Forearm reconstruction with bone allograft following tumor excision: A series of 10 patients with a mean follow-up of 10 years

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Summary

Background: After a tumor resection, the reestablishment of the bone continuity at the forearm remains a challenge for restoring the biomechanics of hand and elbow. Bone allograft might be one option to consider amongst other suitable alternatives but there are insufficient data available to substantiate its value.

Patients and methods: We retrospectively investigated a series of 10 consecutive patients that had presented a bone tumor at the forearm. After bone excision, the segmental loss was replaced either by a bone allograft or an osteochondral allograft. Patients were reviewed clinically and with radiographs.

Results: The mean follow-up was $110 \pm 99$ months. Fracture of the allograft was the most prevalent complication occurring in four patients, mainly in the osteoarticular group. Four patients were surgically revised: two of them had a fracture of the allograft that required a new one, another one had a painful stiff wrist requiring removal of the allograft and arthrodesis with autograft and the fourth one had a non-union of an intercalary allograft that was treated by a distal ulnar joint resection. Intercalary allograft had fewer complications than osteoarticular allografts and they had a better functional MSTS score with an average of 79% of a normal function compared to osteoarticular allografts with an average score of 62%. There was no infection. At the latest follow-up, one reconstruction of the forearm with an allograft failed and concerned the distal radius joint.

Discussion: A bone allograft when available can be considered as one amongst other suitable options for the reconstruction of the forearm skeleton.

Level of evidence: Level IV, retrospective series.

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Introduction

A large defect at the forearm is a real challenge for the restoration of the biomechanics of the elbow and hand. These bone loss is mainly caused by a wide resection of bone tumor. Nowadays, ablative surgery or even conservative surgery but with a joint suppression cannot be further considered should an anatomical reconstruction be possible. There are different options for a skeletal restoration among which are: translocation of an adjacent segment [1,2], a corticocancellous bone autograft [3,4], a vascularized or non-vascularized fibula [5–8], a progressive bone transport technique [9,10], a joint arthrodesis [11,12], an osteochondral or bone allograft [13–16] or a prosthetic implant [17].

We have advocated the use of a bone allograft because it allows a restoration of an immediate true anatomy without harvesting or weakening another bone. In case of failure with the allograft, this option permits another choice such as a vascularized fibula [3].

In 1991, we have published our first results of the use of osteochondral allograft at the upper limb among which four of them were at the forearm [15]. By osteochondral allograft, it is meant that only one side of a joint is replaced. Allografts of total joint at the elbow such as a distal humerus with its ulnar counterpart have been excluded from the present investigation as we had reported their early failures with their subsequent abandon [18].

We now report the clinical results of allografts at the forearm with a consecutive series of 10 patients who had a bone loss from elbow to wrist with a longer follow-up. The main objective was to assess the reliability of a bone allograft as a material to reconstruct a forearm.

Patients and methods

From 1987 to 2009, 10 consecutive patients as listed in Table 1 have been operated for a bone tumor at the forearm, creating a bone or an osteoarticular defect at the forearm. They were all primarily reconstructed with a bone allograft from the same location (a bone defect at the radius will be treated with an allograft from a similar radius). Five patients had a hemi-joint allograft: three at the proximal radius and two at the distal radius. The mean length of the osteoarticular allograft was 9.8 ± 4 cm. Four patients had an intercalary bone allograft, three of them being at the radius. The mean length of the intercalary allograft was 7.6 ± 1 cm. One patient had the radial nerve sacrificed for tumor proximity at the elbow. AO 3.5 plate (Synthes, Belgium) and if necessary long K wires were used for allograft fixation. In two cases, cement was injected in the allograft to augment the hold of the screw. Whenever possible, muscles and tendons were re-inserted on their anatomical attachments that were left on the allograft. Bone allografts had been sterilly procured from selected organ donors by our tissue bank in an operating theatre and were stored deep-frozen at −80 °C [15]. Cancellous bone autograft from the iliac crest was systematically added at the junction with host bone. Patients had the forearm immobilized in a cast for about 6–8 weeks and had physiotherapy thereafter. Prophylactic antibiotics were given for a period ranging from 3 days to 1 week.

Table 1: Patient data.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex-Age</th>
<th>Diagnosis</th>
<th>Location</th>
<th>Length (cm)</th>
<th>Chemotherapy</th>
<th>Radiation</th>
<th>Surgery</th>
<th>Fracture</th>
<th>Infection</th>
<th>Prox. healing</th>
<th>Dist. healing</th>
<th>Revision</th>
<th>MSTS score (pts)</th>
<th>Dominance</th>
<th>Follow-up (month)</th>
<th>Chemo-</th>
<th>Radiation</th>
<th>Surgery</th>
<th>Fracture</th>
<th>Infection</th>
<th>Prox. healing</th>
<th>Dist. healing</th>
<th>Revision</th>
<th>MSTS score (pts)</th>
<th>Dominance</th>
<th>Follow-up (month)</th>
</tr>
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<tbody>
<tr>
<td>D.MF</td>
<td>M-25</td>
<td>GCT</td>
<td>Dist. Radius</td>
<td>6</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Y es</td>
<td>No</td>
<td>Y es</td>
<td>Y es</td>
<td>No</td>
<td>22/30</td>
<td>Nd</td>
<td>264</td>
<td>16</td>
<td>No</td>
<td>No</td>
<td>Y es</td>
<td>No</td>
<td>Y es</td>
<td>Y es</td>
<td>No</td>
<td>22/30</td>
<td>Nd</td>
<td>264</td>
</tr>
<tr>
<td>C.J</td>
<td>F-18</td>
<td>OSS Ulna</td>
<td>Dist. Radius</td>
<td>8</td>
<td>Y es</td>
<td>Yes</td>
<td>No</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>No</td>
<td>17/30</td>
<td>Nd</td>
<td>256</td>
<td>28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>17/30</td>
<td>Nd</td>
<td>256</td>
</tr>
<tr>
<td>B.M</td>
<td>M-36</td>
<td>OSS Radius</td>
<td>Dist. Radius</td>
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<td>Y es</td>
<td>Yes</td>
<td>No</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>No</td>
<td>12/12</td>
<td>Nd</td>
<td>256</td>
<td>28</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>12/12</td>
<td>Nd</td>
<td>256</td>
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<tr>
<td>T.D</td>
<td>M-41</td>
<td>GCT</td>
<td>Dist. Radius</td>
<td>4</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>19/30</td>
<td>Nd</td>
<td>235</td>
<td>12/12</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>19/30</td>
<td>Nd</td>
<td>235</td>
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<tr>
<td>T.C</td>
<td>F-19</td>
<td>Ewing</td>
<td>Dist. Radius</td>
<td>4</td>
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<td>Yes</td>
<td>No</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>8</td>
<td>Nd</td>
<td>273</td>
<td>18</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Y es</td>
<td>Y es</td>
<td>Y es</td>
<td>8</td>
<td>Nd</td>
<td>273</td>
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</table>
The initial diagnosis included seven high-grade sarcoma (five Ewing's sarcoma and two osteosarcoma), two recurrent giant cell tumors and one extensive bone cyst caused by echinococcus. Chemotherapy was given to patients with high-grade sarcoma and two of them received in addition postoperative radiotherapy at a dose of 60 Gy.

The operated arm was the dominant side in six patients, two being in the osteoarticular group.

Patients were followed with radiographs. Nonunion was assessed at 1 year postoperatively. Clinically, mobility of the joint was evaluated with a goniometer and the function of upper limb was assessed according the Musculoskeletal Tumor Society (MSTS) system. The maximum of the theoretical function is based on a five-point scale for six parameters with a total of 30 points [19]. All patients in the study consented for these investigations.

Differences in demographic and clinical characteristics of both groups were analyzed for categorical variables with Chi² tests and for continuous variables with Student t-test. Assumptions of normality and equal variances were made. Significance was set at $P < 0.05$.

**Results**

The mean follow-up period was $110 \pm 99$ months. The mean length of bone resection was $9 \pm 3$ cm. There was no local recurrence of the initial disease but one patient died from the disease at 12 months. Fracture and nonunion were the most frequent complications occurring respectively in four and three patients. Table 2 lists the main data according to the allograft category. There were five fractures, four of which occurred in the osteoarticular group (Fig. 1). Two allografts of the proximal radius had an early fracture and required an exchange with a similar allograft. Another two allografts of the proximal radius had a well-tolerated fracture that required no further treatment. One of these fractures healed spontaneously. A late symptom-free fracture was observed at 15 years in an intercalary allograft.

![Figure 1](image1.png)  
**Figure 1** a: fracture of a proximal radius allograft after intense rowing in a boat at 6 months after surgery (patient # 2); b: same patient. Radiological aspect of a second allograft, 21 years after explantation of the first one that was fractured. No pain. Active as soldier.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Data according to the allograft category.</th>
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<tbody>
<tr>
<td></td>
<td>Osteoarticular allografts</td>
</tr>
<tr>
<td>Patients</td>
<td>$n = 5$</td>
</tr>
<tr>
<td>Age</td>
<td>$27 \pm 11$ years</td>
</tr>
<tr>
<td>Follow-up patient</td>
<td>$175 \pm 116$ months</td>
</tr>
<tr>
<td>Allografts</td>
<td>$n = 7$</td>
</tr>
<tr>
<td>Length of resection</td>
<td>$9.8 \pm 4$ cm</td>
</tr>
<tr>
<td>Follow-up allograft</td>
<td>$126 \pm 115$ months</td>
</tr>
<tr>
<td>Fracture</td>
<td>$4/7$</td>
</tr>
<tr>
<td>Nonunion</td>
<td>$1/7$</td>
</tr>
<tr>
<td>Revision</td>
<td>$3/7$</td>
</tr>
<tr>
<td>Explantation</td>
<td>$3/7$</td>
</tr>
<tr>
<td>MSTS score</td>
<td>$62 \pm 12%$</td>
</tr>
</tbody>
</table>

MSTS: Musculoskeletal tumor society.
at the ulna. Seven of the 12 allografts, in this series, had no fracture (Figs. 2 and 3).

Nonunion of the allograft occurred in three patients of the series, two of them having received irradiation. There were seven anastomotic junctions with the host bone in the osteoarticular group and one nonunion was only observed. In the intercalary group, there were 10 junctions available between host bone and allograft. Four junctions in two allografts developed a nonunion as assessed by radiographs at 1 year while three allografts had an uneventful healing. Nine of the 12 allografts had no healing trouble.

Six allografts had neither a fracture nor a nonunion occurrence after a mean follow-up of 120 ± 112 months after surgery (Figs. 1b, 2, 3).

One osteoarticular distal radius developed 15 months after surgery, a gradual chondrolysis requiring conversion with a wrist arthrodesis.

In the present series of 10 patients with a follow-up of 125 months, four surgical revisions were needed and three of them concerned an osteoarticular allograft.

Late gradual osteoarthritic changes were observed in the osteoarticular allografts (Figs. 1b, 3a). There was neither infection nor unexpected postoperative palsy.

**Figure 2**  a: radiological aspect of an intercalary allograft of the radius, 8 years after surgery (patient # 7); b: same patient. Lateral aspect of the intercalary allograft that was fixed with two screws and cement 8 years ago.

**Figure 3**  a: anteroposterior radiograph of a distal radius allograft (patient # 1). Aspect at 22 years after surgery. Fixed lateral translation of the distal radius since surgery. Mild pain at the wrist with on demand intake of non-narcotic analgesic; b: lateral radiograph of the grafted wrist in flexion at 22 years after surgery. Clinically, flexion was measured at 30°; c: lateral radiograph of the grafted wrist in extension at latest follow-up. Extension was measured at 50°.
Function of the upper limb was assessed at the last follow-up (Tables 1 and 2). Seven patients had no pain or only episodic discomfort. Two patients took occasionally painkillers. One patient with a distal radius allograft needed to take daily medication for the pain due to chondrolysis before revision. Pronation and, in particular supination, were the most affected movements. The residual motion was $52 \pm 28^\circ$ in pronation and $37 \pm 32^\circ$ in supination. The loss concerned predominantly the osteoarticular group. Flexion of elbow was $125^\circ$ and lag of extension never exceeded $30^\circ$. The loss of mobility at the wrist was gradual in the failed osteoarticular distal radius while the other patient had $50^\circ$ of mobility in flexion and extension.

The function was better in the intercalary group with an average of $23.8 \pm 4$ points or $79 \pm 13\%$ of the maximal function whereas in the osteoarticular group, the score reached $18.6 \pm 3.5$ points or $62 \pm 12\%$ of an optimal function (Figs. 4 and 5). Three patients with an osteoarticular hemi-joint have more than 200 months of follow-up with a useful forearm being able to lift a light weight (one pound) or to take a toddler in both arms. The overall mean score at long-term in this series was $70.6 \pm 14\%$. All patients had a useful arm.

Any significant difference could not be found at statistical analysis due to the limited number of patients. Investigated groups were non homogenous in terms of population characteristics and conclusive comparison between both groups of limited size could not be achieved.

Discussion

This series, initiated in 1987, reports long-term results of skeletal reconstruction of the forearm with bone allografts after tumor resection. Giant-cell tumor at the distal radius excepted, bone tumor location at the forearm remains a rare event [20]. In a large series of bone allografts implanted after tumor resection, the forearm represented less than 5\% of the cases [21].

The allograft related follow-up period was rather long but with a large scattering as the screened period was ended at the death of the patient or at the allograft explantation.
Fracture was the most prevalent complication of bone allografts implanted at the forearm and concerned four of the 10 patients. Three of them had an osteoarticular graft. Fracture occurred more often in the osteoarticular group and was an early event in the two cases that required implantation of a new allograft. The finding of fracture prominence was also observed in allografts used in children and confirms our earlier report [15,22]. The highest prevalence of fracture in bone allografts contrasted with previous series reporting nonunion as being the most frequent complication of a bone allograft [21—23]. In series of allografts where there is a greater reported prevalence of fracture, there is a relative higher proportion of osteoarticular grafts or allografts used for arthrodesis. Those categories of allografts are more exposed to fracture [14,20,22,23]. Conversely, nonunion is predominant in series of bone allografts where intercalary ones were more frequent [14,21,23]. Fracture remains an unpredictable occurrence. Two allografts at the proximal radius fractured and were replaced by a second allograft at 15 months after initial surgery. One of these two allografts is still well functioning after more than 20 years in an active young patient whereas the second allograft in the other patient had also a fracture that healed spontaneously with a satisfactory function. Fixation of a rather thin bone such as in the forearm is difficult. Plating is more appropriate but when associated to intramedullary kirschner wires, drilling of a cortical screw-hole has to be very oblique and this requirement may favour fracture of the bone cortex. The use of intramedullary cementation of the allograft combined to plate fixation has been performed once with success in the present investigation and might be a good option for preventing fracture as suggested by Donati et al. [24].

Nonunion was the second highest complication occurring in three patients having had chemotherapy and for two of them local radiation. Unhealed bone junctions were predominantly observed in the intercalary group where it concerned half of the patients as reported by others [14,21,23]. Chemotherapy and radiotherapy are well-known favouring factors for developing non-union [21,25]. It is worth noting that seven out of the 10 patients had an uneventful healing observed within 1 year after surgery. Whether the exclusive use of plate fixation with locking screws for a more rigid fixation at the forearm could have decrease the rate of nonunion in this series cannot be answered by the present investigation. Six allografts had neither fracture nor nonunion in their course of healing after a mean 10 years of follow-up.

Progressive failure of the osteoarticular allograft was observed once at the distal radius, occurring after 15 months in a young man. Conversion into an alloarthrodesis of the wrist was not challenging and has also been previously reported [20]. Four proximal radius and one distal one functioned satisfactorily. Secondary osteoarthritis at the radioulnar joint was observed at the grafted joint and also at the radio-ulnar joints. These changes were free of pain and late events.

There was no sepsis in this small series while our infection rate in the overall use for massive allografts in orthopaedic surgery was 6% [23].

Function of the reconstructed upper limb was satisfactory to all the patients except one with distal radius allograft. Pain was a concern for one patient with a failed allograft. Two others took occasionally painkillers. The level of function was maintained with the time. Prosupination was the most affected movement and occurred more frequently in the osteoarticular group. Intercalary allografts had a better functional score probably because elbow and wrist were less affected by the reconstruction. No statistical conclusion could be drawn from this investigation due to the limited number of patients.

One of the advantages of using a bone allograft is that it offers a true anatomical replica if the allograft has been procured from the same location as the excised bone and if it has been matched for size. Any significant size mismatch at the forearm bones will trouble the prosupination movement.

The use of a bone allograft in this location appears to be satisfactory at long-term. Its use as an osteoarticular allograft at the upper limb is less restricted than at the lower limb where mechanical constraints appeared too high for a frozen-preserved cartilage. Its use as an intercalary bone might be considered at both upper and lower limbs. Using an allograft exposes the patient to a very low risk of a transmitted disease. However, with the cumulative safety levels from the donor selection to biological investigation, such risks related to the use of an allograft remain remote [26].

Using an anatomical material for the reconstruction avoids considering any non anatomical reconstructive surgery such as earlier reported [1,2,11,12] or the extensive use of bone autograft with subsequent donor site morbidity [3,4,10]. A customised endoprosthesis is another option but long-term experience is still lacking [17]. Should a failure of the reconstruction occurred, any another procedure including the use of a fibula whether or not vascularised is still available with an expected good result at long term [5—8].

A bone allograft remains a suitable material to consider amongst other options for a long-term reconstruction of the forearm after a tumor excision.

Disclosure of interest

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

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References

Forearm reconstruction using bone allograft


