Is combining massive bone allograft with free vascularized fibular flap the children’s reconstruction answer to lower limb defects following bone tumour resection?

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Summary
Purpose of the study: Bone tumours are frequent conditions in children, and their surgical resection may lead to extensive defects which reconstruction is often challenging. Indeed, local conditions do not promote bone healing, and the achieved surgical result requires to be life-lasting. Capanna suggested a reconstruction technique combining massive allograft and free vascularized fibular flap. The first one is intended to withstand mechanical stress, and the second one offers biological and vascular support to improve bone healing and prevent infections.

Materials and methods: We report our experience with this technique when applied to the lower limb in a prospective study including seven children, with a mean follow-up of 44 months.

Results: Bone healing was achieved by one single procedure in 85.7% of the cases, usually 7 months after surgery. Six out of seven patients achieved a final and long-lasting outcome, five of them following a simple surgical history. Partial weight-bearing was post-operatively allowed at about 2 months, full weight-bearing was initiated at about 5.5 months.

Discussion: A low complication rate was reported despite the extent of the disease and the type of the surgical procedure. Capanna’s combined reconstructive technique appears very efficient in the management of massive bone defects following tumour resection in children’s lower limb.

Level of evidence: Level IV. Retrospective therapeutic study.

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Introduction

Limb reconstruction following bone tumour extirpation has always been considered as a therapeutic challenge since carcinologic resection usually leads to large segmental defects. Bone tumours are common condition in children and the surgical outcomes of reconstruction should be long-lasting [1]. Prosthesis reconstruction might appear as the only effective solution, however, biological reconstruction should be preferred whenever possible. Massive isolated allografts provide a good primary mechanical strength but are subject to infections and lack of long-term integration. Free vascularized fibular flaps provide a well-integrated tissue which better resists infection but demonstrates a primary mechanical weakness. Capanna described a combined reconstruction technique [2] which associates the advantages of both methods by using a free vascularized fibular flap fitted into a massive cylindric allograft without cumulating their drawbacks.

We used this technique in the management of seven children suffering from lower limb bone tumours. They were prospectively reviewed in the Nancy University Hospital Centre with a mean follow-up of 44 months.

Material and methods

Seven children with a primitive bone tumour of the lower limb were managed from January 2003 in the Department of Paediatric Orthopaedic Surgery of Nancy University Hospital Centre according to this technique, a free vascularized fibular flap being fitted into a massive allograft without cumulating their drawbacks.

The prospective clinical and radiographic follow-up of all patients was ensured by the same senior observer. Repeated standard radiographs were made to control the healing process and enhance the child postoperative comfort.

Operative technique

All children were operated on by two surgical teams jointly, each team including the same senior operators. One team performed the tumour resection and the second one the reconstruction of the defect at the same time. The operating data are shown in Table 2.

The mean length of the bone defect was 17.6 cm. The mean operative time was 10.20 hours for the whole procedure. The fibula was harvested from the contralateral leg in six out of seven cases in order to facilitate the double teamwork. A unilateral fibular harvesting was performed due to the sidelying position of the patient, necessary for tumour resection. A skin paddle was harvested in five cases for postoperative monitoring of the fibular graft viability, thus providing an osteoseptocutaneous flap. In two cases, the skin paddle was not harvested due to the depth of the recipient site (Patients N°1 and 7, involving a hip and a proximal femur), since the septal vessels were too short and did not allow superficialization of the skin flap.

The reconstruction consisted of a long diaphyseal intercalary graft in four patients (Patients N° 1, 4, 5, 6). An arthrodesis was necessary in three patients. Two arthrodeses of the knee were performed after resection of an osteosarcoma of the distal femur in Patient 2 and of a proximal tibial osteosarcoma in Patient 3, both patients reporting a joint invasion. The third arthrodesis involved an osteosarcoma of the femoral neck with intra-articular invasion (Patient 7).

The allograft was secured using a titanium bridging plate in conjunction with additional screws maintaining the fibula in the two diaphyseal shafts at the edge of the defect. The microvascular anastomoses were performed according to the available local vessels with suture of an artery and a vein.

In five cases (patients who had not finished growing), the donor site was reconstructed using a non-vascularized tibial bone plug, directly fitted into the remaining distal and proximal fibular fragments.

Monitoring and radio-clinical control

A continuous clinical monitoring of the skin paddle viability was executed in the continuous care unit during the first postoperative days. Strict confinement to bed was advocated during a 5-day period. All patients were given an anticoagulant or platelet anti-aggregant therapy. The recipient site was immobilized in six cases to protect the synthesis and enhance the child postoperative comfort.

The prospective clinical and radiographic follow-up of all patients was ensured by the same senior observer. Repeated standard radiographs were made to control the healing process, the fibular and allograft evolution within the device.

Figure 1 Details of the operative technique: the fibula is harvested with a skin paddle for vascular monitoring of graft viability (A), and fitted into the allograft which has been partially reamed (B).
Table 1  Epidemiologic data of the series.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Age at surgery (year)</th>
<th>Age at revision (year)</th>
<th>Follow-up (months)</th>
<th>Location</th>
<th>Lesion</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>8.5</td>
<td>14</td>
<td>63</td>
<td>Proximal femur</td>
<td>Aneurysmal cyst</td>
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<tr>
<td>2</td>
<td>M</td>
<td>12</td>
<td>17</td>
<td>62</td>
<td>Distal femur</td>
<td>Osteosarcoma</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>17</td>
<td>20</td>
<td>36</td>
<td>Proximal tibia</td>
<td>Osteosarcoma</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>10</td>
<td>13</td>
<td>42</td>
<td>Mid femur</td>
<td>Osteosarcoma</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>13</td>
<td>16</td>
<td>42</td>
<td>Proximal tibia</td>
<td>Aneurysmal cyst</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>15</td>
<td>18</td>
<td>37</td>
<td>Proximal tibia</td>
<td>Ewing</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>9</td>
<td>11</td>
<td>27</td>
<td>Proximal femur</td>
<td>Osteosarcoma</td>
</tr>
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</table>

No CT scan was performed due to the risk from radiation exposure. Proximal and distal junctions of each reconstruction were specifically analysed and the integration process was completed once the fibula could not be differentiated from the allograft. On the other hand, in most cases, the fibula remained visible and distinct from the allograft at a distance from the junction even after full weight-bearing was initiated.

The functional result was evaluated taking into account the immobilization duration as well as the time to partial and full weight-bearing (Table 3).

Results

Weight-bearing

The mean length of hospital stay was 13.3 days of which 6.7 days were spent in the continuous care unit. This surgical procedure never delayed the postoperative adjuvant chemotherapy protocol.

The recipient lower limb was immobilized in a plaster cast maintaining the overlying and subjacent joints during 50.8 days and an antalgic splint was applied for a period of 45 days over the donor site in three patients. Weight-bearing of the donor site was initiated early after splint removal and did not report any complication. Partial weight-bearing was allowed for the recipient limb at 65.7 days and full weight-bearing at 165 days.

Healing

Mean time to bone healing per primam was 7 months in 12 junctions (among the 14 junctions of the 7 patients) (Fig. 2). Two cases of non-union were observed, one of which involved a hip arthrodesis with bridging plate (Patient 7). However, this patient functional outcome was satisfactory despite the lack of consolidation. At last follow-up, his fibular graft is osteopenic with no signs of proper integration within the allograft. No skin paddle had been harvested due to the depth of the recipient site and the viability of the graft is therefore debatable even if it demonstrates satisfactory healing of the distal junction. The other case of non-union was involved the proximal junction of a knee arthrodesis (Patient 3). It was revealed by a varus deformity secondary to a fall occurring at one postoperative year in a patient who did not visit immediately which accounts for the delayed management of this complication (Fig. 3A). Final healing was achieved through a cortico-spongious bone graft secured by means of a new plate osteosynthesis (Fig. 3B).

Distal healing was achieved in all patients since both non-unions involved the proximal junction. The per pri-

Table 2  Operative modalities.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Defect (cm)</th>
<th>Cutaneous flap</th>
<th>Length of allograft (cm)</th>
<th>Donor site reconstruction</th>
<th>Length of surgery</th>
<th>Length of hospital stay and intensive care</th>
<th>Overall length of hospital stay (days)</th>
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<tr>
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<td>6</td>
<td>14</td>
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<td>13</td>
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<tr>
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<td>20</td>
<td>No</td>
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<td>8</td>
<td>15</td>
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<td>Yes</td>
<td>19.5</td>
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<td>6</td>
<td>10</td>
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<tr>
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<td>9:00</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>Yes</td>
<td>18.5</td>
<td>No</td>
<td>11:20</td>
<td>4</td>
<td>10</td>
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<tr>
<td>7</td>
<td>13.5</td>
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<td>11</td>
<td>16</td>
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<td>Mean value</td>
<td>17.6 (sd17.6.3)</td>
<td>15.9 (sd2.15.97)</td>
<td></td>
<td></td>
<td>10h20 (sd 1h42)</td>
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</table>
Table 3 Clinical and radiographic outcomes.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Proximal healing (months)</th>
<th>Distal healing (months)</th>
<th>Partial WB (days)</th>
<th>Full WB (days)</th>
<th>Allograft behaviour</th>
<th>Fibular behaviour</th>
<th>Intraoperative complications</th>
<th>Bone complications</th>
<th>Infection complications</th>
<th>Infectious complications</th>
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<td>1</td>
<td>3</td>
<td>3</td>
<td>90</td>
<td>150</td>
<td>Complete integration</td>
<td>Complete integration</td>
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<td>No</td>
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<tr>
<td>2</td>
<td>3</td>
<td>5</td>
<td>90</td>
<td>135</td>
<td>Complete integration</td>
<td>Complete integration</td>
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<td>No</td>
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<tr>
<td>3</td>
<td>6</td>
<td>6</td>
<td>90</td>
<td>180</td>
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<td>Complete integration</td>
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<td>No</td>
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<td>Post-fall fracture</td>
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<tr>
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<td>11</td>
<td>50</td>
<td>210</td>
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<td>Complete integration</td>
<td>No</td>
<td>No</td>
<td>Angulation</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>3</td>
<td>45</td>
<td>190</td>
<td>Complete integration</td>
<td>Complete integration</td>
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<tr>
<td>6</td>
<td>5</td>
<td>6</td>
<td>45</td>
<td>150</td>
<td>Complete integration</td>
<td>Complete integration</td>
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<td>No</td>
<td>Deep</td>
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<tr>
<td>7</td>
<td>24</td>
<td>24</td>
<td>50</td>
<td>240</td>
<td>Partial WB</td>
<td>Distal healing</td>
<td>Osteopenic non-integrated</td>
<td>No</td>
<td>Pseudarthrosis</td>
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</table>

Harvest site

Harvest of the fibula induced an impairment of hallux joint extension in six out of seven patients which was resolutive within a few months, and a transient paresis of the common fibular nerve in one patient, which completely resolved after 5 months.

Reconstruction of the donor site was successfully performed using a non-vascularized tibial bone plug in six out of seven cases. Patient 7 developed an atrophic non-union at both extremities of the tibial bone plug with no functional impact.

Local complications

Two arterial thrombotic events were reported and immediately managed successfully. No surgical revision for vascular reasons was later necessary.

Two infectious complications were observed but were not bacteriologically documented: one case of superficial infection with wound dehiscence at Day 45 which resolved after direct excision-closure of round skin defect (Patient 5). One deep infection occurring at Day+1, managed with probabilistic antibiotic treatment for a 3-month period (negative sampling) followed by plate removal once healing was achieved at Day+3. This female patient (Patient 4) had sustained a fall 1 month after removal of the device, responsible for a fracture at the proximal junction, demonstrating satisfactory healing at last follow-up after management with external fixation.

General complications

Medical postoperative complications were reported in six patients due to the treatment and condition (2 drug-induced neuropathies, two cases of transfused anaemia, one candida septicaemia with no effect on the operative site, and 2 urinary tract infections).

Discussion

In our study, we prospectively evaluated a homogeneous series of seven paediatric patients operated on by the same surgical team for bone tumours. The mean follow-up is almost 4 years and no patient was lost to follow-up. However, our series includes a small sample of patient due to the
Figure 2 Tibial diaphyseal resection of an Ewing sarcoma (A) with overall postoperative aspect (B) and at 2-year follow-up (C and D). (Patient n°6).

infrequency of these indications of massive resection and to
the recent reconstructing technique.

Reconstructing technique

This reconstructing method is in direct competition with
other techniques such as isolated massive allograft, isolated
vascularized fibular flap or the induced membrane tech-
nique.

The Capanna’s technique reports better bone fusion suc-
cess rates than the isolated allograft techniques as reported
in various studies [1,3,4,5]. Moreover, this technique offers a
better resistance to infection and fewer local complications
[6].

Its main advantage, compared with isolated free fibular
grafts, is the initial mechanical resistance which reduces
the time to weight-bearing without increasing the risk of
fracture. Actually, iterative fractures of the isolated fibu-
lar graft are almost unavoidable to promote its progressive
thickening through successive fractures. Therefore, Zaret-
ski et al. [7] advocate the use of combined allograft-free
fibular flap in the reconstruction of lower limb defects.

Our patients could early resume normal functional activities
with a mean partial weight-bearing duration of more than 2
months. Full weight-bearing was initiated between 5 and 6
postoperative months. We were then at the beginning of our
experience and we currently tend to reduce these periods
of time with a partial weight-bearing initiated at 45 days
and full weight-bearing at 3 months after surgery, without
reporting an increase in the complication rate to date. These
periods of time are barely conceivable when using isolated
fibula reconstructions [1,4,6] and represent an undisputable
advantage of this technique [8].

Masquelet et al. [9] have suggested another technique
in the reconstruction of large diaphyseal defects: a cement
spacer is placed during the resection phase providing a par-
tial mechanical resistance but does not allow weight-bearing
in most cases despite the use of an internal osteosynthe-
sis device when necessary. Secondly, a cortico-spongy bone
graft is performed after cement removal in order to
take advantage of the bone growth factors promoted by the
pseudo-synovial membrane induced by the latter. He man-
aged 35 patients with a 4 to 25 cm defect, allowing full
weight-bearing at 8.5 months. Blau et al. [10] report the
case of the surgical resection of an Ewing’s sarcoma of the
femur in a child for whom reconstruction was performed
using the induced membrane technique. Final full weight-
bearing was initiated 4 months after the second procedure

Figure 3 Patient n°3 managed by resection and knee
arthrodesis in the treatment of an osteosarcoma of the prox-
imal tibia invading the joint. Reconstruction was complicated
by non-union of the proximal junction. Radiographic aspect at
18 months postoperatively prior to surgical revision (A), conso-
olidation of graft junction 9 months after surgical revision (B).
(a partial weight-bearing had been allowed with the first device). The induced membrane seems to provide growth factors which promote osteogenesis from the first month after placement of the cement spacer [11]. However, this technique has been scarcely evaluated in the literature, except by those who promote it. It would help provide a very satisfactory radiographic anatomical outcome but at the cost of a prolonged discharge and a two-stage surgical procedure. Moreover, the postoperative chemotherapy requires postponing the second bone graft procedure until the end of the treatment due to the haematological weakness of the patient. This second procedure is thus performed beyond the ideal period of time advocated by Masquelet which is about 2 months after cement placement. Capanna’s technique is less aesthetic radiographically but allows earlier functional recovery in a one-stage surgery: this might improve the quality of life of the patients who unfortunately do not benefit from a long life expectancy.

**Healing time**

Healing of 12 out of 14 graft-host bone junctions was achieved in a mean time of 7 months. Our healing rates and times correlate those reported in the literature and appear satisfactory given the unfavourable context induced by the adjuvant treatments. Moran et al. [1] report the outcome at 52-month follow-up in seven patients with a good or excellent functional result for 13 cm defects. He attributes the healing process speed to the graft vascularization and to the stability of the device which reduces the fibular periosteal ischemia time. Recolonisation of the allograft involved both extremities along with the endosteum. The vascular supply of the free fibular graft during the healing process has proved useful in the management of allograft non-union with an external bridging method using the free vascularized fibular graft (”onlay” method) [12,13].

The founders of this technique report the radiographic behaviour of this construct in 24 patients using conventional radiography and CT scan analysis. Three types of behaviour are observed [14]: in some patients, the fibula gets thinner and demonstrates progressive integration with the allograft in the absence of fracture and when load is mainly placed on the allograft. In the second type of behavior, fracture or delayed union of the allograft occurs: the fibula reacts and heals with appearance of dense cortical hypertrophy which proceeds from the multiple infra-radiographic fractures of the fibula as observed when it is isolated. In the last type of behavior, the fibula does not change in density or size and demonstrates fractures without healing: this behaviour is interpreted as a graft necrosis. One of our patients demonstrating non-union had this type of radiographic aspect. However, healing of the distal junction could be observed (Patient 7).

Despite this interesting healing rate, some patients will demonstrate non-union. This complication was only reported in arthrodeses in which the great lever arm factor had certainly prevented proper healing. It can be classically managed with simple cancellous graft [15] as successfully performed in one of our patient (Patient 3) or as reported by Moran et al. [1].

**Complications**

The overall complication rate in our series was significant but the fragile condition of these patients should be taken into account. In one case, the radiographic behaviour suggests a fibular necrosis (Patient 7) occurring in a patient in who graft monitoring using a skin paddle was not possible. Therefore, we believe that skin paddle is a reliable method.
for postoperative monitoring of the fibular graft viability, providing immediate detection of early vascular failures and allowing early adapted treatment.

Two traumatic fractures were observed in our series of seven patients. Moran et al. reported similar results at more than 2 postoperative years with satisfactory final healing. According to Manfrini et al. [14], these fractures could be attributed to a type 2 behaviour.

However, the complication rates of this technique, free vascularized fibula fitted into an allograft, are significantly lower than those reported by isolated allografts, in the short but above all long-term.

Lastly, despite our complication rate, only two out of seven patients required a single reintervention (non-union treatment in Patient 3, excision-suture of wound dehiscence in Patient 5) demonstrating good outcome without sequelae. Only one patient (Patient 4) underwent several additional procedures (infection on the device, removal of the device then post-traumatic fracture) which resulted in good outcome without sequelae. The overall reintervention rate is low, particularly when only considering surgical revisions resulting from mechanical complications following one-stage techniques.

**Donor site sequelae**

No major sequelae of the donor site were reported. A transient paresis of the common fibular nerve was noted and resolved after 5 months. Six out of seven patients reported an impaired hallux joint extension, regressive within a few months in all patients. Moreover, reconstruction of the harvested fibula was carried out using a non-vascularized tibial bone plug fitted between both fragments. This technique allowed restitution ad integrum of the bone in four cases and appears as an interesting technique in children to reduce sequelae of the harvest site. One patient demonstrated atrophic non-union at both extremities of the bone plug (Patient 7) but with no functional effect. These complications correlate those reported by Lafosse with different degrees and rates but, unlike him, we have not observed any residual ankle valgus up to now [16].

The only drawback involves the scar aspect at the harvest site of the monitoring skin paddle: it demonstrated a good outcome without sequelae. Only one patient (Patient 7) (pseudarthrodesis of the proximal femur) demonstrated atrophic non-union at both extremities of the bone plug (Patient 7) but with no functional effect. These complications correlate those reported by Lafosse with different degrees and rates but, unlike him, we have not observed any residual ankle valgus up to now [16].

**Conclusion**

The Capanna’s technique allowed us to achieve satisfactory carcinologic and functional outcome in six out of seven patients, partial functional result was achieved in one patient (Patient 7) (pseudarthrosis of the proximal femur).

The combination of an allograft reinforced by a free vascularized fibula promotes initial and long-term mechanical stability with few complications, in particular of mechanical order. The healing rate is better than in any other available technique and revision due to non-union is facilitated. Functional recovery is rapidly achieved when considering the complexity of the surgical procedure. The indications are infrequent but this technique is part of our therapeutic arsenal in the reconstruction of lower limb defects due to its good preliminary results. Monitoring of the graft viability using a skin paddle is essential in achieving successful outcome since it allows immediate management of early vascular complications. Bone reconstruction of the donor site using a non-vascularized tibial bone plug ensures satisfactory anatomic restitution. However, a prospective study should be conducted in a greater sample population, even if difficult to perform in this type of pathology, to confirm the suggested benefits of this technique.

**Conflict of interest**

None.

**References**


[13] Bae DS, Waters PM, Gebhardt MC. Results of free vascularized fibula grafting for allograft nonunion after limb salvage surgery

