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Osteoarticular allograft reconstruction after resection of the distal radius

survival and functional results at ten to 24 years follow-up

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Aims
Various reconstructions of the distal radius after tumour resection have been proposed. Osteoarticular allografts can restore a functional joint, but the long-term durability of this reconstruction has been questioned. Data on long-term results are scarce in the literature. The aim of our study was to answer the following questions: What is the long-term survival of osteoarticular distal radius allografts with a minimum follow-up of ten years? What is the long-term patient satisfaction?

Methods
From 1999 to 2013, we performed 23 reconstructions with osteoarticular allografts after distal radius resection. Patients had a mean age of 36 years (14 to 69); 17 had giant cell tumour, three Ewing's sarcoma, two osteosarcoma, and one osteoblastoma. All patients were evaluated for allograft survival and functional outcome (Musculoskeletal Tumor Society (MSTS) score and Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire score).

Results
One patient was lost to follow-up at 53 months. One patient died for concomitant disease at 44 months. Of the remaining 21 patients, one underwent revision arthrodesis at 48 months. A total of 20 allografts remained in situ at follow-up for a mean of 213 months (22 to 293). The mean MSTS was 25.7 (18 to 30), and the mean DASH was 10.4 (0 to 30). According to the MSTS parameter of emotional acceptance, all patients with a surviving allograft scored still satisfied or higher.

Conclusion
In our experience, osteoarticular allografts in distal radius reconstruction can be a long-lasting procedure with long-term patient satisfaction. Few and conflicting results are reported in the literature; even when comparing series, it is difficult to clearly identify factors that may explain the differences in reported results.

Take home message
- Distal radius reconstruction with osteoarticular allografts can be a long-lasting procedure with long-term patient satisfaction if avoidance of heavy activity is accepted from the outset.
- It remains difficult to clearly identify the factors that may explain the differences in reported results between different series.
- It may be advisable to select patients for this procedure by offering an alternative arthrodesis reconstruction to patients who are heavy manual workers.

Introduction
Reconstruction after distal radius resection for malignant or aggressive benign tumours is a challenging procedure. Several reconstructive techniques have been proposed and no technique has been shown to be clearly superior to the others in terms of outcomes. Due to the rarity of the indications for these

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procedures, few series have been reported in the literature, and data on long-term outcomes are particularly lacking.

Reconstructive procedures after distal radius resection can be divided into two groups: motion preserving and non-motion preserving techniques. Surgical options in the first group include osteoarticular allografts, vascularized proximal fibula transfer with arthroplasty, and custom prostheses.

In the second group, arthrodesis is performed using an allograft, a non-vascularized autograft from the iliac crest, fibula, or tibia, a vascularized fibula transfer, or a procedure of ulna centralization. Both total wrist arthrodesis and partial arthrodesis (radioscapholunate arthrodesis) have been described.

Arthrodesis reconstruction offers a more stable wrist and, if achieved, a durable result, but the lack of joint mobility reduces the patient's ability and dexterity. On the other hand, motion-preserving reconstructions are more prone to degeneration over time, and a high incidence of complications has been reported with both biological and prosthetic reconstructions.[1] Custom-made wrist hemiarthroplasty or total arthroplasty has been described by several authors in recent years, but rarely with a consistent number of cases and with inconstant results,[2,3] although there are some recent series reporting more successful results and lower complication rates. [4-6]

Osteoarticular allografts have shown good short- to medium-term results,[5,7-13] but the long-term durability of these implants has been questioned due to progressive degeneration of the reconstructed joint. The aim of our study was to answer the following questions:

- What is the survival rate of osteoarticular allografts in distal radius reconstructions with a minimum follow-up of ten years?
- What are the functional outcomes of patients with surviving allografts more than ten years after surgery?

Methods

Study population

From May 1999 to October 2013, we performed 23 reconstructions with an osteoarticular allograft after distal radius resection for bone tumours. Inclusion criteria for this study were: primary surgery at our centre with resection of the distal radius and reconstruction with an osteoarticular allograft; and minimum follow-up of ten years after surgery or failure of the allograft before ten years.

We considered as valid follow-up a clinical examination and radiological evaluation or, in case the patient was not available to return to our centre for evaluation, also a telephone interview of the patient with the completion of two functional questionnaires.

During the above-mentioned period, osteoarticular allograft was the most frequent, but not the only procedure we used for distal radius reconstructions. We usually reserved osteoarticular allograft reconstruction of the distal radius for patients with low energy functional requirements, while offering heavy workers a reconstruction with wrist arthrodesis, which we mostly performed by an autologous vascularized fibula transfer fixed with a plate. In paediatric patients a microsurgical reconstruction of the distal part of the radius with a vascularized proximal fibula transfer, including the physis with its growth plate, was usually preferred, in order to maintain a growth potential of the reconstructed radius. The experience and results with both these techniques at our centre have already been described by our Plastic Reconstructive and Microsurgery equipe .[14,15]

Patient characteristics

One patient was lost to follow-up 53 months after surgery, and one patient died of concomitant disease 44 months after surgery. Therefore, 21 patients were included in the study. The characteristics of the patients are shown in Table I.

Surgical technique

Prior to surgery, a distal radius or whole radius allograft was selected from the tissue bank database with the best achievable match to the patient's native radius. In all cases, a fresh-frozen allograft stored at -80°C was used. The graft did not undergo any sterilization process; microbiological safety was assumed to be achieved by the combination of careful screening of candidates, sterile procedures for harvesting and processing, soaking in antibiotic solution, and quality control testing of the product.

A volar approach was used on the radial side of the forearm and wrist. The radial artery and vein were identified and preserved. The brachioradialis was detached from the radius at its distal insertion. The distal radius was progressively isolated. The pronator quadratus muscle was usually killed together with the resection specimen. A proximal osteotomy was performed at the planned level based on the preoperative MRI. A specimen from the medullary canal at the osteotomy site was sent for frozen section. A transverse osteotomy was performed in all but one case where a step-cut osteotomy was performed. Capsulotomy was performed circumferentially, saving as much capsule attached to the carpal bones and distal ulna as permitted by the extent of the tumour. A compression plate was used for allograft fixation. Two interfragmentary screws were used in the case that received a step-cut osteotomy. Accurate circumferential capsulorraphy was performed between the patient's residual wrist capsule and the allograft capsule. No additional distal radioulnar stablization was used. In eight cases, cement was injected into the medullary canal of the graft prior to fixation to the host radius to increase its mechanical strength. Due to the long period covered by this study, the regimen of antibiotic prophylaxis varied over time, shifting from vancomycin + tobramycin in the early years to vancomycin + piperacillin-tazobactam more recently. Antibiotics were given for five days in the earlier period and three days afterwards. After surgery, the patient wore an above-the-elbow cast (in neutral position) for 30 days, followed by a below-the-elbow splint for a further 25 days. A progressive rehabilitation programme was then started, including passive and active exercises.

Evaluation methods

At the time of our study, all patients had already completed ten years of oncological follow-up according to current protocols.

The evaluation protocol for the present study included:

- Review of all medical records to collect data on tumour histology, surgical procedure, adjuvant treatments, patient demographics, postoperative complications or failures

Table I. Patients' demographic and clinical characteristics.

Pt	Age, yrs	Sex	Diagnosis	Resection length, cm	FUP, mnths	Complications	Further surgery	Flex	Ext	Sup	Pron	Radiograph score	DRUJ score	MSTS	DASH
1	16	F	Giant cell tumour	9	293	No	No	N/A	N/A	N/A	N/A	N/NA	N/A	30	0.0
2	28	M	Giant cell tumour	9	48	Allograft fracture, treated with allograft revision. Fracture of second allograft	Revision new allograft at 11 months. Revision arthrode- sis at 48 months	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	44	M	Giant cell tumour	7.5	265	No	No	N/A	N/A	N/A	N/A	N/A	N/A	26	9.2
4	15	F	Ewing's sarcoma	13	256	No	No	N/A	N/A	N/A	N/A	2	2	30	0.0
5	35	M	Giant cell tumour	7	251	No	No	48	60	71	68	2	1	25	6.7
6	25	F	Giant cell tumour	6	249	Partial allograft fracture	No	35	35	55	60	3	1	18	25.0
7	14	F	Giant cell tumour	6	237	EPL rupture	Tendon repair	30	55	77	70	2	1	20	25.0
8	56	F	Giant cell tumour	5	235	No	No	N/A	N/A	N/A	N/A	3	2	19	30.0
9	35	M	Giant cell tumour	7	230	No	No	N/A	N/A	N/A	N/A	N/A	N/A	26	6.0
10	45	F	Giant cell tumour	6	228	No	No	N/A	N/A	N/A	N/A	3	2	30	8.3
11	25	F	Giant cell tumour	7	224	No	No	50	67	80	82	3	1	30	6.7
12	13	M	Osteosarcoma	9.5	229	No	No	75	72	82	72	1	1	29	0.0
13	54	F	Giant cell tumour	5.5	215	Nonunion	No	N/A	N/A.	N/A	N/A	N/A	N/A	20	12.5
14	42	M	Giant cell tumour	6.5	213	No	No	39	30	50	60	3	2	22	7.0
15	33	M	Giant cell tumour	6.5	203	Nonunion	Bone grafting	25	45	72	67	3	2	23	21.7
16	51	M	Giant cell tumour	7	200	No	No	39	45	72	65	2	2	30	3.3
17	62	F	Ewing's sarcoma	11	176	No	No	N/A	N/A	N/A	N/A	N/A	N/A	25	30.0
18	49	F	Osteoblastoma	7.5	163	No	No	45	67	77	67	2	1	29	2.6
19	58	F	Giant cell tumour	8	144	No	No	45	50	77	75	N/A	N/A	30	0.0
20	30	F	Parosteal osteosarcoma	11	134	Nonunion	Bone grafting	71	70	72	75	3	1	25	10.0
21	18	M	Ewing's sarcoma	8	122	Nonunion	Bone grafting	40	35	72	62	3	1	28	4.2

DASH, Disabilities of the Arm, Shoulder and Hand questionnaire; DRUJ, distal radio-ulnar joint; EPL, extensor pollicis longus; Ext, extension; F, female; Flex, flexion; FUP, follow-up; M, male; MSTS, MusculoSkeletal Tumor Society upper limb score; N/A, not available; Pron, pronation; Pt, patient; Sup, supination.

(allograft failure was defined as the need for graft retrieval and the need to perform a new reconstructive procedure).

- Patient interview and completion of a functional questionnaire according to Musculoskeletal Tumor Society (MSTS) upper limb score,[16] and Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) score[17] (mandatory for inclusion in the study).
- Clinical assessment and range of motion recording (if feasible).
- Radiological assessment (if feasible). If radiographs were available at follow-up, the degree of degenerative joint disease was classified according to the Knirk and Jupiter classification.[18] In addition, we decided to classify radiological findings at the radioulnar joint as follows:
  - Grade 0: no widening of the distal radio-ulnar joint (DRUJ), no or moderate arthritis.
  - Grade 1: no or slight widening, advanced arthritis with osteophytes.
  - Grade 2: marked widening with loss of congruence between the radioulnar arch and the first arch of Gilula.

Statistical analysis

R software v. 4.4.0 (R Foundation for Statistical Computing, Austria)[19] was used for statistical analysis. Survival was assessed using the Kaplan-Meier method. Differences between groups were assessed using Fisher's exact test. The conventional value of 5% was used as the significance threshold for evaluating two-tailed p-values. Statistical significance was set at $p < 0.05$.

The study was conducted in accordance with the 1975 Declaration of Helsinki.[20] Approval was obtained from the local institutional ethics committee (ref. 10197/2017; retrospective observational study).

Results

A total of 15 patients were affected by giant cell tumour, three by Ewing's sarcoma, two by osteosarcoma, and one by osteoblastoma. All patients had localized disease at presentation, as assessed by CT scan of the chest in giant cell tumours and of the chest and abdomen in osteosarcomas and Ewing's sarcomas. Patients with Ewing's sarcoma and osteosarcoma received pre- and postoperative chemotherapy. None of the patients with giant cell tumours were treated with denosumab. The mean age of patients at surgery was 36 years (14

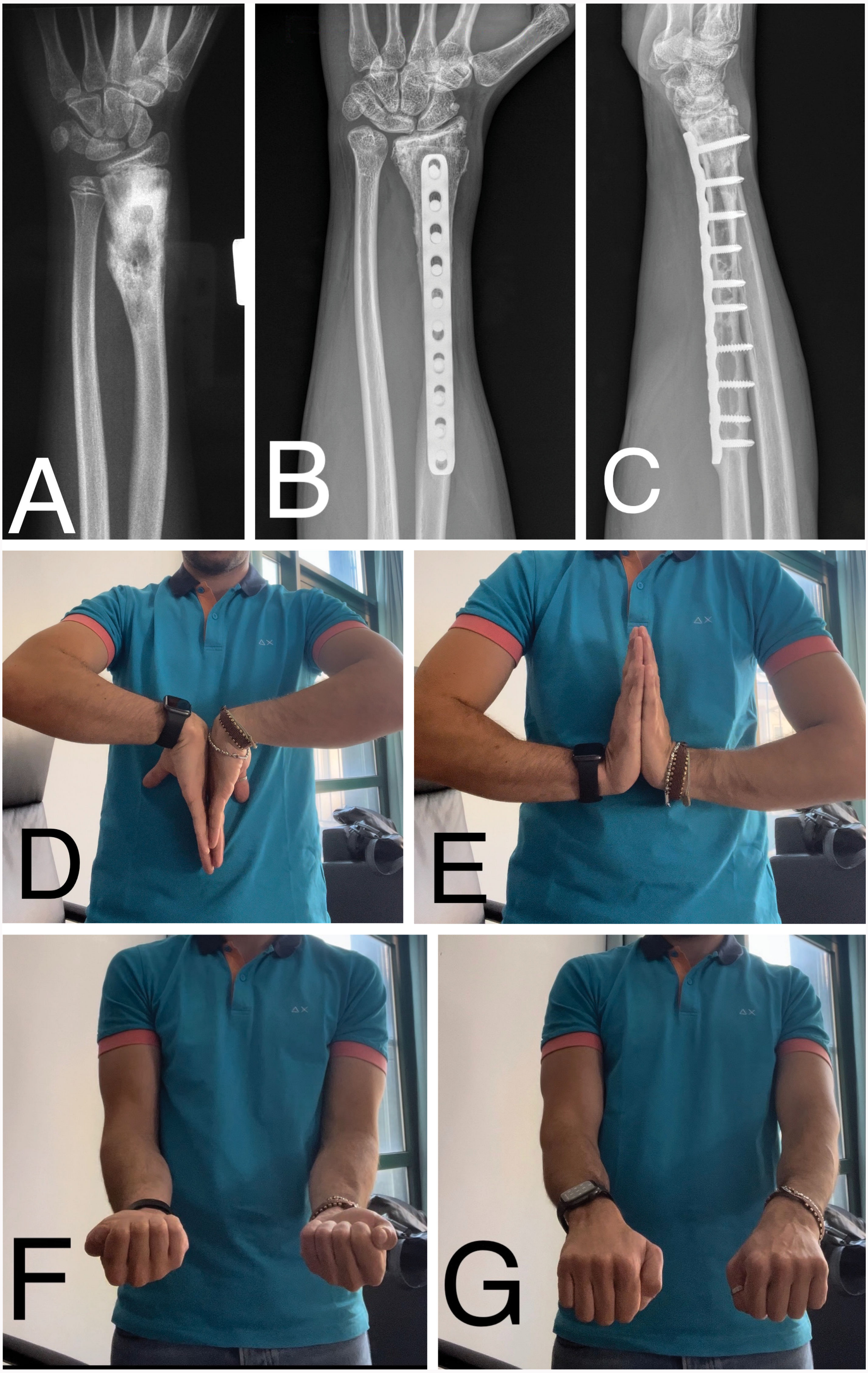

Fig. 1
Male patient, aged 13 years at the time of the surgery, affected by osteosarcoma of left distal radius. A) Anteroposterior (AP) preoperative radiograph. B,C) AP and lateral radiograph view at 229 months (19 years) after surgery. D-G) Clinical results at follow-up, showing range of motion at latest follow-up.

Fig. 2
Female patient, aged 25 years at the time of surgery, affected by giant cell tumour: anteroposterior radiological findings at 224 months after surgery, showing a grade 3 osteoarthritic degeneration and a grade 1 distal radio-ulnar joint score.

Fig. 3
Female patient, aged 45 years at the time of surgery, affected by giant cell tumour: anteroposterior radiograph findings at 228 months after surgery, showing a grade 3 osteoarthritic degeneration and a grade 2 distal radio-ulnar joint score (large widening and loss of congruence between radioulnar arch and first arch of Gilula).

to 69). The dominant hand was affected in ten of 21 patients (Table I).

There were no tumour recurrences in our series. One patient underwent a revision arthrodesis at 48 months; 20 allografts remained in situ at follow-up for a mean of 213 months (122 to 293). The patient who underwent revision arthrodesis was included in the evaluation of graft survival but excluded from the evaluation of clinical outcomes at follow-up.

Allograft survival according to Kaplan-Meier analysis was 95.2% at both 15 and 20 years after surgery.

Five patients underwent further surgery: three patients underwent debridement of the osteotomy site and augmentation with autograft from the iliac crest due to nonunion of the allograft; one patient underwent tendon reconstruction for rupture of the extensor pollicis longus; one patient (mentioned above) underwent revision with a new allograft due to failure of the allograft (resorption and fracture) and then revision to arthrodesis after a second failure.

Another patient presented with nonunion at the osteotomy site but refused further surgery. Therefore, we observed nonunion in four out of 21 patients (19%). All three nonunions treated with a second operation eventually healed. There were no infectious complications.

Due to the time elapsed since surgery and the fact that many patients lived far away, direct clinical evaluation was not possible in all patients; patients who were unable to return to our centre were evaluated by telephone interview. We were able to assess wrist range of motion in 12 cases (Table I and Figure 1). The average range of motion in these 12 patients was: flexion 42° (20° to 70°), extension 47° (20° to 70°), supination 69° (50° to 85°), pronation 66° (55° to 80°).

Anteroposterior (AP) and lateral (LL) radiographs of the wrist and forearm were available at the last follow-up in 14 of 20 patients. Of these 14 patients, none had a Knirk and Jupiter score of 0, one had a score of 1, five had a score of 2, and eight had a score of 3.[18]

Radiological evaluation of the distal radioulnar joint according to the above criteria showed grade 1 in eight patients (Figure 2) and grade 2 in six patients (Figure 3). No patient was classified as grade 0.

Functional scores were recorded in all 20 patients. The mean MSTS was 25.7 (18 to 30), and the man DASH was 10.4 (0 to 30).

According to the MSTS parameter of emotional acceptance, all patients with a surviving allograft still scored satisfied or better. The MSTS score had already been recorded in a previous study 14 years earlier in 15 of our patients with a mean follow-up of 58.9 months.[13] A comparison of the

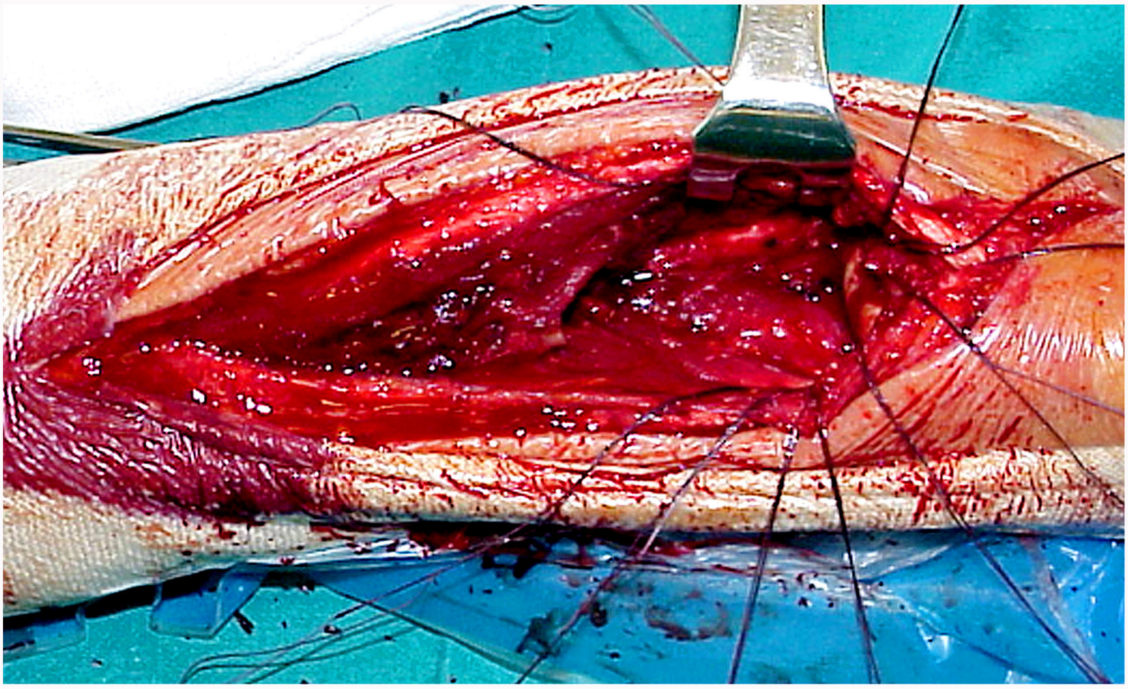

Fig. 4
Intraoperative view, showing preparation of the recipient site for accurate circumferential suturing between residual capsule of the host and capsule of the allograft.

MSTS scores at these two different times showed an average loss of one point, with three patients losing more than three points. Considering only the group of patients with more than 230 months of follow-up (seven patients), the average loss of MSTS score between the two assessments was three points, showing a slight increase in progressive functional impairment with longer follow-up.

A Fisher's exact test was performed to evaluate possible associations between radiological degenerative grade 3 and lower MSTS scores (< 26) or higher DASH scores (> 9), but no association was found (p = 0.592 and p = 0.301, respectively), even though 62.5% of grade 3 patients had an MSTS score < 26 compared with 33% of grade 1 or 2 patients. In our numbers, there was also no clear association between grade 2 distal radioulnar joint degeneration and worse functional outcomes.

Discussion

There is a paucity of data on the long-term results of distal radius reconstruction with osteoarticular allograft. Preservation of motion in reconstructed joints has always been a central concern of orthopaedic surgeons involved in the treatment of bone tumours. The use of osteoarticular allografts has seen a dramatic decline in lower limb reconstructions in recent decades due to the rapid articular degeneration that occurs in weightbearing joints.[21]

As a result, megaprostheses or allograft-prosthesis composites are now the leading reconstructive options in the lower limb or large joints of the upper limb. In smaller non-weightbearing joints, such as the wrist, it could be hypothesized that osteoarticular allografts may have a better survival rate, but the durability of this type of implant has also been questioned in distal radius reconstructions, also because arthrodesis is a fairly well tolerated and functional alternative option in the wrist.

Other options for maintaining wrist motion include custom-made megaprostheses or vascularized or non-vascularized proximal fibular transfer with arthroplasty. For megaprostheses, results are still few and inconstant,[1-6] although the number of publications on the subject is increasing, while wrist arthroplasty after proximal fibula transfer is a viable option, but congruence of the opposing surfaces is limited and the risk of instability is high,[22,23] although it can be limited by strict and solid reconstruction of the wrist capsule.[24] Therefore, the use of an osteoarticular allograft remains a valid choice today and it is of particular interest to verify its long-term results.

The results of a series of 24 osteoarticular allografts with a mean follow-up of 10.9 years (2.1 to 22.3) were reported by Kocher et al in 1998.[10] Eight patients (33%) underwent revision arthrodesis, six because of reconstruction failure (25%) and two because of tumour recurrence; 14 other complications requiring surgery were noted in their series.

Li et al[11] in 2015 reported on a series of 17 patients with a mean follow-up of seven years. Two patients had the allograft removed and revised, one for reconstruction failure (6%) after allograft fracture and one for tumour recurrence.

Recently, a report on the long-term results of a larger series of osteoarticular allografts after distal radius resection was published by Lans et al.[25] A series of 33 patients were analyzed with a median follow-up of 4.2 years for the whole series, with ten patients clinically evaluated at a longer follow-up with a median of 13 years. 55% of patients had undergone further surgery and 36% presented with allograft failure requiring revision (three) or arthrodesis (nine), with a further three patients undergoing arthrodesis due to tumour recurrence.

Albergo et al in 2020[26] reported the long-term results (ten to 34 years) of 39 osteoarticular allograft reconstructions, but only in eight cases the distal radius was the bone involved; the survival free of allograft removal at ten years was 85% and the survival free of reoperation for any reason at ten years was 72%.

Our series included 21 patients with a minimum follow-up of ten years in the 20 patients with surviving primary reconstruction; 28.6% (six patients) underwent further surgical procedures, but only one patient had reconstruction failure and underwent arthrodesis (4.8%). Despite a longer follow-up, our results seem to show a better survival rate (95.2%) than both the series reported by Kocher et al[10] and Lans et al,[25] which are the series with the longest follow-up among those presenting more than 20 cases.

When also considering series with shorter follow-up, reported revision rates after mechanical allograft failure are quite variable, ranging from 0% to as high as 43%[5,7–12,25,27,28] with one paper reporting a 100% revision rate but including only two cases.[21]

Allograft revision, usually conversion to arthrodesis or more rarely new osteoarticular allograft reconstruction, is usually motivated by mechanical failure (fracture/resorption of the allograft) or degenerative joint disease with consequent pain and dysfunction. Infection seems to be a rare complication in the distal radius. In our series, no infections occurred, in agreement with the majority of previous reports, which mostly reported no infections[7–12,25,27,28] or only isolated cases of deep septic complications.[5]

Nonunion between the allograft and the host radius is common, with an incidence ranging from 0% to 42%[5,7–12,25,27,28] but it is usually a minor complication that can be resolved in most cases with the use of autologous iliac crest bone grafts without compromising the survival of the reconstruction. A reduction in the incidence of nonunion has been reported with the use of step-cut osteotomy.[29]

Why there is such a large variation in reported revision rates between series is difficult to determine. The survival of allografts in our series, with a revision rate of 4.8%, appears to be better when compared with the few other series with a comparable long follow-up, which report revision rates of 25% to 43%.[10,25,27]

We have attempted to compare the surgical techniques used in these series, but we have not found any significant differences. A particular role of distal radioulnar joint stability could be hypothesized and a better result has been reported in patients who received an adjunctive Kapandji procedure.[11] Temporary fixation of the reconstructed joint with a percutaneous Kirschner wire has also been proposed.[7,8,10] However, in our series we did not use any adjunctive surgical procedure to stabilize the DRUJ, neither temporary nor definitive, relying only on a meticulous and circumferential suture of the residual capsule to the capsule of the allograft (Figure 4).

The use of cement in the medullary canal of the allograft, which we used in eight out of 21 patients, could perhaps help to reduce allograft fracture, which is one of the main causes of failure[10,25] and which occurs with a rate of 0% to 39% in different series,[5,7–12,25,27] but this procedure to reinforce the graft has only been used in a few reported series and not in all patients of the series;[11,12,25] therefore, there are insufficient data to establish its efficacy.

Another useful trick to reduce allograft fractures is the use of T-shaped long distal radius plates or moulded straight diaphyseal plates covering the entire metaphyseal and epiphyseal region to mechanically protect the entire allograft.

Initial postoperative management differed between series, with a consensus on immobilization in a plaster cast for several weeks (six to eight), but with some authors using an above-the-elbow cast,[5,7,8,10-13] some of them with a subsequent change to a below-the-elbow cast[7,8,10,11,13] (as we did in our series), and other authors using a below-the-elbow cast from the beginning.[25] An initial above-the-elbow cast could offer a more complete immobilization, including a complete restriction of prono-supination movements, and this could allow a more stable repair of the soft-tissues during the first weeks after surgery, but we don't have data to make an adequate comparison between the two postoperative protocols.

Looking at functional outcomes in patients with surviving allografts, results in published series are more homogeneous than reconstruction survival, with average MSTS scores ranging from 71% to 93%[7,8,11,27,28] and DASH scores ranging from 8 to 20.[12,25,27,28] Functional outcomes in our series were not dissimilar, with an average MSTS score of 85.7% and a DASH score of 10.4%.

In our experience, the level of satisfaction of patients with surviving allografts at long-term follow-up was consistently high or good, even in the presence of very variable functional and radiological scores, with all patients still rating themselves as satisfied or better (100% satisfied to enthusiastic, according to the MSTS emotional acceptance parameter).

This positive self-assessment was found even in patients with advanced radiocarpal degeneration, extensive distal radioulnar joint derangement, and obvious range-of-motion limitations, and we believe it is closely related to the general absence of significant pain, which maintains the patients' subjective satisfaction even in the presence of partial functional impairment.

No clear correlation was found between radiological scores and outcomes, but it must be considered that the small number of patients may have influenced the results of the statistical analysis.

Why the reported long-term survival results of osteoarticular allografts differ significantly between series remains controversial.

Patient selection and education may also play a role. We have always reserved osteoarticular allograft reconstruction of the distal radius for patients with low-energy functional demands and offered arthrodesis reconstruction to heavy workers or patients with high-resistance demands. In addition, all patients were instructed from the outset to avoid functional loads and to limit the functional demands on the reconstructed joint, using the hand and wrist for light activities and avoiding heavy loads. This may have contributed both to delaying structural and functional degeneration of the reconstructed joint and to maintaining an adequate level of subjective satisfaction, as the patients have always been aware of a persistent need for functional limitation in their daily activities.

In conclusion, in our experience, osteoarticular allografts in distal radius reconstruction can be a long-lasting procedure with long-term patient satisfaction if avoidance of heavy activity is accepted from the outset. It may therefore be advisable to select patients for this procedure by offering an alternative arthrodesis reconstruction to patients who are heavy manual workers. While there is general agreement that short-term results are satisfactory, there are few and conflicting data reported in the literature on the long-term results of osteoarticular allografts after distal radius resection. It remains difficult to clearly identify the factors that may explain the differences in reported results between different series.

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Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

Ethical review statement

The study was conducted in accordance with the 1975 Declaration of Helsinki. Approval was obtained from the local institutional ethics committee (ref. 10197/2017 (retrospective observational study)).

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