



# Three-dimensional characterization of the anteverted glenoid (type D) in primary glenohumeral osteoarthritis

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**Background:** The Walch classification describes glenoid morphology in primary arthritis. As knowledge grows, several modifications to the classification have been proposed. The type D, a recent modification, was defined as an anteverted glenoid with or without anterior subluxation. Literature on the anteverted glenoid in primary osteoarthritis is limited. The purpose of this study, therefore, was to analyze the anatomic characteristics of the type D glenoid on radiographs and computed tomography (CT).

**Methods:** The shoulder arthroplasty databases from 3 institutions were examined to identify patients with primary glenohumeral osteoarthritis and glenoid anteversion ( $\geq 5^\circ$ ), with or without anterior subluxation. The type D study cohort consisted of 18 patients (3% of the osteoarthritis cohort) and was a mean of 70 years old, with 11 women and 7 men. All radiographs were reviewed, and computed tomography Digital Imaging and Communications in Medicine (National Electrical Manufacturers Association, Rosslyn, VA, USA) data were analyzed on validated 3-dimensional imaging software. Rotator cuff fatty infiltration, glenoid measurements (anteversion and inclination), and humeral head subluxation according to the scapular plane were determined.

**Results:** In the study cohort, the mean glenoid anteversion was  $12^\circ$  (range,  $5^\circ$ - $24^\circ$ ), the mean inclination was  $0^\circ$ , and the mean anterior subluxation was 38% (range, 6%-56%). Eight patients (44%) had a biconcave glenoid with a posterosuperiorly positioned paleoglenoid and an anteroinferiorly positioned neoglenoid, and 10 patients had a monoconcave glenoid. Fatty infiltration of the rotator cuff muscles never exceeded Goutallier stage 2.

**Conclusion:** The type D glenoid is an addition to the original Walch classification and is characterized by glenoid anteversion ( $\geq 5^\circ$ ), anteroinferior humeral head subluxation, and absence of severe subscapularis fatty infiltration.

The Conseil d'Orientation Scientifique, Ramsay Générale de Santé Comité d'Éthique—Institutional Review Board approved this study (IRB No.: COS-RGDS-2018-04-002-Avis IRB-WALCH-G).

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**Level of evidence:** Anatomy Study; Imaging

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**Keywords:** Shoulder osteoarthritis; glenoid; Walch classification; shoulder arthroplasty; reverse arthroplasty; anteverted glenoid

Walch et al<sup>2,17,18</sup> classified glenoid morphology in primary osteoarthritis of the shoulder in 1999. Initially, 5 types were described on the axial plane from a 2-dimensional (2D) computed tomography (CT) scan. The initial classification, which was based on glenoid pathomorphology and humeral head subluxation, included A1: centered humeral head, minor erosion; A2: centered humeral head, major central erosion; B1: posterior subluxation of the humeral head, no bony erosion; B2: posterior subluxation of the humeral head, posterior erosion with biconcavity of the glenoid; and C: dysplastic glenoid with at least 25° of retroversion not caused by erosion.<sup>2,17,18</sup>

The Walch classification has recently been modified using more reliable 3D CT reconstructions.<sup>3,5</sup> The 3D reconstructions provide corrected axial 2D images that are precisely in the plane of the scapula, regardless of patient positioning, allowing for more accurate assessments of version and subluxation. The proposed modifications include new subtypes B3 and D (Fig. 1). The type D was initially defined as an anteverted glenoid, with or without osteoarthritis-related anterior humeral head subluxation of less than 40%. Recent publications by Jacxsens et al<sup>8,9</sup> using 3D reconstructions and measurements reported normal subluxation ranging between 55% and 45%, modifying the threshold of 40% initially published.

Literature on the anteverted glenoid in primary osteoarthritis limited, and thus, the anatomic characteristics and the threshold value for pathologic anteversion are not well

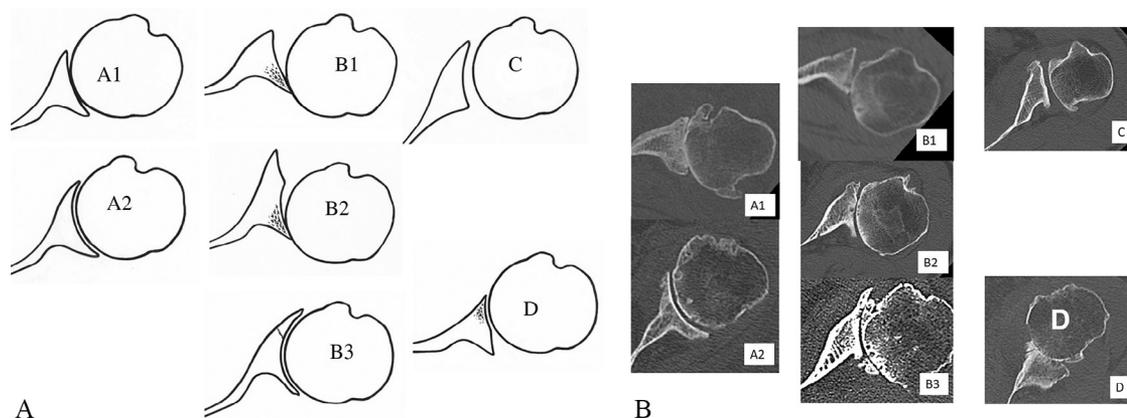
established. This study analyzed the anatomic characteristics, including glenoid version, inclination, humeral head subluxation, and rotator cuff muscle fatty infiltration of the type D glenoid, on radiographs and computed tomography (CT) using validated medical imaging software.

## Materials and methods

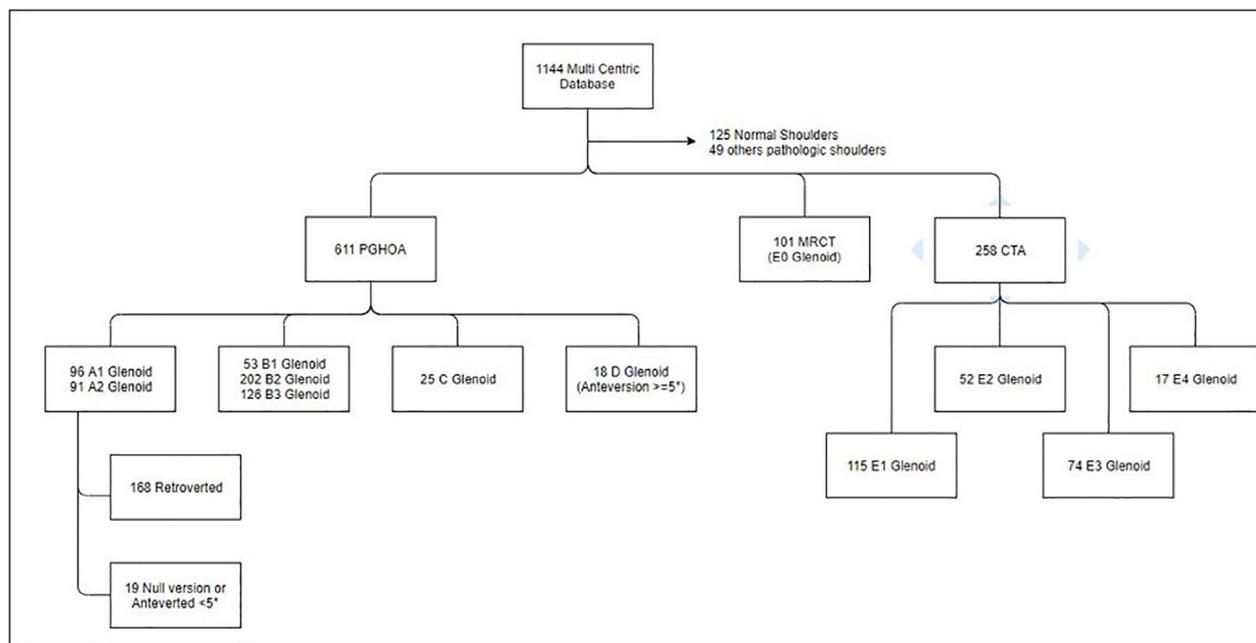
### Patients

The shoulder arthroplasty databases from 3 institutions (Lyon and Nice, France, and London, ON, Canada) are the base of this study (Fig. 2). Among the 1144 CT scans available, our database included 125 CTs of normal individuals (48 men and 77 women) with no identifiable shoulder pathology and no history of shoulder pain who were a mean age of  $54 \pm 19$  years (52 left and 73 right shoulders). The patients in the normal cohort were aged older than 18 years without an upper age limit, and all patients gave their informed consent. The CT scans included the entire scapula. Exclusions from the normal CT cohort included any history, symptoms, or imaging findings consistent with rotator cuff pathology, instability, trauma, or arthritis. Shoulders were also excluded if any of these findings were positive for even the contralateral shoulder.

There were 611 cases classified as primary osteoarthritis. Each CT scan was classified according to the modified Walch classification by 2 experienced surgeons (M.O.G. and G.W.), and all patients with glenoid anteversion were identified. In this database, the average version of the 96 A1 glenoids was  $-6^\circ \pm 6^\circ$  (range,  $+4^\circ$  to  $-21^\circ$ ), whereas the average version of the 125 normal shoulders was



**Figure 1** The modified Walch classification of glenoid erosion is shown in (A) a representative medical illustration and (B) in an axial computed tomography scan slices. The Walch classification: A1: centered humeral head, minor erosion; A2: centered humeral head, major central erosion; B1: posterior subluxation of the humeral head, no bony erosion; B2: posterior subluxation of the humeral head, posterior erosion with biconcavity of the glenoid; B3: posterior subluxation of the humeral head >70% and a monoconcave erosion of the glenoid; C: dysplastic glenoid with at least 25° of retroversion not caused by erosion; and D: glenoid anteversion  $\geq 5^\circ$  with or without anterior subluxation <45%.



**Figure 2** Flowchart of our database. Among a series of 1144 computed tomography scans, there were 125 normal shoulders, 611 with primary glenohumeral osteoarthritis (PGHOA), 96 A1 glenoids (19 with glenoid anteversion between 0° and 4°) and 18 type D glenoids (3% of all primary osteoarthritis). MRCT, massive rotator cuff tear; CTA, computed tomography arthrography.

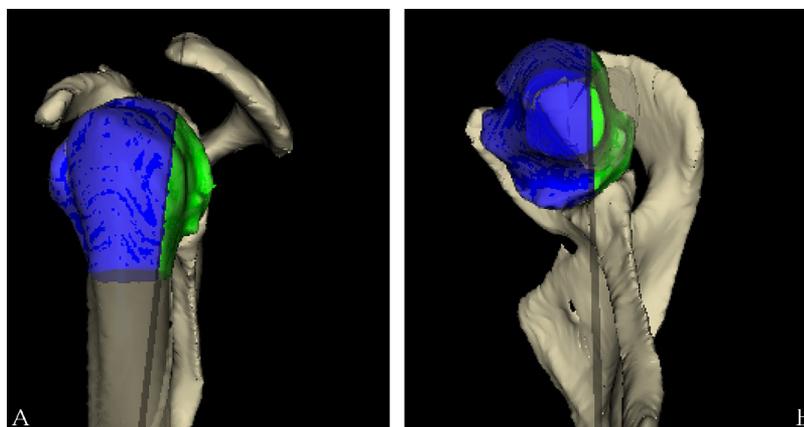
**Table I** The type D study cohort of 18 patients with 3-dimensional measurements, epidemiologic characteristics and computed tomography and radiographic appearances

Patient	Sex	Age (yr)	Anteversion (°)	Inclination (°)	Subluxation (%)	Fatty infiltration			Morphology on		Side
						Sscap	Sspin	Ispin	CT scan	X-ray image	
1	F	77	6	-2	35	2	2	1	Biconcave	Biconcave	Left
2	F	74	11	+4	49	1	1	1	Biconcave	Biconcave	Right
3	M	82	9	+21	45	1	2	1	Monocave	Monocave	Left
4	F	69	13	+15	36	0	1	1	Monocave	Monocave	Left
5	F	62	9	-5	49	1	1	1	Monocave	Monocave	Left
6	M	63	11	+2	44	2	1	1	Monocave	Monocave	Left
7	F	85	24	-6	15	2	2	2	Monocave	Biconcave	Left
8	M	63	8	+9	40	2	1	1	Monocave	Monocave	Left
9	F	66	7	+11	49	1	1	1	Biconcave	Biconcave	Right
10	F	80	24	-5	6	2	2	2	Biconcave	Biconcave	Left
11	F	58	6	+6	48	0	0	0	Monocave	Monocave	Left
12	M	53	5	-9	41	0	0	0	Biconcave	Biconcave	Right
13	M	71	7	+12	32	0	0	0	Biconcave	Biconcave	Left
14	F	69	21	-11	22	1	2	2	Biconcave	Biconcave	Right
15	F	72	16	+12	20	1	0	1	Monocave	Monocave	Right
16	M	64	23	-5	19	1	1	1	Monocave	Monocave	Left
17	F	72	11	-2	56	1	1	0	Monocave	Monocave	Right
18	M	73	7	+7	47	1	1	1	Biconcave	Biconcave	Left

Sscap, subscapularis; Sspin, supraspinatus; Ispin, infraspinatus; CT, computed tomography; F, female; M, male.

-7 ± 5° (range, +6° to -18°). To avoid a potential overlap with the A1 subtype and normal shoulders, we selected only individuals with ≥5° anteversion, irrespective of the subluxation percentage. As such, 19 patients with glenoid anteversion between 0° and 4° were excluded. Patients with arthritis secondary to previous surgery, massive rotator cuff tear, cuff tear arthropathy, inflammatory arthritis, instability arthropathy, and post-traumatic arthritis were excluded.

The type D study cohort consisted of 18 patients (11 women and 7 men; Table I). There were 12 left shoulders and 6 right shoulders. The cohort was an average age of 70 years (range, 53-85). All patients had CT scans with complete Digital Imaging and Communications in Medicine (DICOM; National Electrical Manufacturers Association, Rosslyn, VA, USA) data as well as standard shoulder radiographs that were performed under



**Figure 3** Humeral head subluxation percentage was calculated by dividing the 3-dimensional volumetric portion of the humeral head posterior to the scapular plane (green) by the whole volume of the humeral head. (A) A sagittal view of a type D glenoid in a left shoulder with the black — representing the scapular plane. (B) The same shoulder from an inferior vantage point with 17% of the humeral head posterior to the scapular plane (17% subluxation).

fluoroscopic control, including anteroposterior (AP) views with a double obliquity beam.

## Analysis

The type D morphologic analysis was conducted on validated 3D imaging Glenosys software (Imascap, Brest, France).<sup>4,5,10,15,19</sup> The CT DICOM data were uploaded to the Glenosys software program, which allows automated segmentation of the humerus and scapula, definition of scapular planes, and determination of glenoid version, inclination, and humeral head subluxation. The version angle is automatically computed as the angulation between the scapular plane and the glenoid best-fit sphere centerline projected on the transverse scapular plane. Because the method uses all of the points of the scapula and glenoid, there is no need to manually define any point on the 3D models.

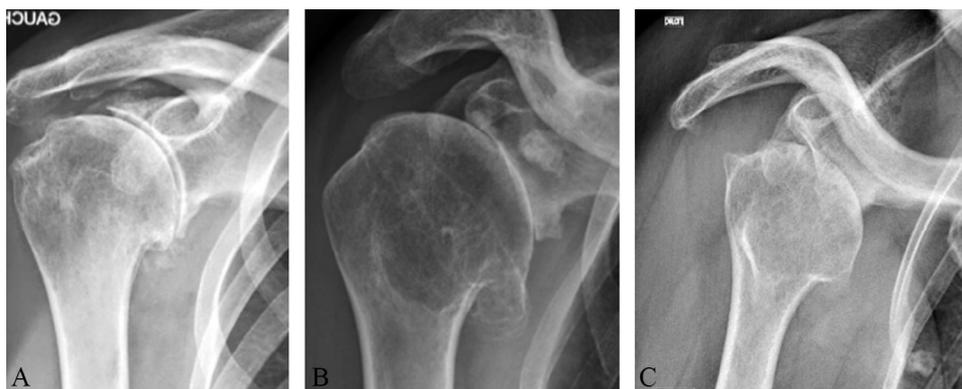
The inclination is measured on the basis of the transverse line that runs through the supraspinatus fossa between the trigonum scapulae and the middle of the glenoid vault. This line is also detected automatically. The inclination angle is defined as the angle between

the transverse line and the glenoid plane projected on the scapular plane.

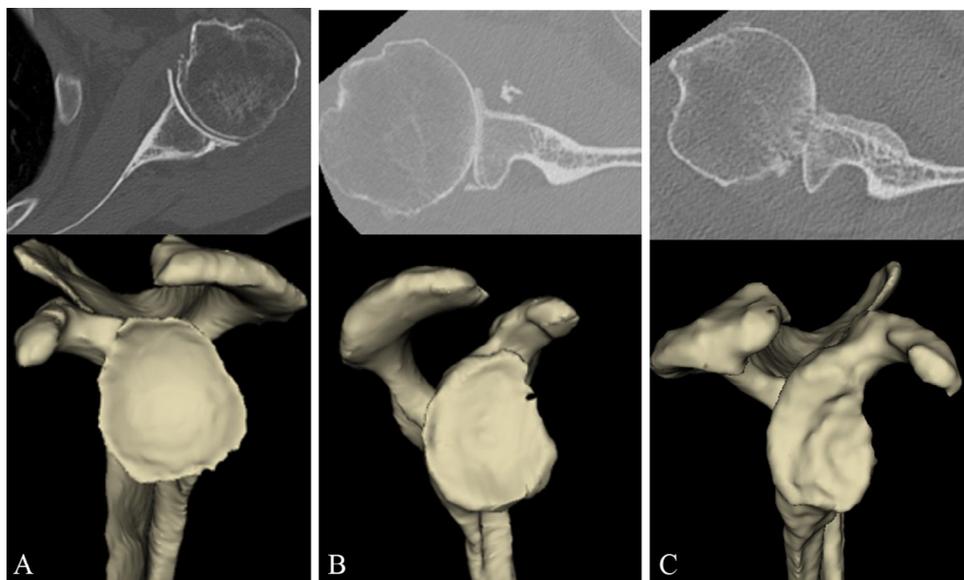
The percentage of humeral head subluxation according to the scapular plane was calculated by dividing the 3D posterior volumetric portion of the humeral head by the whole volume of the humeral head (Fig. 3). For example, humeral head subluxation in a perfectly centered head is 50% because half of the humeral head is posterior to the scapular plane. Anterior subluxation was defined as less than 45% according to the recently published threshold.<sup>8,9,11,16</sup> This 3D measurement eliminates the variability in 2D axial slice selection.

Fatty degeneration of the rotator cuff musculature was graded according to the 5 stages of Goutallier et al.<sup>7</sup> The stages include stage 0, normal muscle without any fatty streaking; stage 1, the muscle contains some fatty streaks; stage 2, marked fatty infiltration, but there is more muscle than fat; stage 3, there is as much fat as muscle; and stage 4, there is more fat than muscle.<sup>7</sup>

Standard shoulder radiographs in the AP direction were analyzed to assess the position of the humeral head with respect to the scapula and the glenoid (Fig. 4). The morphology of the glenoid articular surface was assessed on the 2D axial series of images created



**Figure 4** Standard anteroposterior radiographs of type D glenoids shows (A) a monoconcave appearance of the glenoid, (B) slight anteroinferior subluxation of the humeral head with absence of contact between the head and the superior part of the glenoid, and (C) severe anteroinferior subluxation of the humeral head.



**Figure 5** Appearance of type D glenoids on 2-dimensional (top row) and 3-dimensional (bottom row) computed tomography scans: (A) monoconcave appearance, (B) biconcave with slight anteroinferior biconcave appearance; (C) severe biconcavity with an anteroinferiorly positioned neoglenoid.

by the software after reformatting in the plane of the scapula (Fig. 5). The glenoid morphology was also examined in the coronal plane on standard AP shoulder radiographs in neutral rotation. Finally, the type D cohort was compared with other Walch subtypes in the database of primary glenohumeral osteoarthritis to determine whether there are any statistically significant differences in glenoid metrics.

## Statistics

The values for the quantitative variables are expressed as means, medians, and ranges. The values for the qualitative variables are expressed as a number of patients per group and frequency (%). Comparisons were assessed using the Fisher exact or  $\chi^2$  test for categorical variables and the paired Student test or the Wilcoxon rank signed test for quantitative variables. Correlations were assessed using the Spearman or Pearson correlation coefficient for quantitative variables. Linear regression analyses were performed between glenoid measurements (anteversion, inclination, and subluxation) and the qualitative criteria (muscle fatty infiltration, CT scan and radiographic morphologies, and side involved). Statistical analyses were performed with SAS 9.4 software (SAS Institute Inc., Cary, NC, USA). Significance was evaluated by calculating the *P* value and was set at *P* < .05.

## Results

In the type D cohort, the mean glenoid anteversion was 12° (range, 5°-24°) and the mean glenoid inclination was 3° (range, -11° to +21°). Eight patients had inferior inclination at a mean of -6° (range, -2 to -11°), and 10 patients had superior inclination at a mean of +10° (range, +2° to +21°). The average anterior subluxation was 38% (range, 6%-56%).

On the axial slices of the CT scan, 8 patients (44%) had a biconcave glenoid articular surface with the paleoglenoid positioned posterosuperiorly and the neoglenoid positioned anteroinferiorly (Fig. 5). Ten patients (56%) had a monoconcave morphology. The assessment of glenoid morphology on standard AP shoulder radiographs in neutral rotation identified 9 patients (50%) with a monoconcave morphology and 9 (50%) with biconcavity (Fig. 4). The biconcave aspect was defined by the presence of an intact glenoid surface at the superior part of the joint with humeral head subluxation inferiorly and medially creating a second concavity in the coronal plane (Fig. 4).

Fatty infiltration of the subscapularis muscle was stage 0 in 4 patients (22%), stage 1 in 9 patients (50%), and stage 2 in 5 patients (28%). Fatty infiltration in the supraspinatus was stage 0 in 4 patients (22%), stage 1 in 11 patients (61%), and stage 2 in 3 patients (17%). For the infraspinatus, the fatty infiltration was stage 0 in 4 patients (22%), stage 1 in 11 patients (61%), and stage 2 in 3 patients (17%).

## Correlations

There were no statistically significant differences between men and women regarding age (*P* = .62), side involved (*P* = .15), and axial morphology on CT scan (*P* = .32), and coronal morphology on AP radiographs (*P* = .62), muscle fatty infiltration (*P* = .33) and all glenoid measurements (*P* > .50).

Fatty infiltration of the subscapularis muscle was not correlated with any 3D measurement of anteversion, inclination, or subluxation. We found a strong correlation between anteversion and subluxation (*P* < .0001) and a tendency to have a lower superior inclination when the anteversion increases

**Table II** Statistical comparison of humeral head subluxation, glenoid version, and glenoid inclination between type D and the other glenoid types in the database

	Number of shoulders	Average Inclination $\pm$ SD	Average Version $\pm$ SD	Average Subluxation% $\pm$ SD
<b>Normal cohort</b>	125	11 $\pm$ 5	-6 $\pm$ 5	59 $\pm$ 9
<b>A1</b>	96	8 $\pm$ 6	-6 $\pm$ 6	61 $\pm$ 9
<b>A2</b>	91	8 $\pm$ 9	-7 $\pm$ 5	62 $\pm$ 9
<b>B2</b>	202	8 $\pm$ 8	-22 $\pm$ 8	83 $\pm$ 8
<b>B3</b>	126	5 $\pm$ 8	-20 $\pm$ 8	78 $\pm$ 9
<b>D</b>	18	3 $\pm$ 9	12 $\pm$ 7	36 $\pm$ 14
<b>p</b>		< 0.0001	< 0.0001	a=0.551 b,c,d=0.0462 e=0.0068

( $P = .08$ ). There was no correlation between inclination and subluxation. CT scan and radiographic morphologies were not correlated with age, sex, side, anteversion, inclination, or subluxation.

Comparisons of the type D cohort to other Walch subtypes in the database of primary glenohumeral osteoarthritis determined that the type D group had statistically different values ( $P < .05$ ) of inclination, version, and humeral head subluxation (Table II).

## Discussion

The type D glenoid is an addition to the original Walch classification<sup>2,17,18</sup> and has been described as a glenoid with anteversion with or without anterior humeral head subluxation.<sup>3</sup> Analyzing a population of 611 primary glenohumeral osteoarthritis patients in a database of CT scans performed before shoulder arthroplasty, we found 19 with an anteversion between  $+1^\circ$  and  $+4^\circ$ , which were initially classified as type A1. The database includes 96 type A1 patients for which the average retroversion was  $6^\circ \pm 6^\circ$ . To avoid an overlap between types D and A1 we decided to modify the threshold and arbitrarily set the limit at  $+5^\circ$  anteversion to define the type D glenoid.

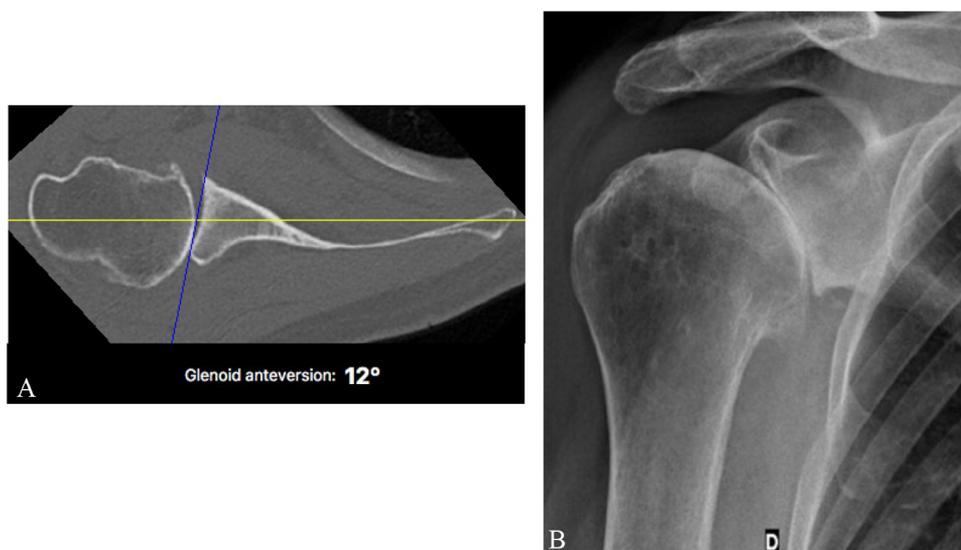
In addition to version, humeral head subluxation of less than 40% was another criterion used to define the new type D.<sup>3</sup> According to the recent literature, the subluxation threshold has been modified to 45% instead of 40%.<sup>8,9</sup> The use of subluxation in the type D is analogous to the use of posterior subluxation in the definition of type B glenoids. When assessing anterior humeral head subluxation on the CT-based imaging software, interestingly, we found only 61%

of our cases fell within the strict definition of anterior subluxation (<45%). The other cases in the type D cohort had subluxations between 45% and 56%.

A careful analysis of each case demonstrated that how the patient was positioned for the CT scan might have influenced the subluxation percentage. In some cases, patients positioned supine autocorrected their anterior subluxation to neutral, because gravity lying supine brought the humeral head posterior. This indicates that in some cases, the anterior subluxation is dynamic rather than static, or at least not a fixed subluxation. When assessing the AP shoulder radiographs done with the patients standing, the humeral head subluxation was more apparent (Fig. 6). The anterior humeral head subluxation on AP radiographs is recognized by the inferior glenohumeral joint overlap of the humeral head and the glenoid (Fig. 4, c).

As such, the assessment of anterior subluxation of a type D glenoid should be conducted not only on a CT scan obtained with the patient positioned supine but also on a standard AP radiograph (double obliquity views done under fluoroscopic control). Therefore, anterior subluxation of <45% measured on a supine CT scan should not be considered as an absolute parameter for the definition of a type D.

In the Walch type B, subluxation of the humeral head can produce a biconcavity (B2) or present as a monoconcavity (B1 and B3). Similarly, the type D with anterior subluxation can produce a biconcavity or a monoconcavity deformity. Initially, consideration was given to defining both a D1 and a D2 glenoid based on monoconcavity vs. biconcavity. Because we could not identify any substantial 3D differences in our cohort between the monoconcave and the biconcave, and given the small size of the cohort, we decided to combine all anteverted glenoids into a single category. Our database



**Figure 6** (A) The axial computed tomography scan of patient 17 shows a monoconcave anterior erosion (anteversion: 12°); however, the 3-dimensional measurement of subluxation is 56%, indicating that the anterior subluxation reduces in supine position. (B) An anteroposterior radiograph of the same patient performed in the standing position shows the humeral head subluxed anteroinferiorly.

included 611 primary osteoarthritis patients; therefore, the occurrence of the type D is relatively rare at 3%.

It is conceivable that muscular imbalance between the anterior and posterior rotator cuff or that subscapularis insufficiency or tear may lead to this asymmetric anterior glenoid erosion. The presence of subscapularis muscle fatty infiltration in primary osteoarthritis was reported, even in the absence of a rotator cuff tear, by Edwards et al<sup>6</sup> in 2002. To investigate the effect of the rotator cuff, the degree of fatty infiltration was analyzed within our cohort: 5 patients had moderate subscapularis fatty infiltration at grade 2, 9 patients had grade 1, and there were no patients with grades 3 or 4 fatty infiltration. The absence of high-grade fatty infiltration of the rotator cuff muscles in our series, in particular of the subscapularis, provides evidence that types D are probably not related to muscle imbalance and specially subscapularis insufficiency.

Overall, the etiology of glenoid anteversion is unknown. In our cohort, we carefully excluded all patients with a previous history of an isolated subscapularis tear or anterior dislocation (instability arthropathy), and none of our patients recalled any traumatic event before the beginning of their shoulder problems. As such, it is difficult to conclude whether some degree of static anteroinferior humeral head subluxation in the standing position leads to the secondary asymmetric anterior erosion.

The literature has demonstrated that the orientation of the glenoid component in anatomic total shoulder arthroplasty is important. That excessive retroversion of the all-polyethylene glenoid component can lead to recurrent posterior translation, instability, and implant failure is well known. The literature on anterior instability and glenoid component anteversion is not as robust; however, similar themes to posterior instability are developing. Matsoukis et al<sup>12,13</sup> reported that

the rate of postoperative prosthetic anterior dislocation was higher in a group of patients with a history of anterior dislocation: in their series, 4 patients (7%) sustained a postoperative anterior dislocation. The authors also reported 4 patients (36%) with recurrent anterior instability among a series of 11 patients with fixed anterior dislocations operated on with an anatomic prosthesis.

Overall, anterior shoulder instability after an anatomic total shoulder arthroplasty is usually associated with some combination of subscapularis muscle or tendon insufficiency or glenoid malpositioning in anteversion.<sup>1,14</sup> As such, the identification of the type D glenoid with an anteverted orientation is important, because surgical measures can be taken to correct the anteversion by eccentric posterior (high-side) reaming or by implanting a reverse shoulder arthroplasty to limit postoperative anterior instability.

This study does have limitations because it is a retrospective study involving a small number of patients with a very rare pathoanatomy. Also, only the glenoid was studied; therefore, associated changes to the humeral anatomy or torsion are unknown. The humerus could not be studied because most routine shoulder CT scans do not include the elbow epicondyles for humeral torsion calculation. However, all patients in our type D cohort had a complete clinical record, shoulder radiographs, and a shoulder CT scan.

It is also possible that establishing the cutoff at  $\geq 5^\circ$  anteversion led us to eliminate the 19 individuals with  $0^\circ$  to  $4^\circ$  anteversion that could be part of this study.

In addition, it would have been interesting to compare our type D cohort to a control group of patients with previous anterior instability. However, the preoperative anterior instability group in our database is too heterogenous because of the previous surgical procedures that affect the glenoid (Bankart repair, bony Bankart repair, Latarjet procedure, etc).

## Conclusion

The type D glenoid described in this report is a more precise definition of the type D glenoid described initially by Bercik et al.<sup>3</sup> It is an addition to the modified Walch glenoid classification. The type D is characterized by glenoid anteversion ( $\geq 5^\circ$ ) and in some cases anteroinferior humeral head subluxation. Fatty infiltration of the subscapularis, with the number of individuals available in our series, does not appear to be associated with anterior glenoid erosion and anteversion.

## Disclaimer

Lionel Neyton, Gilles Walch, and George Athwal are consultants for Wright Medical-Tornier Inc and receive royalties from Wright Medical. Gilles Walch is involved in the development of the Glenosys 3D software (Imascap) that was used in the present study. Pierric Deransart is employee of Imascap SAS. The other 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.

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