Comparing the Use of Axillary Radiographs and Axial Computed Tomography Scans to Predict Concentric Glenoid Wear

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Background: Axillary radiographs traditionally have been considered sufficient to identify concentric glenoid wear in osteoarthritic shoulders; however, with variable glenoid wear patterns, assessment with use of computed tomography (CT) has been recommended. The purpose of the present study was to compare the use of axillary radiographs and mid-glenoid axial CT scans to identify glenoid wear.

Methods: Preoperative axillary radiographs and mid-glenoid axial CT scans for 330 patients who underwent anatomic total shoulder arthroplasty were reviewed. Five independent examiners with differing levels of experience characterized the glenoid morphology as either concentric or eccentric. The morphologies determined with use of axillary radiographs and CT scans were assessed for correlation, and both intraobserver and interobserver consistency were calculated.

Results: Concentric wear identified with use of radiographs was confirmed with use of CT scans in an average of 61% of cases (range, 53% to 76%). Intraobserver consistency averaged 75% for radiographs and 73% for CT scans. There was significant interobserver consistency, as higher levels of training corresponded with greater consistency between imaging analyses (p < 0.001). The most senior observer identified the highest proportion of concentric wear on radiographs (p < 0.001), showed the greatest consistency between attempts when using CT (p < 0.001), and had the greatest agreement of radiographs and CT evaluating glenoid morphology (p < 0.001).

Conclusions: For the experienced shoulder surgeon, concentric glenoid wear identified on axillary radiographs will appear concentric on 2-dimensional CT in approximately 75% of cases. Obtaining a CT scan to confirm glenoid wear patterns most greatly benefits less-experienced surgeons. Across all levels of experience, axillary radiographs and single-slice, mid-glenoid CT scans appear insufficient for consistently predicting wear patterns.

Level of Evidence: Diagnostic <u>Level III</u>. See Instructions for Authors for a complete description of levels of evidence.

Recognition of glenoid wear is a critical step in surgical planning for shoulder arthroplasty because different wear patterns sometimes require modification of the surgical technique and implant selection[1-13]. Axillary radiographs traditionally have been considered sufficient for preoperative assessment of glenoid wear patterns in osteoarthritic shoulders[14]. Several studies have emphasized the use of axillary radiographs in evaluating glenoid morphology because of the ability to anticipate glenoid wear and morphology, the lower costs, and the relatively limited exposure to radiation[15-17]. However, the recognition of eccentric patterns of glenoid wear has led to an emphasis on assessment with use of 2-dimensional computed tomography (CT)[10,18], with 3-dimensional reconstructions further increasing accuracy when determining the location and severity of eccentric wear[18-21]. Consequently, a number of classifications of been developed to facilitate recognition of glenoid wear, including Levine (standard radiographs)[14], Walch (2-dimensional CT)[10], and Bercik (a modification of the Walch classification using 3-dimensional reconstruction)[21].
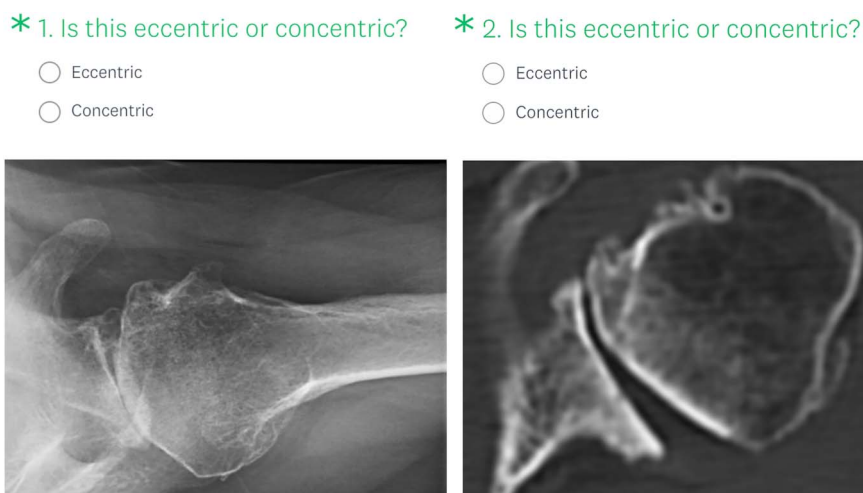
Fig. 1

Example of survey questions. For each axillary radiograph (left panel) and mid-axial CT image (right panel), the reviewer was asked to classify the image as eccentric or concentric wear.

Levine et al.[14] reviewed axillary radiographs for patients who underwent hemiarthroplasty for glenohumeral osteoarthritis, and subdivided glenoid morphology as concentric (Class 1) and eccentric (Class 2) because of the propensity for less satisfactory results in patients with eccentric wear patterns. Hussey et al. adapted the Levine classification to involve the use of axial CT scans to describe concentric and eccentric wear patterns[18]. Although symmetric erosion and relatively evenly distributed cyst/sclerosis formation signifies a concentric, uniconcave glenoid, eccentrically worn glenoids show asymmetry in deformity and resultant biconcavity[18]. Identification of eccentric wear patterns has great importance for anatomic shoulder arthroplasty, as modifications of the surgical technique and/or implant selection may be required as a direct result of the glenoid wear. If an axillary radiograph can reliably identify a concentric wear pattern, then it may be possible to proceed with anatomic shoulder arthroplasty without the use of an additional CT scan for surgical planning purposes, reserving additional imaging for those patients with radiographs demonstrating eccentric glenoid wear.

The purpose of the present study was to compare the use of axillary radiographs and mid-glenoid axial CT scans to identify concentric glenoid wear. We assessed whether axillary radiographs could consistently be used to predict concentric glenoid wear on CT scans, calculated the intraobserver and interobserver consistency for identifying wear patterns, and determined the impact of surgeon experience on the consistency of identifying glenoid wear. We hypothesized that glenoid wear identified on axillary radiographs would correlate well with that identified on CT scans, with good intraobserver and interobserver consistency and improved consistency with increased surgeon experience.

Materials and Methods

We retrospectively queried the Shoulder and Elbow Surgery Registry at our institution in order to identify all patients who had undergone primary anatomic total shoulder arthroplasty between April 2009 and October 2015. The query identified 380 patients with preoperative axillary radiographs and CT scans. Axillary radiographs were reviewed for quality, which led to 50 patients being excluded by the surgeon administrator (K.D.A.) for poor quality secondary to inadequate penetration or patient positioning[18,22]. Preoperative axillary radiographs and mid-glenoid axial CT scans

TABLE I Wear Identification Consistency Proportions*							
	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	P Value	Mean
Consistency between XR attempts	79%	58%	83%	75%	78%	**<0.001**	75%
Consistency between CT attempts	76%	56%	78%	72%	84%	**<0.001**	73%
Consistency between modalities, attempt 1	63%	63%	63%	59%	63%	0.770	62%
Consistency between modalities, attempt 2	65%	75%	58%	62%	61%	**<0.001**	64%

*Observer 1 = a second-year medical student, Observer 2 = a postdoctoral orthopaedic research fellow, Observer 3 = a PGY-4 orthopaedic resident, Observer 4 = a fellowship-trained orthopaedic hand surgeon undergoing shoulder-elbow fellowship training, Observer 5 = a dual-fellowship-trained trauma and shoulder-elbow attending surgeon, XR = axillary radiograph, and CT = mid-glenoid axial CT. Bolding indicates significance.

TABLE II Concentric Wear Observations (Attempt 1)*							
	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	P Value	Mean
Proportion of identification of concentric wear on XR	57%	38%	38%	59%	47%	**<0.001**	48%
No. of cases of concentric wear on XR	188	124	124	196	156	−	−
No. of cases of XR-CT agreement	119	66	66	118	118	−	−
Proportion of cases of XR-CT agreement	63%	53%	53%	60%	76%	**<0.001**	61%

*Observer 1 = a second-year medical student, Observer 2 = a postdoctoral orthopaedic research fellow, Observer 3 = a PGY-4 orthopaedic resident, Observer 4 = a fellowship-trained orthopaedic hand surgeon undergoing shoulder-elbow fellowship training, Observer 5 = a dual-fellowship-trained trauma and shoulder-elbow attending surgeon, XR = axillary radiograph, and CT = mid-glenoid axial CT. Bolding indicates significance.

for the remaining 330 consecutive patients were included for comparative imaging analysis.

Survey Creation

With use of SurveyMonkey (www.surveymonkey.com), the system administrator (K.D.A.) created a survey that included anonymized versions of each of the 330 axillary radiographs and 330 CT scans[23,24]. Images were randomized such that the radiographs and CT scan for any given patient were nonconsecutive. The preoperative morphology for each image was assessed in a closed-question format (Fig. 1), with observers required to identify concentric or eccentric glenoid wear patterns according to the Levine classification[14] for axillary radiographs and the Hussey CT adaptation for mid-glenoid axial 2-dimensional CT images[18].

Survey Protocol

Five independent observers completed the survey: a second-year medical student, a postdoctoral orthopaedic research fellow, a postgraduate year-4 (PGY-4) orthopaedic resident, a fellowship-trained orthopaedic hand surgeon undergoing shoulder-elbow fellowship training, and an attending surgeon with dual trauma and shoulder-elbow fellowship training. Completed survey results were blinded with respect to the observer and confidentially recorded to the SurveyMonkey platform, including the specific date and time of survey completion. Following a "visual wash-out period" of at least 3 weeks, each observer completed the identical survey for a second time to determine both intraobserver and interobserver consistency.

Statistical Analysis

Proportional consistency was calculated for the identification of the wear pattern on axillary radiographs and CT scans alone, as well as for radiographs compared with CT scans. In order to understand if there was a significant difference in the proportion of interobserver consistency, independent-sample Kruskal-Wallis tests with post-hoc Dunn-Bonferroni corrections were performed. Significance was set at 0.05, and statistical analyses were performed with use of SPSS (version 25.0; IBM).

Results

Axillary Radiographs

When using axillary radiographs (Table I), the observer identified the same pattern of wear between the first and second attempts in an average of 75% of cases (range, 58% to 83%; p < 0.001), and the PGY-4 orthopaedic resident was most consistent between attempts (83%).

Mid-Glenoid Axial CT Scans

When using CT scans (Table I), the observer identified the same pattern of wear between the first and second attempts in an average of 73% of cases (range, 56% to 84%; p < 0.001), and the attending was most consistent across attempts when using CT (84%).

Concentric Wear

On average, a concentric wear pattern was identified on 48% of axillary radiographs (range, 38% to 59%; p < 0.001) (Table II). Concentric glenoid wear identified on radiographs was also

TABLE III Impact of Observer Experience on Recognition of Glenoid Wear*					
	Consistency Between XR Attempts	Consistency Between CT Attempts	Consistency Between Modalities, Attempt 1	Consistency Between Modalities, Attempt 2	Proportion of Cases of XR-CT Agreement
Observer with highest value	3	5	NS	2	5
Observer training level	PGY-4 orthopaedic resident	Dual-fellowship-trained trauma and shoulder-elbow attending surgeon		Postdoctoral orthopaedic research fellow	Dual-fellowship-trained trauma and shoulder-elbow attending surgeon

*XR = axillary radiograph, CT = mid-glenoid axial CT, and NS = not significant.

identified on CT scans an average of 61% of the time (range, 53% to 76%; p < 0.001) (Table II). The postdoctoral research fellow and the PGY-4 achieved agreement between radiographs and CT least frequently (53% for both), and the attending surgeon achieved agreement most frequently (76%).

Impact of Experience

The attending surgeon identified the highest proportion of concentric glenoid wear on axillary radiographs (p < 0.001), demonstrated the greatest consistency between attempts when utilizing CT (p < 0.001), and had the greatest agreement between radiographs and CT scans when identifying concentric glenoid wear (p < 0.001) (Tables II and III).

Discussion

The results of the present study support the growing emphasis on obtaining preoperative CT scans when assessing glenoid wear in osteoarthritic patients prior to shoulder arthroplasty, even in the setting of what appears to be concentric wear on radiographs. Although the most experienced surgeon in this study found concentric glenoid wear on radiographs consistent with CT scans in 76% of cases, the average consistency observed across observers was only 61%.

Recent studies have encouraged the use of 2-dimensional CT scans over standard radiographs when assessing preoperative glenoid wear[10,18], with 3-dimensional reconstruction potentially providing further utility[18-21]. Consequently, classification and treatment according to wear pattern have largely been based on advanced CT imaging[10,11,15,17,21,25]. Nonetheless, studies have suggested several benefits to the use of radiographs both preoperatively and postoperatively, including in the determination of glenoid version and wear pattern, assessment of postoperative glenohumeral centering and congruence, and prediction of clinical outcomes[14,26,27]. Furthermore, several foundational but contemporary concepts in shoulder arthroplasty have been anchored by studies that utilized radiographs alone while noting the adequacy in utility[22,26,28-30]. Although CT scans are associated with greater financial cost[26,31,32] and exposure to radiation[26,33-35] than radiographs, the literature has yet to describe the additional clinical value and/or potential cost-value benefit as a result of improved outcomes provided by the use of CT scans in patients undergoing total shoulder arthroplasty, even when integrated with virtual planning software and generation of patient-specific instrumentation.

Previous studies have investigated the consistency of glenoid wear classification systems using various imaging modalities. In a study of the Walch classification involving 3 surgeons, Aronowitz et al. found "substantial" intraobserver consistency (κ = 0.66) with radiographs and "moderate" intraobserver consistency (κ = 0.60) with CT scans[17]. In contrast, Shukla et al. evaluated the Bercik modification of the Walch classification and found interobserver consistency equivalent between radiographs and CT scans (κ = 0.55 and κ = 0.52, respectively)[15]. In both studies, the most senior assessor was considered the control, and no comparative analysis of

observer experience was performed. Kopka et al. compared the use of radiographs and magnetic resonance imaging with the Walch classification and found radiographs to be less reliable, with fair-to-moderate agreement (κ = 0.21 to 0.51) between the two[36]. Finally, Hussey et al. reported higher interobserver and intraobserver consistency when using the modified Levine classification (κ = 0.54 and κ = 0.70, respectively) compared with the Walch classification (κ = 0.60 and κ = 0.70, respectively) for the assessment of glenoid wear patterns on CT scans[18]. In the present study, assessors were able to identify concentric wear patterns in an average of 61% of cases when using radiographs, with improved consistency among the most experienced observers.

Despite a preponderance of literature on the classification of glenoid morphology, there remains a lack of evidence evaluating the impact of surgical experience on the use of preoperative imaging in the evaluation of osteoarthritic patients. Surgical experience has been shown to correlate with more favorable clinical outcomes and overall surgical costs in shoulder arthroplasty[37-44]; however, robust studies are lacking that evaluate variation in radiographic reviewing (and subsequent surgical planning) as a result of differing levels of clinical experience. The present study provides insight into this conundrum, with significant differences observed among different levels of training when classifying glenoid wear patterns with use of both radiographs and CT scans.

Obtaining routine CT scans for all shoulder arthroplasty patients has not been universally advocated, largely because planning is unlikely to change for the concentrically worn glenoid, as implant selection and surgical techniques are unlikely to be modified following additional advanced imaging. Although CT scanning does provide additional, possibly beneficial data (including determination of glenoid size, version, and inclination; identification of subchondral cysts, subchondral thickness, and bone density; and better estimation of glenoid component fit and positioning), much can still be appreciated on radiographs. Furthermore, if a surgeon believes that preparation of the glenoid in order to provide complete backside support of the component deserves the highest priority during glenoid component implantation, irrespective of glenoid version[45], then the primary focus of preoperative imaging would be to differentiate concentric from eccentric glenoid wear. Using this rationale, the ability to achieve complete backside support in a glenoid with concentric wear is typically straightforward and would not necessitate advanced imaging. Thus, if radiographs and CT scans consistently identified concentric wear, then the need for CT could be avoided. This study demonstrates that for an experienced attending surgeon, concentric wear identified on radiographs was also identified on CT scans in 76% of cases, with significant differences among varied levels of experience (range, 53% to 76%). Although an experienced surgeon may be comfortable with an accuracy rate of 76% when they identify glenoids as having a concentric wear pattern, not identifying eccentric wear patterns in the other 24% is of concern. Thus, a preoperative CT scan would help improve the ability to recognize glenoid wear patterns prior to a surgical procedure.

As with all studies, the present study has limitations. Clinical outcomes were not included in the analysis; thus, the impact of the glenoid wear classification was not evaluated. Additionally, intraoperative observations, which could have been used as a gold standard for determining concentric and eccentric wear patterns, were not recorded. Furthermore, although both axillary radiographs and CT images were standardized and screened, there are typically small variations in image quality seen even within a single imaging center. Additionally, it is possible that uniformity of assessment of overall glenoid morphology could have been improved with the use of scroll-through, 2-dimensional CT, which was not available for this study.

Nonetheless, the intraobserver consistency showed a higher rate of consistent identification of the same wear pattern in radiographs (average, 75%) compared with CT scans (average, 73%), although both exhibited a high degree of consistency.

In conclusion, for an experienced shoulder surgeon, recognition of concentric glenoid wear on radiographs should correlate with mid-glenoid CT scans in approximately 75% of cases. Radiographs appear to be insufficient at consistently differentiating concentric from eccentric wear patterns among those with less experience. ∎

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