JSES International 8 (2024) 104–110

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Effect of osteophyte removal on simulated range of motion using 3-dimensional preoperative planning software for reverse total shoulder arthroplasty

Joseph J. Ruzbarsky, MD[a,b], Annalise M. Peebles, BA[b], Lauren Watkins, PhD[b], Amelia R. Kruse, BS[b,c], Brendan M. Lilley, BA[d], Stephanie K. Eble, BA[e], Patrick J. Denard, MD[f], Anthony A. Romeo, MD[g], Matthew T. Provencher, MD, MBA, CAPT, MC, USNR (Ret)[a,b,*]

[a]*The Steadman Clinic, Vail, CO, USA*
[b]*Steadman Philippon Research Institute, Vail, CO, USA*
[c]*William Beaumont School of Medicine, Rochester, MI, USA*
[d]*Frank H. Netter MD School of Medicine, North Haven, CT, USA*
[e]*Geisel School of Medicine at Dartmouth College, Hanover, NH, USA*
[f]*Southern Oregon Orthopaedics, Medford, OR, USA*
[g]*Department of Orthopaedic Surgery, DuPage Medical Group, Chicago, IL, USA*

A R T I C L E I N F O

Keywords:
Glenohumeral osteophyte
Range of motion
Reverse total shoulder arthroplasty
Osteophyte removal
Mechanical impingement
Three-dimensional preoperative planning software

Level of evidence: Basic Science Study; Computer Modeling

Background: Glenohumeral osteophytes (OPs) can adversely influence postoperative range of motion (ROM) following shoulder arthroplasty due to mechanical impingement. Though commercial three-dimensional preoperative planning software (3D PPS) is available to simulate ROM before and after OP resection, little is known about the magnitude of effect OPs and their subsequent removal have on simulated glenohumeral ROM.

Methods: Included patients were 1) indicated for reverse total shoulder arthroplasty (rTSA) using 3D PPS and 2) presented with glenoid and/or humeral head OPs on preoperative two-dimensional computed tomography (2D-CT) imaging. Thirty patients met the inclusion criteria (9 females, 21 males; mean age 70.45 ± 4.99 years, range 63-80 years). All subjects (n = 30) presented with humeral OPs (mean volume: 2905.16 mm^3, range 109.1-11,246 mm^3), while 11 subjects also presented with glenoid OPs (mean volume 108.06 mm^3, range 37.59-791.4 mm^3). Preoperative CTs were used to calculate OP volume (mm^3) and OP circumferential extent (clockface). Mean clockface position for circumferential humeral OPs originated at 6:09 (range 4:30-7:15) and extended to 8:51 (range 8:15-10:15). Mean clockface position for glenoid OPs originated at 3:00 (range 2:00-5:00) and extended to 6:16 (range 3:00-7:30). 3D implants on PPS were standardized to achieve 0° of version, 0° of inclination and 4 mm of net lateralization. Thirty-nine and thirty-six mm glenospheres were used for males and females, respectively. 3D PPS was used to evaluate simulated ROM differences before and after OP removal in the planes of adduction (ADD), abduction, internal rotation (IR), external rotation (ER), extension, and flexion. Impact of OP volume and circumferential extent on pre and postop removal ROM were also analyzed.

Results: Humeral OP removal significantly increased impingement-free ADD, IR, ER, extension, and flexion. Removal of larger (mm^3) humeral OPs positively correlated with improvement in IR (R = 0.452, *P* = .011), ER (R = 0.394, *P* = .033), and flexion (R = 0.500, *P* < .01). Greater circumferential extent of humeral OPs correlated with worse preremoval ROM in the planes of ADD (R = 0.364, *P* = .02) and extension (R = 0.403, *P* = .04), and improvements in ER postop removal (R = 0.431, *P* = .03).

Ethical Committee Approval was obtained through the Vail Health Institutional Review Board: IRB No. 2021-089-TSC.

*Corresponding author: Matthew T. Provencher, MD, MBA, CAPT, MC, USNR (Ret), Steadman Philippon Research Institute, The Steadman Clinic, 181 W Meadow Dr, Ste. 400, Vail, CO 81657, USA.

E-mail address: mprovencher@thesteadmanclinic.com (M.T. Provencher).

https://doi.org/10.1016/j.jseint.2023.08.011

Conclusion: Humeral OP removal significantly increases impingement-free ADD, IR, ER, extension, and flexion in simulated 3D PPS models following rTSA. Magnitude of simulated ROM improvement is influenced by initial humeral OP volume and circumferential clockface extent. Surgeons should consider these effects when using 3D PPS for rTSA planning to optimize postoperative ROM prognostics.

Osteophytes (OPs), one of the classic features of osteoarthritis, are bony overgrowths that occur in periarticular regions due to joint degeneration.[21] In shoulder osteoarthritis, OPs most commonly manifest around the inferior portion of the glenoid or humeral head.[11] Presence of OPs in these regions is theorized to contribute to decreased range of motion (ROM) and potential axillary nerve compression in circumstances of very large OPs due to mass effect.[12,13]

In cases of glenohumeral arthritis with significant glenoid retroversion or in cuff tear arthropathy, patients can be treated through prosthetic replacement with a reverse total shoulder arthroplasty (rTSA) procedure. While the rTSA procedure reliably relieves pain, postoperative ROM results remain variable.[2,4] Glenohumeral OPs are thought to adversely influence postoperative ROM in certain planes of the shoulder following rTSA. Some limitations in ROM can occur due to mechanical impingement, in which either the glenosphere or humeral prosthesis contact OP(s) of the opposing glenohumeral structure and/or create tension on surrounding soft tissue structures.[3,5,10]

OP incidence and size have traditionally been identified and described qualitatively from plain radiographs, but these images are complicated by overlapping structures and cannot be used to characterize OP volume quantitatively.[13] Three-dimensional (3D) preoperative planning software (3D PPS) has been increasingly adopted to model anatomy and bony deformities from diagnostic imaging to assist in preoperative planning of implant positioning and fixation for shoulder arthroplasty.[8,18,20] 3D techniques can also improve OP characterization and their impacts on glenohumeral arthritic wear patterns and motion.[19,15] While the importance of adequate OP removal on postoperative motion outcomes has been well studied in lower joint arthroplasty,[14] there remains a paucity of literature that investigates how size and resection of glenohumeral OPs affect ROM of the shoulder on 3D PPS related to rTSA procedures. As optimizing functional outcomes following rTSA remains critical, a thorough understanding of the effect of glenohumeral OP size and resection on ROM using 3D PPS is an essential step in preoperative planning for rTSA.

The aim of this retrospective study is to investigate the impact of glenohumeral OP removal on simulated ROM using 3D PPS. It is hypothesized that 1) removal of glenohumeral OPs will significantly improve simulated ROM and 2) volume and circumferential extent of OP removal will positively correlate with improvements in simulated ROM.

Methods

Participant selection

Following institutional review board approval (IRB No. 2021-089-TSC), a retrospective review was performed of patients seen between 2019 and 2021 who presented with glenohumeral arthritis and were subsequently treated with an rTSA procedure. Patients were included if they 1) were between the ages of 18 and 85 years old, 2) underwent an rTSA procedure, 3) presented with glenoid and/or humeral head OP(s) on preoperative two-dimensional computed tomography (2D-CT) imaging, and 4) had existing 3D PPS plans on the senior author's (M.T.P) PPS database (Tornier BLUEPRINT; Stryker, Kalamazoo, MI, USA). Presence of OPs was confirmed by the senior author (M.T.P.) and 1 additional fellowship-trained orthopedic shoulder surgeon (J.J.R) on 2D-, 3D-CT, and X-ray imaging for each patient. Patients were excluded from analysis if they had history of any prior ipsilateral shoulder surgeries. 3D implants on PPS were standardized to achieve 0° of version and 0° of inclination with ultimately 4 mm of lateralization. Augmented baseplates were used in instances of glenoid deformities of greater than 20 degrees and preoperatively planned for baseplate seating of greater than 90% in all cases. Thirty patients (15 right shoulders and 15 left shoulders) who had glenohumeral OPs and underwent a subsequent primary rTSA between January 2019 and July 2021 were included (9 females, 21 males; mean age 70.45 ± 4.99 years, range 63-80 years). Thirty-nine and thirty-six mm glenospheres were used for males and females, respectively.

Osteophyte volume

The computed tomography (CT) series with the highest, near-isotropic resolution available for each patient's case was used to assess OP volume (mean resolution 0.52 mm × 0.52 mm × 0.43 mm). 2D- and 3D-CT images were first reviewed by the senior author (M.T.P) and an additional fellowship-trained orthopedic shoulder surgeon (J.J.R) who annotated OPs of interest. OPs were then delineated on patients' 2D-CT images using 3D segmentation software (ITK-SNAP, version 3.6.0[22]) to calculate total, glenoid, and humeral OP volumes (mm^3) (Fig. 1). All subjects (n = 30) presented with humeral OPs (mean volume 2905.16 mm^3, range 109.1-11,246 mm^3), while 11 subjects also presented with glenoid OPs (mean volume 108.06 mm^3, range 37.59-791.4 mm^3).

Extent of osteophytes

Glenohumeral OP extent was determined based on previously cited literature.[6,7,9,17] Extent of humeral OPs was determined using the clockface position along the plane of the native anatomic neck, as defined by the 3D PPS, on patients' respective 3D-CTs (Fig. 2). The most superior point of the anatomic neck was defined as 12 o'clock, whereas 6 o'clock corresponded to the most inferior point.[17] Clockface positioning was similarly used for glenoid OPs; the supraglenoid tubercle was first identified (12 o'clock) and a line was then drawn down the glenoid center (defined by the 3D PPS) to determine its corresponding 6 o'clock position along the inferior glenoid rim (Fig. 3).[6,7] Nine o'clock was defined as directly anterior for all patients.

Osteophyte removal and ROM analysis

3D PPS (Tornier BLUEPRINT; Stryker, Kalamazoo, MI, USA) was used to perform digital OP removal and ROM simulation. Simulated

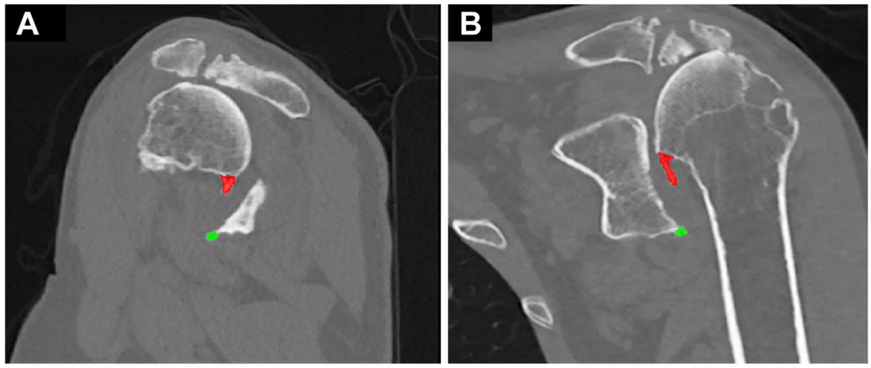

Figure 1 (**A**) Sagittal and (**B**) coronal image of 2 dimensional computed tomography scan illustrating annotations of glenoid and humeral head osteophytes (OPs).

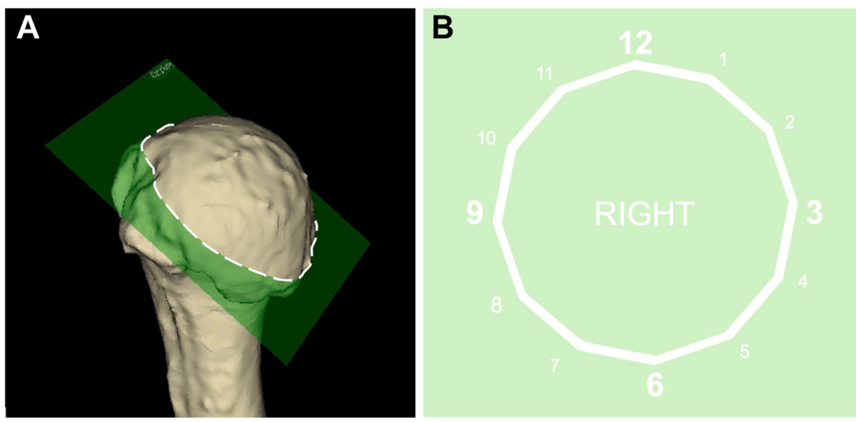

Figure 2 The plane of the native anatomic humeral neck (green) of the right arm. The most superior point of the anatomic neck was defined as 12 o'clock, whereas 6 o'clock corresponded to the most inferior point. Nine o'clock was defined as directly anterior for all patients.

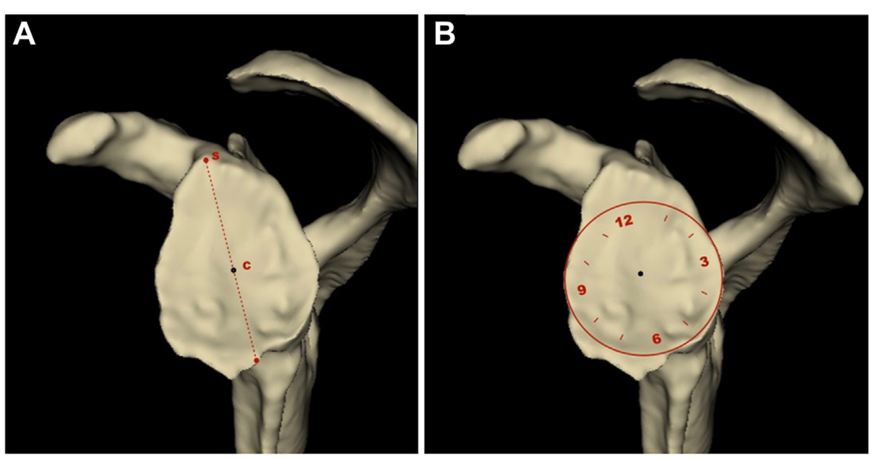

Figure 3 (**A**) A 3-dimensional (3D) reconstructed *en face* image of the glenoid of the right arm. The supraglenoid tubercle (S) was identified, and a line was drawn down the 3D preoperative planning software -determined glenoid center (C) to determine its corresponding position along the inferior glenoid rim. (**B**) A clockface was created using a best-fit circle, in which the supraglenoid tubercle (12 o'clock) and its corresponding 6 o'clock position along the inferior glenoid rim are annotated. Nine o'clock was defined as directly anterior for all patients.

ROM in the planes of adduction (ADD), abduction (ABD), internal rotation (IR), external rotation (ER), extension, and flexion was performed prior to OP removal on each patient's 3D scapular model – each with an appropriately sized rTSA prosthesis based on the software's internal algorithm (Fig. 4*A*). This was performed as well on 3D humeral neck models (Fig. 5*A*). OPs previously identified by the senior author (M.T.P) and 1 other fellowship-trained orthopedic shoulder surgeon (J.J.R) on 3D-CT imaging were then removed from the patients' 3D scapular models (Fig. 6) and 3D humeral neck models (Fig. 7) and rerun through the same planes of motion to determine OP impingement effects on simulated ROM (Fig. 4*B*, Fig. 5*B*).

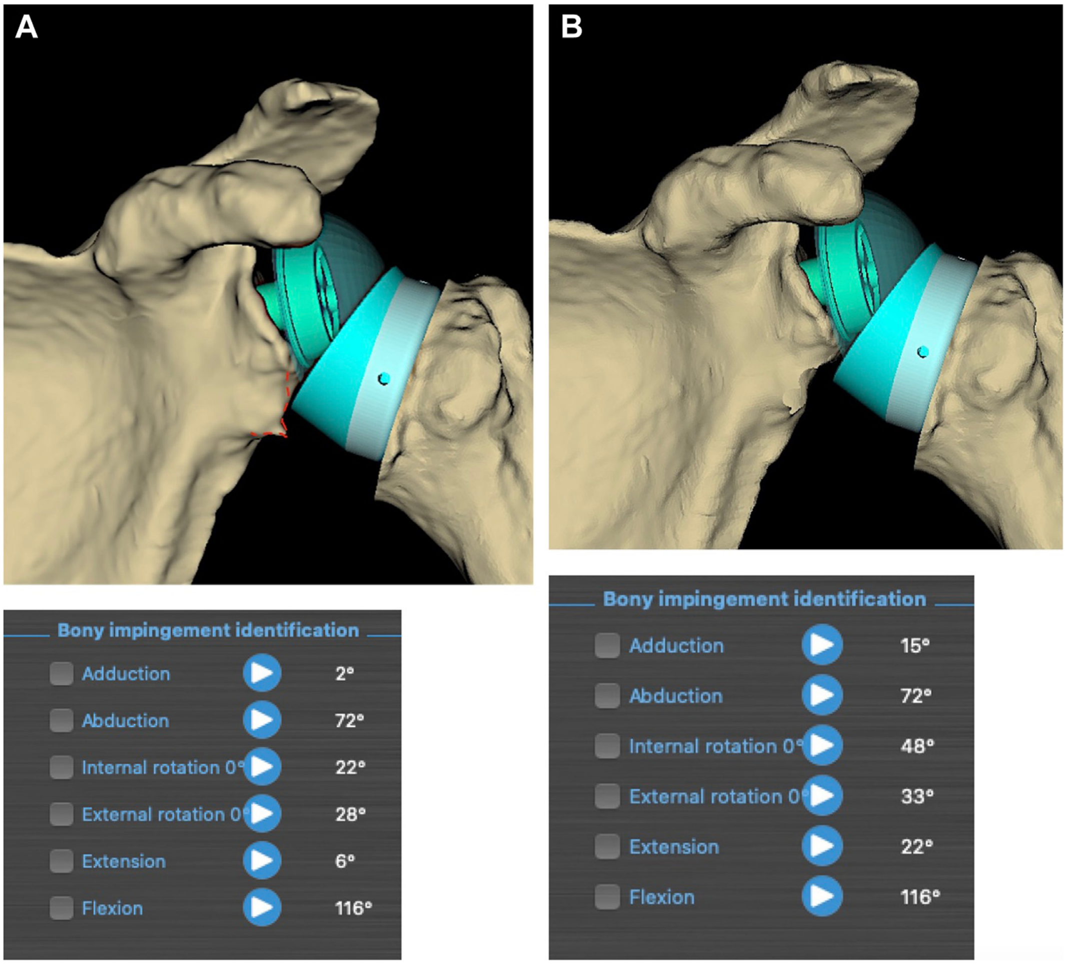

Figure 4 Simulated range of motion measurements (adduction, abduction, internal rotation, external rotation, extension, and flexion) using 3D preoperative patient-specific instrumentation, Tornier BLUEPRINT (Stryker, Kalamazoo, MI, USA) (**A**) preremoval of OP on inferior glenoid (······) and (**B**) postremoval of OP on inferior glenoid.

Statistical analysis

A Wilcoxon singed rank test was performed to evaluate significant differences between pre and postop removal ROM (alpha = 0.05). A Pearson's correlation coefficient was used to examine correlations between bipolar, glenoid, and humeral OP volume and the change in simulated ROM (alpha = 0.05). A Pearson's correlation coefficient was also used to determine correlations between circumferential extent of humeral and glenoid OP and changes in simulated ROM (alpha = 0.05). All statistical analysis were performed using MATLAB R2021b (MathWorks, Natick, MA, USA).

Results

Effect of OP removal on ROM

Humeral OP removal significantly increased mean ADD (+7.8°, range 0°-24°, $P < .001$), IR (+20.3°, range 0°-92°, $P < .001$), ER (+22.85°, range 0°-62°, $P < .001$), extension (+21.1°, range 0°-120°, $P = .014$), and flexion (+17.7°, range 0°-114°, $P = .025$). Removal of bipolar OPs had a similar, significant improvement on ADD (+8.82°, range 0°-35°, $P = .018$), IR (+2.27°, range 0°-10°, $P = .043$), ER (+12.64°, range 0°-43°, $P = .019$), and extension (+15.18°, range 0°-57°, $P = .040$) (Table I). There was no significant difference in ROM improvements between humeral vs. bipolar OP removal of similar total volumes (±300 mm^3).

Effect of OP extent on pre and postremoval ROM

Circumferential humeral OPs were detected in all patients (n = 30). The mean clockface position for circumferential humeral OPs originated at 6:09 (range 4:30-7:15) and extended to 8:51 (range 8:15-10:15). Localized humeral OPs (n = 4) were located at 2:30, 3:30, 8:30, and 11:00, respectively. Greater circumferential extent of humeral OPs weakly correlated with worse preremoval ROM in the planes of ADD (R = 0.364, $P = .02$) and extension (R = 0.403, $P = .04$) and improvements in ER postop removal (R = 0.431, $P = .03$). The mean clockface position for circumferential glenoid OPs (n = 9) originated at 3:00 (range 2:00-5:00) and extended to 6:16 (range 3:00-7:30). Localized glenoid OPs (n = 3) were located at 2:00, 6:30, and 11:00, respectively. There was no significant correlation between circumferential extent of glenoid OP and preremoval ROM in any planes of motion. However, removal of glenoid OPs with greater circumferential extent strongly correlated with improvements in ADD postop removal (R = 0.776, $P = .01$).

Effect of OP volume on pre and postremoval ROM

Larger humeral and bipolar OP volume correlated with worse preremoval flexion (humeral: R = −0.557, bipolar: R = −0.555, $P < .01$), but there were no significant correlations in OP volume and preremoval ROM in the planes of ADD, ABD, ER, IR, or flexion. There was no significant correlation between glenoid OP volume

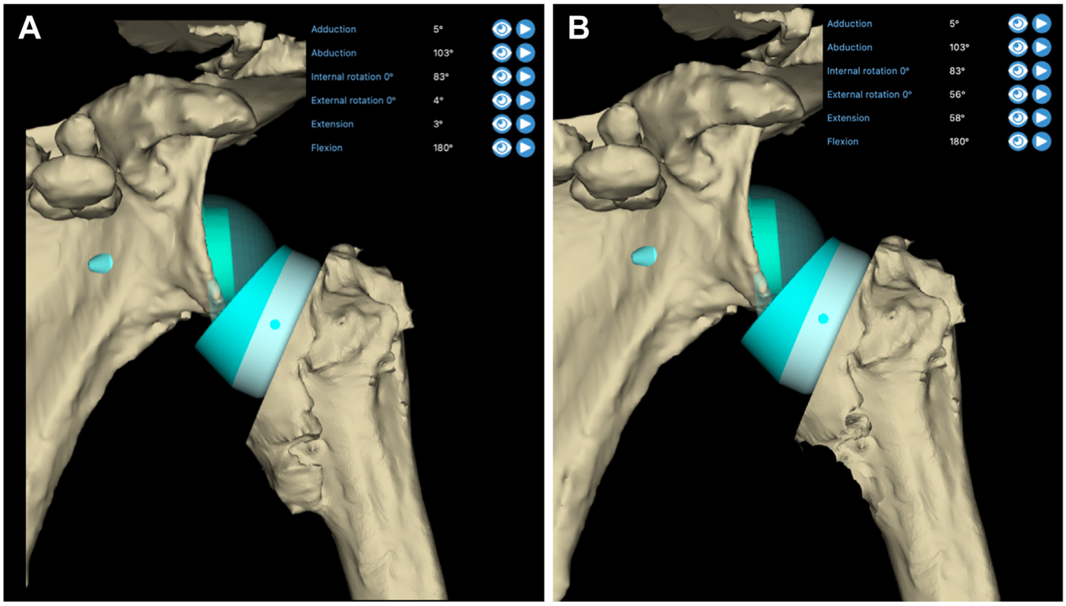

Figure 5 Simulated range of motion measurements (adduction, abduction, internal rotation, external rotation, extension, and flexion) using 3D preoperative patient-specific instrumentation, Tornier BLUEPRINT (Stryker, Kalamazoo, MI, USA) (**A**) preremoval of OP on humeral neck (······) and (**B**) postremoval of OP on humeral neck.

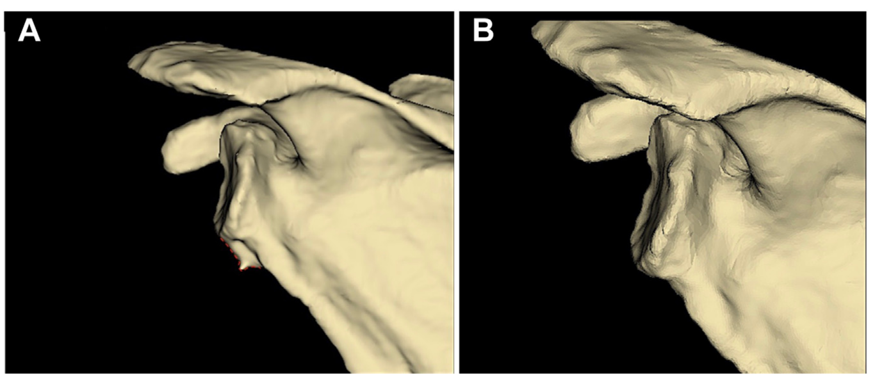

Figure 6 3D scapula created using Tornier BLUEPRINT (Bloomington, MN) software depicting (**A**) preremoval of OP on inferior glenoid (······) and (**B**) post removal of OP on inferior glenoid.

and preremoval ROM in any planes of motion. Removal of larger (mm^3) humeral and bipolar OPs positively correlated with improvement in IR (humeral: R = 0.452, *P* = .011; bipolar: R = 0.446, *P* = .012), ER (humeral: R = 0.394, *P* = .033; bipolar: R = 0.376, *P* = .037) and flexion (humeral: R = 0.500, bipolar: 0.496, *P* < .001). Removal of larger (mm^3) glenoid OPs was correlated with improvement in IR, only (R = 0.817, *P* = .002) (Table II).

Discussion

The present study sought to elucidate the impact of glenohumeral OP removal on simulated ROM using 3D PPS following rTSA. Results illustrate that 1) humeral and bipolar OP removal significantly increases ADD, ER, IR, extension, and flexion, 2) removal of larger humeral and bipolar OPs correlates with increases in IR, ER, and flexion, while removal of larger glenoid OPs correlate with increases in IR and 3) greater circumferential extent of humeral OPs weakly correlate with worse preremoval ADD, extension, and improved postremoval ER. These findings emphasize the critical importance of glenohumeral OPs in the setting of rTSA, particularly on the humerus, that affect postoperative simulated ROM on 3D PPS.

The observed ROM trends can best be explained by the interaction between the OPs and the rTSA prosthesis, and their combined effect on rotational mechanics of the shoulder. OPs located on the humerus and glenoid act as potential mechanical "blocks" during glenohumeral rotation, in which impingement of the OPs on other bony structures or prosthetic components obstructs shoulder ROM. In the case of an OP on the anterior to inferior region of the glenoid that is not resected during rTSA, the humeral prosthesis may be obstructed during rotational or leveraging motions such as IR or ADD, and ABD, respectively. Alternatively, a large inferior humeral OP can prevent rotation of the humeral prosthesis across the horizontal and frontal planes as it acts as a block against the glenosphere. Considering these interactions, OPs of larger size would expectedly intensify the disrupted mechanics and subsequent rotational motion of the glenohumeral joint. The current study's findings are consistent with a cohort study by Kircher et al[9] that retrospectively reviewed 120 standardized radiographs of patients with advanced osteoarthritis of the shoulder and found that OP size was negatively correlated with active and passive

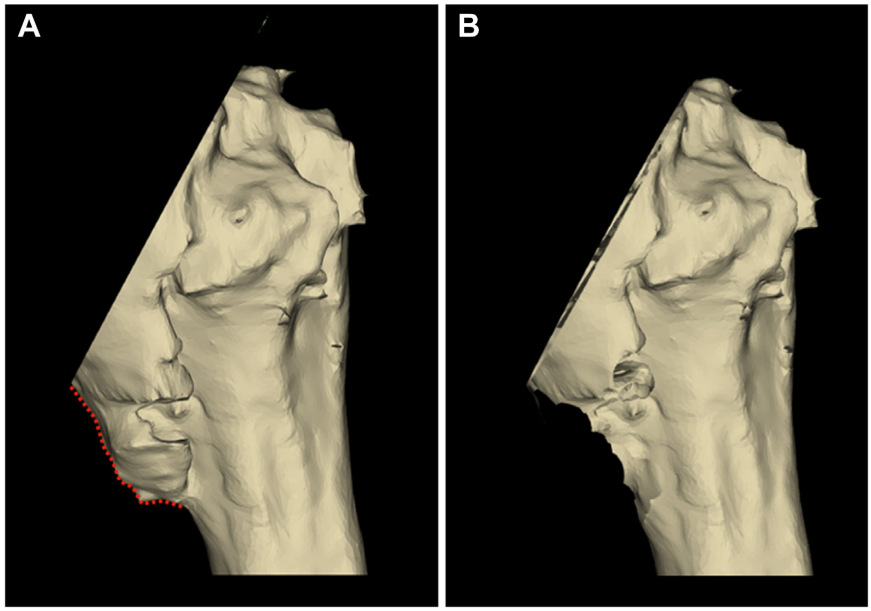

Figure 7 3D scapula created using Tornier BLUEPRINT (Bloomington, MN) software depicting (**A**) preremoval of OP on humeral neck (······) and (**B**) postremoval of OP on humeral neck.

Table I
Effect of humeral and bipolar osteophyte removal on simulated range of motion (ROM) (°) in the planes of adduction (ADD), abduction (ABD), internal rotation (IR), external rotation (ER), extension, and flexion.

	ROM plane	Mean preop	Mean postop	Mean pre- to postop change	*P* value
HUMERUS	ADD	5.9 (0-18)	13.7 (0-33)	7.8 (0-24)	<.001*
	ABD	70.85 (38-88)	71.4 (59-88)	0.55 (0-7)	.179
	IR	44.1 (0-96)	64.4 (0-92)	20.3 (0-92)	<.001*
	ER	13.8 (0-35)	36.65 (0-70)	22.85 (0-62)	<.001*
	Extension	19.3 (0-120)	40.4 (0-120)	21.1 (0-120)	.014*
	Flexion	82 (0-135)	99.7 (70-138)	17.7 (0-114)	.025*
BIPOLAR	ADD	9.18 (0-41)	18 (2-43)	8.82 (0-35)	.019*
	ABD	73.91 (21-95)	78.91 (63-95)	5 (0-52)	.313
	IR	67.64 (41-97)	69.91 (28-98)	2.27 (0-10)	.043*
	ER	20.91 (0-58)	33.55 (14-58)	12.64 (0-43)	.019*
	Extension	16.27 (0-63)	31.45 (6-120)	15.18 (0-57)	.040*
	Flexion	101.18 (63-126)	104.55 (79-126)	3.36 (0-16)	.067

*Denotes significance (alpha = 0.05).

Table II
Correlation between volume (mm^3) of osteophyte (OP) removal and change in ROM (°) from pre- to post-removal, in the planes of adduction (ADD), abduction (ABD), internal rotation (IR), external rotation, (ER), extension, and flexion.

	Bipolar OP volume		Humeral OP volume		Glenoid OP volume	
ROM plane	Correlation coefficient	*P* value	Correlation coefficient	*P* value	Correlation coefficient	*P* value
ADD	0.123	.511	0.129	.488	−0.371	.262
ABD	−0.076	.685	−0.073	.695	−0.289	.389
IR	0.446	.012*	0.452	.011*	0.817	.002*
ER	0.376	.037*	0.394	.033*	−0.115	.736
Extension	0.496	.005*	0.500	.004*	0.083	.809
Flexion	0.128	.491	0.139	.457	−0.464	.151

*Denotes significance (alpha = 0.05).

flexion, ABD, ER, and IR. Notably, the authors reported that there was no significant correlation between loss of joint space and OP size. These findings, along with those of the current study, suggest that OPs - and their respective size - are an independent predictor of glenohumeral ROM and should therefore be managed appropriately during rTSA in efforts to optimize postoperative shoulder motion.

While the current study illustrates the mechanical effects that OPs have on postoperative ROM predictions using 3D PPS, these findings only highlight the direct consequences of OP impingement and are likely a conservative estimate of the true ROM limitations that would be encountered during glenohumeral motion following rTSA. While OPs of the shoulder joint are primarily a disease of articular cartilage, the secondary musculoskeletal changes to surrounding joint tissues that these bone spurs disrupt cannot be ignored. In their retrospective cohort study, Simovitch et al[16] investigated radiographic parameters in 77 consecutive post-operative shoulder radiographs that predispose patients to scapular notching following rTSA and report that OPs along the inferior glenoid rim were detected in 27% (n = 21) of patients. While no direct correlation was made between postoperative OPs and instances of scapular notching by the authors, it is speculated that OP-induced scapular notching following rTSA would exacerbate symptoms of glenohumeral pain and inflammation, further restricting range of shoulder motion.[1] Additional musculoskeletal changes to the surrounding joint tissue are illustrated in the aforementioned study by Kircher et al,[9] in which the authors propose that significantly decreased shoulder ROM in all planes that correlated to an increased OP size could be a result of a decreased joint volume and subsequent tightening of the capsule, mechanically restricting joint motion further. These musculoskeletal changes, in conjunction with the mechanical impingement effects that OPs have on glenohumeral biomechanics, emphasize the necessity of improved preoperative understanding of OP volume and resection to optimize shoulder ROM following rTSA.

Limitations

This investigation has several limitations. First, both the OP volume measurement and the simulated ROM were performed using CT images and 3D CT-based motion analysis software. The glenohumeral motion simulation can therefore only reflect bony impingement and bone-based motion and does not account for soft tissue limitations (e.g., capsular contractures) or implant-related constraints (e.g., version) that may also limit motion post-operatively after rTSA. Furthermore, there is no correlation between projected postoperative motion with actual postoperative motion. The purpose of this study was to demonstrate the utility of OP removal in conjunction with the rTSA and motion. Both execution of OP removal and the actual resultant postoperative motion would be useful, but both were not primary objectives. A second limitation is that this was a cohort of convenience of patients undergoing rTSA and not a diagnosis-specific group. As a retrospective study, existing CT images with the highest resolution were selected for volume calculations and 3D modeling, but the precise resolution varied. The cohort represented various etiologies of indications including massive chronic rotator cuff tears, cuff tear arthropathy, failed rotator cuff repairs, and posttraumatic arthritis. Therefore, the strength of the results of OP volume on motion for each individual indication for rTSA may be weakened, although this heterogeneous cohort improves generalizability for motion assumptions for any etiology of OPs.

Conclusion

Humeral OP removal significantly increases impingement-free ADD, IR, ER, extension, and flexion in simulated 3D PPS models following rTSA. The magnitude of simulated ROM improvement is influenced by initial humeral OP volume and circumferential extent. Surgeons should consider these effects when using 3D PPS for rTSA planning to optimize postoperative ROM prognostics.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Aspden RM. Osteoarthritis: a problem of growth not decay? Rheumatology (Oxford) 2008;47:1452-60. https://doi.org/10.1093/rheumatology/ken199.
2. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res 2016;102:S33-43. https://doi.org/10.1016/j.otsr.2015.06.031.
3. Chae J, Siljander M, Wiater JM. Instability in reverse total shoulder arthroplasty. J Am Acad Orthop Surg 2018;26:587-96. https://doi.org/10.5435/jaaos-d-16-00408.
4. Chalmers PN, Boileau P, Romeo AA, Tashjian RZ. Revision reverse shoulder arthroplasty. J Am Acad Orthop Surg 2019;27:426-36. https://doi.org/10.5435/jaaos-d-17-00535.
5. Chalmers PN, Rahman Z, Romeo AA, Nicholson GP. Early dislocation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:737-44. https://doi.org/10.1016/j.jse.2013.08.015.
6. Dekker TJ, Peebles LA, Goldenberg BT, Millett PJ, Bradley JP, Provencher MT. Location of the glenoid Defect in shoulders with Recurrent Posterior glenohumeral Instability. Am J Sports Med 2019;47:3051-6. https://doi.org/10.1177/0363546519876282.
7. Hirose T, Nakagawa S, Sato S, Tachibana Y, Mae T. Computed tomography features of glenoid osteophytes in traumatic anterior shoulder Instability: comparison between Younger and older patients. Orthop J Sports Med 2019;7:2325967119846908. https://doi.org/10.1177/2325967119846908.
8. Iannotti JP, Walker K, Rodriguez E, Patterson TE, Jun BJ, Ricchetti ET. Accuracy of 3-dimensional planning, implant Templating, and patient-specific instrumentation in anatomic total shoulder arthroplasty. J Bone Joint Surg Am 2019;101:446-57. https://doi.org/10.2106/jbjs.17.01614.
9. Kircher J, Morhard M, Magosch P, Ebinger N, Lichtenberg S, Habermeyer P. How much are radiological parameters related to clinical symptoms and function in osteoarthritis of the shoulder? Int Orthop 2010;34:677-81. https://doi.org/10.1007/s00264-009-0846-6.
10. Lemmens L, Geelen H, Depypere M, De Munter P, Verhaegen F, Zimmerli W, et al. Management of periprosthetic infection after reverse shoulder arthroplasty. J Shoulder Elbow Surg 2021;30:2514-22. https://doi.org/10.1016/j.jse.2021.04.014.
11. Macías-Hernández SI, Morones-Alba JD, Miranda-Duarte A, Coronado-Zarco R, Soria-Bastida MLA, Nava-Bringas T, et al. Glenohumeral osteoarthritis: overview, therapy, and rehabilitation. Disabil Rehabil 2017;39:1674-82. https://doi.org/10.1080/09638288.2016.1207206.
12. Mook WR, Petri M, Greenspoon JA, Millett PJ. The Comprehensive Arthroscopic Management procedure for Treatment of glenohumeral osteoarthritis. Arthrosc Tech 2015;4:e435-41. https://doi.org/10.1016/j.eats.2015.04.003.
13. Morton AM, Akhbari B, Moore DC, Crisco JJ. Osteophyte volume calculation using dissimilarity-excluding Procrustes registration of archived bone models from healthy volunteers. J Orthop Res 2020;38:1307-15. https://doi.org/10.1002/jor.24569.
14. Rodriguez-Elizalde S, Yeager AM, Ravi B, Lipman JD, Salvati EA, Westrich GH. Computerized virtual surgery demonstrates where acetabular rim osteophytes most reduce range of motion following total hip arthroplasty. HSS J 2013;9:223-8. https://doi.org/10.1007/s11420-013-9337-9.
15. Samilson RL, Prieto V. Dislocation arthropathy of the shoulder. J Bone Joint Surg Am 1983;65:456-60.
16. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. https://doi.org/10.2106/jbjs.F.00226.
17. Suter T, Kolz CW, Tashjian RZ, Henninger HB, Gerber Popp A. Humeral head osteotomy in shoulder arthroplasty: a comparison between anterosuperior and inferoanterior resection techniques. J Shoulder Elbow Surg 2017;26:343-51. https://doi.org/10.1016/j.jse.2016.07.010.
18. Tetsworth K, Block S, Glatt V. Putting 3D modelling and 3D printing into practice: virtual surgery and preoperative planning to reconstruct complex post-traumatic skeletal deformities and defects. SICOT J 2017;3:16. https://doi.org/10.1051/sicotj/2016043.
19. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty 1999;14:756-60.
20. Walch G, Vezeridis PS, Boileau P, Deransart P, Chaoui J. Three-dimensional planning and use of patient-specific guides improve glenoid component position: an in vitro study. J Shoulder Elbow Surg 2015;24:302-9. https://doi.org/10.1016/j.jse.2014.05.029.
21. Wojdasiewicz P, Poniatowski A, Szukiewicz D. The role of inflammatory and anti-inflammatory cytokines in the pathogenesis of osteoarthritis. Mediators Inflamm 2014;2014, 561459. https://doi.org/10.1155/2014/561459.
22. Yushkevich PA, Piven J, Hazlett HC, Smith RG, Ho S, Gee JC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. Neuroimage 2006;31:1116-28. https://doi.org/10.1016/j.neuroimage.2006.01.015.