Reconstruction of the proximal humerus after wide resection of tumours

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In 45 patients we assessed the functional results and complications for three different reconstructive procedures after resection of primary tumours of the proximal humerus. An osteoarticular allograft was used in 11, a clavicula pro humero operation in 15 and a tumour prosthesis in 19. The glenoid was resected with the proximal humerus in 25 patients. The axillary nerve was resected in 42 patients.

The complication rate was lowest after reconstruction with a tumour prosthesis. The clavicula pro humero operation resulted in the most revisions. Cumulative survival rates for all the reconstructive procedures were similar.

At follow-up at two years the functional results for the three reconstructive procedures were the same with a mean functional rating of 79% (Musculoskeletal Tumor Society). Excision of the glenoid had no influence on the functional result.

Our findings indicate that the use of a tumour prosthesis is the most reliable limb-salvage procedure for the proximal humerus. The clavicula pro humero is an appropriate procedure if a prosthesis cannot be used.

The proximal humerus is one of the primary sites of tumours and is the fourth most common site for osteosarcoma, high-grade chondrosarcoma and Ewing’s sarcoma. Amputation of the upper limb is very mutilating and artificial limbs provide limited function and poor cosmesis. For these reasons, limb-preserving techniques were established soon after adjuvant treatment had been introduced.

The most important aspect of limb-salvage surgery is to preserve elbow and hand function after excision of tumours of the proximal humerus, even although the shoulder may remain flail with a limited active range of movement.

Several techniques have been described for replacement of the proximal humerus. The use of tumour prostheses and osteoarticular allografts was first reported approximately 35 years ago. The transposition of the clavicle in order to replace the humerus (clavicula pro humero) was originally used in phokomelia and was subsequently described as a biological reconstruction after the resection of malignant bone tumours.

A primary aim is to improve shoulder function. The biological surface of the allograft, or the autogenous clavicle, offers better integration for soft tissue, which may increase stability and function of the shoulder.

We have assessed the three reconstructive procedures used at our institution during the past decade in order to define their indications.

Patients and Methods

Between September 1988 and June 1998, we treated 45 patients with a primary malignant bone tumour of the proximal humerus with wide intra- and extra-articular resection. Reconstruction of the bony defect was undertaken with an osteoarticular allograft in 11 patients, autogenous clavicle in 15 and a tumour prosthesis in 19 (Fig. 1). The histological diagnosis was osteosarcoma in 27 patients, Ewing’s sarcoma in seven, and a high-grade chondrosarcoma in 11. All patients with an osteosarcoma received neoadjuvant chemotherapy according to the protocol of the Cooperative Osteosarcoma Study. Those with Ewing’s sarcoma had received combined radiochemotherapy according to the Cooperative Ewing’s Sarcoma Study and the European Intergroup Cooperative Ewing’s Sarcoma Study. Patients with a chondrosarcoma underwent local surgical treatment exclusively.

In all patients, we undertook a wide resection using a transdeltoid approach which included the biopsy scar. Extra-articular resection, including the glenoid, was carried out in 25 patients and intra-articular resection in 20. The axillary nerve was usually resected with the tumour. As a result, the abductor mechanism was not intact in 42 patients.
The mean length of the humerus which was resected was 16 cm (8 to 28). According to the Musculoskeletal Tumour Society (MSTS) resection classification system \(^{10}\) (Fig. 2), the defects were classified as S23 (one patient), S234 (13 patients), S2345 (11 patients), S34 (12 patients), S345 (seven patients) and S345E1 (one patient). Reconstructions were carried out as described in earlier publications. \(^{6,11-15}\) We used a knitted tube of polyethylene terephthalate (attachment tube MUTARS, Implantcast, Buxtehude, Germany) to facilitate reconstruction of soft tissues. \(^{16}\) The tube was fixed to the prosthesis by heavy non-absorbable sutures. The remaining parts of the capsule, tendons and muscles were fixed to the tube. Postoperatively, the shoulder was kept in a Gilchrist bandage \(^{17}\) for four weeks, after which gentle exercises were started.

The three reconstructive groups were analysed for age at diagnosis, length of defect and length of follow-up using the Kruskal-Wallis test and glenoid resection, abductor resection, gender and diagnosis (Table I) by the chi-squared test. We also studied oncological parameters, including overall survival, and local and systemic relapses.

Complications which required surgical revision were analysed. Estimates of the event-free survival of the reconstructions were generated by Kaplan-Meier survival analysis. An event was defined as the removal of an implant because of a complication such as a fracture or an infection. Functional assessments were based on the MSTS functional assessment system for the upper limb. This assesses pain, function, emotional acceptance, hand positioning, manual dexterity, and lifting ability. \(^{18}\) Scores were determined by the orthopaedic surgeon at the final follow-up. The mean functional follow-up was 59 months (23 to 106).

**Results**

Patients with a prosthesis were significantly older (p = 0.006), but all other parameters showed no significant differences. The osteoarticular allograft group had significantly fewer glenoid resections (p = 0.016) and significantly more intact abductor mechanisms (p = 0.007). At
The mean functional score for all patients was 79% (57 to 90) and the results of the three different reconstructive procedures were very similar (Table I). The osteoarticular allograft had a score of 74% (57 to 90), the clavicula pro humero of 82% (67 to 87) and the prosthesis of 79% (67 to 87). Nearly all categories showed a similar result, irrespective of the reconstructive procedure (Table I). Resection of the glenoid did not influence the functional score (Table II).

The estimated survival rate of all reconstructive procedures at five years was nearly 80% (Fig. 3). When comparing implant survival and patient survival, we found that all limb-salvage procedures for the proximal humerus were satisfactory for long-term survival. The functional results were assessed in all surviving patients with the primary reconstruction still in place after at least two years. During the first two years, 11 patients died, and four lost their primary reconstruction. Two patients lost their primary implant and died within the first two years. Two patients were receiving therapy because of recurrence of the tumour and died 26 and 30 months after diagnosis.

The most surgical revisions (p = 0.002) were needed after a clavicula pro humero procedure (Table I). A major problem was the stability of the graft and the interface between the clavicle and the humerus. Recurrent fractures led to a complete removal of the rotated clavicle in two patients. Because of the anatomical shape of the clavicle, and the different diameters of the humerus and the clavicle, osteosynthesis was difficult to undertake with standard plates. A special plate was therefore created with a smaller and bendable part for the clavicle and a stronger part for the humerus. The four infections (Table I) were treated by open revision and local and systemic antibiotics. In one patient, the clavicle was removed and replaced with a cement spacer. Three revisions were undertaken because of a prominent acromion with impending skin perforation.

The osteoarticular allograft reconstructions were revised either because of fracture (three patients) or pseudarthrosis (one patient). Two were revised because of local recurrence of tumour.

None of the 26 disease-free surviving patients was able to abduct their shoulder more than 90°. Five could achieve active abduction of more than 30°. Three of these patients were reconstructed using a clavicula pro humero (one patient with an allograft and one with a prosthesis). All clavicula pro humero reconstructions except one gave a stable shoulder (Fig. 4). Two patients with a prosthesis and two with an osteoarticular allograft had unstable joints. All patients with shoulder instability coped with their condition and refused further surgical procedures.

**Discussion**

Since the introduction of effective adjuvant treatment for osteosarcoma and Ewing’s sarcoma, limb-salvage surgery for the proximal humerus has become well estab-
Restoration of hand and elbow function was very successful when compared with shoulder disarticulation, but it became obvious that limb reconstruction after resection of the proximal humerus created a flail shoulder in most patients.

An important advance was the improvement of the biological behaviour of the surface of the implant. The surface of allografts shows good reattachment of tendons and muscles. The clavica pro humero procedure, with preservation of the acromioclavicular ligaments and the presence of a biological surface, seems to provide the best stability and optimal soft-tissue reattachment even after resection of the glenoid (Table II). For a prosthesis, growth of soft tissue into the attachment tube may create indirect stability. We found that these concepts applied to our patients.

All patients with clavica pro humero reconstruction except one had a stable shoulder. There was no difference in stability between an allograft and a prosthesis.

Better soft-tissue attachment is only one factor which may influence postoperative shoulder abduction. Preservation of the deltoid muscle, the axillary nerve, and the rotator cuff is probably even more important. In contrast to the popliteus muscle in the knee, the neurovascular bundle in the shoulder has no muscular barrier. The axillary nerve is in direct contact with the bone and the brachial plexus is less mobile in this region. In almost all our patients with a high-grade sarcoma the axillary nerve could not be preserved because of extension of the tumour. The abductor mechanism was therefore disrupted in almost all of these patients.

O'Connor et al. and Damron et al. showed that resection or preservation of the glenoid produced a significant difference in postoperative function. In our series, resection of the glenoid had no measurable influence on the active range of movement. Most patients had no active glenohumeral abduction above 30°. This is probably because of the disrupted abductor mechanism, which seems to be more important than the glenoid in active abduction.

It has been shown that infiltration of the shoulder by tumour is difficult to assess on preoperative radiological images. We therefore recommend extra-articular resection of the proximal humerus if there is any doubt of invasion of the joint by tumour. The overall complication rate for resections of the proximal humerus is low in both our series and others. In regard to the different reconstructions, two-thirds of clavica pro humero procedures required a surgical revision (p = 0.002). It is known that biological reconstructions of the proximal humerus can create more complications. Wada et al. reported complications in six of eight patients with a vascularised fibular graft. O'Connor
et al. reported several fractures after a shoulder arthrodesis with allograft and a vascularised fibular graft. Both patients who underwent removal of the clavicle after recurrent fractures were over 20 years of age and age must therefore play a part.

In our series the initial problems were solved and the cumulative survival of the clavicula pro humero procedure was equal to that of the use of a prosthesis. This suggests that the high incidence of complications after biological reconstructions may be outweighed by the long-term result. In practice, we only undertake this procedure in the growing child. The clavicula pro humero procedure does not require microsurgery, in contrast to free fibular transfers. Metaphyseal graft fracture is a well-known problem of osteoarticular allografts. The proximal humerus is a non-weight-bearing bone, which may decrease this problem. Nevertheless, the implant-related revision rate was still high in our series, as in others. Tumour prostheses have the lowest complication rates. Implant-related problems are minimised with modern modular tumour prostheses.

We conclude that if the abductor mechanism is not preserved, resection of the glenoid plays a minor role in the eventual functional outcome. Prosthetic replacement of the proximal humerus, in combination with the attachment tube, is the safest procedure with few implant-related complications. The clavicula pro humero procedure is an alternative in patients in whom a prosthesis cannot be used because of the size of the bones or the age of the patient, or in countries where tumour prostheses are not available.

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References