A Review Paper

# Variation in Neck-Shaft Angle: Influence in Prosthetic Design

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## Abstract

**Surgeons performing anatomical reconstruction of the shoulder during prosthetic replacement should consider the size of the humeral head and the placement of the head within the humerus. Prosthetic systems with a wide range of modular head sizes, eccentric tapers, and adjustable neck-shaft angles and versions help surgeons to better adapt a prosthesis to a patient's bone anatomy. Surgical technique remains critical for proper placement of the prosthesis and for correction of other soft-tissue and bony abnormalities associated with the pathology. In this article, we review some principles of prosthetic design and surgical technique to anatomically reconstruct the humeral head. We also review the clinical consequences of prosthetic humeral head malpositioning.**


The goals of unconstrained prosthetic replacement of the glenohumeral joint are to anatomically reconstruct the articular surfaces, to restore flexibility to the capsular constraints, and to repair or rehabilitate the rotator cuff, deltoid, and periscapular muscles so that normal, pain-free motion is restored. In some disease processes in which there is severe rotator cuff deficiency or bony deformity, current surgical techniques and devices cannot achieve these goals. When the pathology is amenable to anatomical reconstruction, the prosthetic components and surgical techniques should allow the surgeon to reproduce normal humeral anatomy.

Prosthesis designers have identified several important anatomical and biomechanical factors, including humeral head size and shape, humeral head offset, and humeral neck-shaft angle and version. These factors define placement of the humeral head in 3-dimensional (3-D) space. When the prosthetic head is placed in exactly the same 3-D space as the normal anatomical humeral head, then an anatomically correct reconstruction is achieved. Prosthetic design features help to achieve this goal. Significant deviation in anatomical reconstruction influences prosthetic performance and clinical outcome. In this article, we review the effects of these anatomical factors on prosthetic design.


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## Humeral Head: Its Size and Its Center of Rotation

Current prosthetic design assumes that the natural humeral head is a sphere and that its size is determined by its radius of curvature and thickness or neck length. There is wide variation in humeral head size.[1,2] The ratio of humeral head thickness to radius of curvature is remarkably constant (~0.7–0.9), regardless of patient height and humeral shaft size.[1,2] The humeral surface area available for contact with the glenoid is also directly proportional to the humeral head thickness and humeral head radius. Humeral head surface area is closely correlated with the size of the anterior–posterior and superior–inferior dimensions of the glenoid fossa; therefore, the relationship of the articular surface area of the humerus and the glenoid is relatively constant irrespective of humeral shaft length and patient height.[1-3]

The first goal of surgery is to select an anatomically sized humeral prosthetic head. The second goal is to place the humeral head in an anatomical position within the 3-D space originally occupied by the normal anatomical humeral head, thereby recreating the normal center of humeral rotation. Anatomical placement from a surgical perspective relates to recreation of the anatomical humeral head version and neck-shaft angle and of the anatomical medial–lateral and anterior–posterior offsets of the humeral head in relation to the longitudinal axis of the medullary canal. These anatomical relationships vary among patients; prosthetic design and surgical technique must be customizable in order to reproduce these variations or to compensate for differences between the native anatomy and the prosthetic anatomy. When this is successfully accomplished during surgery, the anatomical humeral head center of rotation is reproduced.

Intraoperative identification of the anatomical neck-shaft angle, anatomical humeral head version, and anatomical head size requires meeting 4 surgical goals:

1. Meticulous and complete removal of all osteophytes from around the entire humeral head.
2. Direct visualization of the entire superior and posterior rotator cuff insertion on the superior and posterior portions of the greater tuberosity—which will allow visualization of the bare area of the humeral head posteriorly.

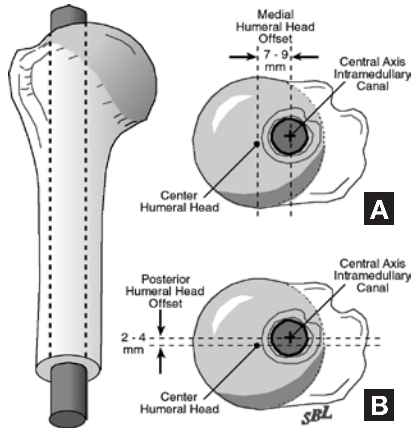


**Figure 1.** **(A)** In the coronal plane, the humeral head offset is approximately 7 to 9mm medial to the central axis of the intramedullary canal. **(B)** In the axial plane, the humeral head offset is 2 to 4mm posterior to the central axis of the intramedullary canal. Illustrator, Steven B. Lippitt, MD.

3. When the first 2 goals are met, then the osteotomy begins superiorly at the insertion of the supraspinatus tendon and ends inferiorly at the articular margin, thereby defining the anatomical neck-shaft angle. Anteriorly, the osteotomy starts at the anatomical neck and exists in the middle of the bare area posteriorly, thereby defining anatomical humeral head version. When these landmarks are visualized correctly and used for the humeral head resection, then this osteotomy can be made without a cutting guide. When this method is used, the location of the humeral osteotomy is independent of the location of the humeral shaft, and an intramedullary cutting guide is not required or desired. When this method of humeral osteotomy is used, then a humeral prosthesis allows for variation in the orientation of the humeral head with respect to the location of the stem. In this circumstance, a press-fit stem can be inserted in its proper location within the humeral canal, and the humeral head can be independently placed on the osteotomy surface. This feature of humeral prosthetic design and adjustability is a feature of third-generation prostheses.
4. Humeral head size is determined first by selecting a head size that covers the humeral osteotomy surface completely, without any overhang. When a prosthetic system is designed to respect the general relationship of humeral radius and thickness, then only a few head sizes will satisfy this criterion. Final selection of head size, within this limited set of components, involves other criteria, including preoperative templating, intraoperative comparison of the size of the resected head with that of the prosthetic head, and trial reduction with evaluation of motion, stability, and tissue tension.

## Humeral Head Offset and Center of Rotation

The center of the humeral head does not coincide with the projected center of the humeral shaft.[4] In other words, the point that represents the center of the humeral head does not lie on the line projected proximally into the humeral metaphysis from the central axis of the intramedullary canal of the humeral diaphysis.[2,4-7] The distance between the center of the humeral head and the central axis of the intramedullary canal is defined as the humeral head offset.[2,4,5,7] Although humeral head offset is defined in 3-D space, it is commonly described in 2 planes, coronal and axial. Like most other proximal humeral anatomical parameters, humeral head offsets vary.[2,4-7] In the coronal plane, the humeral head offset is approximately 7 to 9mm medial to the central axis of the intramedullary canal; in the axial plane, it is 2 to 4mm posterior to the central axis of the intramedullary canal (Figure 1).[2,4,5,7]

Humeral head offset is correlated with humeral head radius and humeral head thickness.[2] However, for a given humeral head size and a given humeral head offset, the location of the humeral articular surface can vary with respect to humeral retroversion and head to greater tuberosity height. Humeral retroversion averages 20° to 30°, and the range is wide (20°–55°).[2,4,7,8] The vertical distance between the highest point of the humeral articular surface and the highest point of the greater tuberosity is approximately 8mm (range, 2–12mm).[1,2]

Ideally, the prosthetic humeral head should be placed in the center of the cut surface of the humeral metaphysis. As the center of the natural humeral head does not coincide with the central axis of the intramedullary canal of the humeral diaphysis, the prosthetic humeral head must also be offset with respect to the center line of the prosthetic stem. A properly positioned prosthetic humeral head can be achieved with a fixed-angle design when 3 criteria are met:

1. The prosthetic and anatomical humeral offsets are identical.
2. The humeral head osteotomy is made exactly along the anatomical neck (anatomically correct neck-shaft angle and version).
3. The prosthetic head size also corresponds exactly to the natural anatomy.

When these criteria are satisfied, the center of the stem taper, using a fixed-angle prosthetic, is in the center of the osteotomy surface, and the centered humeral head taper is ideally suited to reproduce the humeral head center of rotation. When these criteria are not met, which happens for many patients, then an eccentric humeral head taper helps correct for a mismatch in the center of the stem taper and the center of the osteotomy surface. Not using an eccentric taper in this situation results in malpositioning of the prosthetic humeral head.

When an eccentric taper is not available or the amount of eccentric taper placement is insufficient to correct for the location of the stem in the canal, then humeral head malpositioning can also be corrected by undersizing the humeral stem and cementing within the intramedullary canal so that the humeral head is

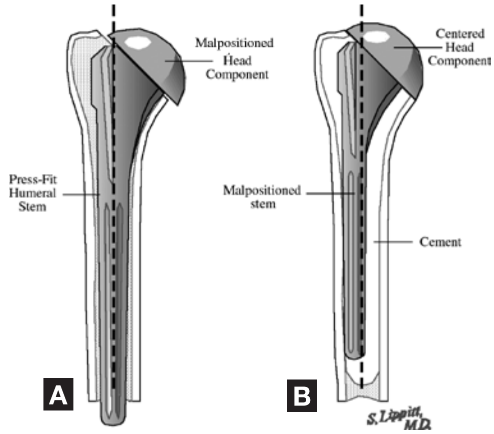


**Figure 2.** **(A)** In this example, the mismatch in the humeral head offset with a press-fit stem and centered head taper results in malpositioning of the humeral head component inferiorly. **(B)** The malpositioning is corrected by cementing an undersized humeral stem offline to the central axis of the intramedullary canal so that the humeral head component is centered on the cut surface of the metaphysis. Illustrator, Steven B. Lippitt, MD.

centered on the cut surface of the metaphysis. This action results in malpositioning of the humeral stem in relation to the central axis of the intramedullary canal (Figures 2A, 2B), which is preferable to humeral head malpositioning. With a press-fit, noncemented humeral stem that fills the intramedullary canal, an eccentric taper humeral head is required to avoid humeral head malpositioning (Figure 2B). When using a press-fit stem to perform an anatomical humeral head osteotomy, it is therefore necessary to reproduce anatomical neck-shaft angle and version, have a wider range of head sizes, and have the option to use an eccentric taper humeral head or a centered taper humeral head specified by the anatomical needs of the individual patient (Figures 3A, 3B). Prosthetic systems that allow for variations in neck-shaft angle and version with respect to stem position also allow for adapting the prosthetic anatomy to the patient's anatomy.

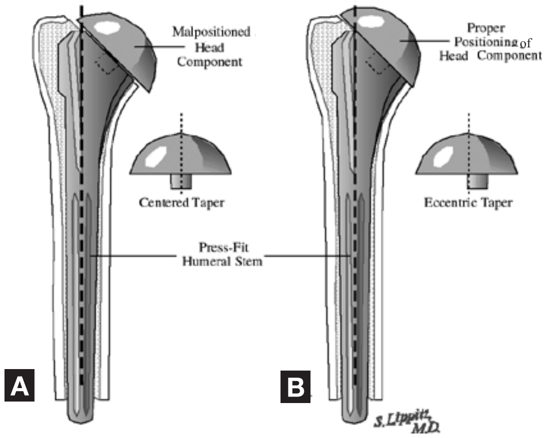


**Figure 3.** **(A)** The mismatch in the humeral head offset with a press-fit stem and centered head taper results in malpositioning of the humeral head component inferiorly. **(B)** In this case, an eccentric taper humeral head orients the humeral head superiorly and provides proper humeral head positioning. Illustrator, Steven B. Lippitt, MD.

## Humeral Neck-Shaft Angle and Center of Rotation

The neck-shaft angle is defined as the angle subtended by the central intramedullary axis of the humeral shaft and a line perpendicular to the base of the articular segment. Mean neck-shaft angle is 135° to 140°.[1,2,4,6] Most patients fall within this narrow range, but humeral neck-shaft angle demonstrates significant individual variation (range, 125°–150°).[1,2,4,6]

The relationship between prosthetic anatomical variability (ie, variable neck-shaft angle, variable humeral head offset, accuracy of humeral reconstruction with press-fit humeral stems) was highlighted by Pearl and colleagues,[9,10] who used a computerized optimization algorithm and cadaver anatomical data to show that the 4 press-fit humeral stems with fixed neck-shaft angles and the 1 medial–lateral offset per humeral head size, which were in common use at the time of their study, could not accurately reconstruct the humeral articular surface.[9] Specifically, despite optimized stem and head placement, the humeral head

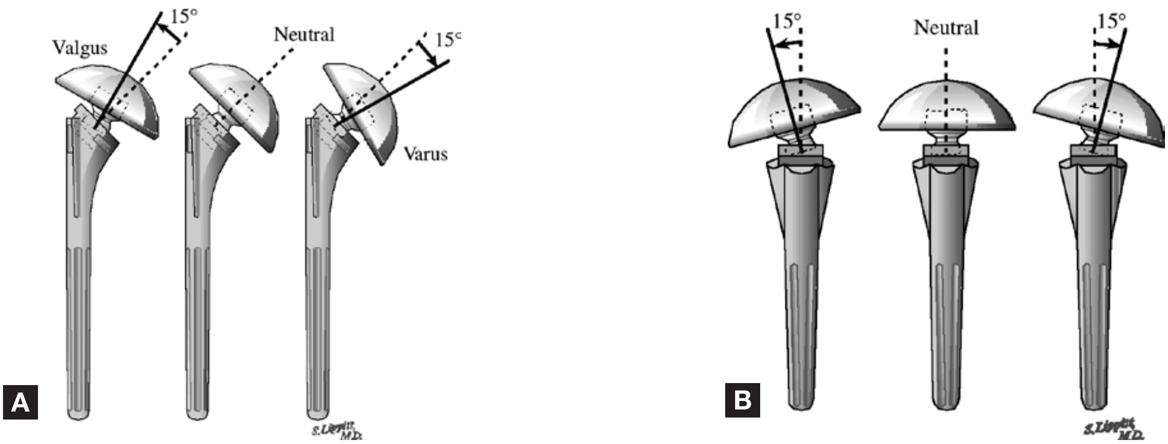


**Figure 4.** **(A)** The Global Adjustable Prosthetic™ (Global AP; DePuy Johnson & Johnson, Warsaw, Ind) allows varying orientation of the humeral head component, including up to 15° valgus or 15° varus from the standard neutral position on the stem. **(B)** The modular Global AP system allows for varying the orientation of the humeral head component, including up to 15° anterior or 15° posterior from the standard neutral position on the stem. Illustrator, Steven B. Lippitt, MD.

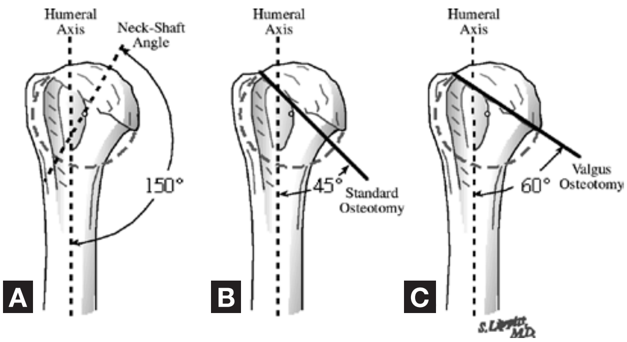


**Figure 5.** **(A)** Example of a 150° valgus humeral neck-shaft angle in a humerus with degenerative joint disease. **(B)** Standard humeral osteotomy outlined at 45° to the humeral axis irrespective of the valgus head. **(C)** Valgus humeral osteotomy outlined at 60° to the humeral axis corresponding to the humeral valgus anatomy. Illustrator, Steven B. Lippitt, MD.

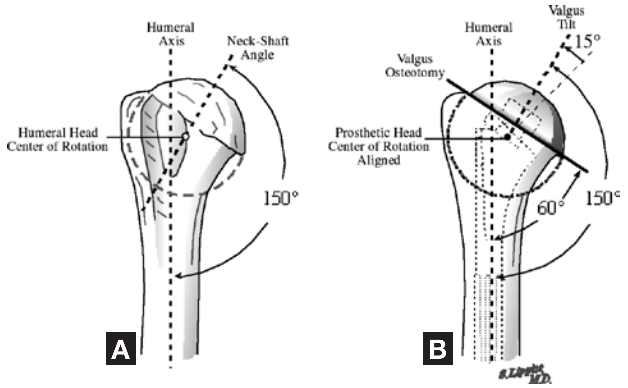


**Figure 7.** **(A)** Preoperative humeral head center of rotation is identified in the same humerus with the 150° valgus humeral neck-shaft angle. **(B)** The Global AP system is tilted in 15° valgus to orient with a 60° valgus humeral osteotomy. This results in concentric alignment of the center of rotation between the prosthetic head component and the original center of rotation of the valgus head. Illustrator, Steven B. Lippitt, MD.

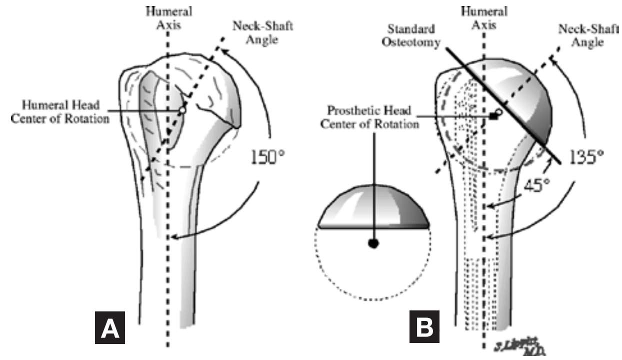


**Figure 6.** **(A)** Preoperative humeral head center of rotation is identified in this humerus with a 150° valgus humeral neck-shaft angle. **(B)** Standard humeral head replacement with a 45° humeral osteotomy results in movement of the prosthetic head center of rotation inferior and lateral, compared with the original center of rotation of the valgus head. Illustrator, Steven B. Lippitt, MD.

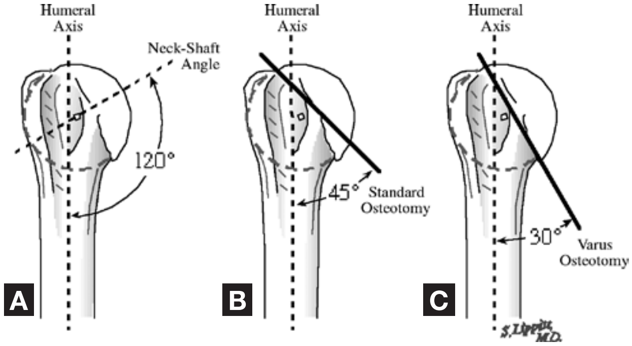


**Figure 8.** **(A)** Example of a 120° varus humeral neck-shaft angle in humerus with degenerative joint disease. **(B)** Standard humeral osteotomy outlined at 45° to the humeral axis irrespective of the varus head. **(C)** Varus humeral osteotomy at 30° to the humeral axis corresponding to the humeral varus anatomy. Illustrator, Steven B. Lippitt, MD.

center was displaced 14.7mm (range, 3.3–31.4mm) from its original position. Ameliorating this problem required using a smaller head size, which resulted in a 26° (range, 11°–41°) decrease in the humeral articular surface arc. The additional prosthetic design feature of variability in prosthetic neck-shaft angles and humeral head offsets resulted in a more accurate recreation of the humeral articular surface, with center of rotation displacement of 2.1mm and decrease in surface arc of 12°.[10]

The normal variability of the humeral neck-shaft angle creates some difficult choices with respect to prosthetic design. An implant system with only a fixed neck-shaft angle can result in an anatomical reconstruction of the articular surface only if its neck-shaft angle matches the neck-shaft angle of the natural humerus in which it is being implanted. Neck-shaft angle differences between the implant and the natural humerus cannot be corrected by changing humeral head thickness, radius, or offset without placing the articular surface of the head in a nonanatomical location or changing head volume.[2] If the neck-shaft angle of a fixed-angle implant is less than that of the natural humerus, then a varus osteotomy is produced in relation to the anatomical head. The position of the prosthetic humeral head is then too low on the humeral metaphysis, and the greater tuberosity is too high compared with normal anatomy. When the prosthetic neck-shaft angle is larger than the natural humerus, a valgus osteotomy is produced in relation to the anatomical neck-shaft angle, resulting in an articular surface that is superior and lateral to the anatomical location of the native humeral head. The joint volume contains the volume of the prosthetic head and the volume of the remaining natural head, resulting in overstuffing of the joint and loss of motion. This problem cannot be avoided by decreasing the humeral head size without also decreasing the articular surface area.[2]

The ability to vary humeral neck-shaft angle has been incorporated into a few modern shoulder prosthetic systems. The Global Adjustable Prosthetic™ (Global AP;

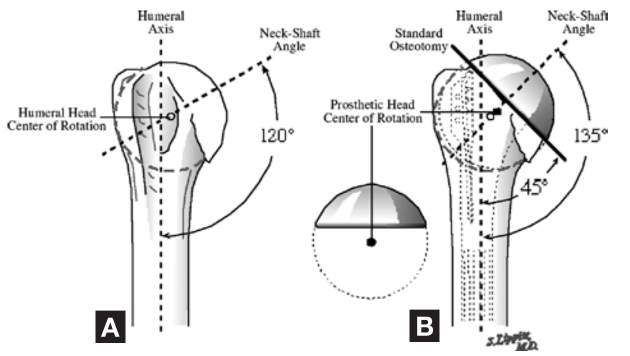


**Figure 9.** **(A)** Preoperative humeral head center of rotation is identified in this humerus with a 120° varus humeral neck-shaft angle. **(B)** Standard humeral head replacement with a 45° humeral osteotomy results in movement of the prosthetic head center of rotation superior and medial, compared with the original center of rotation of the varus head. Illustrator, Steven B. Lippitt, MD.

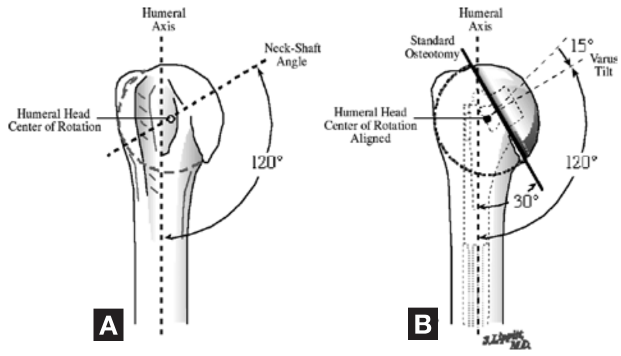


**Figure 10.** **(A)** Preoperative humeral head center of rotation is again identified in the same humerus with a 120° varus humeral neck-shaft angle. **(B)** The Global AP system is tilted in 15° varus to orient with a 30° varus humeral osteotomy. This results in concentric alignment of the prosthetic head center of rotation, compared with the original center of rotation of the varus head. Illustrator, Steven B. Lippitt, MD.

DePuy Johnson & Johnson, Warsaw, Ind) is the newest system to offer variability in neck-shaft angle and humeral version. The Global AP also offers a simple fixed-angle design of 135° for the majority of patients who fall within this mean neck-shaft angle. Both the variable-angle and the fixed-angle designs are offered for both centered and eccentric prosthetic heads. The variable ball taper design of the Global AP allows for infinite variability within a range of 30° of neck-shaft angle (150°–120°) and 30° of version (Figures 4A, 4B). Significant deviation in the humeral center of rotation occurs when a fixed-angle prosthetic device is used to enforce a 135° neck-shaft angle when a patient has a 150° valgus neck-shaft angle (Figures 5, 6). An osteotomy with the correct valgus neck-shaft angle reproduces an anatomical center of rotation (Figure 7). Similarly, when a patient has a 120° varus neck-shaft angle, and a fixed-angle 135° neck-shaft angle device is used, the center of rotation is not reproduced (Figures 8, 9). When prosthetic neck-shaft angle variability is available, then anatomical center of rotation is also reproduced (Figure 10).

In most cases, the humeral neck-shaft angle is 135°, and a fixed-angle neck-shaft prosthetic design allows for reproduction of the humeral center of rotation with a simple and more cost-effective prosthetic solution.

Other prosthetic systems allow for adjustable head position for both version and neck-shaft angle (Anatomica; Zimmer, Inc., Warsaw, Ind) or 4 options of fixed neck-shaft angle (Aequalis; Tornier, Inc., Warsaw, Ind).

The goal of shoulder arthroplasty is to center the humeral head within the space of the osteotomy surface (Figure 8A). The consequences of nonanatomical placement of the humeral head within the 3-D space of the original anatomical humeral head can result in several functional problems. When the prosthetic humeral head is malpositioned anteriorly on the humeral metaphysis, the edge of the implant overhangs the anterior cortex of the humeral metaphysis, which could produce excessive tension on the subscapularis repair and result in poor healing of the subscapularis or loss of external rotation. In addition, the anteriorly displaced humeral head anteriorly displaces the humeral center of rotation, leaving the posterior portion of the metaphysis uncovered. When the humerus is placed in abduction and external rotation, at the extreme of motion, this uncovered humeral metaphysis may impinge against the posterosuperior glenoid and interfere with smooth humeral head motion or may damage the glenoid component as a result of internal glenoid impingement.[3] Inferior malpositioning of the humeral head results in decreased or reversed distance between the greater tuberosity and the humeral head. When the humeral head is then centered within the glenoid, the greater tuberosity can impinge against the acromion or coracoacromial ligament. The degree of humeral head malpositioning that alters humeral kinematics or clinical outcome has been studied. In a cadaver study by Williams and colleagues,[11] as little as 4mm of inferior displacement of the humeral head resulted in abnormal subacromial contact. In addition, articular malpositioning of 4mm in any direction resulted in small changes in range of motion and translation of the humeral head during both active and passive joint positioning. Williams and colleagues recommended reconstructing the humeral articular surface to within 4mm of the native humerus to minimize subacromial contact and maximize range of motion.

## Summary

Glenohumeral component design should be based on the known anatomical and biomechanical relationships of the normal shoulder. The goal of prosthetic reconstruction of the glenohumeral joint should continue to be anatomical reconstruction of the articular surfaces with restoration of normal glenohumeral kinematics. Reconstruction of the anatomical center of the humeral head first requires selecting an anatomically sized prosthetic head and then placing it correctly within the 3-D space with respect to the other anatomical landmarks of the humerus. Anatomical placement is related to humeral head size, humeral offsets, humeral version, and neck-shaft angle.

Given the severe soft-tissue and occasional osseous abnormalities found in patients with glenohumeral arthritis, these goals may not be achievable in all cases. However, as long as bone-stock and soft-tissue quality are adequate, prosthetic designs that most closely mimic normal anatomy and allow the most intraoperative flexibility with regard to prosthetic sizing and placement are likely to improve chances of achieving these goals. The important features of most current anatomical implant systems are modularity between stem and humeral head, anatomically sized humeral heads with offset capabilities, and options for variability in neck-shaft angle and humeral version. However, it should be remembered that shoulder replacement is and always will be a technique-dependent procedure. These techniques are surgeon-dependent, related to surgical exposure and management of soft-tissue pathology. In addition, attention to the surgical details related to humeral preparation for humeral head resection and to preparation of the humeral stem within the neutral axis of the medullary canal is also important to the success of the surgery. No prosthetic implant design can substitute for good surgical technique.

## Authors' Disclosure Statement

All authors are consultants for DePuy Orthopaedics, Inc., and Drs. Williams and Iannotti receive a royalty payment for some of the DePuy shoulder prosthetics, including the one discussed in this article.

## References

1. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. *J Bone Joint Surg Am*. 1992;74:491-500.
2. Pearl ML, Volk AG. Coronal plane geometry of the proximal humerus relevant to prosthetic arthroplasty. *J Shoulder Elbow Surg*. 1996;5:320-326.
3. Jobe CM, Iannotti JP. Limits imposed on glenohumeral motion by joint geometry. *J Shoulder Elbow Surg*. 1995;4:281-285.
4. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. *J Bone Joint Surg Br*. 1997;79:857-865.
5. Ballmer FT, Sidles JA, Lippitt SB, Matsen FA III. Humeral head prosthetic arthroplasty: surgically relevant geometric considerations. *J Shoulder Elbow Surg*. 1993;2:296-304.
6. McPherson EJ, Friedman RJ, An YH, Chokesi R, Dooley RL. Anthropometric study of normal glenohumeral relationships. *J Shoulder Elbow Surg*. 1997;6:105-112.
7. Roberts SN, Foley AP, Swallow HM, Wallace WA, Coughlan DP. The geometry of the humeral head and the design of prostheses. *J Bone Joint Surg Br*. 1991;73:647-650.
8. Kronberg M, Brostrom LA, Soderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop*. 1990;253:113-117.
9. Pearl ML, Kurutz S. Geometric analysis of commonly used prosthetic systems for proximal humeral replacement. *J Bone Joint Surg Am.* 1999;81:660-671.
10. Pearl ML, Kurutz S, Robertson DD, et al. Geometric analysis of selected press fit prosthetic systems for proximal humeral replacement. *J Orthop Res.* 2002;20:192-197.
11. Williams GR Jr, Wong KL, Pepe MD, et al. The effect of articular malposition after total shoulder arthroplasty on glenohumeral translations, range of motion, and subacromial impingement. *J Shoulder Elbow Surg*. 2001;10:399-409.