Allograft-Prosthesis Composite Reconstruction of the Proximal Part of the Humerus

Functional Outcome and Survivorship

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Background: Limb salvage following resection of a tumor in the proximal part of the humerus poses many challenges. Reconstructive options are limited because of the loss of periarticular soft-tissue stabilizers of the glenohumeral joint in addition to the loss of bone and articular cartilage. The purpose of this study was to evaluate the functional outcome and survival of the reconstruction following use of a humeral allograft-prosthesis composite for limb salvage.

Methods: An allograft-prosthesis composite was used to reconstruct a proximal humeral defect following tumor resection in thirty-six consecutive patients at one institution over a sixteen-year period. The reconstruction was performed at the time of a primary tumor resection in thirty cases, after a failure of a reconstruction following a previous tumor resection in five patients, and following excision of a local recurrence in one patient. The mean duration of follow-up of the living patients was five years. Glenohumeral stability, function, implant survival, fracture rate, and union rate following the reconstructions were measured. Functional outcome and implant survival were analyzed on the basis of the amount of deltoid resection, whether the glenohumeral resection had been extra-articular or intra-articular, and the length of the humerus that had been resected.

Results: One patient sustained a glenohumeral dislocation. Deltoid resection (partial or complete) resulted in a reduced postoperative range of motion in flexion and abduction but had no effect on the mean Musculoskeletal Tumor Society score. Extra-articular resections were associated with lower Musculoskeletal Tumor Society scores. All patients had either mild or no pain and normal hand function at the time of final follow-up. The overall estimated rate of survival of the construct, with revision as the end point, was 88% at ten years. There were three failures due to progressive prosthetic loosening that necessitated removal of the construct. Four patients required an additional bone-grafting procedure to treat a delayed union of the osteosynthesis site.

Conclusions: An allograft-prosthesis composite used for limb salvage following tumor resection in the proximal part of the humerus is a durable construct associated with an acceptable complication rate. Deltoid preservation and intra-articular resection are associated with a greater range of shoulder motion and a superior functional outcome, respectively.

Level of Evidence: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Wide excision of the proximal part of the humerus is currently the indicated procedure for definitive local control of malignant and some benign-aggressive tumors of the proximal part of the humerus. The pursuit of negative surgical margins often mandates resection of the glenohumeral joint along with associated soft tissues, including the rotator cuff and deltoid muscles, either in part or in their entirety. Intra-articular excision requires incision of the shoulder joint capsule and all rotator cuff tendons. The remaining amount of the rotator cuff tendon varies, making subsequent repair difficult. Furthermore, the tendons are rendered functionless because their points of insertion on the humerus are

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resected with the tumor. Extra-articular excision sacrifices the entire capsule and glenoid as well as most of the rotator cuff tendons. This type of excision is primarily indicated in cases in which the tumor traverses the glenohumeral joint. The reconstructive possibilities following proximal humeral resection are limited and include use of (1) an osteoarticular allograft, (2) a large-segment endoprosthesis, (3) an allograft-prosthesis composite, or (4) an arthrodesis with an intercalary allograft and/or a vascularized fibular graft.

The primary theoretical advantage of an osteoarticular allograft over a prosthesis is the availability of capsular soft-tissue attachments with which to reconstruct the remnant host soft tissues. In time, the soft tissues may adhere with scar tissue, resulting in a more physiologic construct at the glenohumeral articulation. However, the complications associated with this type of reconstruction include subchondral collapse (a rate of 50%), fracture (13% to 30%), infection (12%), and nonunion (50%) as well as late degenerative arthritis89. Although using an endoprosthesis circumvents most of these complications, the prosthesis lacks the functional soft-tissue attachment sites of an allograft, and thus it may be unstable and may also become loose or fracture10.

Using an allograft-prosthesis composite combines the potential advantages of an allograft’s soft-tissue tendinous and capsular attachments with the benefits of a humeral prosthesis and theoretically avoids the disadvantages of each. For instance, the articular degeneration and subchondral collapse seen with osteoarticular allografts can be avoided with use of a prosthetic humeral head replacement. We sought to document the outcome, survivorship, and complication rates of a shoulder allograft-prosthesis composite. Eight variables were examined: glenohumeral stability, functional outcome, prosthetic survival, loosening, fracture, union of the osteosynthesis site, infection, and oncologic outcome.

The literature on this type of reconstruction is scant, and long-term results have not been reported, to our knowledge. The purpose of our current study was to evaluate the functional outcome and implant survival after use of an allograft-prosthesis composite for reconstruction following resection of a tumor in the proximal part of the humerus. Furthermore, our goal was to determine whether the functional outcome and survivorship of this type of reconstruction were superior to those of the alternatives, an osteoarticular allograft and an endoprosthesis.

Materials and Methods

We performed a retrospective review of a database of all musculoskeletal tumors treated at our institution in order to identify patients who had undergone a prosthesis composite reconstruction of the proximal part of the humerus following tumor resection. Between December 1991 and February 2008, thirty-six consecutive patients (twenty male and sixteen female) were identified. The institutional review board of the hospital granted approval for the study. The median age at the time of the index procedure was twenty-three years (range, six to seventy-four years). The most common diagnosis was primary high-grade osteogenic sarcoma (nineteen patients). The remaining diagnoses included chondrosarcoma (eight patients); oligometastasis to the humerus (three patients, including one with metastatic renal cell carcinoma, one with metastatic angiosarcoma from the spleen, and one with metastatic osteogenic sarcoma from the distal part of the femur); and (in one patient each) Ewing sarcoma, giant-cell tumor, malignant fibrous histiocytoma of bone, radiation-induced secondary high-grade osteogenic sarcoma eighteen years after radiation for Hodgkin lymphoma, plasma-cells myeloma, and angiosarcoma.

The humeral allograft-prosthesis composite was used as the initial reconstructive technique following primary resection of the tumor in thirty patients and as a revision procedure in six patients. Five of the six revisions were of a failed osteoarticular allograft (three patients) or endoprosthesis (two) that had been used after a previous resection of an Enneking stage-IIB sarcoma. One patient underwent the reconstruction with the allograft-prosthesis composite following resection of a recurrent grade-2 chondrosarcoma.

Twenty-eight patients (78%) received adjuvant chemotherapy after the tumor resection and reconstruction. All patients with high-grade osteogenic sarcoma or Ewing sarcoma received systemic neoadjuvant and adjuvant chemotherapy. In addition, the patients with angiosarcoma, multiple myeloma, and metastatic disease received chemotherapy. Eight patients did not receive systemic adjuvant treatment. No patient received neoadjuvant or adjuvant radiation therapy for treatment of the resected tumor.

The mean duration of follow-up after use of the allograft-prosthesis composite was five years (range, four months to eleven years) for the living patients. Only the thirty-four patients with more than two years of follow-up were included in the analysis of the functional outcome. Eleven patients died at a median of eighteen months (range, four to seventy-four months) following the diagnosis: nine died of metastatic sarcoma, one died of metastatic carcinoma, and one died of complications related to the treatment of leukemia. No patient was lost to follow-up.

Both clinical and radiographic postoperative outcome measures were evaluated. Functional parameters were assessed at the time of the latest follow-up with use of the Musculoskeletal Tumor Society (MSTS) scoring system for the upper extremity. The MSTS score is based on six features: pain, function, emotional acceptance, position of the hand, manual dexterity, and lifting ability; each is assigned a maximum value of 5, with a maximum total score of 30. The amount of active shoulder motion (abduction and forward elevation) at the time of the most recent follow-up was determined from a review of office charts. These parameters were measured and recorded in each case by the surgeon who performed the surgery. Postoperative radiographs were evaluated for the presence or absence of union at the host-allograft junction site. For the purpose of this study, we considered a patient to have radiographic evidence of union once the formation of bridging callus exceeded 50%, as demonstrated by two orthogonal views.
and as determined by a single observer (A.A.). A successful union was defined as the presence of these radiographic findings in conjunction with the clinical findings of no pain (as subjectively described by the patient) and no tenderness (as objectively determined on physical examination) at the osteosynthesis site. The diagnosis of a nonunion was made if the aforementioned radiographic and clinical findings were not evident within twelve months postoperatively, or within twelve months following cessation of chemotherapy in those patients who underwent adjuvant treatment. Both the radiographic and the clinical criteria had to have been met in order to qualify as a union of the allograft-host junction site.

Survivorship analysis was performed with use of the Kaplan-Meier method. The end point was failure of the allograft-prosthesis composite reconstruction defined as the removal or revision of the prosthesis for any reason other than local recurrence of disease. We distinguished between a revision (removal and/or revision of the allograft-prosthesis composite due to failure) and a reoperation (any subsequent operation that did not result in the removal of the construct, such as bone-grafting or soft-tissue reconstruction). A recommendation that a revision or reoperation be performed was considered to be a failure even if the patient refused or was medically unfit for surgery.

The study group was stratified and analyzed on the basis of three distinguishing features: (1) the presence or absence of the abductor mechanism at the time of the reconstruction (an intact deltoid, a partial deltoid resection, or a total deltoid resection), (2) the type of resection (extra-articular or intra-articular), and (3) the length of the resection of the humerus (<50% or >50% of the humeral length as measured on preoperative radiographs). Resection length has been found to influence outcome and implant survival following tumor resection and reconstruction of the lower extremity; however, the relevance of resection length in humeral reconstructions remains undetermined.

The implant survival rate, the MSTS functional score, and the range of motion in abduction and flexion were analyzed according to the three features described above. The differences in the mean amounts of abduction and flexion among the three categories of deltoid resection were analyzed with one-way analysis of variance. The differences in the mean amounts of flexion and abduction and the MSTS scores based on the resection type (extra-articular or intra-articular), humeral resection length, and extent of deltoid resection were analyzed with use of a two-tailed Student t test. A p value of <0.05 was deemed to be significant.

Surgical Technique
All procedures were performed at a single institution by four fellowship-trained oncology surgeons (J.H.H., C.D.M., P.J.B., and E.A.A.) using essentially the same technique. The extent of the resection was classified according to the system of the Musculoskeletal Tumor Society. For resection of primary tumors of the shoulder girdle, a longitudinal deltopectoral approach was used with the patient in a semilateral position. The previous biopsy track was excised in continuity with the resected specimen. When possible, care was taken to preserve the axillary and radial nerves posteriorly. However, ten cases required resection of the axillary nerve because of tumor involvement. The rotator cuff tendons and the glenohumeral joint capsule were separated and transected proximal to their insertion on the humerus.

According to the modified Malawer classification of proximal humeral resections, the resection type was classified as A or B on the basis of the presence or absence of a deltoid remaining for reconstruction. All patients required excision of the biopsy track; thus, type A indicated that <2 cm of the

![Fig. 1](image_url)

Soft-tissue reconstruction consisted of suturing the host capsule to the capsule of the allograft in a vest-over-pants fashion.
anterior deltoid around the excised biopsy track had been removed. Type B was further subdivided according to whether the deltoid resection was partial or total. Ten patients underwent a type-A resection (retention of the deltoid), and twenty-six patients underwent a type-B resection, which was partial in thirteen and total in thirteen. All ten patients with an axillary nerve resection had a total resection of the deltoid.

The decision whether to perform an intra-articular or extra-articular resection was made during the preoperative planning stage. Preoperative evidence of joint invasion by the tumor dictated an extra-articular, joint-sacrificing resection. Intra-articular involvement was determined by a finding of direct invasion of the articular space on preoperative magnetic resonance imaging or by the presence of a joint effusion in the glenohumeral space identified clinically or on magnetic resonance imaging. Intra-articular resection involves transection of the rotator cuff tendons and joint capsule. By definition, the glenohumeral joint is not violated during an extra-articular resection, and thus the capsule is kept intact. A tumor localized to the glenohumeral joint without involvement of the glenoid or scapular body was treated with an extra-articular resection of the glenoid. In these cases, the rotator cuff muscles were dissected away from their scapular origins, the capsule was kept intact, and the glenoid was osteotomized medial to the capsular attachments. These partial scapulectomies involved resection of the glenoid only, with retention of the scapular body, the acromion, and the coracoid. In the current series, there were twelve extra-articular resections.

After distal soft-tissue dissection was completed, a humeral osteotomy was performed at the intended level as guided by preoperative imaging studies. When the patient had a primary malignant bone tumor, specimens of distal bone marrow and from clinically worrisome soft-tissue margins were removed with curettage and examined with frozen-section analysis.

Once the surgical margins were deemed to be negative, the reconstructive procedure commenced. Fresh-frozen osteoarticular allografts with soft-tissue attachments were obtained from the University of Miami Tissue Bank and were thawed in the operating room immediately before use. The articular surface of the allograft was cut at the anatomic neck, and the medullary canal was sequentially reamed to accommodate either a standard cemented or custom press-fit long-stem Bio-Modular shoulder prosthesis (Biomet, Warsaw, Indiana). During canal preparation, the allograft capsule and rotator cuff were incised and everted to preserve them and to maximize lateral exposure during broaching and reaming. In all cases, the prosthesis was cemented into the allograft, and this composite was then inserted with or without cement into the distal host bone at 35° to 40° of retroversion with respect to the forearm (25° to 35° of humeral retroversion). A slight amount of over-retroversion was used to enhance anterior coverage and reduce the risk of anterior instability. Cement was not used in the distal host bone when the press-fit fixation of the prosthetic stem had been achieved. Twenty-eight of the patients with a press-fit stem had anti-rotational supplemental fixation with a compression plate (one), interlocking screws (five), or tension-band wiring (one). In five cases in which the stem was cemented, supplemental fixation (a dynamic compression plate in four and interlocking screws in one) was added to achieve rotational control.

Soft-tissue reconstruction consisted of repair of the host capsule to that of the allograft with use of interrupted, non-

<table>
<thead>
<tr>
<th>TABLE I Effect of Deltoid Resection on Functional Outcome</th>
<th>Mean and Standard Deviation (95% Confidence Interval)</th>
<th>P Value</th>
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</thead>
<tbody>
<tr>
<td>Deltoid Intact (N = 10)</td>
<td>Partial Deltoid Resection (N = 11)</td>
<td>Total Deltoid Resection (N = 13)</td>
</tr>
<tr>
<td>Active abduction (deg)</td>
<td>72 ± 40 (51-93)</td>
<td>52 ± 22 (41-63)</td>
</tr>
<tr>
<td>Active flexion (deg)</td>
<td>70 ± 46 (42-98)</td>
<td>59 ± 24 (46-72)</td>
</tr>
<tr>
<td>MSTS score</td>
<td>26 ± 1.5 (25.1-26.9)</td>
<td>26 ± 1.2 (24.8-27.2)</td>
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TABLE II Effect of Glenohumeral Resection Type on Functional Outcome

<table>
<thead>
<tr>
<th></th>
<th>Mean and Standard Deviation (95% Confidence Interval)</th>
<th>P Value</th>
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<tr>
<td></td>
<td>Intra-Articular (N = 22)</td>
<td>Extra-Articular (N = 12)</td>
</tr>
<tr>
<td>Active abduction (deg)</td>
<td>56 ± 8 (52.5-69)</td>
<td>26 ± 5 (23-28)</td>
</tr>
<tr>
<td>Active flexion (deg)</td>
<td>57 ± 8 (53-60)</td>
<td>53 ± 16 (44-62)</td>
</tr>
<tr>
<td>MSTS score</td>
<td>28 ± 0.7 (27.3-28.3)</td>
<td>26 ± 0.5 (25.7-26.3)</td>
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</table>

TABLE III Effect of Humeral Resection Length on Functional Outcome

<table>
<thead>
<tr>
<th></th>
<th>Mean and Standard Deviation (95% Confidence Interval)</th>
<th>P Value</th>
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<tbody>
<tr>
<td></td>
<td>&lt;50% Resection (N = 21)</td>
<td>&gt;50% Resection (N = 12)</td>
</tr>
<tr>
<td>Active abduction (deg)</td>
<td>47 ± 26 (36-58)</td>
<td>61 ± 45 (35-87)</td>
</tr>
<tr>
<td>Active flexion (deg)</td>
<td>49 ± 28 (37-61)</td>
<td>78 ± 45 (53-103)</td>
</tr>
<tr>
<td>MSTS score</td>
<td>26 ± 2.8 (24.8-27.2)</td>
<td>27 ± 2.3 (25.8-28.3)</td>
</tr>
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</table>
patient had an MSTS score of 24 and maintained full function of the hand and elbow, permitting him to work as a store clerk and to be a college student more than ten years after the surgery.

Five patients demonstrated radiographic evidence of superior migration of the humeral head without any symptoms of instability. None of these patients had any clinical evidence of anterior or posterior glenohumeral instability.

Functional assessment at the time of final follow-up revealed a mean active range of motion of 56° (range, 0° to 150°) of flexion and 50° (range, 10° to 140°) of abduction. The mean MSTS upper-extremity functional outcome score was 26 (range, 20 to 30). All patients had normal dexterity and use of the hands. The patients with deltoid resection had a reduced range of motion in both abduction and flexion as compared with those in whom the deltoid had been preserved. The mean active abduction measured 72°, 52°, and 19°, respectively, in those with preservation, partial resection, and total resection of the deltoid (p = 0.003), and the mean active flexion measured 70°, 59°, and 23°, respectively (p = 0.02) (Table I).

Although the mean MSTS score following the intra-articular resections differed significantly from that following the extra-articular resections (28 compared with 26, p = 0.03) (Table II), such a small numeric difference in scores is of dubious clinical relevance. We did not identify a significant difference in mean abduction, flexion, or MSTS score on the basis of the length of the humeral resection (>50% or <50% of the humeral length) (Table III). However, because the post-hoc power calculation was <80% for all of these calculations, the sample size was insufficient for the purpose of testing these relationships.

Three failures required revision of the allograft-prosthesis composite. One patient, a thirteen-year-old boy with osteogenic sarcoma, had prosthetic loosening secondary to osteolysis and underwent revision to an endoprosthesis eight months after the index procedure. At the time of the index procedure, only a very thin cement mantle was achieved because of use of a standard-size prosthetic stem that was oversized for a child. This implant was successfully revised to a smaller, custom stem in order to achieve a larger cement mantle. The second patient, a twenty-seven-year-old man with chondrosarcoma of the proximal part of the humerus, was found to have resorption at the osteosynthesis site resulting in early loosening of the implant within seven months after the index procedure. This result was probably due to a combination of nonunion and instability at the allograft-host junction. The third patient, an eleven-year-old boy with osteogenic sarcoma of the humerus, had a per-

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**Fig. 3**

This series of radiographs illustrates an example of how an allograft-prosthesis composite can fail and be salvaged. A: Despite the apparent adequacy of the initial technique, as seen on the postoperative radiograph, loosening occurred. B: Bone resorption is seen on both the host and the allograft side of the attempted osteosynthesis site. It is not possible to determine retrospectively if rotational instability at the junction led to bone resorption and nonunion, or if nonunion occurred first, allowing the prosthesis-cement interface to fail. C: Internal fixation with a neutralization plate supplemented with iliac bone graft resulted in union and preservation of the allograft and the shoulder reconstruction.
Sient radiolucent line at the host bone-implant interface, which was treated ten months postoperatively with iliac crest autologous bone graft, a strut allograft, and cable fixation. Because of progressive loosening, the construct was revised again eighteen months after the index procedure. Revision involved removal of the allograft-prosthesis composite and replacement with a new allograft-prosthesis composite with intussusception of the allograft into the host bone to increase the stability at the host-allograft junction. The postoperative course of all three patients was uneventful following the latest revision procedure.

On the basis of the Kaplan-Meier analysis, with revision of the implant as the end point, the overall implant survival was estimated to be 88% at ten years (Fig. 4). Survival at ten years was found to be 82% in the twenty-seven patients in whom the resection was <50% of the humeral length and 91% in the nine in whom it was >50%. With the numbers studied, this difference was not significant (p = 0.42). We could not identify a significant difference in implant survival at ten years according to whether the deltoid had been preserved, partially resected, or totally resected, with the implant survival rates being 75%, 90%, and 92%, respectively (p = 0.40). On the basis of the numbers studied, we also found no difference in implant survival according to whether the resection was extra-articular or intra-articular (81% and 94%, respectively; p = 0.36).

Periprothetic osteolysis in the distal host bone occurred in three patients (two with a cemented and one with an uncemented stem). In two patients, this resulted in loosening and subsequent failure of the implant requiring revision to an endoprosthesis (as described above). In the third patient, the region of osteolysis remained stable and asymptomatic following a bone-grafting procedure.

No allograft fractures requiring revision were seen in this series of patients. An atraumatic, undisplaced fracture of the greater tuberosity developed in one patient six years following the reconstruction. It was associated with a brief episode of discomfort, which resolved, and had remained asymptomatic at the time of follow-up. No functional deficit had resulted from the fracture.

Four delayed unions required a second procedure for autogenous iliac crest bone-grafting. All of these delayed unions occurred in patients who had a cemented construct without any supplemental fixation performed at the time of the index procedure. In each case, specimens were obtained for culture and frozen-section analysis at the time of bone-grafting to confirm the absence of infection and tumor recurrence, respectively. Two cases were treated with cancellous autogenous bone graft from the iliac crest, which was augmented with plate fixation and cerclage wiring. One case was treated with autogenous iliac crest graft, a nonvascularized fibular strut allograft, and cerclage wiring. In the fourth case, the reason for the second surgery was the appearance of radiolucencies near the osteosynthesis site that raised suspicions that there was a local recurrence. Multiple samples taken from the host-allograft junction revealed no evidence of tumor. These biopsy sites were filled with demineralized bone matrix allograft (Grafton DBM Gel; Osteotech, Eatontown, New Jersey). No additional fixation was used. Union was achieved following the grafting procedure in all four cases.

Wound complications occurred in two patients. In one patient, superficial skin ulceration developed in the area of a prominent acromion and osseous protrusion was imminent. This problem was treated with debridement of the prominent acromion and coverage with a rotational latissimus dorsi flap. In another patient, wound dehiscence and superficial infection occurred three months postoperatively. It was treated with a staged procedure consisting of irrigation and debridement with application of a vacuum-assisted wound dressing (V.A.C.; KCI, San Antonio, Texas) followed by a delayed reconstruction with a rotational latissimus dorsi myocutaneous flap. No patient required removal of the allograft-prosthesis composite because of deep infection.

No amputations were performed in this series. The surgical margins were negative for tumor in all cases. One patient had a local recurrence of a high-grade chondrosarcoma ten months after the initial resection and allograft-prosthesis composite reconstruction. She underwent a repeat wide excision and reconstruction with an endoprosthesis. There were no other local recurrences following the index procedure in this series.

Discussion

When compared with the findings in the literature, the results of the current study suggest that allograft-prosthesis composite reconstruction is at least as good as reconstruction with either an osteoarticular allograft or a large-segment endoprosthesis. It should be noted that the published studies have included predominantly intra-articular resections, and fewer flaps were used. Our results were at least as good as those in published studies in terms of (1) glenohumeral stability, (2) functional outcome, (3) prosthetic survival, (4) component loosening, (5) fracture, and (6) union of the host-
allograft junction. Furthermore, the results following allograft-prosthesis composite reconstruction are comparable with those of the alternative procedures in terms of infection and oncologic outcome.

Glenohumeral Stability
Frequently, large-segment endoprostheses have been complicated by glenohumeral instability, but the dislocation rates have varied. In a study of ten patients, Malawer et al. reported no cases of instability and preservation of hand and elbow function in all patients. Conversely, Bos et al. reported that five of eighteen patients sustained dislocations that required revision surgery. Asavamongkolkul et al. reported an 11% prevalence of subluxation or dislocation in sixty patients. Ross et al. showed instability to be a problem associated with a variety of endoprosthetic designs, with sixteen subluxations and three dislocations observed after twenty-five procedures performed with several different implants. In that series, the lack of soft-tissue attachments may have contributed to the high rate of glenohumeral instability. This may be mitigated by the use of static suspension (with Dacron tapes) or dynamic suspension (with muscle transfer) to augment the construct at the glenohumeral articulation.

Osteochondral allografts provide mechanisms to preserve capsular tissue and subsequently may be associated with lower rates of glenohumeral instability. Gebhardt et al. reported that, of twenty-three patients treated with an osteoarticular humeral transplant with soft-tissue attachment, only one experienced anterior subluxation of the shoulder. Notably, all but three patients in that series had a more extensive (type-IIb or III) primary tumor that required resection of the deltoid and shoulder joint. (Humeral resection was done for palliative purposes due to metastatic disease in two of the three patients.) The exclusion of extra-articular resections resulting in preservation of the deltoid muscle in that series contrasts with the situation in our series, in which thirteen of thirty-six patients had a total deltoid resection and another thirteen had a partial resection of the deltoid.

O’Connor et al. reported that there were no cases of glenohumeral instability in eight patients treated with an osteoarticular humeral allograft. These results contradict those in the series reported by Getty and Peabody, which we believe is the most recent and largest study of patients treated with osteoarticular humeral allografts in the literature; in that study, eleven of sixteen patients experienced glenohumeral instability (eight dislocations and three subluxations). Because of the high rate of instability and other complications, including allograft fracture and infection, the authors concluded that use of an osteoarticular allograft should not be the reconstructive method of choice following resection of a tumor in the proximal part of the humerus.

In the current series, a single dislocation occurred in one patient after a revision allograft-prosthesis composite reconstruction. Five patients demonstrated radiographic evidence of proximal migration of the humeral head, without symptoms, and none of the other thirty patients had clinical or radiographic evidence of instability. We attribute these results to careful soft-tissue balancing of the glenohumeral capsule and the available rotator cuff tendons, which minimized the risk of glenohumeral instability.

Functional Outcome
Functional results associated with osteoarticular allografts have varied among series. Gebhardt et al. reported the functional result to be excellent in one patient, good in eleven, fair in one, and a failure in five, with 67% of the patients having an overall excellent or good result. The authors noted that the range of motion “seldom exceeded 45 degrees of abduction or forward flexion.” In another study of osteoarticular allografts, by Getty and Peabody, the mean score derived with the modified MSTS functional evaluation was 70% at the time of final follow-up; the maximum active glenohumeral abduction was 40°, and flexion and extension were limited to a similar degree.

Similar results have been found after endoprosthetic reconstruction. Ross et al. noted that “active flexion, extension and abduction at the shoulder were each reduced to less than 30° in every patient” while passive motion was almost normal, reflecting the impaired soft-tissue function inherent to this method of reconstruction.

In the current study, the mean MSTS score was 26 points. Mean active flexion and abduction were 56° and 50°, respectively, and 70° and 72° when the deltoid was preserved. While the active range of motion was comparable with, or superior to, that following osteoarticular allograft or endoprosthetic reconstruction, the patients in our series showed less of a range of motion than did the four patients treated with a humeral allograft-prosthesis composite in the study by Jensen and Johnston (average active abduction, 82.5°).

Survivorship
Survivorship of reconstructions with osteoarticular allografts has been reported to be 68% at five years, and survivorship of endoprosthetic reconstructions has been reported to be 100% at a median of ten years. Our results fall midway between these, with an estimated ten-year survival rate of 88%.

Osteolysis and Loosening
It is not evident why the rate of loosening associated with the reconstructions in our patients was lower than that reported in the literature. Up to 28% of humeral endoprostheses were reported to fail as a result of loosening at a mean of 13.5 months postoperatively. In our series, loosening occurred in three patients (8%) at a mean of eleven months postoperatively. All three patients required revision of the construct. We used various methods to supplement stem fixation in twelve of the thirty-six cases, with interlocking screws used in the humeral stem in six, tension-band wiring used in one, and plate fixation used in five. None of the prostheses with supplemental fixation loosened, a finding that supports the notion that the three aforementioned techniques of augmenting fixation may be of structural benefit.
Fracture

There were no diaphyseal allograft fractures in this series, perhaps because of the use of intramedullary fixation with a long-stem prosthesis instead of plate fixation. In addition, fixation with polymethylmethacrylate cement may have helped by increasing the strength of the allograft and decreasing the fracture risk. In comparison, the rate of allograft fracture requiring intervention was reported to be 30% in one series of osteoarticular allografts and 25% in another, and the rate of subchondral fracture of the osteoarticular allograft was 50% in a series from the Mayo Clinic. By definition, the allograft-prosthesis composite eliminates the potential for subchondral fracture and the use of stem fixation with or without cement can prevent diaphyseal fractures.

Nonunion

The rate of nonunion associated with allografts of the humerus has been reported to range from 4% to 50% in series. The most common allograft-related complication in our series was delayed union at the host-allograft junction, which occurred in four patients (11%). There is evidence to suggest that the prevalence of nonunion following reconstruction with a large structural allograft is substantially higher in patients treated with adjuvant chemotherapy than it is in patients not treated with chemotherapy. Three of our patients who had a delayed union had adjuvant chemotherapy, a finding consistent with the higher risk of this complication reported in the literature. All four patients with delayed union demonstrated healing at the osteosynthesis site following bone-grafting. One of our patients had a nonunion, which was associated with loosening of the implant. This was successfully treated with revision of the allograft-prosthesis composite as reported above in the description of the three failures in this series. Our results are comparable with those reported by Hornicek et al., who, in what we believe to be the largest series of allograft reconstructions at a variety of anatomic sites, observed a nonunion in 11% of their cases.

Infection

The allograft infection rate has been reported to range from 4% to 50% in series. Gebhardt et al. reported a deep infection in three patients with chemotherapy, and Getty and Peabody reported one deep infection among sixteen patients. Jensen and Johnston reported two cases of superficial infection after eleven procedures with an autoclaved autograft-prosthesis composite; both infections resolved with local debridement and intravenous antibiotics. A deep infection rate of 3% as well as several cases of superficial wound infection have been reported in a series of patients treated with an endoprosthesis. The infection rate in the current series compares favorably with the rates in these reports: there was one superficial infection and no deep infection requiring removal of the implant. Our low threshold for supplementing the soft-tissue coverage with use of a rotational muscle flap may have contributed to the low rate of wound complications and deep infection.

Study Limitations

One of the limitations of this study is its retrospective nature. The measurements of range of motion, which were retrieved in the chart review, were recorded by multiple observers, providing an element of inconsistency of these measurements. Furthermore, the study was found to have insufficient power to determine the effect of resection type and length on functional outcome.

Overview

In summary, the current study represents the largest series to date of reconstructions of the proximal part of the humerus with an allograft-prosthesis composite. This technique can provide an acceptable functional outcome and good implant survival. Potential reasons for the success of this technique noted in this study include (1) preservation of the deltoid whenever feasible; (2) use of a pedicle flap when necessary to help prevent wound breakdown and subsequent infection; (3) prosthetic replacement of the articular surface, which avoids the subchondral fracture and collapse that is seen with osteoarticular allografts; and (4) careful soft-tissue balancing of the glenohumeral capsule and available rotator cuff tendons to enhance glenohumeral stability.

References


