Imaging of Shoulder Arthroplasties

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OBJECTIVE. In this article, we review the preoperative imaging features used for planning shoulder arthroplasty as well as review the various shoulder arthroplasty component types, discussing the expected normal imaging features and specific complications to look for with each.

CONCLUSION. Given the increasing use of shoulder arthroplasty, it is important to understand the imaging features of the various shoulder arthroplasty complications.

Shoulder arthroplasty is the primary treatment of advanced gleno-humeral arthritis once conservative measures fail, can restore function to patients limited by chronic rotator cuff deficiency, and serves as a treatment option for severe proximal humeral fractures [1, 2]. Preoperative imaging of the bony and soft-tissue anatomy will be a primary determinant of the type of prosthesis that will be used. There are two main categories of prostheses that will be discussed: those that maintain the normal orientation of the ball-and-socket anatomy—here, referred to as anatomic arthroplasties—and those that reverse the ball-and-socket orientation, the reverse shoulder arthroplasties. To provide relevant information in our radiologic report for preoperative planning and on postoperative follow-up imaging, a thorough understanding of shoulder anatomy and expected postoperative appearances and potential complications is important.

Normal Anatomy and Preoperative Imaging

Preoperative imaging is undertaken to assess the degree to which normal soft-tissue and bone anatomy is altered to select the most appropriate surgical procedure for each patient to improve function and reduce pain. Anatomic abnormalities in the humerus, glenoid, and soft tissues affect a patient’s eligibility for various prostheses, which we will discuss.

For anatomic arthroplasties, the goal is to maintain normal humeral anatomy and rotator cuff function. The native humeral head has approximately 30–40° of retroversion in reference to the transapeicondylar axis at the elbow and has an inclination of approximately 130–140° in relationship to the humeral shaft [3]. The superior humeral head projects above the superior margin of the greater tuberosity approximately 5 mm [4] (Fig. 1A).

The native glenoid has an average of 1–4° inclination and between 2° antversion and –9° of retroversion [5, 6]. The glenoid may undergo eccentric erosion, often superiorly and posteriorly, from arthritis and altered mechanics from rotator cuff deficiency [7]. Glenoid retroversion requires surgical correction to prevent early prosthetic failure in both anatomic shoulder arthroplasties and reverse total shoulder arthroplasties (RTSAs). Therefore, a planning CT study is commonly performed to assess glenoid version, configuration, and available bone stock for placing a prosthesis. The glenoid version angle is measured between a reference line drawn from the superior medial scapular border to the center of the glenoid and a line tangent to the glenoid articular surface (Fig. 1C). Glenoid version is best assessed on 3D scapular reformatted images because positioning and scapular tilt can alter measurements more than 5° [8–10]. Available bone stock for surgical correction of glenoid version and placement of glenoid component stabilizing pegs or screws are also typically assessed on CT. Bone stock is reported as the depth of cancellous bone between the glenoid articular surface and the narrowing at the glenoid neck with measurements reported superiorly, centrally, and inferiorly [11, 12] (Fig. 1B). Evaluation of the integrity of

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the acromion process should also be made because it may undergo marked thinning, either from erosion by the humeral head from chronic rotator cuff tear and superior subluxation or from prior acromioplasty. This thinning can predispose to fracture in a patient undergoing a reverse shoulder arthroplasty, where the deltoid mechanism becomes the primary abductor of the shoulder applying increased stress to the acromion [2].

Preoperative soft-tissue assessment of shoulder musculature is most often performed with ultrasound (US) or MRI [13]. Patient suitability for an anatomic shoulder arthroplasty requires an intact or reparable rotator cuff. Reverse shoulder arthroplasty, used to treat irreparable rotator cuff tears causing pseudoparalysis, requires deltoid functionality at a minimum [2]. MRI with reformating of 3D isotropic sequences can create accurate “pseudo” CT images for assessment of bone stock (Fig. 1B) and glenoid version while simultaneously depicting the rotator cuff and deltoid, obviating the need for additional CT [14].

Anatomic Shoulder Arthroplasties

Humeral head resurfacing and stemless shoulder arthroplasty were developed to treat younger patients with primary humeral head abnormalities, such as avascular necrosis or focal humeral cartilage defects. Advantages include maintenance of maximal proximal humeral bone stock and facilitation of future revision operations [15]. Humeral resurfacing entails reaming of the humeral articular surface and placement of a press-fit metal-alloy cap that is stabilized by a short central peg. Resurfacing may be partial (reaming and placement of a press-fit metal-alloy cap that is stabilized by a short central peg). Reverse humeral arthroplasty, used to treat reparable rotator cuff tears causing pseudoparalysis, requires deltoid functionality at a minimum [2]. MRI with reformating of 3D isotropic sequences can create accurate “pseudo” CT images for assessment of bone stock (Fig. 1B) and glenoid version while simultaneously depicting the rotator cuff and deltoid, obviating the need for additional CT [14].

Normal Imaging of Humeral Components

Radiography is the primary imaging technique used to evaluate shoulder arthroplasties [18]. An immediate postoperative radiograph is obtained to exclude glenohumeral dislocation and periprosthetic fracture [19]. Follow-up imaging of two to four radiographs, including true anteroposterior (AP) or Grashey (obtained in 30–45° posterolateral oblique tangent to the glenohumeral joint) and axillary and scapular Y views, is typically performed at 3–6 weeks after surgery to serve as a baseline study to which all future studies should be compared [18].

The humeral head should be centered in relation to the glenoid. The humeral component should be flush against the bone without radiolucency surrounding the cap, central peg, or stem. On the immediate postoperative imaging, the humerus may be inferiorly subluxed due to deltoid muscle inhibition [20]. This should resolve on follow-up imaging to appear as a smooth arc between the medial humeral cortex, inferior glenoid, and scapular neck on the AP radiograph. The humeral stem is expected to be centered within and aligned with the humeral shaft [20]. The superior margin of the humeral head should project 2–5 mm above the top of the greater tuberosity when measured perpendicular to the humeral shaft [4]. For noncemented stemmed components, less than 0.6 mm of lucency is expected at the bone-prosthesis interface [4]. For cemented stemmed components, the cement should be evenly distributed around the prosthesis and there should be no radiolucency between the cement and prosthesis [4]. Radiolucency at the bone-cement interface should be less than 2 mm and remain stable after the first year of follow-up [21].

Humerar Component Complications

Loss of humeral height above the greater tuberosity is a clinically significant complication and indicates malpositioning or subsidence of the humeral component [4]. Subsidence, the progressive decrease in the height of the humeral component in relationship to the greater tuberosity, becomes clinically significant when greater than 5 mm [21]. Humeral head height below the greater tuberosity may produce painful subacromial impingement [22] (Fig. 3). Alternatively, excessive protrusion of the humeral head above the greater tuberosity can produce increased tension on the rotator cuff [20]. Both can lead to a rotator cuff tear. Mild superior humeral head migration over time is common after shoulder arthroplasty [23]. However, a narrowed humeral-acromial space of less than 7 mm or anterior decentering of the humeral head on the axillary view suggests a rotator cuff tear [4]. Although CT arthrography, MRI performed using a metal artifact reduction technique, and US have been reported to be viable techniques for rotator cuff tear evaluation after arthroplasty, metallic artifacts may interfere with tear visualization in all except US [13, 18, 24, 25].

Isolated humeral component loosening is relatively uncommon, accounting for 1.4% of all total shoulder arthroplasty complications [26]. Loosening should be suggested when radiolucent lines measuring greater than 0.5 mm are seen about a press-fit component or when lucency of 2 mm or greater is seen at the bone-cement interface in cemented components. Cement fracture or component migration also indicates loosening radiographically [21]. Aspiration and culture of glenohumeral joint fluid should be recommended to exclude infection when loosening is encountered [26]. After Staphylococcus species, Propionibacterium acnes is the next most frequently cultured organism, commonly colonizing the pilosebaceous glands of the chest and back [27]. The clinical signs of infection are often absent in the setting of P. acnes and laboratory inflammatory markers, such as erythrocyte sedimentation rate and C-reactive protein level, are often normal [27–29]. A request for extended culture monitoring for 14 days of aspirates of total shoulder arthroplasties is needed to improve detection because P. acnes is a slow-growing anaerobe [30].
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The most common long-term complication encountered in humeral hemiarthroplasty is glenoid erosion [31] (Fig. 2D). Imaging reveals progressive joint space narrowing and often deceleration of the humeral head from asymmetric glenoid erosion. The humeral stem component also changes stress distribution in the proximal humerus, resulting in humeral bone resorption around the proximal prosthesis termed “stress shielding” [4]. Radiographically, stress shielding is recognized as cortical thinning and increased porosity of the cortex [4] (Fig. 2D).

Anatomic Total Shoulder Arthroplasty

Total shoulder arthroplasty replaces both the glenoid and humeral articular surfaces. An intact rotator cuff is required to prevent joint instability, humeral head subluxation, and accelerated component wear and loosening. Because the humeral components have been addressed, a discussion of the key features of the glenoid component will follow.

Glenoid Component Design

Early efforts to improve glenoid component stability led to the development of metal-backed implants. These implants had a high failure rate, including screw breakage, component fracture, and polyethylene dissociation from the metal, and in general, the majority have been metal-backed implants [32, 33]. Thus, most glenoid implants in use today are composed entirely of radiolucent ultra-high-molecular-weight polyethylene. These implants may have a central polyethylene keel or two or more pegs fixed to the underlying cancellous bone with polymethylmethacrylate cement [34].

Eccentric Reaming, Augmented Glenoid, and Bone Graffing

Glenoid replacement in the setting of posterior glenoid bone loss and excessive retroversion is technically challenging and is characterized by higher complication and revision rates [35, 36]. Eccentric reaming of the anterior glenoid is commonly used to improve glenoid version before component implantation. However, overly aggressive reaming of defects with greater than 10°–15° of retroversion can substantially reduce the glenoid bone stock. If retroversion exceeds 15°, the surgeon will often consider alternatives to eccentric reaming, such as posterior glenoid bone grafting (autograft or allograft) or an augmented glenoid implant with thicker posterior wedge-shaped or step-cut polyethylene [36]. Short-term and early midterm results for augmented glenoid components have been promising, but more studies are required to determine the long-term viability [37–39]. Alternatively, bone grafting has shown an increase in complication rates of nonunion, graft resorption, and subsidence [36, 40].

Imaging

Normal appearance of the glenoid component—The glenoid component should be positioned perpendicular to the long axis of the scapula on the axillary view (i.e., ideally with no retroversion) and without superior or inferior angulation on the Grashey view [41–43] (Fig. 4A). Because the polyethylene components are radiolucent, the central keel or peg typically contains a linear radiopaque marker to allow radiographic confirmation of stable positioning of the glenoid component over time.

Radiolucency surrounding the glenoid component keel or pegs is a common finding [44, 45]. When incomplete and less than 1.5 mm in thickness, these radiolucent lines are nonspecific and do not necessarily indicate loosening [4]. The width and location of the radiolucent lines should be reported and evaluated for progression; classification systems are available for communicating the location and extent of radiolucent lines [46, 47].

Glenoid component loosening or failure—Glenoid component loosening accounts for 37% of all total shoulder arthroplasty complications and occurs more frequently than humeral component loosening [26]. Biomechanical factors contributing to eccentric edge-loading are associated with glenoid component failure. These factors include placement of the component in more than 10° retroversion and rotator cuff deficiency [26, 48]. Radiologic indicators of loosening include progressive radiolucent lines on serial radiographs; lucent lines greater than 1.5 mm (Figs. 5A and 5B); cement fragmentation; and component migration (Fig. 4B), subsidence, or tilt [49]. The loosening may lead to the development of particle disease and osteolysis adjacent to the components (Fig. 5). CT is more sensitive and reproducible than radiography at showing and characterizing radiolucent lines and the extent of osteolysis around a prosthesis [50]. CT is recommended when radiographic findings are negative but particle disease is suspected and for planning revision [51]. MRI examinations performed with metal artifact reduction techniques have resulted in improved visualization of the bone-prosthesis interface and potential areas of osteolysis around the components [25, 52]. When glenoid component loosening develops, similar to humeral component complications, aspiration and culture should be performed to exclude infection.

Reverse Total Shoulder Arthroplasty Indications

Paul Grammont designed the first RTSA in 1985 for patients with glenohumeral joint osteoarthritis with rotator cuff deficiency [53]. In patients with full-thickness rotator cuff tears, the unopposed deltoid contraction raises the humeral head instead of the normal motions of elevation and abduction. This painless phenomenon is termed “pseudoaplasia” [54]. Biomechanically, the RTSA medializes the center of rotation of the glenohumeral joint [55, 56], restoring deltoid tension for humeral elevation and abduction in these patients. This results in a significant improvement in the functional range of motion.

Over the past 3 decades, several other indications for RTSA have been added, including proximal humerus fracture, rheumatoid arthritis, tumor, osteonecrosis, and revisions of failed hemiarthroplasty and anatomic total shoulder arthroplasty [1, 57, 58].

Prosthesis Types

The Grammont semiconstrained design, now in version III (Delta III, DuPuy International), includes a glenosphere, which is a polished cobalt-chromium-molybdenum hemisphere-shaped ball connected to a metal baseplate called a “metaglene” [59]. The metaglene is fixed to the glenoid by a central press-fit peg and locking and nonlocking screws angled to resist shear forces. In patients with poor glenoid bone stock, graft material can be used to reinforce the glenoid component [12]. The metal humeral component is monoblock or modular and can be cemented or uncemented. It includes a small customizable polyethylene-lined cup oriented to a humeral neck-shaft angle of 155° [2].

Another category of prosthesis is a design with a lateralized center of rotation. The goal of lateralization is to decrease impaction of the humerus on the inferior scapula [60]. These models have lower neck-shaft angles of 145° (Equinoxe, Exactech) and 135° (RSP, DJI Global; SMR, LimaCorporate; comprehensive), in an attempt to decrease mechanical impingement of the humerus on the inferior scapula [59]. This design includes the reverse shoulder prosthesis (RSP, DJI Glob-
Scapular notching is a unique complication of RTSA. Biomechanically this complication is hypothesized to result from mechanical impingement of the superomedial aspect of the humeral component against the inferior scapular neck during arm adduction [62]. Scapular notching has been found to occur more often in RTSA with a medialized center of rotation than in RTSA with a lateralized center of rotation (44.9% vs 5.4%) [60], with reported rates of scapular notching in 50–66% of patients with RTSA with a medialized center of rotation during the first 2 postoperative years [68, 69].

On radiographs, bone resorption will be identified along the inferior margin of the scapula (Fig. 7). The Sirveaux classification is used to report notching [70, 71] (Fig. 7A). Grade 1 is limited to the pillar. Grade 2 notching contacts the lower metaglene screw. When notching extends over the entire inferior metaglene screw, it is grade 3. Involvement under the metaglene baseplate is classified as grade 4 notching. The significance is that grade 3 and 4 notching may require revision because of component loosening [70]. Additionally, notching may produce an adduction deficit that results in particle disease, which is radiographically apparent as osteolysis [59]. Although lateralization of the center of rotation significantly decreases notching, it results in a greater reported rate of metaglene loosening. This complication occurs because of increased torque and shear forces on the glenoid component [60, 72, 73]. Loosening will appear as progressive radiolucency or radiolucency greater than 2 mm surrounding the metaglene (Fig. 8). Additionally, the metaglene may no longer appear flush with the native glenoid.

Anterosuperior dislocation or instability is another unique but common complication of RTSA, occurring in up to 20–31% of patients [2, 12]. The dislocation is anterosuperior because of the unopposed deltoid contraction. The humerus will appear superior on AP and scapular Y radiographs and anterior on axillary radiographs (Fig. 9). Dislocation can occur perioperatively after an interscalene block and movement of the patient between beds with a sheet.

A final unique complication of RTSA is fracture of the acromion or scapular spine (Fig. 10). These fractures have a prevalence of 5–6.9% [57]. Type 1 fractures involve the anterior acromion near or including the coracoacromial ligament footprint. These fractures typically heal without surgical intervention [74]. Stress fractures that occur in the anterior acromion just posterior to the acromioclavicular joint are categorized as type 2. Type 3 fractures are located in the posterior acromion or scapula and biomechanically result from the stress of the superior baseplate screw [2].

Newer designs have decreased previous reports of metaglene migration and disassembly of components [12]. This complication may also occur rarely from incomplete seating of the glenosphere in the metaglene at the time of placement, warranting careful attention for flush contact between these components on initial postoperative imaging.

Similar to infection in total shoulder arthroplasty, infection in RTSA radiographically may appear normal or may appear as radiolucency, bone resorption, periostitis, and soft-tissue swelling. The most common bacteria are Staphylococcus species and P. acnes; detection of P. acnes infection requires extended laboratory culture for 14 days [27, 30].

Conclusion

An understanding of the preoperative imaging features and expected postoperative appearances of the various shoulder arthroplasty components is crucial in assisting the orthopedic surgeon with planning shoulder arthroplasty and early recognition of complications.

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**Fig. 1**—Shoulder measurements and alignment in 47-year-old man with shoulder pain. A, Radiograph, Grashey view, of humerus shows normal humeral head inclination (a) of 135° (normal, 120°–140°), humeral head height (b) of 6 mm (normal, 8 ± 3 mm), and normal humeral-acromial distance (c) (normal > 6 mm) with head centered on glenoid and smooth arc between medial cortex of humerus and neck of glenoid. B, Reformatted isotropic MR arthrogram, axial view, obtained from examination for evaluation of rotator cuff allows bone stock measurement (line) of central cancellous bone depth similar to how measurement is performed on CT.

(Fig. 1 continues on next page)
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Fig. 1 (continued)—Shoulder measurements and alignment in 47-year-old man with shoulder pain. C, Three-dimensional reconstructed CT image in craniocaudal projection shows 7° retroversion of glenoid (normal). Note that version appears neutral on prior axial image (B), where abduction and kyphosis can introduce 5–10° of error in version measurement. Long line denotes reference long axis of scapula from medial scapular border to center of glenoid, and short line denotes glenoid version measured fitting line tangent to glenoid articular surface.

Fig. 2—Radiographs, Grashey views, of variety of humeral components that are used for shoulder arthroplasty. A, 39-year-old woman with partial resurfacing hemiarthroplasty. B, 55-year-old man with total resurfacing hemiarthroplasty with press-fit cap covering entire humeral articular surface that is stabilized by short central peg. C, 60-year-old woman with stemless humeral component in total shoulder arthroplasty. Image shows metallic humeral head replacement connected to short, press-fit metaphyseal component with variable-shaped fins (arrow) paired with cemented polyethylene glenoid component (arrowheads). Line = radiopaque glenoid marker. D, 53-year-old man with press-fit stemmed hemiarthroplasty. There is mild concave erosion of glenoid centrally. Note cortical thinning and relative lucency in lateral proximal humeral metaphysis from stress shielding (arrows).
Fig. 3—78-year-old man with shoulder pain and decreased range of motion 6 years after left total shoulder arthroplasty with noncemented humeral component. Anteroposterior radiograph, Grashey view, shows subsidence of humeral component, superior margin of humeral component 7 mm below superior margin of greater tuberosity (dashed line), and concave remodeled undersurface of acromion from subacromial impingement. Solid line = radiopaque glenoid marker.

Fig. 4—69-year-old man with total shoulder arthroplasty. A, Anteroposterior (AP) radiograph, Grashey view, shows incomplete radiolucent lines measuring less than 2 mm (small arrows) around inferior and central glenoid pegs. Radiolucency should be described but is nonspecific. Note radiopaque marker (line) in central peg is in appropriate perpendicular orientation to glenoid surface (large arrow). B, AP radiograph, Grashey view, obtained 1 year after A and onset of shoulder pain shows fractured glenoid component with displaced central peg (large arrow) and additional radiolucent polyethylene pegs surrounded by small mantle of cement (small arrows) in axillary recess of shoulder joint. Line = radiopaque glenoid marker.

Fig. 5—Loosening in keel versus pegged cemented glenoid components. A, Anteroposterior (AP) radiograph, Grashey view, of 60-year-old woman with shoulder pain shows total shoulder arthroplasty with loose keeled glenoid component (black arrows) indicated by complete radiolucency measuring greater than 2 mm around keel at bone-cement interface. Loosening has led to particle disease with osteolysis at proximal humeral metaphysis (white arrows). Note that humeral head has subsided below greater tuberosity. Lines = radiopaque markers. Inset shows illustration of radiolucent keeled component. (Drawing by Bernard SA) B, AP radiograph, Grashey view, of 59-year-old woman with painful total shoulder arthroplasty shows loose pegged glenoid component indicated by surrounding radiolucency at bone-cement interface measuring greater than 2 mm around all glenoid pegs (arrows). Line = radiopaque marker. Inset shows illustration of radiolucent pegged component. (Drawing by Bernard SA)
Fig. 6—Normal appearances of reverse total shoulder arthroplasty (RTSA). A and B, Grashey (A) and axial (B) radiographs of right shoulder of 66-year-old woman show RTSA consisting of glenosphere ball, metaglene baseplate, and radiolucent polyethylene liner between glenosphere and humeral component. Small amount of heterotopic ossification is noted inferior to medial humerus. C and D, Grashey radiographs of right shoulder of 65-year-old woman (C) and left shoulder of 58-year-old man (D). Grashey view of right shoulder of medialized RTSA shows smaller lateral humeral offset (LHO) than Grashey view of left shoulder with lateralized RTSA.
Fig. 7—Scapular notching with reverse total shoulder arthroplasty (RTSA).  
A, Illustration of Sirveaux classification. Grade 1 is limited to pillar. Grade 2 notching contacts lower metaglene screw. Grade 3 extends over entire lower metaglene screw. Grade 4 extends under metaglene baseplate. (Drawing by Petscavage-Thomas J)  
B and C, Grashey radiograph (B) and coronal CT image (C) of 61-year-old man with RTSA of left shoulder. Images show inferior scapular notching (arrows) that does not contact inferior screw. This is grade 1, limited to pillar.

Fig. 8—Loosening of reverse total shoulder arthroplasty (RTSA) in 72-year-old man. Grashey radiograph of RTSA shows radiolucency greater than 2 mm around humeral component bone-cement interface (white arrow) with valgus tilt and subsidence resulting in medial cortical endosteal erosion at tip. Note abnormal lucency between metaglene baseplate and glenoid as well as notching along inferior aspect of glenoid (black arrows).
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Fig. 9—Dislocation of reverse total shoulder arthroplasty in 55-year-old man. 
A, Radiograph, Grashey view, of right shoulder shows anterosuperior position of humerus in respect to glenoid. 
B, Radiograph, axial view, confirms anterior dislocation. Because of deficiency of rotator cuff, humeral head displaces in anterosuperior “escape” pattern.

Fig. 10—52-year-old man with reverse total shoulder arthroplasty and shoulder pain. Axial CT image in bone window settings shows healing fracture (arrow) through lateral scapular spine, which represents type 3 acromion stress fracture.

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