Proximal humerus allograft prosthetic composites: technique, outcomes, and pearls and pitfalls

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Abstract The proximal humerus is the second most common location of primary bone sarcomas and a frequent location of benign locally aggressive primary osseous tumors. In contrast to other locations, tumors in this region impose significant challenges for local control and reconstruction. This is due to glenohumeral joint anatomic characteristics such as lack of intrinsic stability and dependence on dynamic and static stabilizers. In addition, the close proximity of the axillary nerve and axillary vascular bundle places these at risk of resection when attaining local control. Allograft prosthetic composites (APCs) of the proximal humerus are one of the methods for mobile reconstruction. This modality presents lower fracture rates when compared to osteoarticular allografts and lower rates of subluxation and instability than endoprosthesis. Recent literature documents a trend for superior functional outcome at comparable complication rates. APC reconstruction is an important tool in the orthopedic oncologist armamentarium.

Keywords Proximal humerus · Allograft · Prosthetic composite · Reconstruction

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Introduction

The proximal humerus is the second most common location of primary malignant bone tumors such as osteosarcoma, chondrosarcoma, and Ewing's sarcoma [1]. It is also a frequent location of benign locally aggressive primary bone tumors such as giant cell tumor (GCT) and aneurysmal bone cyst (ABC) [1]. Not uncommonly, lesions related to metastatic bone disease or multiple myeloma may occur in this area [1].

Compared to other locations, tumors in the proximal humerus and the shoulder girdle impose greater challenges in management in terms of local control and subsequent reconstruction. The glenohumeral joint is not intrinsically stable like other joints such as the hip or the elbow, and its great mobility and ability to position the hand in different areas of space depends substantially on dynamic stabilizers (rotator cuff, glenohumeral ligaments) and static structures (labrum, glenoid). Local control implies in many cases resection of these structures, which are not easy to reconstruct, especially the dynamic ones. Secondly, the close relation between the proximal humerus and the axillary nerve and circumflex vessels poses additional challenges as resection of the axillary nerve might be necessary for local control, leaving portions of the deltoid muscle being only useful for soft tissue coverage but functionally incompetent. Lastly, soft tissue coverage is often problematic after resection leading to a higher risk of infection.

Mobile or articulated methods for reconstruction of the proximal humerus include osteoarticular allografts, endoprostheses, and allograft prosthesis composites. Each of these methods has advantages, limitations, potential risks, and complications as well as pitfalls and pearls for surgical technique. The following chapter discusses the history, development of allograft prosthetic composites, surgical technique, postoperative treatment and rehabilitation, expected clinical

outcome, and lastly, complications. These sections will be discussed contrasting the authors' experience with the published literature.

History

The first documented use of allograft in the humerus dates from the late nineteenth century. In 1880, a Scottish surgeon, Sir William MacEwan, harvested the tibia from a child with rickets and use it to replace the infected humerus in a 4-year-old child [2]. Subsequent developments in surgical technique and allograft use such as hemostasis, asepsis, and good apposition of the bone fragments were highlighted by Phemister in 1914 [3].

Early work in the twentieth century determining important factors for successful bone allograft transplantation facilitated and prepared the way for allograft successful use, which was greatly developed in the early 1980s. In 1908, Lexer reported the use of 23 whole osteoarticular and 11 hemicondylar allografts transplanted for a variety of surgical problems [4]. He presented a 50 % success rate in his series at a follow-up study in 1925 [5]. In 1954, Chase and Herndon along other researchers found that immunogenicity of allografts could be diminished by the freezing process [6]. During the 1960s and 1970s, Parrish [7, 8], Volkov [9–11], and Ottolenghi [12, 13] were pioneers in the development and use of fresh-frozen allografts to reconstruct osteoarticular and intercalary defects.

Henry Mankin pioneered allograft reconstruction techniques in the late 1970s and early 1980s [14•, 15–17]. Gehardt et al. [18•] reported on a series of 20 patients whom presented, as the most common diagnosis, chondrosarcoma and giant cell tumor of bone. Most patients (15) rated their functional outcome as good or excellent and 5 as poor. Three patients with failures required revision surgery with a subsequent fair outcome. The most common observed complications included allograft fracture in 7 patients and infection in 3 patients [18•].

Following investigations of the general use of allografts and, specifically, humeral allograft reconstruction demonstrated a high prevalence of fractures, infections requiring revision, non-unions, delayed unions, and osteoarticular degeneration. Mankin et al. [14•] reviewed more than 870 massive frozen allografts with an infection rate of 11 %, allograft fracture of 19 %, non-union of 17 %, and joint instability of 6 %. Less common complications included the transmission of viral infections [14•].

Aponte-Tinao et al. [19] reported in 2013 their experience using osteoarticular allografts in different locations of the upper extremity. Twenty-one patients of these series had reconstructions of the proximal humerus. Fractures occurred in 5 patients (24 %), and local recurrence was seen in 2. Allograft

survival rates were reported as 79 % at 5 years and 69 % at 10 years [19].

Despite these drawbacks, osteoarticular allografts provide a biologic reconstruction that preserves bone stock. This is particularly important in young and active patients in whom primary malignancies of bone are more frequent. Other advantages include preservation of soft-tissue attachments that translates in better mechanical function in abduction as well as more glenohumeral stability when compared to other modalities of reconstruction.

In 1991, Gitelis reported the use of allograft prosthetic composites (APCs) in the oncologic setting in 22 patients [20]. This technique was proposed as an alternative to allograft-only reconstruction. Theoretical advantages included the increased construct rigidity and potential lower risk of fracture as well as the lack of osteoarticular degeneration [20].

Allograft prosthetic composites have been used since then in both oncologic and non-oncologic reconstruction surgeries [21].

Development of allograft prosthetic composites

The first combined use of fibular autograft and a metallic prosthesis (Neer prosthesis) was first reported by Imbriglia et al. in 1978 [22]. The authors use this type of reconstruction in a 13-year-old patient with a chondrosarcoma of the proximal humerus. At the 30-month follow-up, the patient had 45° of active abduction and external rotation without evidence of recurrence or metastatic disease [22].

In 1987, Rock published the outcome in five allograft composite reconstructions of the proximal humerus. Four of the 5 patients had excellent clinical result with no complications such as loosening, fracture, or infection at a 60-month follow-up [23]. Jensen and Johnston [24] reported on 19 patients that underwent wide resection of primary bone sarcomas with subsequent reconstruction with autoclaved allografts, allografts, or methylmethacrylate and Neer II composites. Four of these patients had reconstruction with fresh-frozen allograft and Neer prostheses. No complications or subsequent surgeries were reported. The average abduction was 82.5° [24].

To date, multiple investigations have evaluated clinical outcomes of allograft prosthetic reconstructions alone or in comparison to other modalities of reconstruction such as osteoarticular allografts and endoprosthesis (Table 1).

Indications

If the deltoid and axillary nerve can be preserved (Malawer type IA resection), an allograft prosthetic composite using a reverse arthroplasty is an option. If the axillary nerve cannot be saved during the index resection or the abductor

Table 1 Summary of the literature evaluating survival, clinical follow-up, and complication rates in allograft prosthetic reconstruction of the proximal humerus

Authors	Year	Number of patients	Survival rate at follow-up, <i>n</i> (%)	Follow-up (months)	Infection rate, <i>n</i> (%)	Fracture rate, <i>n</i> (%)	Joint instability, <i>n</i> (%)	Non-union, <i>n</i> (%)	Complication rate, <i>n</i> (%)
Abdeen et al.	2009	36	33 (88)	60	1 (2)	1 (3)	1 (2)	4 (11)	10 (28)
Aponte-Tinao et al.	2013	16	(90)	120	1 (6)	0 (0)	0 (0)	2 (12.5)	3 (18)
Black et al.	2007	6	5 (83)	55	0 (0)	0 (0)	0 (0)	1 (16)	2 (33)
Jensen et al.	1995	4	4 (100)	65	0 (0)	0 (0)	0 (0)	0 (0)	3 (21)
Manfrini et al.	2011	3	1 (33)	24	0 (0)	2 (66)	0 (0)	0 (0)	0 (0)
Moran et al.	2009	11	11 (100)	68	0 (0)	0 (0)	4 (27.5)	2 (14)	6 (55)
Potter et al.	2009	16	15 (94)	98	2 (13)	1 (6)	3 (19)	1 (6)	7 (44)
Ruggieri et al.	2011	14	11 (78)	25	1 (7)	2 (14)	0 (0)	0 (0)	3 (21)
Suk et al.	2002	6	5 (83)	52.4	0 (0)	2 (33)	0 (0)	1 (16)	1 (17)
van de Sande et al.	2011	10	9 (90)	120	2 (20)	2 (20)	4 (40)	0 (0)	15 (150)
Wang et al.	2011	14	12 (86)	48	0 (0)	0 (0)	2 (16)	2 (16)	4 (32)

musculature of the shoulder has to be sacrificed, a better alternative of treatment is a metallic endoprosthesis. This reconstruction works as a spacer that allows using the upper extremity for daily living activities, but at the sacrifice of active shoulder function.

When an intra-articular resection can be performed, preservation of the deltoid is beneficial for postoperative function. In a case series from Memorial Sloan Kettering Cancer Center in 2009, Abdeen et al. [25•] reported on 36 reconstructions demonstrating the impact of deltoid preservation. Average active abduction and forward flexion in patients with intact deltoid were significantly greater than those in patients with partial and total resections (72° vs. 52° vs. 19°, abduction; 70° vs. 59° vs. 23°, flexion, respectively) [25•]. The length of resection and extra-articular resections of the humerus demonstrated a trend towards inferior abduction and forward flexion [25•].

Surgical technique

The surgical resection is done with the patient under general anesthesia in the semi-lateral position with the assistance of a bean bag or in beach chair position. Care should be taken in padding all the osseous prominences (Fig. 1). A Foley catheter is inserted, and compression boots in both lower extremities are used, given the usual duration and extend of the surgery.

Traditionally, we used an extensile approach based on the deltopectoral approach that can be extended distally as an anterolateral approach to the arm. Proximally, it can be extended to the midclavicular area following posteriorly, over the midline of the scapula. If the biopsy tract from a CT-guided biopsy is visible or there is a scar from a previous open biopsy, these should be excised by being incorporated into the specimen (Fig. 2).

If possible, the goal of surgery is an intra-articular resection with adequate margins that preserves the axillary and the radial nerves. MRI T1 images with intravenous contrast are helpful in guiding resection margins (Fig. 3). If intra-articular extension of the tumor is present or joint effusion is visualized, an extra-articular resection, which sacrifices the entire joint, is performed.

The deltoid and axillary nerve are preserved if possible. The rotator cuff tendons are dissected from the glenohumeral capsule and tagged with number 2 Ethibond or PDS sutures proximal to their insertion in the humerus (Fig. 4). After

Fig. 1 Positioning in the operating room in the beach chair using the standard prepping and draping technique. Additional support with the “spider” positioner

Fig. 2 **a** Deltopectoral incision. **b** Superficial layer of the deltopectoral approach. *D* deltoid muscle, *CV* cephalic vein, *PM* pectoralis major

dissection of these structures, the capsule is also resected, leaving a circumferential cuff for reattachment of the allograft capsule (Fig. 5). Once the proximal resection is completed, the distal cut in the humerus is done with a saw either in a transverse manner or with a step-cut osteotomy to increase the contact surface (Fig. 6). Frozen intraoperative bone marrow

biopsy should be done in the case of primary malignant bone tumors to check margins prior to final reconstruction.

In cases where there is adequate bone stock on the glenoid, the deltoid and axillary nerve have been preserved and a reverse arthroplasty is an option (Fig. 7). In this setting, the glenoid is prepared first. The glenoid is reamed, and the

Fig. 3 MRI of the right shoulder in a 74-year-old female with chondrosarcoma of the proximal humerus. T1 fast-suppressed post-contrast images. **a** Coronal view. **b** Sagittal view. **c** Axial view

Fig. 4 Deep plane demonstrating tagging of structures such as the biceps tendon and pectoralis major with number 2 Ethibond sutures. The same technique is used to tag structures of the rotator cuff

baseplate is fixed to the glenoid. The baseplate is secured as inferiorly as possible to avoid scapular notching. Once the baseplate is secured, the glenosphere is placed.

The articular surface of the allograft is cut based on the prosthesis to be used, and the intramedullary canal is prepared to fit a standard or custom long stem (Fig. 8). The distal (host)

Fig. 5 Repair of structures of the allograft to the host remaining structures using the “vest (host) over pants (graft)” technique (courtesy of Ayesha Abdeen, MD)

humerus is reamed sequentially to receive either a cemented or press-fit stem. Once the prosthesis is secured in the allograft, the construct is inserted in approximately 20° of retroversion. The construct can be augmented with a plate at the allograft-host junction. In cases where there is bone available proximal to the deltoid insertion, a step-cut osteotomy can be utilized to increase the area of allograft-host interface for bony union. This can be secured using cerclage wiring. Figure 9 demonstrates the allograft composite with an anatomic arthroplasty.

Our preference is to cement the allograft to the prosthesis proximally. Distally, the prosthesis is press fitted in young patients and cemented in the elderly. This may be augmented with an additional locking plate for rotational control at the junction site (Fig. 7). The cemented portion of the stem increases the rigidity of the allograft and decreases the risk of allograft fracture. The press-fit portion provides a durable junction, facilitating bone integration while avoiding long-term problems with cementation such as loosening in young patients. Some surgeons prefer a shorter cemented stems and fixation of the allograft to host bone with a plate. We prefer to bypass the host-allograft junction with the stem because this adds more stability and rigidity to the construct.

After allograft reconstruction, the soft tissues about the allograft are attached to the host structures. Suture anchors can be inserted in the glenoid neck, which can be used to attach the allograft capsule to the native glenoid. The tendons of the rotator cuff from the allograft are attached to the corresponding host structures. In cases where a reverse shoulder arthroplasty is used, a latissimus dorsi tendon transfer can be used to improve external rotation and coverage.

The surgical wound is closed over suction drains, which are kept in place for 4 days or until output is less than 30 cm³ per day. A routine sterile dressing is applied over the surgical wound. Table 2 presents the summary of pearls and pitfalls for surgical technique.

Postoperative treatment and rehabilitation

Antibiotic prophylaxis is given by some groups for 7 days or 24 to 48 h by others. Others recommend the antibiotic use while the drains are in place. Nevertheless, there is no data to support this intervention. Additionally, some groups use oral antibiotics for 1 to 3 months after surgery. Our preference is the use of antibiotics intravenously until drains are removed, and it should be continued orally for 1 month after the day of discharge from the hospital (6 weeks from index procedure) [14, 15]. There are no clear guidelines in the literature to support the use of one protocol over the other.

We generally do not use additional DVT prophylaxis other than 5000 U of subcutaneous heparin or 325 mg of ASA unless a free flap is needed for closure. DVT prophylaxis

Fig. 6 **a** Transverse osteotomy of the humerus. **b** Step-off osteotomy of the humerus

(low molecular weight heparin) is used in patients with pre-existing mobility limitations or at additional risk of deep venous thrombosis.

Immobilization in a sling with an abduction pillow or a splint maintaining the shoulder in 20°–30° of forward flexion and 20°–30° of abduction is preferred [25•].

For an anatomic endoprosthesis, the arm is immobilized for 3 weeks. Then, passive motion to neutral external rotation is started. Active external rotation is usually started at 6 weeks

after surgery but limited to 15°. Muscular strengthening of the shoulder musculature is started 3 months after surgery.

An alternative modality of postoperative immobilization consists of spica application with the arm in abduction at 120° and in forward flexion at 160° with the elbow in flexion at 10° (Fig. 10). The spica is molded the day before surgery when the patient is awake in the described position. Then, the

Fig. 7 Postoperative radiograph of the shoulder in a patient with reverse total shoulder prosthesis and allograft reconstruction of the right proximal humerus. Note the stem bypassing the junction site, cemented proximally and distally. Additional plate fixation for rotational control

Fig. 8 Preparation for allograft to receive cemented total shoulder prosthesis. In this case, reverse total shoulder stem

Fig. 9 **a** Preparation of allograft prosthetic with anatomic endoprosthesis preparation. **b** Surgical insertion of the construct. **c** Final radiographic result (courtesy of Dempsey Springfield, MD)

spica is bivalved and removed the day of surgery and reapplied after completion of the procedure, securing it with an ace wrap. The patient is maintained in this position for 8 weeks. At that time, the patient is allowed to bring the arm down progressively, 1-week period, with the assistance of a shoulder abduction brace to decrease pain. Then, the

described protocol for active assisted range of motion is begun. Figure 11 demonstrates the functional results after using this technique.

For a reverse arthroplasty, the shoulder is maintained in a sling and abduction pillow for 6 weeks and then formal therapy is initiated at that time consisting of

Table 2 Pitfalls and pearls

Stage	Pearls and pitfalls
Preoperative planning	<ul style="list-style-type: none"> • Obtain MRI of the entire humerus to confirm the absence of skip lesions according to the primary malignancy • Use this technique preferably for cases in which local control can be attained with an intra-articular resection preserving the abductor mechanism of the shoulder • This technique can be used in resections where the deltoid muscle is partially removed as far as the surgeon and patient are cognizant of the expected functional limitation • Selected an adequate allograft that matches well the anatomy and has good quality soft-tissue attachments
Positioning	<ul style="list-style-type: none"> • Padding of all bone prominences is a key during positioning • Sloppy lateral position with the assistance of a bean bag allows for anterior and posterior exposure in a regular rotating surgical bed
Surgical resection	<ul style="list-style-type: none"> • Tag all tendons as they are resected from the area of clear margin (Ethibond # 2) • When possible, osteotomize the coracoid process instead of peeling from it tendinous and ligamentous structures. Exposure is better, and bone-to-bone healing is better than tendon-to-tendon repairs • Leave a cuff of host capsule when possible • Confirm a frozen negative intramedullary margin before starting the reconstruction
APC preparation	<ul style="list-style-type: none"> • Always cement stem into the allograft • Always clean the cement from the distal portion of the long stem when using press-fit or cemented long stems (our preference). The distal part of the stem can be covered with Ioban during the insertion phase of the stem in the allograft • Clean cement from distal portion of allograft bone to avoid interference at the junction between the allograft and host bone
APC stabilization	<ul style="list-style-type: none"> • Trial and confirm retroversion of 30° before fixation • If press fitting, doing slowly with a cerclage cable to avoid intraoperative fractures • If using locking plates laterally for fixation (our preference), use unicortical screws and/or cerclage. Angle of the screw in these plates cannot be changed to avoid the stem • Use 6 points of unicortical fixation proximally and distally to the junction • If using a non-locking plate, change the angle of the screws to avoid the stem. Take into consideration that drilling through the cement is difficult
Closure	<ul style="list-style-type: none"> • Always overlap host tissue over allograft soft tissue • Use interrupted stitches to close the capsule • If portions of the deltoid were de-attached from the clavicle, use suture anchors to restore attachments • If coracoid was not osteotomized, use the same technique with suture anchors to restore insertions of the biceps, pectoralis minor, and coracobrachialis muscles

Fig. 10 Abduction spica for postoperative prolonged immobilization protocol (courtesy of Dempsey Springfield, MD)

active assisted range of motion with an emphasis on forward flexion.

Clinical outcomes

A number of small series have been reported by Gitelis [20], Jensen [24], and Suk [26]. Black et al. [27] treated 6 consecutive patients with allograft prosthetic composites. At an average of 55-month follow-up, the mean DASH score was 68.5, the mean shoulder score was 59 (28–87), and the SF-36 mean was 41.5 for the PCS domain and 57.7 for the MCS domain [27]. Manfrini et al. [28] presented good and excellent results in 13 of 14 consecutive patients at 25-month follow-up. The mean upper extremity Musculoskeletal Tumor Society

(MSTS) score was 77 % [28]. Ruggieri et al. [29] reported their outcomes on 14 pediatric patients at an average follow-up of 25 months. The overall complication rate was 21 % (3 of 11 patients) with two fractures and one infection [29].

As noted earlier, Abdeen et al. [25•] documented the importance of deltoid preservation for shoulder function. Active flexion was also better in patients with the deltoid intact than in those with a partial or total deltoid resection [25•]. Despite these statistically significant differences, the MSTS score was comparable between the three groups: intact deltoid, partially resected deltoid, and totally resected deltoid. Reconstruction survival with Kaplan-Meier analysis demonstrated an 88 % survival rate at 10 years [25•].

Potter et al. compared allograft prosthetic composite reconstruction to osteoarticular allograft and endoprosthetic

Fig. 11 Functional results after protocol with prolonged immobilization (courtesy of Dempsey Springfield, MD)

reconstruction [30•]. Seventeen patients had an osteoarticular allograft reconstruction, 16 an allograft prosthetic composite, and 16 an endoprosthetic reconstruction. At a median of 98 months, the authors found mean MSTS functional scores of 79 % in the allograft prosthetic composite group, 71 % in the osteoarticular allograft patients, and 69 % in the endoprosthetic reconstruction group. Shoulder instability was more commonly seen in endoprostheses, while fractures and construct failures were significantly higher with osteoarticular allografts [30•].

van de Sande et al. [31] reported comparative outcomes in 10 patients treated with allograft prosthetic composites, 13 with osteoarticular allografts, and 14 with modular tumor prosthesis reconstructions. At an average follow-up of 10 years, 27 of the 38 patients were disease free [31]. Contrary to Potter, the authors found lower MSTS scores in APC reconstruction patients (72 %) than in osteoarticular allograft patients (76 %) and endoprosthesis patients (77 %). The authors recommended endoprosthetic reconstruction because of a lower complication rate and comparable functional scores to osteoarticular allografts [31].

Wang et al. [32] treated 6 patients with endoprostheses, 12 with osteoarticular allografts, and 7 with APC reconstructions. Two patients died because of disease, 2 had recurrence, and 2 had metastatic disease [32]. The authors found better MSTS function in patients treated with APC reconstructions (27 points) than in modular prostheses (22.5 points) and osteoarticular allografts (24.6 points). Joint instability and subluxation were common complications, most notably in the endoprosthesis group.

Aponte-Tiniao et al. [19] reported results of allograft reconstruction of various locations in the upper extremity. Of the 70 consecutive patients, 16 were proximal humerus APC constructs. The complication rate at 5 years was 25 % with 1 patient with local recurrence, 1 with infection, and 2 with non-unions. The MSTS functional score demonstrated comparable results with osteoarticular allografts, 25 and 23 points, respectively [19].

Teunis et al. performed a systematic review including 29 publications with 693 patients [33•]. Of these, 11 studies (141 patients) reported on allograft prosthetic composites. APC MSTS functional scores ranged from 57 to 91 % (osteoarticular allografts, 50 to 78 %; endoprosthesis, 61 to 77 %). The number of patients and the lack of comparability between studies did not allow identifying differences in terms of the function between modalities of reconstruction [33•].

Wang et al. [34] published results on 55 consecutive patients from 1990 to 2007 that required surgical resection of the proximal humerus including the abductor mechanism. The authors compared arthrodesis, endoprosthesis, and APC reconstruction. Overall, the recurrence rate was 7 % (4 of 55 patients) [34]. At a follow-up of 87 months, the authors assessed comparatively the function in the 39 living patients.

Twelve patients received arthrodesis, 17 endoprostheses, and 10 APC reconstructions. The authors found better results with primary arthrodesis in patients with significant involvement of the abductor mechanism of the shoulder [34].

Existing studies do not definitively identify a superior reconstruction technique, but there is evidence to suggest that APC constructs may be beneficial in the setting of an intra-articular resection (Malawer type IA) with the abductor mechanism intact.

Complications

Complication rates range from 0 to 50 %, van de Sande et al. reported a complication rate of 150 %, with many patients experiencing more than one problem. Table 1 presents the summary of complication and survival rates of the published studies in the literature evaluating APC shoulder reconstruction.

The systematic review by Teunis reported complications consisting of infection, subluxation and dislocation, non-unions, and delayed unions [33•]. Fracture rates are higher in the osteoarticular allograft group. Fracture rates between endoprosthesis and APCs are comparable. Revision surgery is higher in patients with osteoarticular allografts, which is a product of the higher fracture rate [33•].

Most common complications in APC reconstruction include fractures, superficial and deep infections, and delayed union at the junction site. Aseptic or septic loosening and joint instability occur rarely.

Summary

Allograft prosthetic composite (APC) constructs are a safe and reproducible surgical technique that is part of the armamentarium for oncologic reconstruction of the proximal humerus. Adequate indications are a key to obtain a satisfactory functional outcome. Intra-articular resection with preservation of the abductor mechanism provides the better likelihood of a good-to-excellent functional result. Survival rates are higher than 80 % in the 5-year follow-up. Expected complications include allograft fracture, superficial or deep infections, and delayed union at the junction site.

Compliance with Ethics Guidelines

Conflict of Interest The authors have nothing to disclose.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance

- Dorfman HD, Czerniak B. Bone cancers. *Cancer*. 1995;75(1 Suppl):203–10.
- MacEwan W. Observations concerning transplants of bone. *Proc R Soc Lond*. 1881;32:232.
- Phemister D. The fate of transplanted bone and regenerative power of its various constituents. *Surg Gynecol Obstet*. 1914;19:303.
- Lexer E. Substitution of whole or half joints from freshly amputated extremities by free plastic operation. *Surg Gynecol Obstet*. 1908;6: 601–7.
- Lexter E. Joint transplantations and arthroplasty. *Surg Gynecol Obstet*. 1925;40:782–809.
- Hemdon CH, Chase SW. The fate of massive autogenous and homogenous bone grafts including articular surfaces. *Surg Gynecol Obstet*. 1954;98(3):273–90.
- Parrish FF. Total and partial half joint resection followed by allograft replacement in neoplasms involving ends of long bones. *Transplant Proc*. 1976;8(2 Suppl 1):77–81.
- Parrish FF. Allograft replacement of all or part of the end of a long bone following excision of a tumor. *J Bone Joint Surg Am Vol*. 1973;55(1):1–22.
- Volkov MV, Grishin IG, Makhson NE, Golubev VG, Sarkisian AG. [Indications for free autoplasty of defects using bone, skin or dermo-osseous transplants on vascular pedicles]. *Ortopediia travmatologiya i protezirovaniye*. 1983 Aug(8):1–4. PubMed O pokazaniiakh k svobodnoi autoplastike defektov kostnymi, kozhnymi ili kozhno-kostnymi transplantatami na sosudisto nozhke.
- Volkov MV. Alloplastic and homoplastic complete joint transplants. *La Chirurgia degli Organi di Movimento*. 1969;57(4):287–93.
- Tsiv'ian Ia L, Savel'ev VI, Ryvkina RM, Andrushko NS, Letina VI, Murakhtanova ZM, et al. [The use of bone transplants sterilized with chemical agents]. *Khirurgiya*. 1967;43(7):68–73.
- Ottolenghi CE. Massive osteo and osteo-articular bone grafts: technique and results of 62 cases. *Clin Orthop Relat Res*. 1972;87:156–64.
- Ottolenghi CE. Massive osteoarticular bone grafts. Transplant of the whole femur. *J Bone Joint Surg British Vol*. 1966;48(4):646–59.
- Mankin HJ, Gebhardt MC, Jennings LC, Springfield DS, Tomford WW. Long-term results of allograft replacement in the management of bone tumors. *Clinical Orthopaedics and Related Research*. 1996 Mar(324):86–97. PubMed. **This is the largest series in osteoarticular allograft use and long-term follow-up. It discusses and reports on the common complications with osteoarticular allograft use.**
- Mankin HJ, Doppelt S, Tomford W. Clinical experience with allograft implantation. The first ten years. *Clinical Orthopaedics and Related Research*. 1983 Apr(174):69–86. PubMed
- Mankin HJ, Doppelt SH, Sullivan TR, Tomford WW. Osteoarticular and intercalary allograft transplantation in the management of malignant tumors of bone. *Cancer*. 1982;50(4):613–30.
- Mankin HJ, Fogelson FS, Thrasher AZ, Jaffer F. Massive resection and allograft transplantation in the treatment of malignant bone tumors. *N Engl J Med*. 1976;294(23):1247–55.
- Gebhardt MC, Roth YF, Mankin HJ. Osteoarticular allografts for reconstruction in the proximal part of the humerus after excision of a musculoskeletal tumor. *J Bone Joint Surg Am Vol*. 1990;72(3): 334–45. **This is the largest case series in proximal humerus allograft reconstruction. It discusses at length the outcomes and complications when using this technique.**
- Aponte-Tiniao LA, Ayerza MA, Muscolo DL, Farfalli GL. Allograft reconstruction for the treatment of musculoskeletal tumors of the upper extremity. *Sarcoma*. 2013;2013:925413.
- Gitelis S, Piasecki P. Allograft prosthetic composite arthroplasty for osteosarcoma and other aggressive bone tumors. *Clin Orthop Relat Res*. 1991;270:197–201.
- Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of a reverse shoulder prosthesis-allograft composite. *J Bone Joint Surg Am Vol*. 2009;91(1):119–27.
- Imbriglia JE, Neer CS, Dick HM. Resection of the proximal one-half of the humerus in a child for chondrosarcoma. Preservation of function using a fibular graft and Neer prosthesis. *J Bone Joint Surg Am Vol*. 1978;60(2):262–4.
- Bos G, Sim F, Pritchard D, Shives T, Rock M, Askew L, et al. Prosthetic replacement of the proximal humerus. *Clin Orthop Relat Res*. 1987;224:178–91.
- Jensen KL, Johnston JO. Proximal humeral reconstruction after excision of a primary sarcoma. *Clin Orthop Relat Res*. 1995;311: 164–75.
- Abdeen A, Hoang BH, Athanasian EA, Morris CD, Boland PJ, Healey JH. Allograft-prosthesis composite reconstruction of the proximal part of the humerus: functional outcome and survivorship. *J Bone Joint Surg Am Vol*. 2009;91(10):2406–15. **This paper is the largest series in APC reconstruction of the proximal humerus. It describes in detail the surgical technique and presents results for functional outcome. This paper documents and proves the importance of deltoid muscle and function preservation for satisfactory functional outcome.**
- Suk KS, Shin KH, Hahn SB. Limb salvage using original low heat-treated tumor-bearing bone. *Clin Orthop Relat Res*. 2002;397:385–93.
- Black AW, Szabo RM, Titelman RM. Treatment of malignant tumors of the proximal humerus with allograft-prosthesis composite reconstruction. *J Shoulder Elbow Surg*. 2007;16(5):525–33.
- Manfrini M, Tiwari A, Ham J, Colangeli M, Mercuri M. Evolution of surgical treatment for sarcomas of proximal humerus in children: retrospective review at a single institute over 30 years. *J Pediatr Orthop*. 2011;31(1):56–64.
- Ruggieri P, Mavrogenis AF, Guerra G, Mercuri M. Preliminary results after reconstruction of bony defects of the proximal humerus with an allograft-resurfacing composite. *J Bone Joint Surg Br*. 2011;93(8):1098–103.
- Potter BK, Adams SC, Pitcher Jr JD, Malinin TI, Temple HT. Proximal humerus reconstructions for tumors. *Clin Orthop Relat Res*. 2009;467(4):1035–41. **This is the first study comparing different modalities of reconstruction of the proximal humerus. It demonstrates the functional superiority of APC reconstructions and lower complication rate profile.**
- van de Sande MA, Dijkstra PD, Taminiau AH. Proximal humerus reconstruction after tumour resection: biological versus endoprosthetic reconstruction. *Int Orthop*. 2011;35(9):1375–80.
- Wang Z, Guo Z, Li J, Li XD, Sang HX. Functional outcomes and complications of reconstruction of the proximal humerus after intra-articular tumor resection. *Orthop Surg*. 2010;2(1):19–26.
- Teunis T, Nota SP, Hornicek FJ, Schwab JH, Lozano-Calderon SA. Outcome after reconstruction of the proximal humerus for tumor resection: a systematic review. *Clin Orthop Relat Res*. 2014;472(7): 2245–53. **This review of the literature summarizes the current published literature in reconstruction of the proximal humerus. It concludes that osteoarticular allografts have a higher revision rate secondary to a higher prevalence of fractures. Infection, dislocation, and instability rates were comparable between all methods of reconstruction.**
- Wang J, Shen J, Dickinson IC. Functional outcome of arthrodesis with a vascularized fibular graft and a rotational latissimus dorsi flap after proximal humerus sarcoma resection. *Ann Surg Oncol*. 2011;18(7):1852–9.