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ORIGINAL ARTICLE

Classification of humeral head pathomorphology in primary osteoarthritis: a radiographic and in vivo photographic analysis

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Background: The purpose of this study was to characterize the pathologic changes of the osteoarthritic humeral head.
Methods: The study included 55 patients with primary osteoarthritis who underwent anatomic shoulder arthroplasty. Several radiologic parameters (radiography, magnetic resonance imaging) were assessed. Humeral head deformity in the transverse plane and humeral cartilage erosion in the coronal plane were chosen for photographic measurements from the resected humeral heads.
Results: In the coronal plane, 82% of patients presented with an aspherical humeral head shape with a significantly longer caudal osteophyte. In the transverse plane, 50% of all patients showed a decentered apex. Patients with an aspherical humeral head shape in the transverse plane showed an aspherical humeral head shape in the coronal plane in 94% and a significantly longer osteophyte than patients with spherical humeral head shape, showing a 3-dimensional deformity of the humeral head during progression of primary osteoarthritis. Patients with an osteophyte length between 7 and 12 mm were associated with a glenoid type B2 in 30% and a decentered apex in the transverse plane in 38%. Patients with a humeral osteophyte longer than 13 mm were significantly more frequently associated with a type B2 glenoid (71%; $P < .0001$) and a decentered apex in the transverse plane in 52%.
Conclusion: It seems that the progression of primary osteoarthritis of the glenohumeral joint is characterized by an increasing 3-dimensional deformity of the humeral head related to the glenoid morphology. We therefore propose an extended Samilson-Prieto classification with type A (spherical) and type B (aspherical) and grade I-IV osteophytes.

This study was approved by the Institutional Review Board of the ATOS Clinics Heidelberg and Munich: Study No. 8/14.

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Over time, primary osteoarthritis exhibits progressive joint deformity with osseous remodeling processes and osteophyte formation. The first pathomorphologic changes of primary osteoarthritis are on the humeral side.[8,18] Although precise anatomy- and morphology-based analyses have been conducted describing these changes,[4,6,8,9,12,16] there is still no specific classification system that pertains to the degree or severity of primary osteoarthritis. Rather, the Samilson-Prieto classification for dislocation arthropathy[13] is often used in daily clinical practice.

The pathologic changes in glenoid morphology have been described in detail by Walch.[15,17] Moreover, classifications have been published regarding glenoid version[10,11] and glenoid inclination,[2] as have analyses pertaining to bone density and glenoid shape.[7,14]

This study set out to radiographically and photographically characterize the pathologic changes of the osteoarthritic humeral head and to ascertain the progression of stages from those data. In doing so, we subject the Samilson-Prieto classification for dislocation arthropathy to validation. Moreover, we test the hypothesis that the humeral changes in the coronal and transverse planes correlate with the changes in glenoid pathomorphology according to Walch.[15]

A final aim of this study was to develop a specific classification system for primary osteoarthritis on the basis of the radiologic and photographic data.

Materials and methods

Our study included 55 consecutive patients (21 women, 34 men) with a mean age of 68.7 years (range, 49-87 years) with primary osteoarthritis who underwent anatomic shoulder arthroplasty. Patients with glenoid deformity type C according to Walch[15] as well as all forms of secondary arthritis and patients with prior shoulder surgery were excluded from this study. All patients underwent preoperative clinical and radiologic examination.

Radiographic evaluation was based on standardized true anterior-posterior (AP) projections and axial radiographs as well as magnetic resonance imaging (MRI) examinations of the shoulder. A digital x-ray apparatus was used, and the images were observed and examined using a diagnostic monitor.

We recorded the following radiologic parameters: by the classification according to Samilson and Prieto,[13] shape of the humeral head in the coronal plane (either spherical or aspherical) and shifts of the apex of sphericity in the transverse plane; and according to Walch, posterior subluxation of the humeral head.[16]

The length of the caudal humeral osteophyte was measured in a cranial to caudal direction in AP projection with the forearm in a neutral position (Fig. 1, *A*). The arthritis was then classified using the system presented by Samilson and Prieto,[13] with the following categories: grade 1, <3 mm, mild osteoarthritis; grade 2, 3-6 mm, moderate osteoarthritis; and grade 3, ≥7 mm, severe osteoarthritis.

The humeral head was categorized as either spherical or aspherical in the coronal plane. Classification was performed by AP

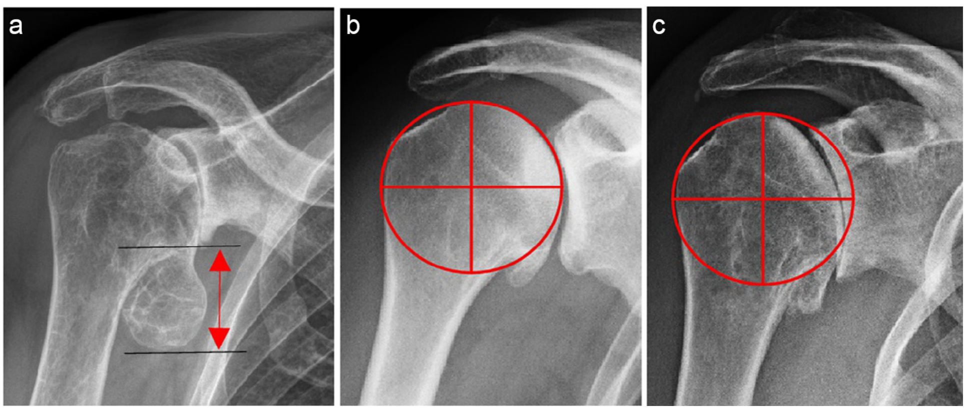

Figure 1 Humeral head measurements in the coronal plane on anterior-posterior radiographs. (**A**) Measuring the caudal humeral osteophyte on anterior-posterior image. (**B**) Spherical head shape with projection of the best-fitting circle onto the cortical boundaries of the humeral head. (**C**) Aspherical head shape. Cortical boundaries on the articular side of the humeral head are not within the confines of the best-fitting circle.

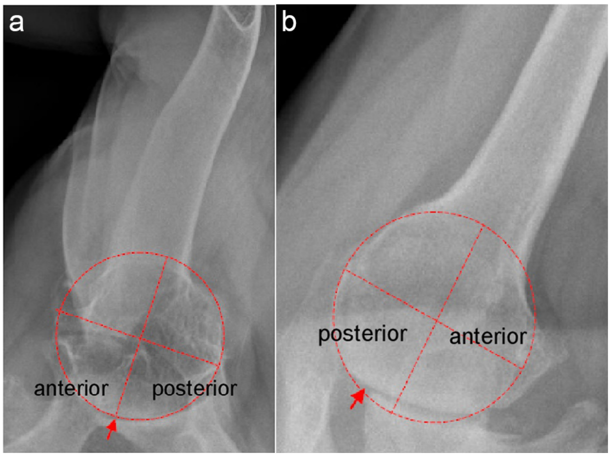

Figure 2 Humeral head apex in the transverse plane on axial view radiograph. (**A**) Example for centered apex (*arrow*). Here, the apex is in line with the center of rotation within the area of the best-fitting circle of the humeral head. (**B**) Example for decentered humeral head apex in the transverse plane. Here, the apex (*arrow*) is posteriorly decentered in relation to the center of rotation and the best-fitting circle of the humeral head.

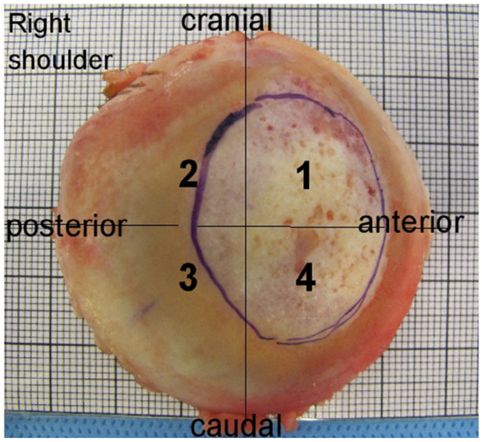

Figure 3 Humeral cartilage wear in the coronal plane. The cartilage-free erosion surfaces were measured by applying a crosshair between the anterior-posterior and cranial-caudal dimensions of the humeral head, resulting in 4 quadrants.

projection with the arm in a neutral position. For this purpose, a best-fitting circle around the center of rotation was projected onto the cortical boundaries of the humeral head (see Fig. 1, *B*). The humeral head was deemed aspherical or flattened when its boundaries on the articular side were not within the circumference of the best-fitting circle (Fig. 1, *C*).

Transverse shifts of the apex of the humeral head were calculated from preoperative axial radiographs of the shoulder. The apex is defined as the highest point of the humeral head in the transverse plane. For this purpose, a best-fitting circle around the center of rotation was projected onto the cortical boundaries of the humeral head. The apex of a round head shape is in line with the center of rotation (Fig. 2, *A*). Where the apex of the humeral head was not in line with the center of rotation, the humeral head was classified as either anteriorly or posteriorly decentered (Fig. 2, *B*).

Posterior decentering or subluxation of the humeral head was determined by analyzing preoperative axial radiographs using the method presented by Walch et al.[16] The subluxation index is defined as a/b × 100%. Humeral heads with an index of 45%-55% were classified as centered. An index of ≥55% is evidence for posterior subluxation, whereas an index of <45% suggests anterior subluxation.

Glenoid morphology was determined and classified in the respective transverse MRI layers preoperatively by the surgeon in accordance with the criteria published by Walch et al.[15] In addition, an intraoperative distinction between B1 and B2 glenoid deformity was determined by the surgeon macroscopically.

Intraoperatively, the humeral head resection was performed using a resection guide controlling the inclination and retroversion according to the bone landmarks of the anatomic neck. Humeral head height and humeral head diameter in the coronal and transverse planes were measured intraoperatively using a measuring gauge. The resected humeral head surfaces were then placed against a millimeter paper–foil grid backdrop and photographed. Photographic measurements were made using the grid in the coronal and transverse planes. The scale provided by the millimeter paper allowed the height as well as the coronal and transverse diameter of the resected humeral head to be determined. Humeral head deformity in the transverse plane and humeral cartilage erosion in the coronal plane were chosen as photographic examination parameters. Overall, intraoperative photographic imaging of the resected humeral head was adequate for evaluation of head deformity in 48 of 55 patients and evaluation of humeral cartilage erosion in 51 of 55 patients.

Maximum cartilage erosion was photographically assessed on the basis of the size of cartilage-free erosion surfaces on the humeral head, which was divided into 4 quadrants: quadrant 1, cranial-anterior; quadrant 2, cranial-posterior; quadrant 3, caudal-anterior; and quadrant 4, caudal-posterior. For this purpose, a crosshair was precisely placed centrally between the AP and superoinferior dimensions of the humeral head to allow measurement of the different quadrants as well as the area with the maximal degree of cartilage wear (Fig. 3).

To determine humeral head deformity in the transverse plane, which was analogous to radiologic assessment on the axial radiograph, we assessed the location of the apex of sphericity. For this purpose, we drew a vertical line from the midpoint of the humeral head AP diameter and perpendicular to the humeral cut line. One of 3 possible positions of the apex relative to the vertical line was noted: centered, anteriorly decentered, or posteriorly decentered (Fig. 4).

Statistical analysis was performed using SPSS 19.0 (IBM, Armonk, NY, USA) and SAS, release 9.3 (SAS Institute, Cary, NC, USA). For detecting differences within a defined group of patients, Wilcoxon signed rank test and McNemar test were used as appropriate. Mann-Whitney *U* test was performed to uncover differences between 2 groups. The level of significance was set at $P = .05$.

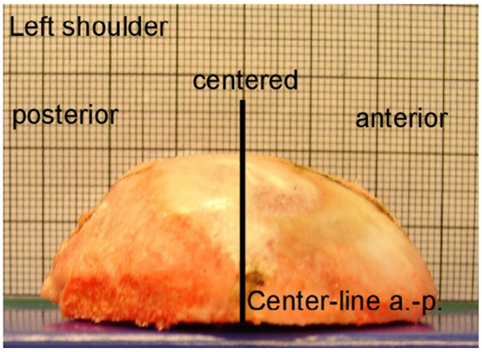

Figure 4 Position of the apex of sphericity in the transverse plane. The position of the apex was determined by drawing a vertical line to the center of the anterior-posterior (*a.-p.*) diameter and was subsequently classified as centered, anteriorly decentered, or posteriorly decentered.

Results

Humeral head morphology in the coronal plane

Applying the Samilson-Prieto classification,[13] 6.8% of patients in our cohort were classified as grade 1, 11.4% were grade 2, and 81.8% were grade 3 osteoarthritis.

Regarding humeral head shape, 17.8% were spherical in the coronal plane, with an average osteophyte length of 10.9 mm (standard deviation [SD], 6.4 mm); 82.2% of humeral heads were aspherical, with a trend ($P = .063$) for longer osteophytes (mean length, 13.8 mm; SD, 12 mm). According to the Samilson-Prieto classification, none of our patients with aspherical humeral heads were classified as grade 1, 13% were classified as grade 2 (mean osteophyte length, 5.2 mm), and 87% were classified as grade 3 (mean osteophyte length, 15.4 mm). Within this originally grade 3 group, 44.4% had an osteophyte length between 7 and 12 mm (mean, 9.4 mm), and 55.6% showed an osteophyte longer than 13 mm (mean, 20.2 mm; $P < .0001$).

Humeral head morphology in the transverse plane

The apex of sphericity in the transverse plane was centered in 50%, anteriorly decentered in 9.1%, and posteriorly decentered in 40.9% of cases. Patients with a decentered apex showed a significantly ($P = .016$) longer caudal humeral osteophyte (mean, 16.5 mm; SD, 6.2 mm) than patients with a centered apex (mean length of osteophyte, 10.2 mm; SD, 8.0 mm).

Cases with a centered apex in the transverse plane showed a spherical humeral head shape in the coronal plane in 30% and an aspherical humeral head shape in 70%. Patients with a decentered apex in the transverse plane showed an aspherical humeral head shape in the coronal plane (94%) significantly ($P = .049$) more often than a spherical humeral head shape (6%).

Humeral cartilage wear pattern

Our photographic analysis using the quadrant system revealed that the maximal cartilage erosion occurred in 75% of the cases in the caudal half of the humeral head (caudal-anterior, 43.8% [n = 24]; caudal-posterior, 31.3% [n = 15]) and in only 25% of the cases in the cranial half (cranial-anterior, 16.7% [n = 8]; cranial-posterior, 8.3% [n = 4]). In humeral heads with a caudal cartilage wear, the apex was centered in 65% in the transverse plane; and in humeral heads with a cranial cartilage wear, the apex was centered in only 20% of the cases in the transverse plane ($P = .061$).

Osteophytes were significantly ($P = .019$) longer when cartilage wear was located in the cranial half of the humeral head than when it was located in the caudal half (mean, 19 mm [SD, 6 mm] compared with 11 mm [SD, 8.7 mm]).

Relation between humeral head changes and glenoid morphology

Glenoid morphology according to Walch et al[15] varied according to the sphericity or asphericity of the humeral head in the coronal plane. In 80% (n = 6), spherical humeral heads were associated with glenoid morphology types A1, A2, and B1; the remainder were type B2 (20%). Only 50% (n = 20) of aspherical humeral heads were associated with glenoid morphology types A1, A2, and B1, whereas 45% were type B2. Spherical humeral heads tend to be primarily associated with glenoid type B1, whereas nonspherical humeral heads more frequently exhibited glenoid type B2 ($P = .076$).

Regarding the length of osteophytes classified according to the Samilson-Prieto classification, in the coronal plane related to the glenoid morphology according to Walch, we observed that patients with an osteophyte grade 1 and grade 2 showed a glenoid type B1 in 67% and B2 in 11%. Patients with an osteophyte grade 3 had significantly ($P = .031$) less frequently a glenoid type B1 but more frequently a glenoid type B2 (45%). Humeral heads with a centered apex in the transverse plane had a Walch subluxation index of 49%, whereas those with a decentered apex in the transverse plane had a subluxation index of 55% ($P = .042$).

The frequencies of the examined humeral and glenoid parameters in relation to osteophyte length are shown in Table I for spherical humeral heads (Samilson-Prieto classification) and in Table II for aspherical humeral heads.

Discussion

The pathomorphology of the humeral head deformity in primary osteoarthritis has not been well described in the literature until now. Youderian et al,[18] Knowles et al,[8] and Jacxsens et al[4] analyzed morphologic humeral head parameters in patients with primary osteoarthritis in relation to glenoid morphology using different measurements on the basis of CT scans. None of the 3 papers included the magnitude

Table I Spherical humeral head shape in coronal plane

Length of osteophyte	Frequency, %	Glenoid morphology according to Walch, %				Transverse displacement of apex, %	Superior cartilage erosion, %	Humeral head subluxation (index >55%) according to Walch, %
		A1	A2	B1	B2			
<3 mm	21	0	33	66	0	0	0	0
3-6 mm	22	12	24	64	0	0	0	0
≥7-12 mm	56	0	16	50	33	14	0	14
≥13 mm	1	0	0	0	100	100	0	100

Table II Aspherical humeral head shape in coronal plane

Length of osteophyte	Frequency, %	Glenoid morphology according to Walch, %				Transverse displacement of apex, %	Superior cartilage erosion, %	Humeral head subluxation (index >55%) according to Walch, %
		A1	A2	B1	B2			
<3 mm	0	0	0	0	0	0	0	0
3-6 mm	13	14	14	55	17	0	0	0
≥7-12 mm	38	6	19	45	30	38	13	41
≥13 mm	49	5	0	24	71	52	28	52

of osteophyte formation, the sphericity of the humeral head, or the posterior translation of the head relative to the center of the glenoid. Furthermore, the progression of primary osteoarthritis is usually described on the basis of the glenoid deformity, which is well described in the literature[1,5] without respect to pathomorphologic changes of the humeral head.

To our knowledge, this is the first paper analyzing the intraoperative pathomorphologic changes in primary osteoarthritis of the humeral head in relation to the glenoid deformity using standard radiographic technique, MRI, and 3-dimensional photographic analysis of 55 patients with chronic painful primary osteoarthritis of the shoulder and clinically necessitating shoulder arthroplasty. Our study analyzed the morphologic humeral head changes in relation to glenoid morphology at the time of shoulder arthroplasty for primary osteoarthritis in 55 patients. The majority (82.2%) of these patients represented an aspherical humeral head shape in the coronal plane with a significantly longer caudal osteophyte. In the transverse plane, 50% of all patients showed a decentered apex (aspherical humeral head shape in the transverse plane), and the other half of our group of patients represented a centered apex. Patients with an aspherical humeral head shape in the transverse plane showed an aspherical humeral head shape in the coronal plane in 94% and a significantly longer osteophyte than patients with spherical humeral head shape, showing a 3-dimensional deformity of the humeral head during progression of primary osteoarthritis.

Furthermore, 75% of the patients showed complete humeral cartilage wear in the caudal half of the humeral head. The majority (80%) of humeral heads representing cartilage wear in the caudal half were aspherical in the coronal plane. The majority (80%) of spherical humeral heads in the coronal plane had a concentric glenoid or a mild eccentric glenoid wear, and the majority of aspherical humeral heads (82%) were associated with an eccentric glenoid wear according to Walch (37% type B1, 45% type B2).

On the basis of our results, 2 types of primary humeral osteoarthritis can be identified. Humeral osteoarthritis type A (spherical osteoarthritis) corresponds to a simple form of osteoarthritis with a round, spherical humeral head and no substantial transverse plane deformation. Cartilage wear is primarily caudal. There is no posterior subluxation. In terms of glenoid morphology, type A humeral osteoarthritis is primarily characterized by concentric glenoid types A1, A2, and B1. When osteophytes reach a length of 7 mm or more, the apex can become decentered with posterior subluxation of the humeral head, and eccentric glenoid types (type B2) can occur. However, the humeral head nonetheless remains spherical in the coronal plane. For this form of primary osteoarthritis, the Samilson-Prieto classification system is both appropriate and sufficient. Humeral osteoarthritis type B (aspherical osteoarthritis) is associated with a more complex pathomorphology. The humeral head is aspherical. Glenoid type according to Walch progressively shifts from concentric types (A1, A2, B1) to the eccentric type B2. Deformation also occurs in the transverse plane, leading to a decentered apex, primary posteriorly. Cartilage wear involves the cranial regions in the sagittal plane. The humeral head is posteriorly subluxed in relation to the joint socket. On average, osteophytes are longer than those in cases of spherical humeral heads. For this form of primary osteoarthritis, the Samilson-Prieto classification seems to be insufficient.

However, there is no specific radiographic classification system for primary osteoarthritis of the shoulder describing the pathomorphologic changes of the humeral head related to the pathomorphologic changes at the glenoid side. Kellgren

Table III Extended classification by Samilson-Habermeyer

Grade	A (spherical)	B (aspherical)
I	<3 mm	<3 mm
II	3-6 mm	3-6 mm
III	7-12 mm	7-12 mm
IV	≥13 mm	≥13 mm

and Lawrence[5] described a general radiologic classification system of primary osteoarthritis in 1957 for hand, cervical spine, lumbar spine, feet, hip, and knee joints including the parameter joint space narrowing, the presence of osteophytes, and general joint deformation. In 1967, Hindmarsh and Lindberg[3] introduced a classification system grading severity of osteoarthritis by instability of the glenohumeral joint, which was slightly modified by Samilson and Prieto,[13] characterized by caudal osteophyte length and joint space narrowing. Our results show that flattened or aspherical humeral heads in the coronal plane present with longer caudal osteophytes than spherical humeral heads. Osteophytes in patients with aspherical humeral heads had a mean length of 13.8 mm (range, 5-36 mm). Their spherical counterparts had a mean length of 10.9 mm (range, 0-14 mm). With caudal osteophytes of 7-12 mm in length, 25% of humeral heads were still spherical. In contrast, only 8% were spherical when osteophyte length reached or exceeded 13 mm. Therefore, we recommend that the Samilson-Prieto classification be expanded to allow increased differentiation in classifying aspherical humeral heads with long osteophytes.

In addition to categorizing caudal osteophytes into 3 grades of severity, differentiation should also be made as to whether the humeral head is spherical (A) or aspherical (B). Both of these parameters can be measured easily and reliably on true AP radiographs. We propose an extended classification for the description of the osteoarthritic deformity of the humeral head (Table III).

In progression of primary osteoarthritis, the location of the contact surface between the humeral head and the glenoid varies. As the length of caudal osteophytes increases, the space within the joint capsule decreases. This results in increasing translation while simultaneously decreasing rotary motion of the humeral head. The pathomorphologic changes to the humeral head render the constituent parts of the joint asymmetric and cause the contact surface with the joint cavity to become larger, which in turn increases erosion. Over time, this leads to humeral head flattening, apex decentering, superior humeral cartilage erosion, subluxation, and eccentric posterior glenoid rim erosion. These 5 factors significantly increase in frequency and severity when osteophyte length is >13 mm compared with spherical humeral heads with shorter osteophytes. In the future, our extended classification should allow better characterization of the progression of pathomorphologic changes that occur in progression of primary osteoarthritis of the glenohumeral joint.

Conclusion

It seems that the progression of primary osteoarthritis of the glenohumeral joint is characterized by an increasing 3-dimensional deformity of the humeral head related to the glenoid morphology. The humeral head becomes aspherical in the coronal plane; the apex is decentered in the transverse plane with superior cartilage erosion, subluxation of the humeral head, and posterior glenoid wear. These 5 factors show a significant increase in frequency and severity when osteophyte length is >13 mm. We therefore propose an extended Samilson-Prieto classification with type A (spherical) and type B (aspherical) and grade I-IV osteophytes.

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Disclaimer

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