J Shoulder Elbow Surg (2019) 28, 387–395

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Augmented glenoid implants in anatomic total shoulder arthroplasty: review of available implants and current literature

Mohammad Ghoraishian, MD[a], Joseph A. Abboud, MD[a], Anthony A. Romeo, MD[b], Gerald R. Williams, MD[a], Surena Namdari, MD, MSc[a,*]

[a]*Department of Orthopaedic Surgery, Rothman Institute–Thomas Jefferson University, Philadelphia, PA, USA*
[b]*Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL, USA*

Glenoid bone loss and retroversion increase the complexity of primary shoulder arthroplasty and affect the outcome. Although eccentric reaming, augmented glenoid implants, bone grafting, and reverse arthroplasty have been used to manage bone loss and retroversion, there is no consensus on treatment. Posteriorly augmented glenoid components can correct retroversion and avoid joint line medialization, which occurs with corrective reaming techniques. Full-wedged, half-wedged, and stepped polyethylene posteriorly augmented designs are currently available for use in the United States. The results of biomechanical and computer model studies support the use of augmented implants for the management of glenoid retroversion of greater than 15°. Currently, most clinical studies are retrospective case series. The short-term results of posteriorly augmented glenoid components are successful, with no clear evidence of the superiority of one design over another and unknown long-term survival rates.
Level of evidence: Level V; Narrative Review

Keywords: Augmented glenoid; glenoid deformity; anatomic arthroplasty; total shoulder arthroplasty; glenoid bone loss; eccentric wear

Total shoulder arthroplasty is a common procedure, and the number of primary and revision arthroplasties performed in the United States increases yearly.[6] The glenoid component is the cause of many late-term failures in anatomic total shoulder arthroplasty (aTSA).[23] Glenoid bone loss and retroversion increase the complexity of managing the glenoid in primary arthroplasty and have been associated with early glenoid loosening.[35,39] There are a variety of recommended methods to manage glenoid bone loss in primary aTSA; however, there are no clear evidence-based guidelines.[18]

Ideally, establishing optimal joint biomechanics with aTSA includes restoration of the axial alignment. Failure to restore the glenoid version to normative values may lead to premature loosening.[7,10,16,24,33] Placing the prosthetic glenoid component in excessive retroversion may result in posterior humeral head displacement and eccentric loading of the glenoid component.[3,5,21,27] Eccentric reaming, bone grafting, augmented prosthetic glenoids, and reverse arthroplasty may be used to manage posterior glenoid bone loss in shoulder arthroplasty.[22,28,30] Presently, the best option is unknown. Augmented glenoid components are a more recent innovation in

*Reprint requests: Surena Namdari, MD, MSc, Rothman Institute—Thomas Jefferson University, Shoulder & Elbow Surgery, 925 Chestnut St, Fifth Floor, Philadelphia, PA 19107, USA.
E-mail address: surena.namdari@rothmaninstitute.com (S. Namdari).

1058-2746/$ - see front matter © 2018 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2018.08.017

shoulder arthroplasty that aim to restore joint alignment and soft-tissue tension.

In this article, we review the glenoid morphology in shoulder arthritis, describe different augmented glenoid component designs, discuss the available biomechanical data, and consolidate the available clinical studies.

Management of posterior glenoid bone loss

Eccentric reaming

Eccentric reaming is the most commonly used technique for managing glenoid retroversion and eccentric bone loss. It restores glenoid version by reaming the remaining native anterior glenoid fossa ("paleoglenoid") to a single concentricity with the deformed glenoid fossa ("neoglenoid"). However, this technique may reduce the subchondral bone available for implant support, result in medialization of the joint line, and decrease the volume of the glenoid vault, especially in glenoids with significant retroversion. Medialization of the joint line can alter rotator cuff and posterior capsular tension, affect joint stability, and increase the risk of cortical perforation of the polyethylene (PE) implant peg or keel. In addition, reduction in subchondral bone support can increase the risk of implant loosening.[9,17,26,31,40]

Glenoid bone grafting

Glenoid bone grafting is an alternative to eccentric reaming. It improves bone stock and version without joint line medialization but is technically demanding and has been associated with graft nonunion, resorption, or collapse, especially when combined with glenoid component cement fixation. Nicholson et al[25] showed full graft incorporation on the postoperative radiographs in their series of 28 osteoarthritic patients who underwent aTSA. After a mean of 4 years' follow-up, they reported broken screws in 11% and displaced central peg markers in 11% of cases, but no cases went on to revision. Klika et al[19] reported a 25% rate of autograft resorption or non-incorporation after an 8-year follow-up of 25 aTSA cases. Other studies have reported similar percentages of periprosthetic radiolucencies and failure with glenoid bone grafting.[12-14,19,30,39]

Reverse total shoulder arthroplasty

Reverse total shoulder arthroplasty has shown considerable promise in the management of glenoid bone loss.[22] Despite the successful results, many studies have reported a higher rate of complications and greater limitation in shoulder motion compared with aTSA.[29,37] In addition, some arthritic patients with posterior glenoid bone loss and retroversion are young active patients and may not be optimal candidates for reverse arthroplasty.

Glenoid morphology classification

Walch et al[38] have proposed the most commonly used classification system for glenoid morphology in arthritis. It is based on the pattern of glenoid wear by reviewing axial computed tomography (CT) scans of arthritic joints. In the Walch classification, type A glenoids have a well-centered humeral head and either minor (type A1) or major (type A2) central erosion. Type B glenoids have posterior subluxation of the humeral head and either narrowing of the posterior joint space (type B1) or asymmetrical loading of the posterior glenoid resulting in biconcave morphology (type B2). Type C glenoids are hypoplastic with retroversion of more than 25°.[38] A modification of the Walch classification has been reported.[2] This modification addresses glenoid morphologies not described in the original classification and has higher interobserver and intraobserver reliability. In this modification, the type B3 glenoid is defined as monoconcave and posteriorly worn, with at least 15° of retroversion or at least 70% posterior humeral head subluxation, and the type D glenoid is one with any level of glenoid anteversion or with humeral head subluxation of less than 40% (anterior subluxation). The definitions of the type A2 and type C glenoids were also updated in the modified classification. In the type A2 glenoid, a line drawn from the anterior rim to posterior rim of the native glenoid transects the humeral head. The new definition of the type C glenoid is a dysplastic glenoid with at least 25° of retroversion "not caused by erosion." The type C2 glenoid has also been described most recently and is a dysplastic glenoid with high pathologic retroversion, high premorbid version, and acquired posterior bone loss, giving it the appearance of a biconcave glenoid with posterior translation of the humeral head[15] (Fig. 1).

Augmented glenoid designs

Glenoid augmentations can be monoblock (built into the implant) or modular (separate attachable wedge). Augmentations are made of PE or metal. Biomechanical and clinical studies have raised concerns regarding the use of metal augmentations. In a cadaveric model of type B2 glenoids, Kirane et al[18] have shown increased anterior compressive and posterior tensile strains by loading a titanium stepped implant compared with a PE stepped implant. This finding may be partly explained by the differences in the modulus of elasticity between titanium, PE, and bone. Cil et al[4] reported that the 10-year survival rate of posteriorly augmented metal-backed glenoid components was 31%. Although a short-term follow-up of an ingrowth metal augmentation has shown good results without any complications or revisions, long-term follow-ups are needed to better evaluate the safety and efficacy.[32] Currently, there are no metal augmentations for anatomic glenoid components available for clinical use in the United States; therefore, this review will focus on PE designs.

Augmented PE glenoid components have differing backside designs. There are currently 3 different designs

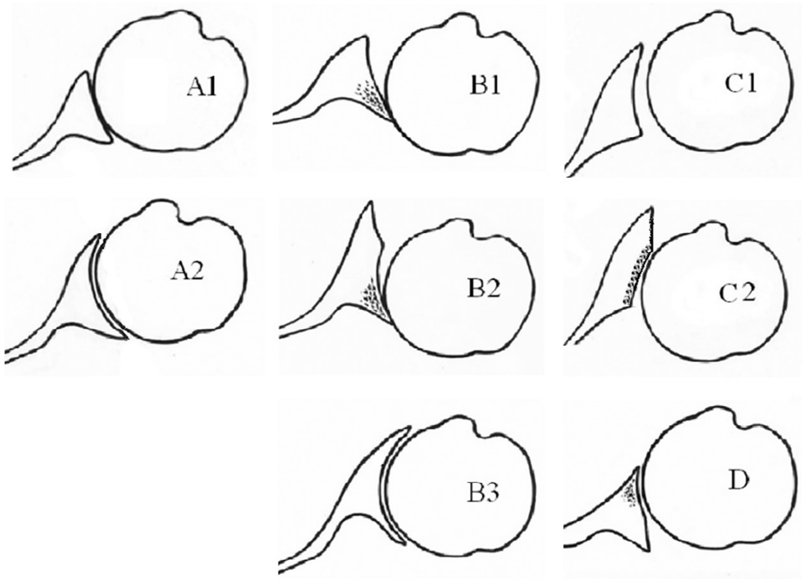

Figure 1 Modified Walch classification. (Reprinted with permission from Bercik MJ et al.[2])

commercially available for use in the United States. “Full-wedged” augmented components have a complete wedge built in the implant from anterior to posterior. Full-wedged implants are available in an all-PE design and a hybrid design with an ingrowth metal “cage.” These glenoid components have an 8°, 12°, or 16° full-wedged posterior augmentation (Equinoxe; Exactech, Gainesville, FL, USA). “Half-wedged” implants have a wedge that starts halfway on the posterior surface of the implant. The commercially available design has 15°, 25°, and 35° half wedges that correct 7°, 12°, and 17° of retroversion, respectively (Aequalis Perform+; Wright Medical Group, Memphis, TN, USA). “Stepped” implants have a built-in stepped surface that contacts the prepared bone perpendicular to the vector of joint loading. In the Global StepTech anchor peg glenoid component (DePuy Synthes, Warsaw, IN, USA), there are 3 step sizes, +3 mm, +5 mm, and +7 mm, that correspond to about 10°, 15°, and 20° of retroversion correction, respectively.

Simulation or finite element analysis studies

Augmentation versus eccentric reaming

On the basis of these studies, augmented components may not be necessary when retroversion is less than 15°, with the surgeon instead using the traditional technique of eccentric reaming to make corrections of less than 10°. In a finite element analysis, Hermida et al[11] showed that stresses in the implant, cement, and glenoid bone are lower when a full-wedged component is used instead of eccentric reaming for a 15° or 17° retroverted, monoconcave (type B3) glenoid. Similarly, Sabesan et al[31] performed a surgical simulation study of 29 different (type B2 and C) glenoids with acquired bone loss and retroversion (mean retroversion, 20.9°). This study showed less medialization and better correction of the joint center of rotation with a stepped augmented component than with eccentric reaming. The results supported using stepped augmented implants for retroversion of more than 16°.[31]

Comparison of different augmented designs

Knowles et al[20] evaluated full-wedged, half-wedged, and stepped augmented implants for the management of type B2 glenoids by virtual implantation. The models were created by 3-dimensional CT scans of 16 patients. The half-wedged implant removed less bone, and the remaining supporting bone had better density. The authors proposed that the appropriate design to minimize the amount of bone removal may be different based on preoperative glenoid morphology. They suggested using 3-dimensional CT scans to determine the appropriate implant. However, in their study, 50% of the glenoids had a neo-version angle of 30° or more. To correct to 0° of version (also clinically debatable), +7-mm stepped prosthetic components (5 of 16 glenoids) were used. Because of the amount of bone removal required during preparation, +7-mm stepped glenoids are less frequently used. Another study on full-wedged and stepped augmented implants showed full-wedged implants to be more bone preserving than stepped components in 10 arthritic type B2 glenoids with mean retroversion of 21° ± 6°.[17] Moreover, Allred et al[1] compared full-wedged implants, stepped implants, and eccentric reaming in a finite element analysis of 3 different models of type B2 glenoids (8°, 13°, and 17° of retroversion). They reported a lower amount of bone removal, lower amount of bone under significant stress, and higher percentage of cortical support in full-wedged components compared with stepped implants and eccentric reaming. The differences between the full-wedged and stepped implants were not statistically significant.[1] On the basis of the available data, it appears that half-wedged and full-wedged implants remove less bone compared with stepped components when used for type B2 glenoids. Future studies should consider normalizing the results with the optimal correction angle and in different patterns of bone loss to give a better idea of the volume of bone removed in each design and for each bone loss pattern. In addition, it remains unclear whether these relatively small differences impact the technical challenges at the time of surgery, the clinical outcomes, and the overall longevity of the implants.

Biomechanical studies

Augmentation versus eccentric reaming

Some biomechanical studies of glenoids with up to 15° of retroversion have reported advantages to eccentric reaming over the use of augmented implants. These studies recommended using eccentric reaming for the correction of retroversion as long as reaming does not violate the subchondral bone. Wang et al[41] compared the use of a full-wedged component with eccentric reaming. Defects were created that resulted in 12° of retroversion in 12 composite scapular models. Implant edge displacement and load were measured. If the extent of glenoid component subsidence into the bone resulted in loosening or destruction of the markers used for edge displacement measurement, this was defined as a failure. The authors showed that almost all of the premature implant failures had been managed by wedged components. More implants failed from the wedged augmentation, and even the implants that survived showed more edge displacement and loosening than the models managed by eccentric reaming. Wang et al raised the concern that the angled backside geometry of the wedged implant may convert axial load to shear stress at the implant-bone interface.

A biomechanical study by Sowa et al[34] assessed glenoid component stability in a type B2 model with 15° of glenoid retroversion. They analyzed 3 different methods of treatment: no retroversion correction with standard implant (Aequalis Perform, size M40), eccentric reaming with standard implant, and half-wedged implant with 15° of posterior augmentation (Aequalis Perform+, size L40). Five artificial scapulae in each group were loaded with physiological shoulder forces. Significantly more micromotion was shown in the first group (standard component implanted in retroversion) at 2000 cycles. Moreover, subluxation of the prosthetic head was noted only in this group. At 10,000 cycles, higher micromotion was noted in the half-wedged implant group compared with the eccentric reaming group ($P < .0001$). The authors recommended glenoid augmentation as a viable option in the management of cases with at least 15° of glenoid retroversion and eccentric wear.

Comparison of different augmented designs

A formal biomechanical comparison of the 3 commercially available augmented glenoid designs has not been performed. Iannotti et al[16] performed a biomechanical study in which glenoid components were implanted on custom-made blocks. They compared a stepped implant with 4 other glenoid designs: 3 full-wedged implants with different backside configurations (flat, symmetrical spherical, and asymmetrical spherical) and a standard anchor peg implant. They showed the least posterior component liftoff when the stepped implant was used and suggested that the stepped implant would be more likely to maintain long-term fixation in vivo compared with the other tested augmentations. Accordingly, Kirane et al[18] reported similar periglenoid strains when comparing a stepped implant used in the setting of a 20° retroverted type B2 glenoid (10 specimens) and a standard component used in the setting of a normal glenoid (5 specimens).

Clinical data

Most clinical studies on augmented implants are case series, typically reported by the designers or consultants associated with the specific implant. Limited studies to date have compared the results of posteriorly augmented glenoid components with other methods of managing glenoid retroversion and bone loss, such as eccentric reaming, bone grafting, and reverse total shoulder arthroplasty. Similarly, no study to date has compared the results of the different commercially available augmented designs. With studies with low levels of evidence, small numbers of patients, and short-term follow-up periods, the theoretically superior results of these advanced designs including stepped implants and wedged implants in comparison with traditional methods of eccentric reaming have not been shown.

Full-wedged design

Wright et al[42] evaluated 24 patients with osteoarthritis and posterior glenoid wear managed with a full-wedged augmented glenoid (Equinoxe) with a minimum of 2 years' follow-up. The patients in the augmented group were matched with a control group of patients treated with nonaugmented glenoids for osteoarthritis without posterior glenoid wear. All patients showed significant improvements in pain and function after treatment. There were no statistical differences between the augmented and nonaugmented groups regarding improvement or postoperative clinical outcomes. A radiolucent line was present in 60% of the augmented group compared with 33.3% of nonaugmented patients. One glenoid met the radiographic criteria for loosening in the augmented group. There were no posterior subluxations. No complications or revisions were reported. The authors concluded that augmentation can be considered for active patients with a healthy and intact rotator cuff and glenoid retroversion of 25° or less.

Stepped implant design

Three studies have reported clinical results of stepped implant designs for the management of retroversion and posterior glenoid bone loss. Stephens et al[36] reported on 21 patients treated with a stepped implant (Global StepTech) for osteoarthritis with glenoid retroversion (average, 20.8°) and posterior bone loss (type B2 in 19 and type C in 2) at a minimum of 2 years' follow-up (mean, 35 months). They found significant improvement in range of motion, visual analog scale pain scores, and functional scores. Significant improvements were noted for glenoid retroversion (11.8°), humeral scapular alignment, and humeral glenoid alignment. Radiolucencies surrounding the glenoid were found in 5 patients (24%), with grade 1 in 4 patients and grade 2 in 1. They were all incomplete and had not progressed. Evidence of bone ingrowth into the flanges of the central peg was seen in 95.2% of implants. No loosening, complications, or revisions were reported. Favorito et al[8] performed a retrospective review of 22 shoulders

Table I Simulation or finite element analysis studies

Author, year	Type of glenoid	Type of implant	Result	*P* value
Knowles et al,[20] 2015	Type B2: 16 cases	Full wedged Half wedged Stepped	Half-wedged implant removed less bone Higher remaining bone density in half-wedged implant compared with stepped	<.001 .048
Kersten et al,[17] 2015	Type B2: 10 cases Mean version: 21° ± 6°	Full wedged Stepped Standard	Least bone removed by full-wedged implant More back surface supported by cortical bone in full-wedged implant	<.001 .01
Sabesan et al,[31] 2014	Types B and C: 29 cases Mean version: 21° ± 10°	Stepped Standard	Less medialization in stepped implant	<.001
Hermida et al,[11] 2014	Type B2: 2 models Version: 15° or 17°	Full wedged Standard with eccentric reaming Standard in retroversion	Lower stress in full-wedged implant cement mantle compared with eccentric reaming Volume of cement likely to survive 10 million cycles highest in full-wedged implant	— —
Allred et al,[1] 2016	Type B2: 3 models Version: 8°, 13°, or 17°	Full wedged Stepped Standard (eccentric reaming)	Least cortical bone removed in full-wedged implant and most in standard implant Highest percentage of cortical bone support in full-wedged implant and lowest in standard implant Highest volume of bone under significant strain in implant with eccentric reaming and lowest in full-wedged implant	.055 .009 <.001

Table II Biomechanical studies

Author, year	Type of glenoid	Type of implant	Result	*P* value
Kirane et al,[18] 2012	Type B2: 10 type B2 glenoids with 20° defect and 5 normal glenoids	Stepped (modular): polyethylene and titanium Standard	Strains were same in stepped implant in B2 glenoid compared with standard implant in normal glenoid	—
Iannotti et al,[16] 2013	Custom-made blocks	Stepped Full wedged with 3 different backside shapes Standard	Lower liftoff in stepped	<.05
Wang et al,[41] 2015	Type B2: 12 composite scapulae with 12° defects	Full wedged Standard (eccentric reaming)	Lower implant edge displacement by superior and inferior edge loading in eccentric reaming Higher survival in eccentric reaming	.025; .009
Sowa et al,[34] 2018	Type B2: 15 artificial bones with 15° of retroversion	Half wedged (15°, keel) Standard with eccentric reaming and keel Standard in retroversion	Most micromotion at 2000 cycles and subluxation in retroverted group Higher micromotion at 10,000 cycles in half-wedged implant compared with eccentric reaming	<.0001 <.0001

Table III Clinical studies

Author, year	Type of glenoid	Implant	Mean age, yr	Follow-up, mo	Cases or controls	Complications	Revisions	Radiographic lucency	Radiographic loosening	Component full seating (grade A)	Other
Wright et al,[42] 2015	Case: posterior wear Control: without wear	Full wedged (Equinoxe) with 8° or 16° of correction Standard	66	30 (22-38)	24 cases 24 controls	None	None	Cases: 60%; score, 1.1 Controls: 33%; score, 0.43	1 patient in case group	—	No difference in outcome between cases and controls
Stephens et al,[36] 2017	Type B2: 19 Type C: 2	Stepped (StepTech) Size 3+ mm (5°): 7 Size 5+ mm (10°): 14	66	35 (24-41)	21	None	None	Grade 1: 4 Grade 2: 1	None	90%	Central peg: bone ingrowth in 95% and osteolysis in 1 case
Favorito et al,[8] 2016	Type B2: 20 Type C: 2 Version: 23.5° (16°-37°)	Stepped (StepTech)	62	36 (26-46)	22 (2 did not have follow-up)	2: anterior dislocation (revised with larger head); posterior dislocation (reverse TSA)	2	Grade 1: 8 Grade 2: 1 Score: 0.53	None	100%	Central peg: bone ingrowth in 63% and osteolysis in 1 case
Youderian et al,[43] 2012	Posterior deficiency	Stepped (StepTech)	—	Up to 15 mo (minimum of 6 mo in 18)	24	2: subscapularis failure, glenoid component failure (revised)	1	Grade 0 or 1: 58% Grade 2: 29% Grade 3: 13%	1	96%	—

TSA, total shoulder arthroplasty.

with posterior glenoid bone loss and retroversion of greater than 15° (mean, 23.5°; type B2 in 20 and type C in 2). The shoulders were treated with a stepped implant (Global StepTech Anchor Peg Glenoid). The authors reported significant improvements in visual analog scale pain scores, range of motion, and functional scores at a minimum of 2 years' follow-up (mean, 36 months). Central peg flange osseous integration was seen in 12 shoulders (63%), and only 1 showed osteolysis. Youderian et al[43] reported on the early results of 24 patients who underwent augmentation with a stepped component (Global StepTech Anchor Peg Glenoid) at a minimum of 6 months' follow-up. Significant improvement in clinical function and pain levels was noted in 94% of cases. There was 1 early failure of the glenoid component in a patient with severe glenoid dysplasia that required revision surgery.

Conclusion

The results of current biomechanical and clinical studies suggest that posteriorly augmented glenoid components may be valuable for specific indications (15°-25° of retroversion and significant posterior subluxation, as well as eccentric wear), improving the surgeon's ability to return axial alignment and subluxation close to normative values without compromising the native bone, as is seen with eccentric reaming techniques. At this time there is no evidence on the superiority of one commercially available design over another. Some authors have proposed individualizing the type of component based on the glenoid morphology, but evidence showing that these recommendations improve outcomes is lacking. The impact of the size of the remaining neoglenoid or deformities now classified as type B3 glenoids on the results of augmented glenoids has not been reported (Tables I-III).

On the basis of the available reports analyzing the biomechanics and outcomes of posteriorly augmented glenoid components, the role of these implants is assuming a greater presence in the armamentarium of surgeons who treat complex deformities of the arthritic glenoid. Although data on long-term radiographic and clinical outcomes are currently lacking, future multicenter clinical investigations to compare the various types of augmented implants with other techniques of glenoid bone loss management will help to provide appropriate-use clinical guidelines for this challenging and unfortunately common problem related to glenohumeral joint arthritis.

Disclaimer

Joseph A. Abboud reports the following for work related to the subject of this article: board or committee member of American Shoulder and Elbow Surgeons; paid consultant for and research support from DePuy; IP royalties from, paid consultant for, and paid presenter or speaker for DJO; IP royalties from and paid consultant for Globus Medical; paid consultant for, research support from, and IP royalties from Integra Life Sciences; editorial or governing board of Journal of Shoulder and Elbow Arthroplasty; editorial or governing board of Journal of Shoulder and Elbow Surgery; IP royalties from Lippincott; stock or stock options from Marlin Medical Alliance; board or committee member of Mid Atlantic Shoulder and Elbow Society; paid consultant for and stock or stock options from Minivasive; editorial or governing board of Orthopedics Today; stock or stock options from Parvizi Surgical Innovation; paid consultant for and research support from Tornier; publishing royalties and financial or material support from Wolters Kluwer Health–Lippincott Williams & Wilkins; paid presenter or speaker for Wright Medical Technology; and IP royalties from, paid consultant for, and research support from Zimmer.

Anthony A. Romeo reports the following for work related to the subject of this article: board (President) or committee member of American Shoulder and Elbow Surgeons; IP royalties from, other financial or material support from, paid consultant for, paid presenter or speaker for, and research support from Arthrex; research support from DJO Surgical; editorial or governing board of Orthopedics; editorial or governing board (Chief Medical Editor) of Orthopedics Today; research support from Ossur; editorial or governing board of SAGE; publishing royalties and financial or material support from Saunders/Mosby-Elsevier; editorial or governing board of, publishing royalties from, and financial or material support from SLACK; research support from Smith & Nephew; and editorial or governing board of Wolters Kluwer Health–Lippincott Williams & Wilkins.

Gerald R. Williams reports the following for work related to the subject of this article: stock or stock options from CrossCurrent Business Analytics; IP royalties and research support from DePuy; IP royalties from DJO; stock or stock options from Force Therapeutics; IP royalties from IMDS; stock or stock options from In Vivo Therapeutics; stock or stock options from OBERD; research support from Synthasome; research support from Tornier; and publishing royalties and financial or material support from Wolters Kluwer Health–Lippincott Williams & Wilkins.

Surena Namdari reports the following for work related to the subject of this article: editorial or governing board of American Journal of Orthopaedics; research support from Arthrex; editorial or governing board of Bone and Joint 360; IP royalties from, paid consultant for, and paid presenter or speaker for DJO; paid consultant for Flexion Therapeutics; stock or stock options from Force Therapeutics; research support from Integra; stock or stock options from MD Live; stock or stock options from MD

Valuate; IP royalties from, paid consultant for, and paid presenter or speaker for Miami Device Solutions; stock or stock options from Parvizi Surgical Innovation; board or committee member of Philadelphia Orthopaedic Society; stock or stock options from RubiconMD; publishing royalties and financial or material support from Saunders Mosby-Elsevier; paid consultant for Synthes; and research support from Zimmer.

The other author, his immediate family, and any research foundations with which he is affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Allred JJ, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Posterior augmented glenoid implants require less bone removal and generate lower stresses: a finite element analysis. J Shoulder Elbow Surg 2016;25:823-30. http://dx.doi.org/10.1016/j.jse.2015.10.003
2. Bercik MJ, Kruse K, Yalizis M, Gauci MO, Chaoui J, Walch G. A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. J Shoulder Elbow Surg 2016;25:1601-6. http://dx.doi.org/10.1016/j.jse.2016.03.010
3. Bryce CD, Davison AC, Okita N, Lewis GS, Sharkey NA, Armstrong AD. A biomechanical study of posterior glenoid bone loss and humeral head translation. J Shoulder Elbow Surg 2010;19:994-1002. http://dx.doi.org/10.1016/j.jse.2010.04.010
4. Cil A, Sperling JW, Cofield RH. Nonstandard glenoid components for bone deficiencies in shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:e149-57. http://dx.doi.org/10.1016/j.jse.2013.09.023
5. Collins D, Tencer A, Sidles J, Matsen F. Edge displacement and deformation of glenoid components in response to eccentric loading. The effect of preparation of the glenoid bone. J Bone Joint Surg Am 1992;74:501-7.
6. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elbow Surg 2010;19:1115-20. http://dx.doi.org/10.1016/j.jse.2010.02.009
7. Farron A, Terrier A, Büchler P. Risks of loosening of a prosthetic glenoid implanted in retroversion. J Shoulder Elbow Surg 2006;15:521-6. http://dx.doi.org/10.1016/j.jse.2005.10.003
8. Favorito PJ, Freed RJ, Passanise AM, Brown MJ. Total shoulder arthroplasty for glenohumeral arthritis associated with posterior glenoid bone loss: results of an all-polyethylene, posteriorly augmented glenoid component. J Shoulder Elbow Surg 2016;25:1681-9. http://dx.doi.org/10.1016/j.jse.2016.02.020
9. Gillespie R, Lyons R, Lazarus M. Eccentric reaming in total shoulder arthroplasty: a cadaveric study. Orthopedics 2009;32:21. http://dx.doi.org/10.3928/01477447-20090101-07
10. Gowda A, Pinkas D, Wiater JM. Treatment of glenoid bone deficiency in total shoulder arthroplasty: a critical analysis review. JBJS Rev 2015;3:1-11. http://dx.doi.org/10.2106/JBJS.RVW.N.00097
11. Hermida JC, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Augmented wedge-shaped glenoid component for the correction of glenoid retroversion: a finite element analysis. J Shoulder Elbow Surg 2014;23:347-54. http://dx.doi.org/10.1016/j.jse.2013.06.008
12. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Joint Surg Am 2001;83:877-83.
13. Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg Am 2013;95:1-8. http://dx.doi.org/10.2106/JBJS.L.00336
14. Iannotti JP, Frangiamore SJ. Fate of large structural allograft for treatment of severe uncontained glenoid bone deficiency. J Shoulder Elbow Surg 2012;21:765-71. http://dx.doi.org/10.1016/j.jse.2011.08.069
15. Iannotti JP, Jun BJ, Patterson TE, Ricchetti ET. Quantitative measurement of osseous pathology in advanced glenohumeral osteoarthritis. J Bone Joint Surg Am 2017;99:1460-8. http://dx.doi.org/10.2106/JBJS.16.00869
16. Iannotti JP, Lappin KE, Klotz CL, Reber EW, Swope SW. Liftoff resistance of augmented glenoid components during cyclic fatigue loading in the posterior-superior direction. J Shoulder Elbow Surg 2013;22:1530-6. http://dx.doi.org/10.1016/j.jse.2013.01.018
17. Kersten AD, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Posterior augmented glenoid designs preserve more bone in biconcave glenoids. J Shoulder Elbow Surg 2015;24:1135-41. http://dx.doi.org/10.1016/j.jse.2014.12.007
18. Kirane YM, Lewis GS, Sharkey NA, Armstrong AD. Mechanical characteristics of a novel posterior-step prosthesis for biconcave glenoid defects. J Shoulder Elbow Surg 2012;21:105-15. http://dx.doi.org/10.1016/j.jse.2010.12.008
19. Klika BJ, Wooten CW, Sperling JW, Steinmann SP, Schleck CD, Harmsen WS, et al. Structural bone grafting for glenoid deficiency in primary total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1066-72. http://dx.doi.org/10.1016/j.jse.2013.09.017
20. Knowles NK, Ferreira LM, Athwal GS. Augmented glenoid component designs for type B2 erosions: a computational comparison by volume of bone removal and quality of remaining bone. J Shoulder Elbow Surg 2015;24:1218-26. http://dx.doi.org/10.1016/j.jse.2014.12.018
21. Matsen FA, Clinton J, Lynch J, Bertelsen A, Richardson ML. Glenoid component failure in total shoulder arthroplasty. J Bone Joint Surg Am 2008;90:885-96. http://dx.doi.org/10.2106/JBJS.G.01263
22. McFarland EG, Huri G, Hyun YS, Petersen SA, Srikumaran U. Reverse total shoulder arthroplasty without bone-grafting for severe glenoid bone loss in patients with osteoarthritis and intact rotator cuff. J Bone Joint Surg Am 2016;98:1801-7. http://dx.doi.org/10.2106/JBJS.15.01181
23. McLendon PB, Schoch BS, Sperling JW, Sánchez-Sotelo J, Schleck CD, Cofield RH. Survival of the pegged glenoid component in shoulder arthroplasty: part II. J Shoulder Elbow Surg 2017;26:1469-76. http://dx.doi.org/10.1016/j.jse.2016.12.068
24. Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. J Bone Joint Surg Am 2013;95:1297-304. http://dx.doi.org/10.2106/JBJS.L.00820
25. Nicholson GP, Cvetanovich GL, Rao AJ, O'Donnell P. Posterior glenoid bone grafting in total shoulder arthroplasty for osteoarthritis with severe posterior glenoid wear. J Shoulder Elbow Surg 2017;26:1844-53. http://dx.doi.org/10.1016/j.jse.2017.03.016
26. Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, Bigliani LU, et al. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be corrected. J Shoulder Elbow Surg 2009;18:680-8. http://dx.doi.org/10.1016/j.jse.2009.03.019
27. Nyffeler RW, Sheikh R, Atkinson TS, Jacob HAC, Favre P, Gerber C. Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. J Shoulder Elbow Surg 2006;15:625-9. http://dx.doi.org/10.1016/j.jse.2005.09.016
28. Orvets ND, Chamberlain AM, Patterson BM, Chalmers PN, Gosselin M, Salazar D, et al. Total shoulder arthroplasty in patients with a B2 glenoid addressed with corrective reaming. J Shoulder Elbow Surg 2018;27:S58-64. http://dx.doi.org/10.1016/j.jse.2018.01.003
29. Ponce BA, Oladeji LO, Rogers ME, Menendez ME. Comparative analysis of anatomic and reverse total shoulder arthroplasty: in-hospital outcomes and costs. J Shoulder Elbow Surg 2015;24:460-7. http://dx.doi.org/10.1016/j.jse.2014.08.016
30. Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis

with severe glenoid bone loss. J Bone Joint Surg Am 2013;95:1290-6. http://dx.doi.org/10.2106/JBJS.L.00097
31. Sabesan V, Callanan M, Sharma V, Iannotti JP. Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component. J Shoulder Elbow Surg 2014;23: 964-73. http://dx.doi.org/10.1016/j.jse.2013.09.019
32. Sandow M, Schutz C. Total shoulder arthroplasty using trabecular metal augments to address glenoid retroversion: the preliminary result of 10 patients with minimum 2-year follow-up. J Shoulder Elbow Surg 2016;25:598-607. http://dx.doi.org/10.1016/j.jse.2016.01.001
33. Shapiro TA, McGarry MH, Gupta R, Lee YS, Lee TQ. Biomechanical effects of glenoid retroversion in total shoulder arthroplasty. J Shoulder Elbow Surg 2007;16(Suppl):90-5. http://dx.doi.org/10.1016/j.jse.2006.07.010
34. Sowa B, Bochenek M, Braun S, Zeifang F, Philippe J, Thomas K, et al. Replacement options for the B2 glenoid in osteoarthritis of the shoulder: a biomechanical study. Arch Orthop Trauma Surg 2018;138:891-9. http://dx.doi.org/10.1007/s00402-018-2915-z
35. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg Am 2015;97:251-9. http://dx.doi.org/10.2106/JBJS.N.00566
36. Stephens SP, Spencer EE, Wirth MA. Radiographic results of augmented all-polyethylene glenoids in the presence of posterior glenoid bone loss during total shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:798-803. http://dx.doi.org/10.1016/j.jse.2016.09.053
37. Triplet JJ, Everding NG, Levy JC, Moor MA. Functional internal rotation after shoulder arthroplasty: a comparison of anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:867-74. http://dx.doi.org/10.1016/j.jse.2014.10.002
38. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty 1999;14:756-60.
39. Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid. J Shoulder Elbow Surg 2012;21:1526-33. http://dx.doi.org/10.1016/j.jse.2011.11.030
40. Walch G, Young AA, Boileau P, Loew M, Gazielly D, Molé D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than five years of follow-up. J Bone Joint Surg Am 2012;94:145-50. http://dx.doi.org/10.2106/JBJS.J.00699
41. Wang T, Abrams GD, Behn AW, Lindsey D, Giori N, Cheung EV. Posterior glenoid wear in total shoulder arthroplasty: eccentric anterior reaming is superior to posterior augment. Clin Orthop Relat Res 2015;473:3928-36. http://dx.doi.org/10.1007/s11999-015-4482-8
42. Wright TW, Grey SG, Roche CP, Wright L, Flurin P-H, Zuckerman JD. Preliminary results of a posterior augmented glenoid compared to an all polyethylene standard glenoid in anatomic total shoulder arthroplasty. Bull Hosp Jt Dis 2015;73:79-85.
43. Youderian AR, Napolitano LA, Davidson IU, Iannotti JP. Management of glenoid bone loss with the use of a new augmented all-polyethylene glenoid component. J Shoulder Elbow Surg 2012;13:163-9. http://dx.doi.org/10.1097/BTE.0b013e318265354d