1 mm per day. One pin was implanted on either side of the distraction zone. The external fixator was removed 1 month after bone contact at the docking site. Mean bone transport time was 11 weeks (range: 7–15 weeks). Mean external fixation time was 5.1 months (range: 3.5 to 8 months). Full weight-bearing was allowed 5.7 months (range: 3.5–13 months) after initiation of transport. In one patient, a pin had to be repositioned. In 3 patients, the transported segment re-ascended after external fixatorablation, requiring repeat external fixation and resumption of transport. There was just 1 case of superficial pin infection. Reconstruction quality was considered “excellent” on the Paley-Marr criteria in 6 cases. The present technique provided excellent reconstruction quality in 6 of the 7 cases. External fixation time was shorter and resumption of weight-bearing earlier than with other reconstruction techniques, notably including bone autograft, vascularized bone graft or the induced membrane technique. Nailing facilitated control of limb axis and length. The complications rate was 50%, comparable to other techniques. This study raises the question of systematic internal fixation of the docking site, to avoid any mobilization of the transported segment. The bone quality, axial control and rapidity shown by the present technique make it well-adapted to reconstruction of diaphyseal bone defect.

Level of evidence: Four-case series.

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1. Introduction

Reconstruction of diaphyseal bone defect is a surgical challenge, due to associated lesions and a high risk of complications. Several techniques have been described: autologous bone graft, vascularized bone graft [1,2], induced membrane [3,4], and bone segment transport [5,6]. Bone transport is technique of choice for severe defects, and initially used an Ilizarov external fixator or multi-pin monorail fixator [6–8]. Paley et al. [9,10] then refined the technique, using an intramedullary nail to guide the bone segment, improving axial control and reducing procedure time, without any change in the external fixator.

We developed a simplified assembly, with a single external fixator pin on either side of the distraction zone. The nail serves as guide for the transported segment, and ensures internal fixation.

The present study reports radiologic and functional results for this technique.

2. Material and methods

2.1. Patients

The single-center multi-operator (2 senior surgeons) series included 7 patients. Table 1 shows the main patient characteristics.
Table 1
Main patient characteristics.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Age (at trauma)</th>
<th>Location</th>
<th>Etiology</th>
<th>Gustilo</th>
<th>Multiple lesions</th>
<th>Neural lesions</th>
<th>Vascular lesions</th>
<th>Cover</th>
<th>Trauma-to-transport time (months)</th>
<th>Number of procedures before transport</th>
<th>Antibiotic therapy time (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>Tibial diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>2</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Free flap</td>
<td>23</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>Tibial diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>3C</td>
<td>Yes</td>
<td>No</td>
<td>Fibular + posterior tibial arteries</td>
<td>Free flap + skin graft</td>
<td>5</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>Femoral metaphysis-diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>3A</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Skin graft</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>Femoral diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>3A</td>
<td>No</td>
<td>Sciatic nerve (plexus origin)</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>Tibial diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>3A</td>
<td>Yes</td>
<td>Permanent</td>
<td>No</td>
<td>Myofascial flap</td>
<td>8 years (6months)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>Tibial diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>2</td>
<td>No</td>
<td>Common peroneal nerve</td>
<td>No</td>
<td>Myofascial flap</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>34</td>
<td>Tibial diaphysis</td>
<td>Post-traumatic osteitis</td>
<td>3A</td>
<td>Yes</td>
<td>No</td>
<td>Skin graft</td>
<td>5</td>
<td>2</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Mean age was 31 years (range: 16–61 years).
Lesion mechanism was in all cases high-energy trauma, systematically with open fracture. There were 5 tibial and 2 femoral shaft fractures (including 1 metaphyseal-diaphyseal femoral fracture).
A covering flap was needed in 4 cases, and was performed within a week of trauma, with negative-pressure wound therapy applied in the meanwhile (Fig. 1).
Mean defect size was 7.2 cm (range: 4–9.5 cm). Mean trauma-to-transport interval was 5.2 months (range: 3–8 months).
In 3 cases (patients 1, 5 and 6), the defect was due to resection of post-traumatic chronic osteitis.
For patient 1, transport was initiated 23 months post-trauma, in a Gustilo II open fracture initially treated by intramedullary nailing. Progression towards septic non-union required bone resection. Transport was indicated after failure of induced membrane reconstruction. Triple antibiotic therapy was initiated ahead of transport.
For patient 5, transport was initiated 8 years post-trauma. The patient presented with iterative fractures on sclerotic bone following repeated failure of reconstruction (autologous bone graft and Papineau’s technique). Three months’ antibiotic therapy was implemented ahead of transport, for enterobacter cloacae-positive samples.
For patient 6, transport was initiated 5 months post-trauma. The patient presented with septic non-union of plate fixation, requiring resection of necrotic bone fragments and adapted triple antibiotic therapy ahead of transport.
The duration of antibiotic therapy was thus personalized.
For patients 1 and 6, probabilistic antibiotic therapy was continued up to complete healing.
A mean 3 procedures (range: 1–6) were performed between trauma and transport.

2.2. Surgical technique
Reconstruction was initiated after skin healing.
Limb length was calculated in relation to the contralateral side or to the fibula.
The defect extremities were prepared by oscillating saw, with cuts perpendicular to the mechanical axis, to optimize contact area when the transported segment reached the docking site.

The nailing technique was classical (Synthes® LFN nail in the femur, Synthes® Expert Tibia nail in the tibia), with systematic reaming 2 mm over the nail diameter. Proximal and distal locking provided assembly stability.
Preparation of the segment for transport began by locating the corticotomy site in the metaphysis. A fixator pin was positioned on either side of the site, clear of the nail, either forward or to the rear (Fig. 2). The two pins were parallel to one another and perpendicular to the nail axis. A “postage stamp” corticotomy was performed via 1 or 2 short approaches between the pins, and completed using a Pauwels chisel. A lengthening fixator (OrthoFix®) was set up on the two pins.
Transport began on day 7, at a rate of 1 mm per day (0.5 mm × 2/day). The patient performed distraction at home. Pin care comprised daily irrigation of each orifice with physiological saline.
Once bone contact with the docking site was achieved, transport was discontinued, with the external fixator left in place for 1 month.
Resumption of weight-bearing was allowed, depending on pain, as soon as the new bone seemed solid enough on radiography.

2.3. Follow-up and progression

Patients were followed up every 2 weeks during transport. Functional results were analyzed on Paley-Maar score [11] (Table 2).
Radiologic results were analyzed on Paley-Maar bone score [11] (Table 3) and Fischgrund et al.’s criteria [12]: external fixation index (EFI: fixation time in months divided by defect length) and radiographic consolidation index (RCI: consolidation time in months divided by defect length).
Consultation with an independent observer was scheduled at end of follow-up.

3. Results

Table 4 presents the main results, at a mean 62 months' follow-up (range: 46–84 months).

Mean external fixation time was 5.1 months (range: 3.5–8 months).
Table 2
Paley-Maar functional score.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>Patient pain-free, walking unassisted, without fixed under- and/or over-lying joint stiffness, without &gt; 20 loss of talocrural or subtalar motion, autonomous for most daily activities without difficulty</td>
</tr>
<tr>
<td>Good</td>
<td>Patient pain-free, autonomous for most daily activities with minor difficulties, with 1 of the following criteria: assisted walking, fixed under- and/or over-lying joint stiffness, &gt; 20 loss of talocrural or subtalar motion</td>
</tr>
<tr>
<td>Moderate</td>
<td>Patient in little or no pain, autonomous for most daily activities with minor difficulties, with 2 of the following criteria: assisted walking, fixed under- and/or over-lying joint stiffness, &gt; 20 loss of talocrural or subtalar motion</td>
</tr>
<tr>
<td>Poor</td>
<td>Patient requiring analgesia or with restricted daily activity or with all of the following criteria: assisted walking, fixed under- and/or over-lying joint stiffness, &gt; 20 loss of talocrural or subtalar motion</td>
</tr>
</tbody>
</table>

Mean transported segment size was 14.1 cm (range: 10–20.9 cm).

Mean interval between start of transport and resumption of weight-bearing was 5.7 months (range: 3.5–13 months). Resumption of weight-bearing was painless in all cases.

Functional scores were excellent in 2 cases.

Four patients had only “good” functional scores, because of post-traumatic ankle stiffness in 2 cases, permanent sciatic deficit of plexal origin in 1 case, and sequelae of patellectomy on non-fusible comminuted fracture in 1 case.

One patient had a moderate functional result, due to post-traumatic knee stiffness (20° residual contracture).

At last follow-up, all patients had returned to everyday and occupational activity. One patient used a cane for long distances.

In all but 1 case (patient 4), unipodal weight-bearing was both possible and painless (Fig. 3).

Paley-Maar bone scores were excellent in 6 cases, and only “good” in 1 due to progressive varus deformity at the docking site. Mean EFl was 0.77 months/cm (range: 0.46–1.75).

Mean RCI was 1.76 months/cm (range: 0.67–3.3) (Fig. 4).

Regenerated bone was solid before docking site consolidation in all cases.

Mean docking site consolidation time was 12 months (range: 8–22 months).
No docking site bone grafts were required. In 3 cases, nail dynamization was performed 3 months after bone contact. There were 5 mechanical complications:

- one external fixator disassembly, due to a fall, was reassembled in emergency and transport was able to be continued;
- one progressive femoral docking site valgus deformity developed on resumption of weight-bearing (Fig. 5). This patient had had a comminuted distal femoral epiphyseal fracture, managed by plate fixation bridging the metaphyseal bone defect, with nail relay at 3 months. This complication was due to unstable distal locking of the nail in the epiphysis, and was treated by femoral varization osteotomy remote from the docking site;
- in 3 cases, re-ascension of the transported segment after ablation of the external fixator required repeat external fixation and transport.

There was 1 superficial pin infection, managed by local treatment and short antibiotic therapy.

There were no cases of fracture of the reconstructed limb.

### 4. Discussion

The bone transport technique comprised 2 stages: progressive osteogenesis by distraction of the transported segment, and docking site consolidation.

EFI corresponds to osteogenesis stage duration, and varies according to technique. Authors using an Ilizarov fixator report EFIs between 1 and 1.9 months/cm [11,13,14]. In transport over an intramedullary nail, fixator ablation is earlier, with EFI ranging from 0.45 to 0.87 [9,10,15,16]. In the present series, mean EFI was 0.77 (range: 0.46–1.75), comparable to other series.

The second stage raises the issue of docking site consolidation. Some authors perform cancellous bone graft, on a case-by-case basis [7,11,13,17] or systematically [10,15,16]. Others use no complementary docking site procedures [6,18]. RCI ranged between 1.1 and 2.1 months/cm in series with docking site graft, and between 1.3 and 2.4 in series without graft. In the present series, no docking site graft was performed, and mean RCI was (range: 0.67–3.3) comparable to other series.

The present simplified assembly achieved results comparable to those of other bone transport techniques over intramedullary nail in terms of transport and consolidation times.

In case of docking site non-union after bone segment transport using an Ilizarov fixator, Rosbruch et al. used intramedullary locking nails [17]. In bone transport over an intramedullary nail, nail dynamization is a simple and relatively non-invasive means of achieving docking site consolidation.

Our first patient had previously been treated by the induced membrane technique described by Masquelet et al. [4]. This technique has the drawbacks of not allowing weight-bearing, long external fixation time, and massive cancellous autograft. Radiologic results were satisfactory in Masquelet’s series, but axial defects, limb-length discrepancies and functional results were not reported. Apard et al. [3] modified the technique, using internal fixation by intramedullary nail; complete weight-bearing was resumed at a mean 4 months after stage 2 of the technique and a mean 8 months after initiation of reconstruction.

In 3 of the present cases, segment re-ascension after ablating the fixator delayed resumption of complete weight-bearing, adding a mean 3.6 (range: 2–5) months’ external fixation. Perhaps this could have been avoided by prolonging fixator time, or by internal fixation of the docking site by staple or plate.

Complete weight-bearing, at a mean 5.7 months (range: 3.5–13 months) after initiation of transport, was painless.

Paley et al. described a system of bone reconstruction analysis based on bone and function criteria [11], which has not previously been applied to bone transport over an intramedullary nail. Authors using Ilizarov fixators report 65–70% excellent bone results and 0–63% excellent functional results. Paley et al. highlighted the fact that functional and bone results do not correlate [11], and explained the poorer functional results by the severity of associated lesions. The present series showed the same difference, with 6 excellent bone results but only 2 excellent functional results. Only patients without associated lesions had both bone and functional results that were excellent. These are qualitative criteria, but are objectively reproducible; it was for this reason that we chose these scales.

The size of the present series did not allow comparison with other reports, but results on the Paley-Maar criteria seem at least equivalent.
The technique of bone transport over a nail originated in limb lengthening over a nail. Kocoaglu et al. reported a 38% complications rate in limb lengthening; notably, premature consolidation (7%) and delayed consolidation in the osteogenesis zone (2%) [19]. Paley et al. explained this delayed consolidation by a lack of assembly stability [6].

There were no cases of delayed consolidation or osteogenesis zone defect in the present series.

Axial control is a major issue in bone reconstruction. In series using Ilizarov fixators, axial defect rates range between 16% and 44% [6,13,17,20]. Oh et al. [10], in a series of 12 bone transports on intramedullary nail, reported 1 case (8%) of axial defect.
In the present series, only 1 patient (patient 3) showed axial defect, with progressive onset at resumption of weight-bearing, due to insufficient nail locking in the distal epiphysis. Nailing stability in the proximal and distal extremities is, in our opinion, the main problem in this technique. When distal locking is defective, we suggest delaying weight-bearing and consider docking site autograft in case of insufficient consolidation on X-ray or CT.

External fixator pin infection is a frequent complication, with rates ranging from 5% to 100% [21]. Using a fixator with a single pin on either side of the distraction site reduces the number of portals of entry.

In the present series, 1 patient had pin infection, managed by local care and antibiotic therapy, without interrupting the bone transport.

Limb-length discrepancy is frequent in reconstruction of diaphyseal bone deficit, reported in 100% of cases by Gopal et al. [22]. Series using ilizarov fixators reported discrepancies exceeding 3 cm [6,11,13,22,23]. In transport over nail, limb length is determined on preoperative planning, reducing the risk of discrepancy. Oh et al. reported no discrepancies exceeding 1 cm, as in the present series.

Stable intramedullary nailing provides a good quality osteogenesis zone, facilitates skin coverage, and improves axial control and limb length (Fig. 4).

The present simplified external fixator assembly reduces the number of portals of entry for infection. It also improves quality of life, with a less cumbersome fixator than the ilizarov type.

5. Conclusion

Bone transport is technically demanding, but provides good results in diaphyseal defect reconstruction. Segmental transport on intramedullary nail reduces external fixator time and allows earlier resumption of weight-bearing. Another advantage is that graft donor sites are spared. We consider that a lengthening external fixator with a single pin on either side of the osteotomy line incurs fewer complications than an ilizarov fixator and improves compliance without jeopardizing reconstruction quality.

The present series was small, but bone reconstruction quality was almost systematically excellent.

Disclosure of interest

The authors declare that they have no competing interest.

References