



Multilevel glenoid morphology and retroversion assessment in Walch B2 and B3 types

Mohammad Samim¹ · Mandeep Virk² · David Mai² · Kamran Munawar¹ · Joseph Zuckerman² · Soterios Gyftopoulos¹

Received: 18 July 2018 / Revised: 23 September 2018 / Accepted: 4 October 2018 / Published online: 17 October 2018
© ISS 2018

Abstract

Objective A major factor that impacts the long-term outcome and complication rates of total shoulder arthroplasty is the preoperative posterior glenoid bone loss quantified by glenoid retroversion. The purpose of this study was to assess if glenoid retroversion varies significantly at different glenoid heights in Walch B2 and B3 glenoids.

Materials and methods Patients with B2 and B3 glenoid types were included following retrospective review of 386 consecutive CT shoulder studies performed for arthroplasty preoperative planning. True axial CT reconstructions were created using a validated technique. Two readers independently measured the glenoid retroversion angles according to the Friedman method using the “intermediate” glenoid at three glenoid heights: 75% (upper), 50% (equator), and 25% (lower). The variances between the three levels for a given patient were calculated.

Results Twenty-nine B2 and 8 B3 glenoid types were included. There was no significant difference in variance of glenoid version among the three levels in B2 or B3 groups. The mean variance in retroversion degree between equator-lower, upper-equator, and upper-lower glenoid was -0.4 , 0.3 , and -0.2 for B2; and -0.2 , 1.9 , and 1.9 for B3 glenoid, respectively. The level of inter-reader agreement was fair to good for variance at equator-lower, and good to excellent for upper-equator and upper-lower glenoid.

Conclusions Glenoid version can be accurately measured at any level between 25 and 75% of glenoid height for Walch B2 and B3. We recommend that the glenoid equator be used as the reference to assure consistent and reliable version measurements in this group of patients.

Keywords Glenoid retroversion · Total shoulder arthroplasty · Glenohumeral osteoarthritis · Walch B2 and B3

Introduction

The glenoid implant positioning has a substantial effect on the long-term outcome and complication rates in patients with total shoulder arthroplasty (TSA) [1–3]. An improperly placed glenoid component increases the risk of loosening and the likelihood of revision surgery [4–11]. The major factor that impacts glenoid component placement is the degree of glenoid retroversion, a result of mechanical wear along the posterior glenoid typically seen in patients with primary glenohumeral osteoarthritis [12–14]. Asymmetric posterior glenoid erosion is thought to result from extended posterior subluxation of the humeral head, although it is not entirely clear whether osteoarthritis is the cause or the result of this abnormal positioning [15, 16].

In order to ensure long-term TSA survival, the glenoid implant needs to be placed in neutral version to allow for adequate seating within the glenoid bone [17]. To achieve this, surgeons often need to ream the glenoid to the depth of maximum wear, which is generally in the posterior direction but is not always

✉ Mohammad Samim
mohammad.samim@nyumc.org

Mandeep Virk
mandeep.virk@nyumc.org

David Mai
david.mai@nyumc.org

Kamran Munawar
kamran.munawar@nyumc.org

Joseph Zuckerman
joseph.zuckerman@nyumc.org

Soterios Gyftopoulos
soterios.gyftopoulos@nyumc.org

¹ Department of Radiology, Hospital of Joint Disease, 301 East 17th Street, Rm 600, New York, NY 10003, USA

² Department of Orthopedic Surgery, Hospital of Joint Disease, 301 East 17th Street, New York, NY 10003, USA

consistent and symmetric. On the other hand, excessive reaming of the glenoid results in a medialized glenoid implant which can cause penetration of the implant fixation pegs or keel through the glenoid vault [17]. Hence, the knowledge of the location and depth of maximum glenoid bone erosion, especially when it is unevenly distributed as in Walch B2 and B3 glenoids, is critical for preoperative planning.

Imaging, in particular 2D and 3D CT, play an important role in the pre-operative assessment of glenoid retroversion. While the availability of 3D CT has increased over the years, 2D CT remains the most common imaging available to assess the glenoid in the pre-operative TSA patient. There are concerns that 2D CT imaging techniques are often not accurately representing the location and degree of retroversion. For example, the most commonly used method to measure retroversion on CT, the Friedman technique [18], has the reader assess the degree of retroversion on axial images four slices below the coracoid which was thought to be at mid glenoid height when CT studies allowed for slice thickness of 5–10 mm [18, 19]. With the new scanners using sub-millimeter slices, the axial slices about the level of coracoid are not at the mid glenoid height and in an average 40-mm glenoid, there can be ten slices that may appear appropriate for measurement based on the original Friedman description. Hence measurements at this level can miss the location of maximum wear in more than 50% of cases [17–20]. Version measurements are also highly dependent on scapular orientation and rotation, patient positioning in the scanner, and orientation of the imaging slices in relation to the scapular body [17, 19, 20].

In advanced cases of primary osteoarthritis, bone erosion has been shown to be asymmetric towards the posteroinferior aspect of the glenoid [17]. This uneven distribution of bone

erosion can potentially affect the retroversion measurements depending on the height at which the glenoid version is measured. Walch et al. introduced a classification system, which was recently modified, for the glenoid morphology in cases of primary osteoarthritis based on the glenoid bone erosion pattern and humeral head position [15, 21]. The modified Walch classification is summarized in Fig. 1. Among the Walch glenoid types, B2 and B3 are the ones characterized by posterior glenoid erosion. The aim of this study was to assess if the degree of retroversion varied along the different heights of the glenoid in patients with advanced primary glenohumeral osteoarthritis in Walch B2 and B3 glenoid morphology.

Materials and methods

This study was approved by the Institutional Review Board of the Ethical Committee of our institution.

Patient collection

A total of 386 consecutive CT shoulder studies of patients with a known history of glenohumeral osteoarthritis performed for shoulder arthroplasty preoperative planning at our institution between 2013 and 2016 were retrospectively reviewed. Two musculoskeletal radiologists (M.S. and S.G.) independently selected the patients who had primary osteoarthritis with either B2 or B3 glenoid types (Fig. 1). When there was a disagreement in determining the glenoid types, the consensus decision with an orthopedic surgeon specialized in shoulder surgery (M.V.) was made to include or exclude patients. Walch classification is

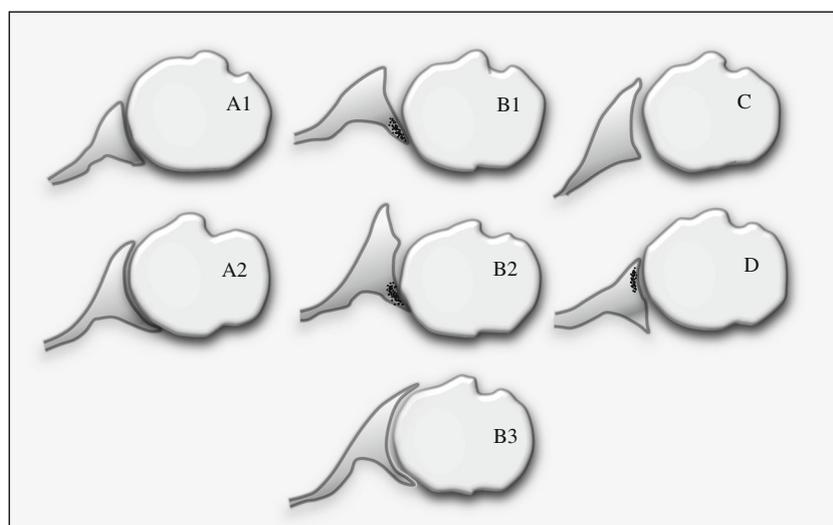


Fig. 1 Schematic representation of modified Walch classification [15, 21]: A1: centered humeral head with minor erosion; A2: centered humeral head with major central glenoid erosion (a line drawn from the anterior to posterior rims of the native glenoid transects the humeral head in contrast to the A1 glenoid); B1: posterior subluxated head with no bony erosion; B2: posterior subluxated head with posterior erosion with

biconcavity of the glenoid; B3: monoconcave and posteriorly worn glenoid with at least 15° of retroversion or at least 70% posterior humeral head subluxation, or both; C: dysplastic glenoid with at least 25° of retroversion; and D: any level of glenoid anteversion or with humeral head subluxation of less than 40%

based on primary glenohumeral osteoarthritis. Therefore, patients who had a history of prior shoulder trauma or surgery, rotator cuff arthropathy with characteristic anterosuperior glenoid bone loss owing to mechanical factors such as humeral head anteroposterior instability resulting from massive cuff tears [22], or inflammatory arthritis were excluded. Patients with CT studies that did not include the entire scapular body, a limitation for glenoid version measurement, were also excluded. The blinded image analysis and measurements were performed 4 weeks after completion of the initial patient selection.

CT imaging technique

Each CT examination was performed on a 40-slice scanner (Siemens Medical) with a protocol consisting of volumetric 0.625-mm acquisitions through the shoulder with the following parameters: 120 kV, 280 mAs, pitch 0.53, and a smooth algorithm. The appropriate field of view was selected to ensure that the entire scapular body, glenoid and humeral head

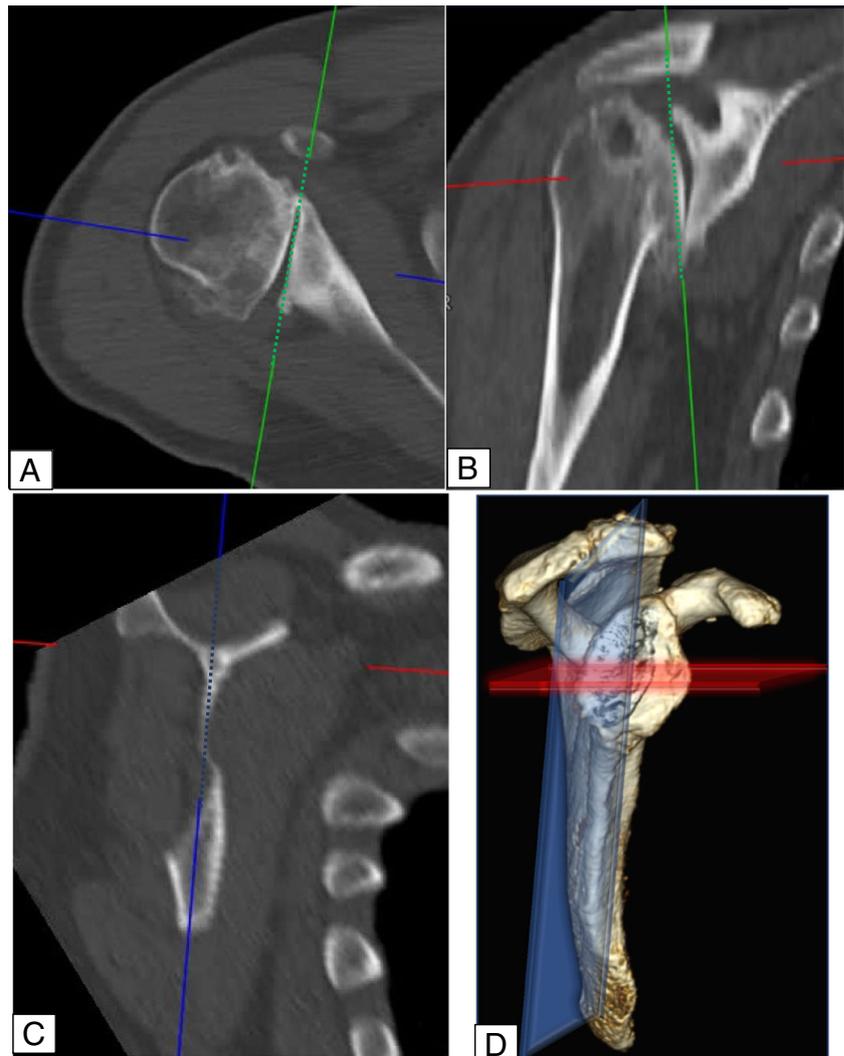
were included. The conventional axial images delivered from the technician to the picture archiving and communication system (PACS) then underwent manual segmentation, multiplanar reformatting and 3D reconstruction.

Image analysis and measurements

Creation of true axial images

The conventional axial images were manually manipulated using the imager workstation (Vitrea Enterprise 6.0 software, Vital Images, Minnetonka, MN, USA) to achieve the true axial slices taking into account the scapular rotation and axis according to the method described by Van de Bunt et al. [20]. Three 3D orthogonal views were used to correct for coronal obliquity of the scapula, medial and lateral scapular anteversion, and its craniocaudal abduction/adduction (Fig. 2). The resultant true axial images were then exported to PACS for measurements.

Fig. 2 Screenshots from the imager workstation showing multi-planar reformatting interface and how the true axial images are made correcting for scapular orientation in all three planes on a B3 glenoid. **a** On the axial slices at mid glenoid level one of the reference axes was aligned along the surface of the glenoid face (*green line*). **b** In the coronal plane, the second reference axis line was aligned to connect the superior and inferior aspects of the glenoid (*green line*). **c** In the sagittal plane the final reference axis (*blue line*) was lined up in the sagittal plane parallel to the orientation to the scapular body where the “Y” configuration of the scapula was visualized. **d** 3D volume reconstruction demonstrates the perpendicular true planes through body of the scapula and glenoid



Glenoid version measurement

The CT studies were anonymized and evaluated independently by two musculoskeletal radiologists (with 8 and 2 years of experience, respectively) blind to the patient's clinical history and prior imaging reports in a random fashion in two separate sessions, separated by 4 weeks. Glenoid version was measured using the method described by Friedman et al. [18] accepted as the current reference standard for measurement of glenoid version (Fig. 3). A line (glenoid line) was drawn from the anterior to the posterior margin of the bony glenoid, and a second line (the scapular line) from the medial border of the scapula through the measured midpoint of the glenoid line. The angle between the glenoid line and a line perpendicular to the scapular line corresponded to the glenoid version. We used the “intermediate” glenoid line, drawn from the anterior edge of the glenoid fossa to the posterior edge without considering irregularities secondary to posterior erosion or osteophytes, as it has been shown to be more accurate in determining the true glenoid version in advanced osteoarthritis [23]. The intermediate line also simulates the surface that can be obtained with minimal bone loss following conservative reaming of the glenoid surface [24].

The glenoid heights were determined based on the description made by Kraus et al. [25]. On the sagittal image at the glenoid surface, a craniocaudal axis was drawn between the most superior aspect (superior tubercle) and the most inferior aspect (inferior tubercle) of the glenoid (Fig. 4). This distance was considered the glenoid height. The glenoid was then

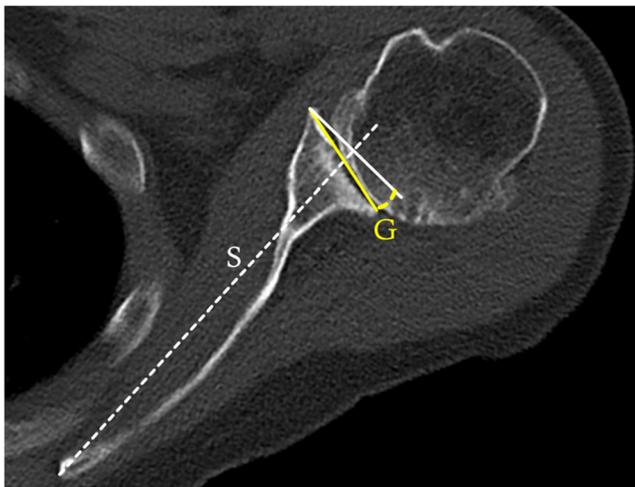


Fig. 3 Glenoid version measurement according to method described by Friedman et al. on a B2 glenoid [18]. The glenoid line (G) was drawn from the anterior to the posterior margin of the bony glenoid, and the scapular line (S) from the medial border of the scapula through the measured midpoint of the glenoid line. The angle between the glenoid line and a line perpendicular to the scapular line (white solid line) corresponded to the glenoid version. Notice the biconcave morphology and posteriorly subluxated head. The retroversion was measured 16 degrees

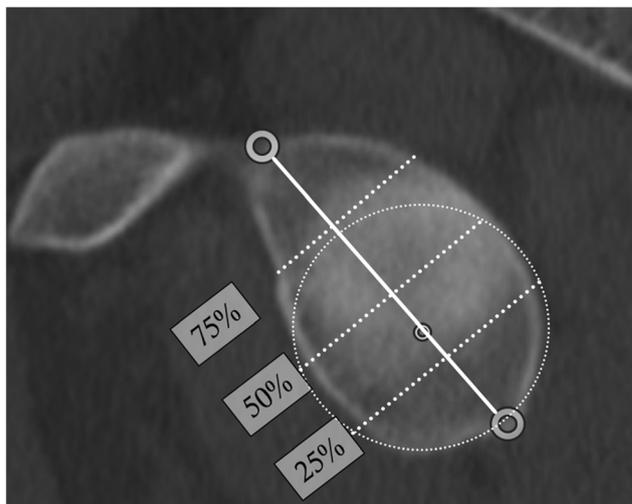


Fig. 4 Defining glenoid height according to method described by Kraus et al. [25]. On the sagittal image at the glenoid surface, a craniocaudal axis was drawn between the superior tubercle and the inferior tubercle of the glenoid. This distance was considered the glenoid height (white solid line). The glenoid was then divided into three segments based on this height: Upper, 75% of height, equator, 50%, and lower, 25% of height

divided into three equal segments based on this height: upper, 75% of height, equator, 50%, and lower, 25% of height. Measurements were made in the corresponding axial slices at these three glenoid heights. Finally, the variances between three levels for a given patient were calculated and analyzed.

Statistical analysis

An exact Mann–Whitney test was used to compare patients with different glenoid types (B2 versus B3) in terms of the difference in the glenoid version angles between different levels of glenoid. The tests were conducted using the results from each individual reader separately and using results averaged over the readers. Inter-reader agreement was assessed for each difference in terms of the concordance correlation (RC) and the intra-class-correlation (ICC) for single measures. Tests were two-sided and conducted at the 5% significance level using SAS 9.3 (SAS Institute, Cary, NC, USA).

Results

Following initial review and excluding all other more obvious glenoid types, we had 23 cases for which we had to do consensus review to determine their glenoid type. There was total of 54 B2 and B3 glenoid types following excluding other types. Subsequently, thirteen patients were excluded due to history of prior surgery or trauma and four were excluded secondary to suboptimal CT coverage. There was final total of 37 patients, 21 males and 16 females, with a mean age of

74 years old (range, 71–101 years old) who met our inclusion criteria. Their CT studies were comprised of 29 B2 and 8 B3 glenoid types. Overall there was no significant difference in variance of glenoid version among the three levels in either B2 or B3 glenoid types (Table 1). The mean variance in retroversion degree for both readers in B2 was -0.4 between equator and lower height, 0.3 between upper and equator, -0.2 between upper and lower height, and for B3 -0.2 between equator and lower height, 1.9 between upper and equator, and 1.9 between upper and lower height. The level of agreement between readers was fair to good for variance at equator-lower height (concordance correlation: 0.58), and good to excellent for upper-equator and upper-lower heights (concordance correlation 0.71 and 0.81 respectively) (Table 2).

The mean glenoid retroversion on true axial images from both reviewers for B2 glenoid was 15.7° for upper glenoid, 15.4° for the equator, and 15.9° for the lower glenoid, and for the B3 glenoid was 20.0° for upper glenoid, 18.5° for the equator, and 18.8° for the lower glenoid. The largest difference between retroversion for the B2 glenoid was seen between equator and lower glenoid (0.4 degree) and for the B3 glenoid between upper and equator glenoid (1.9 degree).

Discussion

We aimed to assess if the degree of retroversion varied along the different heights of the glenoid in patients with advanced primary glenohumeral osteoarthritis and Walch B2 and B3 glenoid morphology. Our study showed that the glenoid version can be accurately measured at any level between 25 and 75% of the glenoid height for Walch B2 and B3 types.

We chose to focus on the B2 and B3 glenoid variants as they are typically characterized by posterior glenoid erosion with biconcave and monoconcave glenoid morphology respectively, and are in most need of accurate imaging quantification before treatment [15, 21, 26]. To the best of the authors'

knowledge, this is the first study which assessed the version at multiple glenoid heights in these two glenoid types.

Our study findings contrast with some previous studies. Hoenecke et al. evaluated the accuracy of glenoid version measurement on 2D CT comparing to 3D CT and reported an average of 5.1° error in the angle measurement between 2D CT slices passing through the tip of the coracoid and the 3D CT [17]. They repeated the measurement on the CT slices 10-mm below the level of coracoid which introduced an additional mean variability of approximately 7° in version measurements and concluded that 2D CT slices were not as accurate for measurements of glenoid version. Rouleau et al. studied retroversion measurement in B2 glenoid at mid height of the glenoid using Friedman technique and the intermediate glenoid line and reported a mean retroversion angle of 25° [23].

These inconsistencies in our results and these two studies are mainly related to the differences in CT axial images used for measurements and patient population. Hoenecke et al. performed the measurements on the conventional axial CT slices which had an average of 35° angle to the scapular body [17]. This resulted in axial slices which were oblique to the glenoid clock face on the correlating sagittal image; the axial slice at the center of the glenoid would in fact connect the 2 and 8 o'clock glenoid clock face instead of 3 and 9 [17] (Fig. 5). This obliquity of axial slices was corrected in our study following three plane reconstruction using a previously validated method [20] (Fig. 5). Similarly, Rouleau et al. performed their assessment on conventional CT, which may have resulted in different mean retroversion. In addition, both studies had a heterogeneous patient population in that only part of their patients had glenohumeral osteoarthritis and there was no specific information of severity of their osteoarthritis.

Our results support the finding that the maximum wear in primary osteoarthritic glenoid occur most commonly in posteroinferior quadrant (8 and 9 o'clock) [17]. In normal individuals, the upper glenoid is more retroverted than the lower glenoid (5 – 11° on average) [27–29]. Inui et al. using

Table 1 The mean, standard deviation (SD), and median of the variances in the glenoid version angles between different levels of glenoid B2 and B3 groups

Difference	Reader	B2 (<i>n</i> = 29)			B3 (<i>n</i> = 8)			<i>P</i> value
		Mean	SD	Median	Mean	SD	Median	
Equator-lower	1	-0.14	4.09	0.00	0.88	3.80	-0.50	0.791
Equator-lower	2	-0.66	4.39	-1.00	-1.25	7.01	0.50	0.518
Equator-lower	Mean	-0.40	3.42	-1.00	-0.19	4.45	0.25	0.618
Upper-equator	1	1.00	3.34	0.00	2.63	4.47	2.50	0.337
Upper-equator	2	-0.34	7.44	0.00	1.25	4.46	0.00	0.580
Upper-equator	Mean	0.33	4.95	0.00	1.94	3.96	1.00	0.367
Upper-lower	1	0.48	5.23	0.00	2.50	5.83	4.00	0.460
Upper-lower	2	-1.00	7.41	0.00	1.25	8.17	2.00	0.253
Upper-lower	Mean	-0.26	5.80	0.00	1.88	6.56	3.00	0.270

Table 2 The concordance correlation (RC) and the intra-class-correlation (ICC) as measures of inter-reader agreement (reproducibility) for each difference

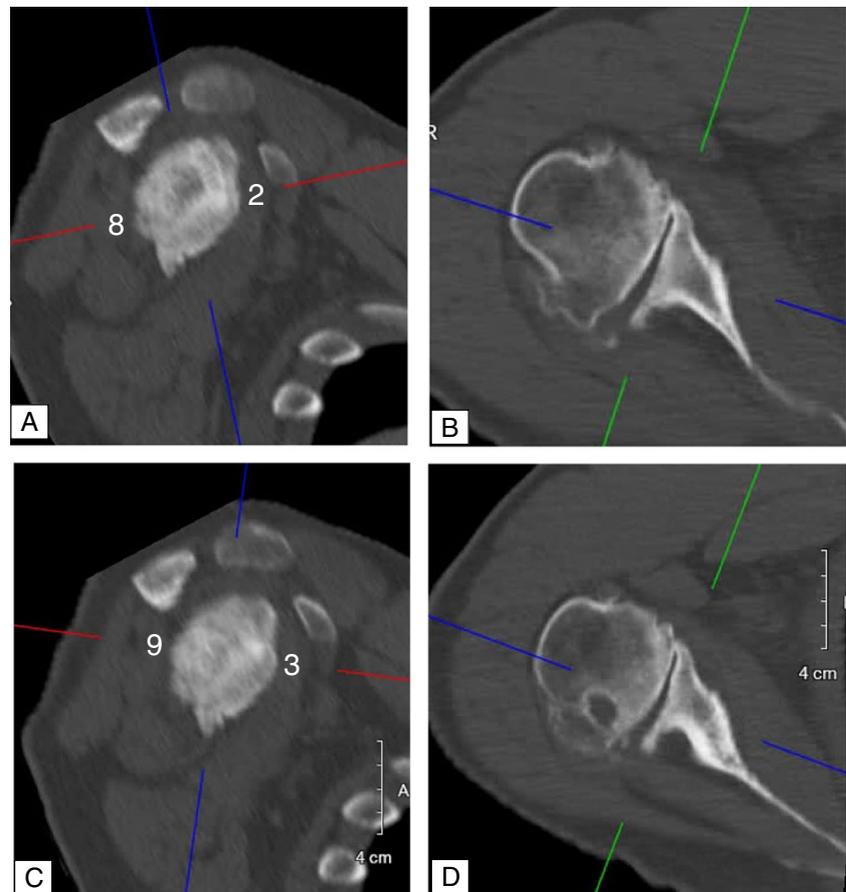
Difference	RC	ICC
Equator-lower	0.58	0.57
Upper-equator	0.71	0.63
Upper-lower	0.81	0.68

3D MRI in 40 asymptomatic individuals, found the greatest degree of retroversion in the highest level ($6.2 \pm 3.3^\circ$) and anteversion in the lowest level ($3.3 \pm 4.1^\circ$) [29]. Bouchaib et al. similarly using axial CT slices to evaluate glenoid version in three glenoid heights reported decreasing retroversion from the upper to the lower glenoid for all of their asymptomatic patients with the mean value for retroversion of 11.9, 6.8, and 4.0° for the upper, middle and lower levels, respectively [28]. Our study by showing no significant difference in the degree of retroversion from upper to lower glenoid in B2 and B3 glenoid types implies that the normal lower glenoid anteversion is lost owing to further uneven posterior wear of the lower glenoid.

The clinical implications of this study relate to the current body of literature that aims to restore glenoid version via defining more reproducible methods to assess glenoid retroversion and bone loss. Studies have indicated that 10° retroversion can be significant and should be corrected [14]. The average retroversion for both B2 and B3 glenoid in our study was above the threshold indicating surgical correction, a challenge during TSA because of reduced of glenoid bone stock and increase risk of bone perforation following excessive glenoid medialization [30]. Surgical approaches including “lowering the front”, anterior glenoid edge reaming, or “raising the back”, posterior bone grafting, can be chosen based on the scale of retroversion and bone loss [31–34]. Additionally, there is association between glenoid retroversion and humeral head subluxation [14], which if not corrected during TSA, can potentially cause abnormal stress across the prosthesis [17]. Hence, accurate knowledge of severity of glenoid bone loss is fundamental for preoperative planning.

We acknowledge that more advanced 3D reconstruction has been defined as the reference method to evaluate glenoid retroversion [19, 33, 35, 36]. The 3D models have provided valuable understanding of the scapular morphology in normal and arthritic glenoids and are becoming more popular for the preoperative

Fig. 5 A 74-year-old man with right shoulder osteoarthritis with biconcave B2 glenoid. Comparing the conventional axial and true axial slices following three planar manipulations and their orientation at the mid glenoid equator. **a, b** The conventional axial axis passes through 2 to 8 o’ clock of glenoid on corresponding sagittal image. **c, d** Following manipulation, the true axial axis passes through 3 and 9 o’ clock



planning [7]. Nevertheless, the result of our study is also applicable to 3D models since the glenoid version can also be measured in different glenoid heights on 3D model. Furthermore, 3D models are not without limitations. There is still need for a preliminary manual process to determine the reference points and scapular and glenoid planes and to perform segmentation of the scapula to define the coordinate system and position of the scapula. This process can be time consuming and since it is dependent on the operator's experience, it is still subject to inter-observer variability [20, 35, 36]. Automated 3D measurement of the glenoid version has been recently introduced [35] although it is still not widely validated, and the reliability of the reference planes defined with the automated method has been questioned [37, 38]. Finally, whether 3D models can translate into better clinical outcomes still needs to be proven.

Limitations

This study has several limitations including the retrospective nature of the study and small sample. We did not exhaustively explore the variabilities in the measurement process such as variability in slice selection or selection of reference points between the reviewers. These variabilities in addition to the fact that our study subjects were in advanced stages of glenohumeral osteoarthritis with severe bony erosions, osteophytes and labral calcification which make identification of landmarks challenging, may have contributed to the differences in angle measurements between the two readers. Studies with healthy participants have shown higher inter-reader correlation compared with studies with more advanced arthritic joints, as seen in the Scalise et al. [39, 40] and Kwon et al. [36] results. Nonetheless, the outcome of no substantial difference in glenoid retroversion in different glenoid heights was consistent between readers.

Conclusions

This study showed that glenoid version can be accurately measured at any level between 25 and 75% of the glenoid height for Walch B2 and B3 types on true axial CT images. We recommend that the glenoid equator be used as the reference in order to assure consistent and reliable version measurements in this group of patients.

Compliance with ethical standards

Disclosure None of the authors has any disclosure.

IRB An appropriate institutional review board approved the study.

Conflict of interest The authors declare that they have no conflicts of interest.

References

- 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.
- Verborgt O, De Smedt T, Vanhees M, Clockaerts S, Parizel PM, Van Glabbeek F. accuracy of placement of the glenoid component in reversed shoulder arthroplasty with and without navigation. *J shoulder Elb Surg Elsevier.* 2011;20:21–6.
- Favard L, Katz D, Colmar M, Benkalfate T, Thomazeau H, Emily S. Total shoulder arthroplasty—arthroplasty for glenohumeral arthropathies: results and complications after a minimum follow-up of 8 years according to the type of arthroplasty and etiology. *Orthop Traumatol Surg Res.* 2012;98:S41–7.
- Kasten P, Pape G, Raiss P, Bruckner T, Rickert M, Zeifang F, et al. Mid-term survivorship analysis of a shoulder replacement with a keeled glenoid and a modern cementing technique. *J Bone Joint Surg Br Bone and Joint Journal.* 2010;92:387–92.
- Edwards TB, Kadakia NR, Boulahia A, Kempf J-F, Boileau P, Némóz C, et al. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. *J Shoulder Elb Surg.* 2003;12: 207–13.
- Bohsali KI, Wirth MA, Rockwood CA. Complications of total shoulder arthroplasty. *J Bone Joint Surg Am.* 2006;88:2279–92.
- Werner BS, Hudek R, Burkhart KJ, Gohlke F. The influence of three-dimensional planning on decision-making in total shoulder arthroplasty. *J. Shoulder Elb. Surg.* 2017;26:1477–83.
- Walch G, Young AA, Melis B, Gazielly D, Loew M, Boileau P. Results of a convex-back cemented keeled glenoid component in primary osteoarthritis: multicenter study with a follow-up greater than 5 years. *J. shoulder Elb. Surg. Elsevier.* 2011;20:385–94.
- Sperling JW, Cofield RH, Rowland CM. Minimum fifteen-year follow-up of Neer hemiarthroplasty and total shoulder arthroplasty in patients aged fifty years or younger. *J. shoulder Elb. Surg. Elsevier.* 2004;13:604–13.
- Martin SD, Zurakowski D, Thornhill TS. Uncemented glenoid component in total shoulder arthroplasty. Survivorship and outcomes. *J Bone Joint Surg Am.* 2005;87:1284–92.
- Fox TJ, Cil A, Sperling JW, Sanchez-Sotelo J, Schleck CD, Cofield RH. Survival of the glenoid component in shoulder arthroplasty. *J Shoulder Elb Surg Elsevier.* 2009;18:859–63.
- Clavert P, Millett PJ, Warner JJP. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion. *J Shoulder Elb Surg Elsevier.* 2007;16:843–8.
- 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 Elb Surg Elsevier.* 2009;18:680–8.
- Farron A, Terrier A, Büchler P. Risks of loosening of a prosthetic glenoid implanted in retroversion. *J Shoulder Elb Surg Elsevier.* 2006;15:521–6.
- Walch G, Badet R, Boulahia A, Houry A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. *J Arthroplast.* 1999;14:756–60.
- Lanzzone R, Carbone S, Albino P, Cassio J-B, Métais P. Retroverted glenoid reconstruction using glenoid plate in reverse shoulder arthroplasty. *Musculoskelet Surg.* 2017;101:121–7.
- Hoenecke HR, Hermida JC, Flores-Hernandez C, D’Lima DD. Accuracy of CT-based measurements of glenoid version for total shoulder arthroplasty. *J Shoulder Elb Surg.* 2010;19:166–71.

18. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. *J Bone Joint Surg Am.* 1992;74:1032–7.
19. Bryce CD, Davison AC, Lewis GS, Wang L, Flemming DJ, Armstrong AD. Two-dimensional glenoid version measurements vary with coronal and sagittal scapular rotation. *J Bone Joint Surg Am.* 2010;92:692–9.
20. Van de Bunt F, Pearl ML, Lee EK, Peng L, Didomenico P. Glenoid version by CT scan: an analysis of clinical measurement error and introduction of a protocol to reduce variability. *Skelet Radiol* 2015;44:1627–1635.
21. Bercik MJ, Kruse K, Yalozis M, Gauci M-O, Chaoui J, Walch G. A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. *J Shoulder Elb Surg.* 2016;25:1601–6.
22. Eajazi A, Kussman S, LeBedis C, Guermazi A, Kempel A, Jawa A, et al. Rotator cuff tear arthropathy: pathophysiology, imaging characteristics, and treatment options. *Am J Roentgenol Am Roentgen Ray Soc.* 2015;205:W502–11.
23. Rouleau DM, Kidder JF, Pons-Villanueva J, Dynamidis S, Defranco M, Walch G. Glenoid version: how to measure it? Validity of different methods in two-dimensional computed tomography scans. *J Shoulder Elb Surg.* 2010;19:1230–7.
24. Denard PJ, Walch G. Current concepts in the surgical management of primary glenohumeral arthritis with a biconcave glenoid. *J Shoulder Elb Surg.* 2013;22:1589–98.
25. Kraus TM, Graveleau N, Bohu Y, Pansard E, Klouche S, Hardy P. Coracoid graft positioning in the Latarjet procedure. *Knee Surg Sports Traumatol Arthrosc.* 2016;24:496–501.
26. Chan K, Knowles NK, Chaoui J, Gauci M-O, Ferreira LM, Walch G, et al. Characterization of the Walch B3 glenoid in primary osteoarthritis. *J Shoulder Elb Surg.* 2017;26:909–14.
27. Lewis GS, Armstrong AD. Glenoid spherical orientation and version. *J Shoulder Elb Surg.* 2011;20:3–11.
28. Bouchaib J, Clavert P, Kempf J-F, Kahn J-L. Morphological analysis of the glenoid version in the axial plane according to age. *Surg Radiol Anat.* 2014;36:579–85.
29. Inui H, Sugamoto K, Miyamoto T, Machida A, Hashimoto J, Nobuhara K. Evaluation of three-dimensional glenoid structure using MRI. *J Anat.* 2001;199:323–8.
30. Hoenecke HR, Hermida JC, Dembitsky N, Patil S, D’Lima DD. Optimizing glenoid component position using three-dimensional computed tomography reconstruction. *J Shoulder Elb Surg.* 2008;17:637–41.
31. 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 Elb Surg Mosby.* 2017;26:1844–53.
32. Edwards TB, Boulahia A, Kempf J-F, Boileau P, Némóz C, Walch G. Shoulder arthroplasty in patients with osteoarthritis and dysplastic glenoid morphology. *J Shoulder Elb Surg.* 2004;13:1–4.
33. Scalise JJ, Codsí MJ, Bryan J, Brems JJ, Iannotti JP. The influence of three-dimensional computed tomography images of the shoulder in preoperative planning for total shoulder arthroplasty. *J Bone Joint Surg Am.* 2008;90:2438–45.
34. Neyton L, Walch G, Nové-Josserand L, Edwards TB. Glenoid corticocancellous bone grafting after glenoid component removal in the treatment of glenoid loosening. *J. Shoulder Elb Surg.* 2006;15:173–9.
35. Boileau P, Cheval D, Gauci M-O, Holzer N, Chaoui J, Walch G. Automated three-dimensional measurement of glenoid version and inclination in arthritic shoulders. *J Bone Joint Surg Am.* 2018;100:57–65.
36. Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. *J Shoulder Elb Surg.* 2005;14:85–90.
37. 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 Elb Surg.* 2015;24:302–9.
38. Gauci MO, Boileau P, Baba M, Chaoui J, Walch G. Patient-specific glenoid guides provide accuracy and reproducibility in total shoulder arthroplasty. *Bone Joint J.* 2016; 98–B:1080–5.
39. Scalise JJ, Codsí MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. *J Shoulder Elb Surg.* 2008;17:487–91.
40. Scalise JJ, Bryan J, Polster J, Brems JJ, Iannotti JP. Quantitative analysis of glenoid bone loss in osteoarthritis using three-dimensional computed tomography scans. *J Shoulder Elb Surg.* 2008;17:328–35.