



# Management of proximal humeral bone loss: a narrative review

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**Background and Objective:** The optimal management of proximal humeral bone loss (PHBL) in shoulder arthroplasty is a debated topic. PHBL is a challenging problem for surgeons due to its effect on implant fixation and stability. Supplemental fixation options in the form of allograft-prosthetic composites (APCs) or reverse shoulder arthroplasty (RSA) endoprostheses are options to consider, each with its own benefits and complication profiles. This narrative review aims to evaluate current strategies for managing PHBL.

**Methods:** A comprehensive literature search was performed using databases including PubMed, Cochrane Library, and Google Scholar using appropriate search terms. Studies published between 2013 and 2024 were included. All included studies were peer-reviewed and addressed PHBL in the setting of shoulder arthroplasty or proximal humerus resection.

**Key Content and Findings:** A total of nineteen studies were included, comprising 7 retrospective case series, 4 prospective case series or cohort studies, 2 systematic reviews, 1 retrospective registry study, 3 descriptive papers of proposed classification systems, and 2 technique papers. Described classification systems categorize PHBL by integrity of the epiphysis, greater tuberosity, calcar, metaphysis, diaphysis, and cortices. Depending on the degree of bone loss, revision RSA without allograft, revision RSA with APC augmentation, and endoprosthesis are described as management options. In patients with greater than 5 cm of PHBL, use of APC or endoprosthesis has proven effective but with high complication profiles and revision rates. No paper directly compares endoprosthesis and APC outcomes.

**Conclusions:** PHBL is a rare but important problem in the setting of tumor resection and revision shoulder arthroplasty. While small cohort studies have reported successful outcomes with both APC and endoprosthesis, systematic reviews have failed to demonstrate a clear benefit of one option over the other. Complication and reoperation rates can be high with both surgical options. With a focus on standardized classification and evaluation of patients with PHBL, we can hope to refine the surgical techniques and indications for optimal patient outcomes.

**Keywords:** Proximal humeral bone loss (PHBL); allograft-prosthetic composite (APC); endoprosthesis; revision shoulder arthroplasty

Received: 16 December 2024; Accepted: 09 April 2025; Published online: 01 July 2025.

doi: 10.21037/aoj-24-70

**View this article at:** <https://dx.doi.org/10.21037/aoj-24-70>

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## Introduction

The optimal management of proximal humeral bone loss (PHBL) in shoulder arthroplasty is a debated topic. With the incidence of primary shoulder arthroplasty on the rise (1), management of PHBL is an important issue to consider in the revision scenario. The etiology of PHBL is multifactorial, including stress shielding, osteolysis, and bone resorption seen in revision shoulder arthroplasty from aseptic or septic implant loosening, as well as following complex proximal humerus fractures, periprosthetic humerus fractures, and proximal humerus fracture nonunions. Moreover, the proximal humerus is the second most common site for osseous sarcomas, with many cases requiring surgical resection (2).

PHBL is a challenging problem for surgeons due to its effect on implant fixation and stability, both from bone and soft tissue loss (rotator cuff, deltoid) (3). Depending on the extent of PHBL, reliance on the metaphysis for humeral component stability may be insufficient, and some degree of diaphyseal fixation with a longer stem may be necessary. However, this torsional stability may be suboptimal within PHBL patients due to an increase in rotational micromotion, and there is a theoretically higher risk of loosening, instability, weakness, and poorer function (4). As a result, supplemental fixation options in the form of allograft-prosthetic composites (APCs) or reverse shoulder arthroplasty (RSA) endoprotheses, such as proximal humeral replacement or total humeral replacement, are options to consider, each with its own benefits and complication profiles.

## Objective

This narrative review aims to evaluate current strategies for managing PHBL. We have also performed a literature review examining outcomes of revision shoulder arthroplasty in the setting of PHBL, with the goal to produce an update on current literature surrounding different management options to aid surgeons with decision-making when confronted with this challenging problem. We present this article in accordance with the Narrative Review reporting checklist (available at <https://aoj.amegroups.com/article/view/10.21037/aoj-24-70/rc>).

## Methods

A comprehensive literature search was performed using

databases including PubMed, Cochrane Library, and Google Scholar. Search terms were “proximal humeral bone loss and revision shoulder arthroplasty”, “allograft prosthetic composite and revision shoulder arthroplasty”, and “proximal humeral replacement and revision shoulder arthroplasty”. Studies published between 2013 and 2024 were included. All included studies were peer-reviewed and addressed PHBL in the setting of shoulder arthroplasty or proximal humerus resection. Studies focusing solely on non-surgical management, studies without outcome measures, and studies without mention of PHBL were excluded. Ultimately, 19 publications with a combination of registry studies, prospective and retrospective cohort studies, systematic reviews, case series, and proposed classification systems met all inclusion and exclusion criteria. Information on study design, patient demographics, type of bone loss, surgical techniques, and outcomes was extracted. The search strategy is summarized in the provided table (*Table 1*).

## Key content and findings

A total of 19 studies were included, comprising seven retrospective case series, four prospective case series or cohort studies, two systematic reviews, one retrospective registry study, three descriptive papers of proposed classification systems, and two technique papers (5-23). Two publications looked at outcomes of reconstruction without allograft augmentation, six publications focused on outcomes and durability of revision RSA with APC, four publications examined revision RSA with endoprosthesis, and seven publications addressed PHBL from a more global perspective and discussed various techniques or methods of grading pre-operative bone stock. The studies varied widely in sample size and review scope.

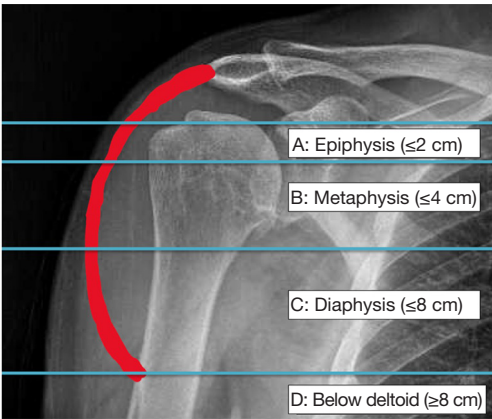
## Classification systems and their uses

Several classification systems and treatment algorithms to guide the management of PHBL have been proposed. The Boileau Classification was originally described in 2016 and then modified in 2020 (5,6). This system takes a macroscopic look at bone stock in terms of remaining bone regions and the deltoid attachment (*Figure 1*). Boileau Type A cases have less than or equal to two centimeters of bone loss with some remaining epiphysis, Type B cases have less than or equal to four centimeters of loss including the entire epiphyses with some metaphysis, Type C cases have

**Table 1** The search strategy summary

| Items                                        | Specification                                                                                                                                                                                                                  |
|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Date of search                               | September 2024                                                                                                                                                                                                                 |
| Databases and other sources searched         | PubMed, Cochrane Library, Google Scholar                                                                                                                                                                                       |
| Search terms used                            | “proximal humeral bone loss and revision shoulder arthroplasty”, “allograft prosthetic composite and revision shoulder arthroplasty”, and “proximal humeral replacement and revision shoulder arthroplasty”                    |
| Timeframe                                    | 2013–2024                                                                                                                                                                                                                      |
| Inclusion and exclusion criteria             | <p>Inclusion criteria: peer-reviewed, focus on PHBL in the setting of shoulder arthroplasty or proximal humerus resection</p> <p>Exclusion criteria: non-surgical management, lack of outcome measures, no mention of PHBL</p> |
| Selection process                            | Selection process lead by L.G. and C.J.C., consensus obtained with all authors based on relevance and robustness of selected studies                                                                                           |
| Any additional considerations, if applicable | Study designs selected: registry studies, prospective and retrospective cohort studies, systematic reviews, case series, and proposed classification systems                                                                   |

PHBL, proximal humeral bone loss.



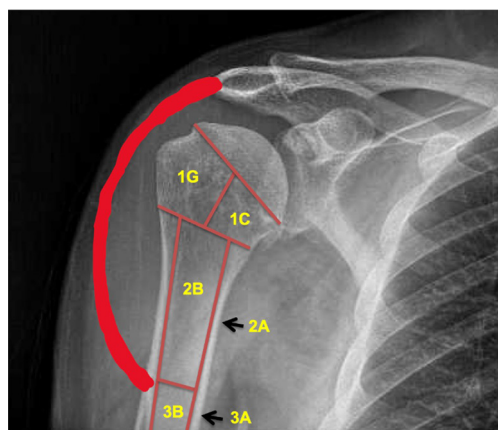
**Figure 1** The modified Bouleau Classification as described by Bouleau *et al.* (2020) (6).

less than or equal to eight centimeters of loss including the entire epiphysis and metaphysis, and Type D cases have over eight centimeters of loss with extension distal to the deltoid attachment. Of note, no study exists validating its interrater reliability or significance.

In 2019, Chalmers *et al.* aimed to characterize bone loss specifically in the setting of revision arthroplasty and created a validated classification system, Proximal Humeral Arthroplasty Revision Osseous inSufficiency (PHAROS), with hopes of guiding appropriate humeral reconstruction techniques (7). The authors performed a comparative

retrospective radiographic study, with six shoulder and elbow fellowship-trained surgeons from five centers collaborating to create a consensus classification. The new system described three major types of bone loss, each with subtypes (Figure 2). Type 1 is defined as loss of the epiphysis with two separate subtypes for loss of the calcar and loss of the greater tuberosity (Type 1C and Type 1G, respectively). Type 2 is defined as loss of the metadiaphysis above the deltoid attachment with two subtypes; Type 2A involves metadiaphyseal cortical thinning of greater than 50%, while Type 2B involves both metadiaphyseal and epiphyseal bone loss. Type 3 is defined as bone loss extending below the deltoid attachment, again with two subtypes; Type 3A involves diaphyseal cortical thinning of greater than 50%, while Type 3B involves combined diaphyseal, metaphyseal, and epiphyseal bone loss.

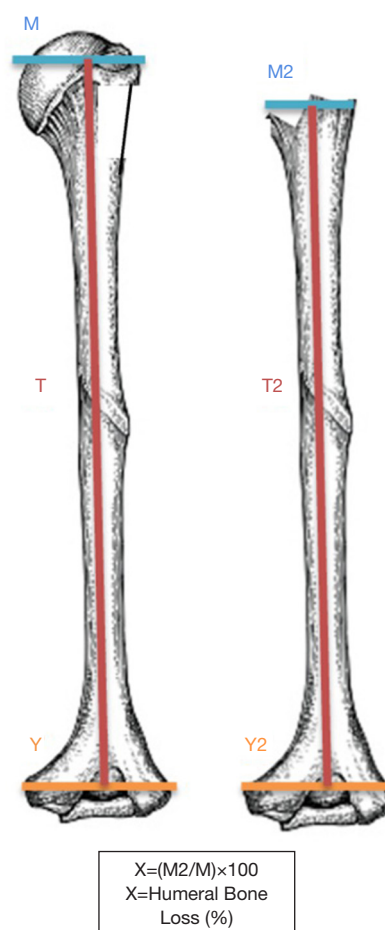
A 2024 study by Baldari *et al.* proposed a new management algorithm to address substantial humeral bone defects based on quantitative measurements, compared to relative anatomical landmarks as described in previous studies (8–10). Their classification, entitled the Proximal Humeral Bone Loss—Specific Classification for Optimal Reconstruction (PHBL-SCORE), offers a new way to incorporate pre-operative radiographic measurements to determine the percentage of bone loss. It is a patient-specific approach utilizing bilateral true anteroposterior humerus radiographs that compares measurements of bone loss relative to the healthy contralateral humerus



**Figure 2** The Proximal Humeral Arthroplasty Revision Osseous in Sufficiency classification as described by Chalmers *et al.* (2019) (7).

(Figure 3). Type A indicates PHBL <5%; Type B indicates PHBL >5% but <15%; Type C indicates PHBL >15% but <40%; and lastly, Type D indicates PHBL >40%. The authors advocate that this system should be adopted universally as a standardized measurement system so that future studies may be more compatible for comparison with one another. Interrater reliability of this system includes a kappa coefficient of 0.798, and it is also easily reproducible with a low cost to implement. Future studies should focus on validating the proposed treatment algorithm associated with PHBL-SCORE with direct comparison to the other classification systems to further delineate their strengths and weaknesses.

The Boileau Classification, PHAROS system, and PHBL-SCORE all aim to evaluate the amount of bone loss as it informs possible reconstruction options. While the Boileau Classification simplifies PHBL quantification with basic radiographic measurements, the PHAROS system builds upon this with consideration of preservation of cuff insertion at the greater tuberosity, calcar integrity, and cortical thickness. Lastly, the PHBL-SCORE offers a patient-specific approach to PHBL analysis that theoretically offers more accuracy based on the anatomy of the healthy contralateral humerus. Although calculating a PHBL-SCORE requires access to more radiographic data than the Boileau Classification and PHAROS system, it remains an easily implementable measurement technique with high interrater reliability. The clinical significance of a patient-specific approach to quantifying PHBL remains unclear. In the absence of a contralateral humerus X-ray, the PHAROS system preserves the simplicity of the Boileau



**Figure 3** The Proximal Humeral Bone Loss—Specific Classification for Optimal Reconstruction calculation as described by Baldari *et al.* (2024) (8).

Classification with more attention to the remaining bone quality and integrity of soft tissue attachment sites.

### Reconstruction options

There are three major categories of reconstruction options in the setting of PHBL: (I) RSA without an allograft; (II) RSA with APC; and (III) RSA with an endoprosthesis. The above classification systems can help to guide surgical treatment strategy based on the amount of PHBL. As mentioned, none of these systems are comprehensive, and due to the rarity of this problem, there is not a standard treatment algorithm that is widely accepted. In general, PHAROS Type 1C and 1G defects are amenable to reconstruction with RSA without any graft, but a longer

stem humeral component may be needed. Type 2A and 2B defects representing more metaphyseal and metadiaphyseal bone loss may be treated with RSA without any graft if there is adequate metadiaphyseal bone stock, but an APC or an RSA with endoprosthesis is needed with more significant proximal bone loss. Type 3A and 3B defects require an RSA with longer proximal humeral APC or an RSA with a larger endoprosthesis (3). Baldari *et al.*'s recommended algorithm is compatible, as these authors suggest Type A defects be treated with increased metal liner size and/or polyethylene, Type B defects be treated with increased metal liner size and polyethylene with cementoplasty, Type C defects be treated with APC or endoprosthesis, and lastly Type D be treated with an endoprosthesis (8).

The most conservative reconstruction option discussed in this review is revision RSA without allograft. This is a reasonable strategy for PHBL isolated to the epiphysis (Type 1 defect) or with adequate metadiaphyseal bone stock (some Type 2 defects). Revision RSA systems with distal stem fixation may also be applied when diaphyseal fixation is required for stem stability due to metaphyseal bone loss. The goals of this surgery are to achieve adequate length, appropriate soft tissue and axillary nerve tension, and appropriate stability to prevent subluxation or dislocation. Stem height that matches the native humerus is crucial to stability, so contralateral full-length humerus radiographs should be obtained pre-operatively for comparison. Restoration of humeral length can be accomplished by cementing the stem proud or utilizing a thicker polyethylene or metallic spacer component. A larger or inferior eccentric glenosphere is another option to confer greater stability, which may be utilized when humeral length is already adequate or additional inferiorization of the joint is desired (3). The smaller amount of proximal bone loss in this setting can be made up for with cement to reconstruct the missing bone (cementoplasty), or some implant systems now offer metal augmentation that attaches to the standard RSA humeral component to make up for the bone loss.

Revision RSA with an APC is a reconstruction option that is described in the literature for Type 2 and 3 defects with or without extension beyond the deltoid insertion (3). Theoretical benefits of augmentation with an APC include greater humeral implant support and reinforcement, restoration of native humeral length, appropriate deltoid tensioning with restoration of deltoid wrap effect, and options for rotator cuff and soft tissue repair depending on the type of graft used (5). However, APCs are costly, technically demanding, and prone to allograft resorption

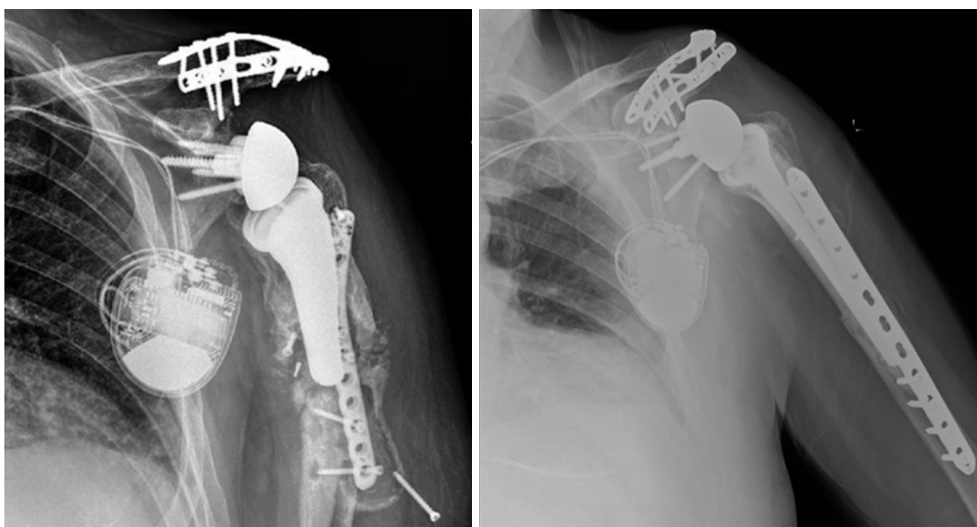
that might compromise their longevity. Fixation between the allograft and native bone is critical to long-term incorporation of the graft. A step-cut may be added to the allograft to add torsional stability and increase surface area at the allograft-native bone junction. The most common fixation techniques include compression plating with a cemented short or long-stemmed humeral component (*Figure 4*) or a cemented long-stemmed humeral component spanning both the graft and the native bone with a compression plate and/or cerclage cables (*Figure 5*). In terms of APC type, use of both proximal humeral allografts and proximal femoral allografts is described in the literature (11). One benefit of the proximal humerus allograft is that it can offer attachment sites for the rotator cuff and the deltoid that can be repaired to native tendons. Proximal femur allografts may be used for more extensive bone defects, and their larger size provides more allograft bone stock with which to work. In general, it is favored to maintain as much healthy native humeral bone stock as possible and utilize a graft that is only as large as is necessary to achieve stable fixation. While there is no consensus in the literature, multiple studies have demonstrated a cut-off of 5 cm of PHBL as a threshold for APC (9,10).

The final reconstructive option for PHBL is RSA with endoprosthesis, which can also be used for Type 2 and 3 defects (3). Instead of relying on allograft bone to recreate the proximal humeral anatomy, these metallic endoprostheses are shaped to recreate the proximal humerus (*Figure 6*). The modularity of both proximal humeral and total humeral endoprostheses allows for restoration of humeral length and deltoid wrap, and some designs even have a metallic meshwork or holes for tendon attachment. These implants are commonly utilized in tumor cases in which wide resection of the proximal humerus is necessary. The benefit of endoprosthesis over APC is that the metallic component is stable and would not resorb over time, however, when used for large PHBL, the lack of soft tissue attachment creates a high risk for instability and reliance on the distal cemented stem, which increases their risk of humeral loosening over time.

## Outcomes and complications

### *Revision reverse arthroplasty without allograft*

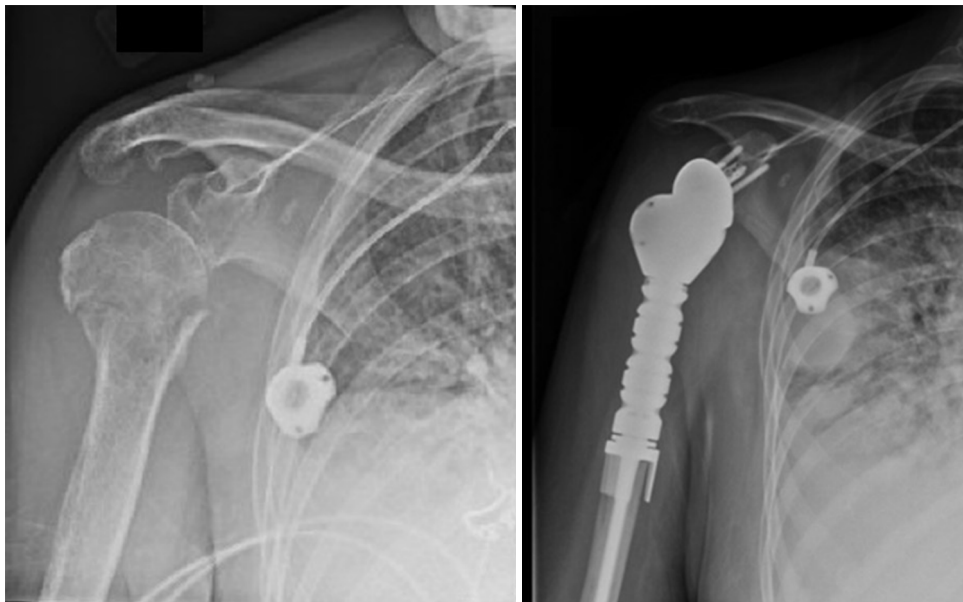
Satisfactory outcomes in revision RSA without use of allograft or endoprosthesis has been described in cases of mild PHBL. Budge *et al.* reported clinical and radiographic



**Figure 4** Preoperative anteroposterior view radiograph (left) of a patient with prior RSA complicated by periprosthetic fracture with nonunion and significant PHBL. Three-month post-operative anteroposterior view radiograph (right) of the same patient after APC with compression plate technique. APC, allograft-prosthetic composite; PHBL, proximal humeral bone loss; RSA, reverse shoulder arthroplasty.



**Figure 5** Preoperative anteroposterior view radiograph (left) of a patient with failed prior RSA and significant PHBL. One-year post-operative anteroposterior view radiograph (right) of the same patient after APC with intramedullary stem fixation. APC, allograft-prosthetic composite; PHBL, proximal humeral bone loss; RSA, reverse shoulder arthroplasty.



**Figure 6** Preoperative anteroposterior view radiograph (left) of a patient with breast cancer with bony metastasis to the right proximal humerus requiring extensive proximal humeral resection. One-month postoperative anteroposterior view radiograph (right) of the same patient after endoprosthesis.

outcomes of 15 patients between 2005 and 2008 undergoing revision RSA without allograft for PHBL with an average follow-up of 34.5 months (range, 25–49 months) (12). The average bone loss was 38.4 mm. Indications for revision to RSA were failed hemiarthroplasty for fracture ( $n=12$ ) and previously infected hemiarthroplasty ( $n=3$ ). Overall, patient-reported outcome measures (PROMs) were significantly improved across all scales: mean Constant Score (CS) (23.0 to 44.2,  $P=0.002$ ), American Shoulder and Elbow Surgeons (ASES) score (38.2 to 68.3,  $P=0.0001$ ), Simple Shoulder Test (SST) score (19.2 to 75.8,  $P=0.0001$ ), and visual analog scale (VAS) pain score (4.6 to 1.6,  $P=0.0007$ ). Range of motion (ROM) significantly improved in forward flexion ( $38.3^\circ$  to  $103.2^\circ$ ,  $P=0.001$ ). Radiographs demonstrated scapular notching in 3 patients, no humeral subsidence or loosening, and one prosthetic fracture of a modular humeral stem. Overall, this suggests that revision RSA without allograft augmentation can provide significant clinical benefit in the setting of PHBL without extensive bone loss beyond the calcar, though this study is limited by its small size and relatively short-term follow-up.

A 2015 study by Stephens *et al.* compared the outcomes of revision RSA without allograft in 16 patients with PHBL and 16 patients without PHBL (13). The average bone loss of the PHBL cohort was 32.3 mm (range, 17.2–66 mm). Patients

were followed for an average of 51.2 months with clinical and radiographic outcomes. Significant improvement was seen across all PROMs as well as with forward flexion in the PHBL cohort: SST score (1.6 to 5.3;  $P<0.001$ ), VAS score (5.4 to 3.1;  $P=0.020$ ), ASES score (30.7 to 66.8;  $P<0.001$ ), and forward flexion ( $52^\circ$  to  $100^\circ$ ;  $P<0.001$ ). No difference was demonstrated in ASES score, SST score, and VAS pain score between the two groups, though the PHBL cohort had significantly worse postoperative ROM scores: forward flexion ( $100^\circ$  vs.  $135^\circ$ ;  $P=0.022$ ) and external rotation ( $19^\circ$  vs.  $34^\circ$ ;  $P=0.009$ ). On radiographs, three PHBL patients had humeral-sided loosening, and five PHBL patients sustained complications. These complications included intraoperative proximal humerus fracture, postoperative humeral shaft fracture distal to the tip of the humeral stem, hematoma resulting in temporary radial and median nerve palsies that resolved spontaneously, dislocation one year after surgery with persistent instability necessitating revision, and acromion fracture. The patient with persistent instability sustained a periprosthetic fracture at the level of the humeral stem 10 years after his revision and was found to have 6.6 centimeters of PHBL intra-operatively, so he was converted to RSA with APC augmentation. These authors reinforce Budge *et al.*'s conclusion that revision RSA alone can provide successful outcomes in patients with

small amounts of PHBL (12). It is important to note that the average PHBL in both studies was less than 40 mm.

### APCs

Bone loss greater than 5 centimeters from the greater tuberosity, or between 15% and 40% by the PHBL-SCORE system, is often considered an indication to augment with APC (9,10). In general, the studies described in this section show that PHBL can be successfully managed with this approach with acceptable PROMs and revision rates, though functional outcomes are inconsistent. Of note, surgical techniques for APC vary considerably across studies, and a superior fixation technique (compression plating with or without cerclage cables versus long-stem intramedullary fixation) is not yet established. Moreover, the studies below look at heterogeneous groups with varying pathologies and indications for use of APC, so direct comparison between papers is difficult.

In 2024, Rampam *et al.* published the largest systematic review on clinical outcomes and complications of APC reconstruction performed after resection of proximal humerus tumors or arthroplasty implant failure (14). In this paper, 25 studies were included with 488 shoulders in total and follow-up of 2.5 to 10 years, with 21 of these studies citing oncologic resection as the main indication for APC reconstruction (15-17,19,24-43). Functional outcome was primarily assessed using Musculoskeletal Tumor Society (MSTS) score at last follow-up for both tumor and failed arthroplasty patients, with average MSTS scores ranging from 57% to 90% across all studies. There was no significant difference between functional outcomes in oncology and failed arthroplasty patients. For oncology patients, the average ASES score in reporting studies ranged from 58 to 64 (15,27,32,33), and average SST score ranged from 3.6 to 6.0 (31-33). In the failed arthroplasty cohorts, the average ASES score in the two reporting studies ranged from 51 to 69, and average SST score ranged from 3.5 to 4.5 (17,29). This review only includes post-operative PROMs and does not report on the delta between pre- and post-operative functional outcomes across the studies. Average post-operative ROM was reported in the majority of the included studies, with average abduction ranging from 32° to 72°, average forward flexion ranging from 54° to 107°, and average external rotation ranging from 8° to 31°. No pre-operative ROM data were reported. Revision and complication rates varied widely, with revision-free implant survival ranging from 41% to 92% at 5 years and 60% to

88% at 10 years in reporting studies, overall implant failure ranging from 9% to 54%, and reoperation rate ranging from 0% to 55% with follow-up varying from 2.5 to 10 years. For studies only including oncology patients, the overall complication rate range was wide at 9% to 61%, while the two studies focusing solely on failed arthroplasty patients had complication rates at the lower end of this spectrum at 16% and 19%. Aseptic loosening and graft-host nonunion were the most common modes of failure (range 7% to 54%), with graft-host nonunion rate cited in up to 75% of revision diagnoses in one study by Zuo *et al.* (15). The authors did not distinguish a difference in nonunion rates between different fixation techniques across all 24 studies. Infection rate (15.4% across all studies), soft-tissue failures including cuff dysfunction or coverage failures (7% to 27%), and structural failures including graft resorption or implant failure (8% to 33%) were less commonly reported complications. Overall, this review highlights the heterogeneity in the literature regarding functional outcomes of the APC technique, but the authors also demonstrate that it is a noninferior option to other reconstruction techniques with endoprostheses. This review also demonstrates the high complication and revision rate of patients undergoing RSA with APC.

Graft-host nonunion was one of the most reported complications in the Rampam *et al.* systematic review (14), and there is debate about optimal APC fixation technique. In 2017, Sanchez-Sotelo *et al.* looked at 8 primary and 18 revision RSAs using APC reconstruction performed between 2005 and 2012 in which the compression plate technique was used to achieve graft-host fixation (16). Overall, this cohort saw substantial improvements in pain scores, forward flexion, and external rotation without any significant differences between primary and revision cases. The mean time to union was 7 months, with one patient experiencing delayed union requiring a bone grafting procedure. No patients ultimately required revision for nonunion at the host-allograft junction, bolstering the effectiveness of compression plating in this setting. In total, there were four complications, including one dislocation, one deep infection, one graft fracture, and one periprosthetic fracture distal to the APC. At both 2- and 5-year follow-up, 96% of patients retained their original APC without revision.

A cemented long-stem intramedullary technique is another option for graft-host fixation. Cox *et al.* studied 73 patients between 2002 and 2012 who underwent revision RSA with APC using a cemented long-stem intramedullary

fixation technique with cerclage fixation across the graft-host junction. Average follow-up was 5.66 years (range, 2 to 15 years) (17). Clinical outcome scores, ROM data, and radiographic evaluations were assessed pre- and post-operatively. ASES scores improved from 33.7 to 51.1 ( $P<0.0001$ ) and SST scores improved from 1.3 to 3.5 ( $P<0.0001$ ) at final follow-up. Good to excellent results were reported by 70% of patients, satisfactory results were reported by 17% of patients, and 13% of patients were ultimately unsatisfied at final follow-up. ROM improved in both forward flexion ( $49^\circ$  to  $75^\circ$ ,  $P<0.001$ ) and abduction ( $45^\circ$  to  $72^\circ$ ,  $P<0.001$ ). A proportion of 13.7% of patients ( $n=10$ ) had radiographic evidence of humeral loosening at final follow-up, with two of these requiring revisions. A proportion of 19% of patients ( $n=14$ ) were revised at a mean of 38 months post-operatively, with revision diagnoses including periprosthetic fracture ( $n=6$ ), instability ( $n=2$ ), glenosphere dissociation ( $n=2$ ), humeral loosening ( $n=2$ ), and infection ( $n=2$ ). Reoperation-free survival rate was 88% at 5 years, 78% at 10 years, and 67% beyond 10 years. Overall, these authors concluded that APC fixed via cemented long-stem intramedullary technique provides reliable pain relief and improved ROM, with an acceptable complication and revision rate. Although the revision rate was higher in this cohort than in the Sanchez-Sotelo *et al.* study using the compression plating technique (16), this study represents a much larger case series, all performed for failed arthroplasties with longer follow-up.

While instability was not a complication discussed in detail in the Rampam *et al.* systematic review (14), it is an important complication to consider in patients with deficient proximal humeral bone stock and associated soft tissue loss. A retrospective review by Cox *et al.* published in 2024 examined a cohort of 14 patients who underwent RSA with APC, with one primary arthroplasty and 13 revision RSA cases (18). Ten cases used proximal femoral allografts and 4 cases used proximal humeral allografts. A proportion of 42.9% of this cohort had post-operation complications requiring repeat revision RSA, with 35.7% of all patients experiencing instability and 7.1% with post-op wound drainage.

In oncology patients, there is more heterogeneity in pre-operative level of function and amount of bone loss due to tumor size and involvement of surrounding neurovascular structures. A 2019 study published by El Beaino *et al.* examined functional outcomes in a cohort of 21 patients with a median follow-up of 97 months (range, 20–198 months) who underwent APC reconstruction

after proximal humerus tumor resection between 2000 and 2015 (19). 29% of patients ( $n=6$ ) were lost to follow-up at the 5-year mark. Overall, the remaining patients saw a slight deterioration of function over time, with mean MSTS scores at 1 and 5 years of 86% and 76%, respectively ( $P=0.015$ ). Similarly, mean active forward flexion decreased from  $101^\circ$  to  $92^\circ$  between 1- and 5-year follow-up, which was not statistically significant. Moreover, ten patients went on to delayed union beyond 1 year, 3 patients experienced aseptic loosening, and 9 patients demonstrated resorption of the greater tuberosity on radiographic evaluation. The cumulative risk of revision was 10.1% at final follow-up of 5 years, with indications for revision including aseptic loosening with concomitant nonunion ( $n=2$ ), severe subluxation ( $n=1$ ), and infection ( $n=1$ ). Overall, at intermediate 5-year follow-up in this cohort, APC reconstruction had an acceptable overall MSTS score with relatively low incidence of revision, albeit higher in this specific tumor cohort than in the general population.

### Endoprosthetic reconstruction

An alternative to recreating proximal humeral anatomy with an allograft is through an anatomically shaped endoprosthesis. The implant itself accounts for recreating humeral length, deltoid wrap, and in some cases, tendinous attachment to the prosthesis. There is debate about whether APC or endoprosthesis can more effectively restore function, and there is no literature that directly compares the two techniques in any standardized fashion. It is also important to consider that much of the literature on endoprosthesis use is in the treatment of tumor patients, who are a different population from failed shoulder arthroplasty patients. Tumor patients tend to be younger, more active, with a more rapid decline in function. Tumor cohorts also display more variability in soft tissue compromise as well as neurovascular status due to potential involvement of structures within the neoplasm, and many have undergone chemotherapy or radiation prior to surgery. Thus, direct comparison of techniques used in tumor and failed arthroplasty patients is challenging.

In the current literature, non-oncologic patients with severe PHBL have demonstrated significant improvements in functional outcomes and pain relief with endoprosthesis reconstruction. A retrospective review by Srinivasan *et al.* published in 2023 studied two-year outcomes of 44 patients who underwent implantation of an endoprosthesis for either failed shoulder arthroplasty or proximal humerus

fracture with severe PHBL (PHAROS Type 2 and Type 3) with an average follow-up of  $36.2 \pm 12.4$  months (20). These patients had a  $26^\circ$  increase in abduction ( $47^\circ$  pre-operatively to  $73^\circ$  post-operatively,  $P=0.006$ ) and a  $31^\circ$  increase in forward flexion ( $49^\circ$  pre-operatively to  $80^\circ$  post-operatively,  $P=0.003$ ) from pre-operative to last documented follow-up. Average daily pain improved by 2.0 points ( $P<0.001$ ). Average SST score improved from 2.5 to 6.0 ( $P<0.001$ ), average ASES score improved from 28.9 to 59.7 ( $P<0.001$ ), and average CS improved from 26.3 to 43.4 ( $P=0.030$ ). 71 patients were included in the analysis of complications and revision for endoprosthesis, with 27 additional patients not having adequate 2-year follow-up to be included in the functional outcome analysis. Overall, twenty complications were reported (28%), resulting in 9 revisions (12.7%). Nine (12.7%) dislocations occurred, all managed with closed reduction. Three patients (4.2%) experienced baseplate loosening, identified radiographically and managed conservatively due to lack of clinical symptoms. Other complications, each observed in only 1 patient (1.4%), included infection, cement extrusion into elbow, glenosphere dissociation, periprosthetic fracture, distal perforation of humerus, scapula fracture, coracoid fracture, and humeral cortex breach. Of note, no cases of early humeral component loosening were reported. This paper demonstrates consistent functional improvement in ROM and PROM data in a non-tumor patient cohort treated with endoprosthesis, though complication rates remain high.

In 2023, Denissen *et al.* published a systematic review and meta-analysis examining functional outcomes after reverse shoulder endoprosthesis in tumor patients (21). Nine studies were ultimately included in the qualitative analysis (22,32,44-50), and six studies were included in the meta-analysis (22,32,44-45,48,50). In total, 123 patients were analyzed across all studies. ROM data showed satisfactory function at 2-year follow-up, with an average of  $105^\circ$  forward flexion,  $105^\circ$  abduction, and  $26^\circ$  external rotation. Mean ASES score was 67 [95% confidence interval (CI): 48–86] and mean MSTS score was 78% (95% CI: 66–91%), which is comparable to APC results in Rampam *et al.* systematic review (MSTS range 57% to 90%) (14). Güven *et al.*'s retrospective evaluation of 10 patients with malignant proximal humerus tumors is highlighted in this paper, and notably at this study's last follow-up (18.2 months average, with a range of 6–27 months), no patients had local recurrence or signs of infection (22). Complication rates and revision rates were not included in the scope of this review.

In 2024, Labrum *et al.* reported on outcomes of modular segmental endoprosthesis for reverse shoulder arthroplasties in both tumor and failed arthroplasty populations with PHBL, including data on complication rates (23). They queried a joint registry database from a single institution for a single system modular RSA endoprosthesis. Between 2012 and 2022, 76 consecutive modular endoprostheses were implanted, and 53 patients had a minimum 1-year follow-up with a mean follow-up of 4.1 years. Oncologic resection was the indication for surgery in 15 patients (28.3%), and failed arthroplasty or proximal humerus fracture was the indication for 38 patients (71.7%). This cohort had a surgical complication rate of 41.5% with a revision rate of 26.4%. Complications included stem aseptic loosening (11.3%,  $n=6$ ), instability (15.1%,  $n=8$ ), periprosthetic fracture (5.7%,  $n=3$ ), infection (7.5%,  $n=4$ ), and glenoid aseptic loosening (1.9%,  $n=1$ ). In total, 26.4% of patients ( $n=14$ ) underwent revision due to one of the complications above. The authors found that the number of prior surgeries was a significant risk factor for revision with a hazard ratio of 1.78. The average time to complication was 1.54 years [standard deviation (SD) 1.8 years], with a bimodal distribution peaking in the first 6 months and again between one and two years. This study provides a more robust analysis of the complication rate associated with endoprosthesis. A modular endoprosthesis RSA is a reasonable salvage option for reconstruction in the setting of PHBL, but the high complication rates must be considered.

### Strengths and limitations

This review synthesizes current literature on PHBL classification systems and management options (Table 2). We included a wide range of study designs over an 11-year span with an emphasis on recent publications and systematic reviews to adequately describe current knowledge. As this is a rare problem, research is limited to primarily small cohort studies without any randomized control trials comparing outcomes based on APC graft type, APC fixation technique, or APC versus endoprosthesis complication and revision rates. Moreover, the two primary patient populations affected by PHBL are revision arthroplasty cohorts and tumor cohorts, each with a unique set of characteristics that make oncologic and non-oncologic patients difficult to compare. Future research should focus on functional outcomes and complications of these two groups separately and aim to compare the variables mentioned above in larger

**Table 2** Indications, advantages, and complications of PHBL reconstruction options

| Surgical considerations | Proximal humerus reconstruction options                                                                                                          |                                                                                                                                             |                                                                                                                             |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
|                         | Revision RSA without allograft                                                                                                                   | Allograft-prosthetic composite                                                                                                              | Endoprosthesis                                                                                                              |
| Indications             | PHAROS Type 1c, Type 1g, and some Type 2 defects<br><br>PHBL-SCORE Type A and Type B (PHBL <15%)                                                 | PHAROS Type 2 and Type 3 defects<br><br>PHBL-SCORE Type C (PHBL >15% but <40%)                                                              | PHAROS Type 2 and Type 3 defects<br><br>PHBL-SCORE Type C and D (PHBL >40%)                                                 |
| Advantages              | Most conservative option, maintenance of maximum amount of healthy native humeral bone stock, equivalent PROMs to revision patients without PHBL | Greater humeral implant support, restoration of native humeral length, soft tissue attachment sites for cuff and deltoid, acceptable PROMs  | Modularity allowing for restoration of length regardless of bone loss, metallic component does not resorb, acceptable PROMs |
| Complications           | Humeral-sided loosening, possibility of progression of PHBL, no data in patients with PHBL >4 cm                                                 | Prone to allograft resorption, graft-host nonunion, inconsistent functional outcomes and revision rates with high variability in literature | High risk for instability, inconsistent functional outcomes and revision rates with high variability in literature          |

PHAROS, Proximal Humeral Arthroplasty Revision Osseous in Sufficiency classification system; PHBL, Proximal Humeral Bone Loss; PHBL-SCORE, Proximal Humeral Bone Loss—Specific Classification for Optimal Reconstruction classification system; PROM, patient-reported outcome measure; RSA, reverse total shoulder arthroplasty.

and more homogenous populations, an effort that will require prospective, longitudinal study designs.

## Conclusions

PHBL is a rare but important problem in the setting of tumor resection and revision shoulder arthroplasty. While small cohort studies have reported successful outcomes with both APC and endoprosthesis for more substantial PHBL, systematic reviews have failed to demonstrate a clear benefit of one option over the other because of the small overall patient numbers and heterogeneity of the studies. Complication and reoperation rates can be high with both surgical options. Efforts to further understand this complex situation and the strengths and limitations of reconstruction options should utilize longitudinal study designs in more homogenous populations with separation of non-oncologic and oncologic patients. Furthermore, there is an absence in the literature of comparative studies evaluating APC and endoprosthesis outcomes and complications in prospective cohorts, an addition that would provide much-needed nuance to our evolving understanding of the advantages and disadvantages of both options. With a focus on standardized classification and evaluation of patients with PHBL, we can hope to refine the surgical techniques and indications for optimal patient outcomes with this challenging problem in

the future with larger studies and longer follow-up.

## Acknowledgments

None.

## Footnote

*Reporting Checklist:* The authors have completed the Narrative Review reporting checklist. Available at <https://aoj.amegroups.com/article/view/10.21037/aoj-24-70/rc>

*Peer Review File:* Available at <https://aoj.amegroups.com/article/view/10.21037/aoj-24-70/prf>

*Funding:* None.

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://aoj.amegroups.com/article/view/10.21037/aoj-24-70/coif>). E.T.R. is a committee member of American Academy of Orthopaedic Surgeons (AAOS) and the American Shoulder and Elbow Surgeons (ASES) Society. He is also on the editorial board of the *Journal of Shoulder and Elbow Surgery* (JSES), and he receives royalties, is a paid consultant and a paid presenter for Enovis. V.E. is a paid consultant and a paid presenter,

and receives royalties from Stryker. He has stock options in Atreon Orthopaedics and OrthoKinetic Track. He is a committee member of the ASES Society. He is also a paid consultant for Synthes and Tygon LLC. J.C.H. has stock in Lazurite and receives consulting fees from Enovis, Shoulder Innovations, and Stryker. The other authors have no conflicts of interest to declare.

**Ethical Statement:** The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/aoj-24-70

**Cite this article as:** Grobaty L, Entezari V, Ho JC, Ricchetti ET, Cogan CJ. Management of proximal humeral bone loss: a narrative review. *Ann Joint* 2025;10:30.