Does Reverse Shoulder Arthroplasty for Tumors of the Proximal Humerus Reduce Impairment?

Lieven De Wilde MD, PhD, Pascal Boileau MD, PhD,
Hans Van der Bracht MD

Published online: 6 January 2011
© The Association of Bone and Joint Surgeons® 2011

Abstract

Background Normal function of the upper limb is seldom restored after limb-sparing surgery for tumors of the proximal humerus. The literature suggests superior shoulder function is achieved in the short term with reverse total shoulder arthroplasty compared to other techniques when performed for conditions with rotator cuff deficiency. It is unclear whether this superiority is maintained when reverse total shoulder arthroplasty is performed for tumors.

Questions/purposes When performed for tumors, we determined whether reverse total shoulder arthroplasty restores function and improves motion, the complications associated with the surgery, and whether reverse total shoulder arthroplasty with autologous grafting is associated with bone resorption.

One or more of the authors (LDW, PB) has received funding from DePuy International Ltd (Leeds, UK) or Tornier, Inc (Amsterdam, The Netherlands). One or more of the authors (LDW, PB) certifies that he or she has or may receive payments or benefits from a commercial entity related to this work. One author (HVdB) certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution has approved the reporting of these cases, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participating in the study was obtained. This work was performed at Ghent University Hospital and Hôpital de l'Archet.

L. De Wilde (✉), H. Van der Bracht
Department of Orthopaedic Surgery and Traumatology, Ghent University Hospital, De Pintelaan 185, 9000 Ghent, Belgium
e-mail: lieven.dewilde@UGent.be

P. Boileau
Hôpital de l'Archet, Nice, France

Patients and Methods We retrospectively reviewed 14 patients who had undergone reverse total shoulder arthroplasty for tumors of the proximal humerus. Four patients died, leaving nine patients for review. The surviving patients were evaluated clinically and radiographically. The minimum followup was 0.6 years (mean, 7.7 years; range, 0.6–12 years).

Results At last followup, mean active abduction was 157° and mean functional Constant-Murley score was 76%. One patient had a deep infection and one developed a loose prosthesis; both were treated with single-stage exchange. At last followup, both patients had reasonable function without evidence of infection or loosening. Radiographic graft resorption was seen in all but one patient.

Conclusions Our observations suggest, at medium-term followup, reverse total shoulder arthroplasty is a reasonable option for tumors of the proximal humerus. It has low morbidity, restores a mean active abduction of 157°, and limits the impairment of activities of daily living.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

The proximal humerus is the third most common site for primary bone tumors and soft tissue tumors [21]. The incidence of soft tissue sarcomas and new bone and cartilage malignancies is approximately 1.8 in 100,000 for each [2, 11, 41], 15% of which occur in the shoulder [12, 22]. Salvage of limb and shoulder function after proximal humeral resection for tumors still presents a challenge. In most patients, resection of the rotator cuff is necessary to obtain adequate margins. The options for reconstructing the

proximal humerus after resection are limited. They include resection arthroplasty, biologic reconstruction, and prosthetic reconstruction.

Surgical treatment of extracompartmental bone tumors (Type I according to the classification of Malawer et al. [34] or S3-S4-S5 according to the Musculoskeletal Tumor Society classification [20]) often requires resection of the rotator cuff. This loss of rotator cuff function results in a pseudoparalytic arm similar to that seen in patients with cuff tear arthropathy (CTA). These latter patients are frequently treated with reverse total shoulder arthroplasty (RSA). With this treatment, in the short term, an active shoulder function with abduction and forward flexion of more than 140° can be expected [17–19], whereas this is limited to less than 90° with resection arthroplasty, biologic reconstruction, or hemiarthroplasty. All limb-sparing treatments of the shoulder have similar disease-free survival, but the complication rate for resection arthroplasty and biologic reconstruction is higher than that for arthroplasty (Table 1). Although forward flexion is restored with RSA, the complete resection of the posterosuperior rotator cuff (infraspinatus and teres minor) required to resect the tumor with wide margins leaves the shoulder with a lag sign (hornblower's sign) due to the loss of active external rotation in abduction. This loss has a dramatic impact on activities of daily living. To address this well-known problem in CTA, a modified latissimus dorsi and teres major tendon transfer has recently been proposed [5, 26]. To assure the longevity of the implant, a composite reconstruction consisting of an intercalary irradiated autograft augmented with a prosthesis is a valid technique to retain the bone stock [16, 36].

We therefore determined (1) whether RSA restores function and (2) improves active motion in external rotation, (3) the complications associated with the surgery, and (4) whether RSA with autologous irradiated grafting is associated with bone resorption in patients treated for tumors of the proximal humerus.

Patients and Methods

We retrospectively reviewed 14 patients with a tumor of the proximal humerus who had undergone a RSA after tumor resection. Twelve had surgery at the Ghent University Hospital between 1997 and 2008, and two patients, who also had the surgery combined with a latissimus dorsi and teres major muscle transfer, were treated at the Hôpital de l'Archet in 2006 and 2008. Only patients with a Type Ia or Ib tumor of the proximal humerus according to the classification of Malawer et al. [34] were included. The mean age at surgery was 45.1 years (range, 19.0–78.9 years). There were eight men and six women. One patient was lost to followup immediately postoperatively because she was followed at another hospital. Four patients died during the time of followup. Of these, a patient with metastatic breast cancer developed cellulitis from skin metastasis. She received palliative treatment and died 5 months postoperatively. The three other patients (one with metastatic disease, one with synovial sarcoma, and one with high-grade chondrosarcoma) died at an average of 15 months after surgery (range, 5–23 months) because of primary tumor progression. No clinical and radiographic data of the nonsurviving patients or the one lost to followup

Table 1. Functional results and oncologic survival for different techniques used to treat wide resection of a tumor of the proximal humerus

Study	Technique	Number of patients	Followup (months)	Mean active abduction	Mean CM	Mean MSTS	Revision rate	Oncologic survival
Tsukushi et al. [44]	Clavicle pro humeri	7	34	< 90°		69%	14%	57%
Getty and Peabody [27]	Osteoarticular allograft	16	47	0°–40°		70%	33%	88%
De Wilde et al. [17]	Reverse shoulder prosthesis	4	38	175° (160°–180°)	85%	90%–96.7%	0%	100%
Jensen and Johnston [31]	Prosthesis	19	65	70°–90°			0%	79%
Capanna et al. [8]	Prosthesis	56		30°–50°			9%	86%
Rödl et al. [38]	Osteoarticular allograft	11		0°–90°		74%	18%	62%
Rödl et al. [38]	Clavicle pro humeri	15		0°–90°		82%	20%	
Rödl et al. [38]	Prosthesis	19		0°–90°		79%	11%	
Amin and Ebeid [1]	Pedicled scapular crest graft	16	36	< 90°		75%	13%	94%
Rose et al. [39]	Vascularized free fibula transfer	15	68			68%	80%	93%
De Wilde et al.	Reverse shoulder prosthesis	7	112	163°	78%		16%	67%
De Wilde et al.	Reverse shoulder prosthesis + muscle transfer	2	16	135°	71%		0%	100%

CM = Constant-Murley Shoulder Outcome score; MSTS = Musculoskeletal Tumor Society score.

are reported in this study. The surviving nine patients were reviewed specifically for this study by two senior orthopaedic surgeons (LDW, PB). The minimum followup for the nine surviving patients was 0.6 years (mean, 7.7 years; range, 0.6–12 years). The mean followup of the patients without muscle transfer was 9.3 years (range, 5.7–12 years) compared to 1.3 years in the two patients with a muscle transfer (range, 0.6–2.0 years).

Preoperatively, staging of the musculoskeletal tumor [23] was performed using blood analysis, ultrasonography, Tc-bone scanning, CT scanning, and dynamic MRI. Biopsy specimens were obtained for histologic diagnosis. Three patients had a benign bone tumor (two recurrent giant cell tumors and one eosinophilic granuloma); 10 had a malignant bone tumor (three osteosarcomas, five chondrosarcomas, and two metastases [one hypernephroma, one breast cancer]); and one had a malignant synovial cell sarcoma. The two patients with a giant cell tumor had already had previous, noncurative, nonprosthetic tumor surgery. One patient with osteosarcoma had been treated curatively with resection, extracorporeal irradiation, reimplantation, and fixation with an intramedullary nail. Due to failure of this reconstruction, conversion to a reverse shoulder prosthesis was performed 11 years after the primary surgery [13]. A multidisciplinary team decided on further treatment and the need for chemotherapy and/or radiotherapy. Three patients received preoperative radiation.

The patients were operated on by a senior surgeon at each center (LDW in Ghent and PB in Nice). Wide resection through a large deltopectoral approach, which included the biopsy site, was performed. In 12 patients, a modified clavicular osteotomy technique as described by Redfern et al. [37] was used. In this technique, a clavicular osteotomy is performed at the insertion of the deltoid muscle [37]. The osteotomy fragment is hinged in the acromioclavicular joint, which is resected to enhance the superior access to the joint. The interval between the deltoid muscle and the pectoralis major muscle is released and the cephalic vein is retracted medially. In all our patients, the pectoralis major muscle, the latissimus dorsi muscle, and the teres major muscle were released. The subacromial tissue was completely resected, creating space for the reverse prosthesis to move [35]. All patients underwent wide resection of the proximal humerus with preservation of the deltoid muscle and resection of the rotator cuff except for the first patient with a recurrent giant cell tumor in whom reattachment of the rotator cuff was attempted. Resection of the anterior part of the axillary nerve was performed twice because this was necessary to perform a “wide” resection. Eleven resected specimens were irradiated extracorporeally with 30,000 rad and replaced after the bulk of the lesion had been removed [45]. The shoulder was reconstructed with a reverse total shoulder prosthesis (seven Delta 3.1 [DePuy International

Ltd, Leeds, UK], four Delta CTATM [DePuy International Ltd], one Delta XtendTM [DePuy International Ltd], two Aequalis[®] Reversed [Tornier, Inc, Amsterdam, The Netherlands]). The largest glenosphere (42 mm) was routinely used as a glenoid component and was fixed with four screws. Intramedullary fixation of the prosthetic stem was achieved with gentamicin-impregnated cement at the level marked at trial reduction. At the humeral side, a 9-mm humeral lengthener was used to adjust the perioperative stability in one patient. On two occasions, detachment of the deltoid muscle was required. Reinsertion into the irradiated specimen was accomplished at the original deltoid insertion level with two transosseous sutures and nonresorbable sutures around the prosthetic stem to prevent tearing out of the necrotic bone. In two patients, transfer of the latissimus dorsi and teres major muscle with reinsertion at the most proximal level of the native bone using the same technique was performed [4].

Postoperatively, most patients were allowed immediate progressive mobilization of the shoulder. Patients with a latissimus dorsi and teres major muscle transfer and those with a deltoid reinsertion were kept in an abduction pillow for 6 weeks with restriction of mobilization. In the other patients, no bandage was applied. Patients were advised to perform passive exercises of the shoulder during the first 3 weeks without physiotherapist supervision. After 3 weeks, patients were encouraged to independently perform active exercises of the shoulder and arm and were allowed light activities of daily living.

Postoperative evaluation was performed according to a multidisciplinary approach. Depending on the type of tumor, postoperative screening for recurrent tumor or metastases was performed at preset time intervals at the oncology unit of our department. In addition, all patients were seen in the outpatient shoulder clinic at 6 weeks, 3 months, 6 months, 1 year, and then annually for clinical and radiographic evaluation of the shoulder prosthesis. At last followup, we recorded the Constant-Murley score [9, 10], the ability to work, and the visual analog scale (VAS) score for pain [29, 30]. The Disabilities of the Arm, Shoulder and Hand (DASH) score [28, 40] was also recorded in all but the two patients with a latissimus dorsi and teres major muscle transfer. The postoperative activities of daily living requiring external rotation (ADLER) score, as described by Boileau et al. [4], and the mobility of the shoulder were recorded to evaluate the difference between patients treated with a combined latissimus dorsi and teres major muscle transfer and those without. The passive shoulder mobility was measured in the supine lying position to stabilize the thoracoscavular mobility. Active mobility was measured in a standing position and was described in relation to the passive mobility. Because of the low number of patients in the two groups,

no statistical comparisons were performed. Complications and subsequent interventions were also recorded.

In all patients, an AP view and a scapular Y view were obtained. Two of the authors (LDW, HVdB) independently evaluated graft resorption and lucencies using the International Society of Limb Salvage (ISOLS) graft evaluation method [36]. Graft resorption and lucencies around the stem were scored 1 (poor) to 4 (excellent) according to this radiographic evaluation form for composite grafts (prosthesis and graft). For the glenoid component, we assessed radiolucencies under the baseplate, around the central peg, and around the fixation screws [43]. The scapular notch was analyzed according to the classification of Sirveaux et al. [33, 43]. Heterotopic bone was graded according to the filling of the space between the lateral glenoid rim and the medial border of the humeral shaft and/or the inferior border of the acromion [32].

Results

The mean functional Constant-Murley score was 76% (range, 56%–84%) (Fig. 1). The mean functional DASH score in the seven patients without a latissimus dorsi and teres major muscle transfer was 18.9 (range, 1.7–40.0). Three patients who had not retired from work had a mean functional DASH score of 7.4 and a mean DASH score for work of 4.2 (range, 0–12.5). The VAS score for pain was 0.86 (range, 0–2).

Mean active abduction was 157° (range, 90°–180°) in the entire cohort. In the group of patients with a latissimus dorsi and teres major muscle transfer, the mean active abduction was 135° (range, 120°–150°), compared to 163° (range, 90°–180°) in the group of patients without the muscle transfer. The two patients in whom a muscle

transfer was performed had an active external rotation of 60° in the abducted position compared to 17° in the group of patients without the muscle transfer (Table 2). The ADLER score was 27.5 (range, 27–28) and 23.6 (range, 14–28), respectively.

Four major complications occurred in three patients, one of whom died of disease. Two patients had one dislocation each that occurred on Days 1 and 27 and each was treated with closed reduction and an abduction pillow for 6 weeks with no further dislocation. One patient had an early deep infection (on Day 40). Two patients required a second surgical intervention. The patient with an early infection was treated with open débridement and antibiotics for 6 months. Two years later, he developed septic loosening (*Propionibacterium acnes*), which was treated with a one-stage revision of the prosthesis [3] and 6 months of oral antibiotics. At latest followup (65 months after the revision surgery), this patient had a Constant-Murley score of 84, a VAS score for pain of 0, an ADLER score of 28, and an active abduction of 180°. One of the two patients who had dislocated early after surgery developed aseptic loosening (negative cultures) with failure of the epiphyseal prosthesis 5 years postoperatively [16]. The prosthesis was replaced by a new long humeral stem prosthesis. At latest followup (73 months after the revision surgery), this patient had a Constant-Murley score of 56, a VAS score for pain of 1, an ADLER score of 14, and an active abduction of 90°.

At medium term, radiographic graft resorption was scored as poor in all but one patient (the first, which was scored good) according to the ISOLS score. Graft resorption was so extensive that the proximal humeral prosthesis was left without bone for approximately 82 mm (range, 48–126 mm) (Fig. 2). We observed no lucencies on the glenoid or humeral sides. A Grade 1 scapular notching was observed in three patients and a Grade 4 in one patient according to Sirveaux et al. [43]. One patient, who received

Fig. 1 A graph shows the mean scores of the different components of the Constant-Murley score and the maximum possible value of each component. ADL = activities of daily living.

Table 2. Passive and active external rotation*

Patient	Passive external rotation		Active external rotation	
	In adduction	In abduction	In adduction	In abduction
1	40°	80°	Lag 10°	Lag 30°
2	10°	70°	Lag 0°	Lag 80°
3	0°	30°	+ 10°	Lag 40°
4	20°	100°	+ 10°	Lag 30°
5	0°	20°	Lag 30°	Lag 30°
6	10°	70°	Lag 20°	Lag 70°
7	20°	70°	Lag 0°	Lag 40°
8†	40°	60°	Lag 0°	Lag 0°
9†	40°	60°	Lag 0°	Lag 0°

* The active mobility is described in relation to the maximal passive mobility; †Patients 8 and 9 were treated with a muscle transfer.

Fig. 2 A radiograph shows a shoulder with RSA with extensive graft resorption and a Grade 1 scapular notching. RSA = reverse total shoulder arthroplasty.

preoperative radiation, presented with a Grade 2 heterotopic bone formation subacromially and at the lateral rim of the inferior glenoid [32]. A prosthetic overhang of at least 2 mm was measured in all patients except the one with a spur formation. All screws had remained unchanged at the original position at the latest followup.

Discussion

Limb-sparing surgery for tumors of the proximal humerus yields good oncologic results, but regardless of the technique used, the patients are left with functional impairment of the shoulder, which almost always precludes activities above shoulder level. To improve shoulder function in these patients, we introduced the use of a reverse total shoulder prosthesis [18]. In patients with a functional deltoid, active glenohumeral abduction to an average of 143° was achieved in the short term [15, 19]. To establish whether this is a reasonable surgical treatment, we therefore determined (1) whether RSA restores function and (2) improves motion, (3) the complications associated with the surgery, and (4) whether RSA with autologous grafting is associated with bone resorption.

Our study has several limitations. First, the number of patients is limited, which makes statistical analysis inappropriate and allows only reporting of key observations. Second, we included patients from two different centers operated on by two different surgeons using a different

prosthesis. These data may therefore differ between these patients, and the DASH score and the VAS score for pain were only obtained for the patients treated without a latissimus dorsi and teres major muscle transfer. Passive shoulder mobility was examined with these patients in a dorsal recumbent position instead of in a standing position. Third, the evaluators were the operating surgeons. Additionally, because we started with this technique early in the 1990s, our learning curve with this approach may have resulted in early complications. Finally, we had a short followup time of the group of patients with a latissimus dorsi muscle transfer where longer followup is necessary to observe whether less bony resorption is seen.

Our observations confirm this procedure provides active shoulder function, with an active abduction of 157° and a Constant-Murley score of 76.4, and the function is maintained at the medium term (Table 1). The low DASH scores indicate limited functional impairment of the musculoskeletal disorders of the upper limb. Our findings are comparable with those for RSA performed for other indications (Table 3). The restoration of a stable glenohumeral fulcrum in combination with the gain of deltoid muscle power permits the shoulder to regain active abduction and forward flexion within the first postoperative weeks [17]. The reason for this seems to be twofold. First, the resection of all the soft tissues around the glenoid and proximal humerus for oncologic reasons gives remarkably good passive mobility, especially in rotation of the shoulder, because room is created [35]. Second, an active motor unit is required to provide strength. Partial resection of the anterior part of the axillary nerve is not a contraindication to this type of treatment, but the loss of active forward flexion is explained by the loss of this motor unit. In these patients, care must be taken to prevent anterior instability (one of the two dislocations we encountered).

The deltoid muscle alone is not able to provide enough power to perform activities of daily living requiring active external rotation. If this function is replaced by a latissimus dorsi and teres major muscle transfer, an improved ADLER score can be obtained at the expense of only limited loss of active abduction (Table 1). The ADLER score of the patients with tumors treated with a RSA combined with such a muscle transfer was comparable to that of patients with CTA who underwent the same treatment [4].

Unfortunately, we did not always eradicate the tumor with this limb-sparing surgery, but our cure rate was comparable with those of other limb-sparing approaches in the literature (Table 1) [8, 27, 38]. In our opinion, this type of surgery is also appropriate for palliative treatment or for pathologic fractures of the proximal humerus with a functioning deltoid.

All but one complication was observed in the early postoperative period and occurred in the earliest patients in

Table 3. Functional results of the reverse total shoulder arthroplasty for different indications

Study	Indication	Number of patients	Followup (months)	Mean active abduction	Mean CM	Mean DASH
Beekman et al. [3]	Infection	11	24		56%	
Flury et al. [24]	Failed conventional shoulder arthroplasty	21	46	90°	56%	61
Gallinet et al. [25]	Proximal humerus fractures	16	12	91°	53%	37
Boileau et al. [6]	Rotator cuff deficiency	42	50		56%	
Simovitch et al. [42]	Rotator cuff deficiency	77	44	111°	78%	
De Wilde et al.	Tumor	9	92	157°	76%	19

CM = Constant-Murley Shoulder Outcome score; DASH = Disabilities of the Arm, Shoulder and Hand score.

this series. The mean followup time of the patients with a complication was 10.3 years. This higher complication rate in the patients with the longest followup can be partially explained by our lack of experience at that time. The complications were comparable to those of RSA in CTA [46]. The dislocations were probably the result of our lack of experience in adjusting prosthetic tensioning and not using postoperative immobilization if the deltoid muscle was partially absent. To prevent dislocation, we advise a “standard” polyethylene insert be used instead of an insert with less contact area (high-mobility insert) combined with optimal prosthetic tensioning so that it is not possible for an opening wedge to be created between the polyethylene and the glenosphere over the full range of movement. Early dislocations can easily be treated with closed reduction under general anesthesia and an abduction pillow in the first weeks postoperatively [7, 17]. The rate of infection in RSA is reportedly at least twice as high as in hemiarthroplasty [3]. We were able to treat this complication with one-stage revision, thorough synovectomy, and long-term antibiotics, whereas the literature still advocates two-stage revision using a spacer impregnated with antibiotics. The only prosthetic failure occurred at 62 months postoperatively at the humeral side as a result of the lack of bony support at the epiphyseal part of the prosthesis, finally resulting in a prosthetic fatigue fracture [8]. This problem was successfully treated with revision of the humeral stem.

We observed only one patient with prosthetic loosening or scapular notching. Prosthetic overhang on the glenoid can explain this, as creating overhang seems the best way to prevent inferior scapular notching [14]. Because, in all but one patient, almost complete fading of the irradiated resected bone was seen, it seems advisable to implant a monoblock prosthesis at the humeral side to improve prosthetic strength.

In conclusion, our observations suggest RSA provides durable midterm function for patients with a tumor of the proximal humerus. The first experience of this treatment in combination with a transfer of the latissimus dorsi and teres

major muscle seems to be a reasonable approach to overcoming the problem of insufficient external rotation strength.

Acknowledgments We thank Iris Wojtowicz and Malcolm Forward for their assistance with editing the English in this manuscript.

References

1. Amin SN, Ebeid WA. Shoulder reconstruction after tumor resection by pedicled scapular crest graft. *Clin Orthop Relat Res.* 2002;397:133–142.
2. Axtell LM, Asire AL, Myers MH, eds. *Cancer Patient Survival, Report Number 5.* US Department of Health, Education and Welfare Publication Number (NIH) 77-992. Washington, DC: US Government Printing Office; 1976.
3. Beekman PD, Katusic D, Karels A, Berghs B, De Wilde L. One-stage revision for chronically infected reverse total shoulder arthroplasty. *J Bone Joint Surg Br.* 2010;92:817–822.
4. Boileau P, Chuinard C, Roussanne Y, Bicknell RT, Rochet N, Trojani C. Reverse shoulder arthroplasty combined with a modified latissimus dorsi and teres major tendon transfer for shoulder pseudoparalysis associated with dropping arm. *Clin Orthop Relat Res.* 2008;466:584–593.
5. Boileau P, Chuinard C, Roussanne Y, Neyton L, Trojani C. Modified latissimus dorsi and teres major transfer through a single delto-pectoral approach for external rotation deficit of the shoulder: as an isolated procedure or with a reverse arthroplasty. *J Shoulder Elbow Surg.* 2007;16:671–682.
6. Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. Reverse total shoulder arthroplasty after failed rotator cuff surgery. *J Shoulder Elbow Surg.* 2009;18:600–606.
7. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. *J Shoulder Elbow Surg.* 2005;14(Suppl S):147S–161S.
8. Capanna R, Van Horn JR, Biagini R, Ruggieri P, Bettelli G, Sola G, Campanacci M. A humeral modular prostheses for bone tumour surgery: a study of 56 cases. *Int Orthop.* 1986;10:231–238.
9. Coboy VB, Morris RW, Kiss J, Carr AJ. An evaluation of the Constant-Murley Shoulder Assessment. *J Bone Joint Surg Br.* 1996;78:229–232.
10. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res.* 1987;214:160–164.
11. Dahlin DC. *Bone Tumors: General Aspects and Data on 6221 Cases.* 3rd ed. Springfield, IL: Charles C Thomas; 1978:156–175.

12. Dahlin DC, Ivins JC. Benign chondroblastoma: a study of 125 cases. *Cancer*. 1972;30:401–413.
13. De Wilde L, Plasschaert F. Prosthetic treatment and functional recovery of the shoulder after tumor resection 10 years ago: a case report. *J Shoulder Elbow Surg*. 2005;14:645–649.
14. de Wilde L, Poncet D, Middernacht B, Ekelund A. Prosthetic overhang is the most effective way to prevent scapular conflict in a reverse total shoulder prosthesis. *Acta Orthop*. 2010;81:719–726.
15. De Wilde L, Sys G, Julien Y, Van Ovost E, Poffyn B, Trouilloud P. The reversed Delta shoulder prosthesis in reconstruction of the proximal humerus after tumour resection. *Acta Orthop Belg*. 2003;69:495–500.
16. De Wilde L, Walch G. Humeral prosthetic failure of reversed total shoulder arthroplasty: a report of three cases. *J Shoulder Elbow Surg*. 2006;15:260–264.
17. De Wilde LF, Plasschaert FS, Audenaert EA, Verdonk RC. Functional recovery after a reverse prosthesis for reconstruction of the proximal humerus in tumor surgery. *Clin Orthop Relat Res*. 2005;430:156–162.
18. De Wilde LF, Van Ovost E, Uyttendaele D, Verdonk R. Results of an inverted shoulder prosthesis after resection for tumor of the proximal humerus [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 2002;88:373–378.
19. Drake GN, O'Connor DP, Edwards TB. Indications for reverse total shoulder arthroplasty in rotator cuff disease. *Clin Orthop Relat Res*. 2010;468:1526–1533.
20. Enneking W, Dunham W, Gebhardt M, Malawer M, Pritchard D. A system for the classification of skeletal resections. *Chir Organi Mov*. 1990;75(Suppl):217–240.
21. Enneking WF, ed. *Musculoskeletal Tumor Surgery*. New York, NY: Churchill Livingstone; 1983:335–410.
22. Enneking WF. Simple cyst. In: Enneking WF, ed. *Musculoskeletal Tumor Surgery*. Churchill Livingstone, New York, NY; 1983:1494–1513.
23. Enneking WF. A system of staging musculoskeletal neoplasms. *Clin Orthop Relat Res*. 1986;204:9–24.
24. Flury MP, Frey P, Goldhahn J, Schwyzer HK, Simmen BR. Reverse shoulder arthroplasty as a salvage procedure for failed conventional shoulder replacement due to cuff failure-midterm results. *Int Orthop*. 2010 March 14 [Epub ahead of print].
25. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L. Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases. *Orthop Traumatol Surg Res*. 2009;95:48–55.
26. Gerber C, Maquieira G, Espinosa N. Latissimus dorsi transfer for the treatment of irreparable rotator cuff tears. *J Bone Joint Surg Am*. 2006;88:113–120.
27. Getty PJ, Peabody TD. Complications and functional outcomes of reconstruction with an osteoarticular allograft after intra-articular resection of the proximal aspect of the humerus. *J Bone Joint Surg Am*. 1999;81:1138–1146.
28. Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (Disabilities of the Arm, Shoulder and Hand) [corrected]. The Upper Extremity Collaborative Group (UECG). *Am J Ind Med*. 1996;29:602–608.
29. Huskisson EC. Measurement of pain. *Lancet*. 1974;2:1127–1131.
30. Huskisson EC. Measurement of pain. *J Rheumatol*. 1982;9:768–769.
31. Jensen KL, Johnston JO. Proximal humeral reconstruction after excision of a primary sarcoma. *Clin Orthop Relat Res*. 1995;311:164–175.
32. Kjaersgaard-Andersen P, Frich LH, Sojbjerg JO, Sneppen O. Heterotopic bone formation following total shoulder arthroplasty. *J Arthroplasty*. 1989;4:99–104.
33. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, Walch G. Scapular notching in reverse shoulder arthroplasty. *J Shoulder Elbow Surg*. 2008;17:925–935.
34. Malawer M, Meller I, Dunham WK. A new surgical classification system for shoulder-girdle resections: analysis of 38 patients. *Clin Orthop Relat Res*. 1991;267:33–44.
35. Middernacht B, De Roo PJ, Van Maele G, De Wilde LF. Consequences of scapular anatomy for reversed total shoulder arthroplasty. *Clin Orthop Relat Res*. 2008;466:1410–1418.
36. Poffyn B, Sys G, Van Maele G, Van Hoorbeke L, Forsyth R, Verstraete K, Uyttendaele D. Radiographic analysis of extracorporeally irradiated autografts. *Skeletal Radiol*. 2010;39:999–1008.
37. Redfern TR, Wallace, Beddow FH. Clavicular osteotomy in shoulder arthroplasty. *Int Orthop*. 1989;13:61–63.
38. Rödl RW, Gosheger G, Gebert C, Lindner N, Ozaki T, Winkelmann W. Reconstruction of the proximal humerus after wide resection of tumours. *J Bone Joint Surg Br*. 2002;84:1004–1008.
39. Rose PS, Shin AY, Bishop AT, Moran SL, Sim FH. Vascularized free fibula transfer for oncologic reconstruction of the humerus. *Clin Orthop Relat Res*. 2005;438:80–84.
40. Roy JS, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. *Arthritis Rheum*. 2009;61:623–632.
41. Rubin P. *Clinical Oncology*. 6th ed. Rochester, MN: American Cancer Society; 1983.
42. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. *J Bone Joint Surg Am*. 2007;89:588–600.
43. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff: results of a multicentre study of 80 shoulders. *J Bone Joint Surg Br*. 2004;86:388–395.
44. Tsukushi S, Nishida Y, Takahashi M, Ishiguro N. Clavicular pro humero reconstruction after wide resection of the proximal humerus. *Clin Orthop Relat Res*. 2006;447:132–137.
45. Uyttendaele D, De Schryver A, Claessens H, Roels H, Berkvens P, Mondelaers W. Limb conservation in primary bone tumours by resection, extracorporeal irradiation and re-implantation. *J Bone Joint Surg Br*. 1988;70:348–353.
46. Werner CM, Steinmann PA, Gilbert M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. *J Bone Joint Surg Am*. 2005;87:1476–1486.