Radiostereometric and Radiographic Analysis of Glenoid Component Motion After Total Shoulder Arthroplasty

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abstract

Aseptic glenoid component loosening is a common cause of total shoulder arthroplasty (TSA) failure, but early detection is difficult because pain often appears late and radiolucent lines are of uncertain significance. This study sought to answer the following questions: (1) What types of glenoid component motion may be observed during the first 3 years following implantation?; (2) Is the appearance of radiolucent lines around the glenoid component a reliable indicator of component motion?; and (3) Are clinical outcomes correlated with early glenoid component motion within the first 3 years after TSA? Eleven patients (mean age, 60.6 years) underwent TSA using a cemented, all-polyethylene glenoid component with tantalum bead implantation. Clinical outcomes (American Shoulder and Elbow Surgeons [ASES] score, visual analog scale [VAS] pain score, and range of motion) were compared pre- and postoperatively, and radiolucencies were graded according to the criteria of Lazarus et al. Patients were evaluated using radiostereometric analysis at 6 months and 1, 2, and 3 years postoperatively to measure component micromotion in translation and rotation. At a mean follow-up of 50.2 months, mean ASES score had improved from 30.3 to 81.3 ($P<.001$), mean VAS pain score had improved from 8 to 1 ($P<.001$), active forward flexion had improved from 109° to 155° ($P=.001$), active external rotation had improved from 28° to 54° ($P=.003$), and internal rotation had improved from the level of the sacrum to L3 ($P=.002$). Radiolucencies were detected around none of the components at 1 year, 6 components at 2 years, and 5 components at 3 years, and these radiolucencies were mostly found around components that experienced high levels of rotational motion. [*Orthopedics*. 2015; 38(10):e891-e897.]

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Total shoulder arthroplasty (TSA) is an important treatment modality for patients with advanced glenohumeral joint destruction of any etiology, and its popularity among surgeons and patients is increasing.[1] The most common complication following TSA is aseptic component loosening, which occurs at a rate of 39%, and 83% of these cases involve loosening of the glenoid component.[2] Severe shoulder pain and the progression of radiolucent lines on standard radiographs are the most commonly used indicators to determine whether a component is loose. However, the significance of radiolucencies is currently a subject of debate because they are often present on radiographs taken in the immediate postoperative period, and their presence has been shown to be influenced by patient positioning and anatomic variations in glenoid version.[3-5] Currently, the timing and typical mechanisms underlying glenoid component loosening have not been well defined.

The use of radiostereometric analysis (RSA) to measure component motion of as little as 0.05 mm (50 µm) has been reported in studies of the shoulder, hip, and knee.[4,6-17] Through the use of tantalum beads inserted into bone and polyethylene, component motion is measured in 3 dimensions using stereoradiography. Clinical correlation of RSA data at the hip has determined that progressive motion detected with RSA predicts later loosening and component failure.[12,13] Four recent studies of glenoid component stability following TSA have also been performed, with 2-year data showing mostly stable implants of both pegged and keeled design.[6-9] The most recent of these studies indicated that radiolucent lines may be of significance.[8]

The current authors performed a prospective study of glenoid component stability using RSA, radiographic findings, and clinical outcomes to answer the following questions: (1) What types of glenoid component motion, and how much motion, may be observed during the first 3 years following implantation?; (2) Is the appearance of radiolucent lines around the glenoid component a reliable indicator of component motion?; and (3) Are clinical outcomes correlated with early glenoid component motion within the first 3 years after TSA?

Materials and Methods

A prospective study of component stability was undertaken following TSA performed between November 2007 and May 2009 after obtaining approval from the institutional review board of the University Hospitals Case Medical Center. Inclusion criteria for the study included all patients undergoing primary TSA for a diagnosis of osteoarthritis with a functioning and intact rotator cuff. Patients agreed to be contacted for clinical, radiographic, and RSA examinations during their postoperative course. The senior author (R.G.) performed all TSAs through a deltopectoral approach using an uncemented humeral component with a metaphyseal taper (Arthrex, Inc, Naples, Florida; or Tornier, Inc, Edina, Minnesota) and a conventional ultra-high-molecular-weight polyethylene (UHMWPE) glenoid component of either a keeled (Arthrex, Inc) or pegged (Tornier, Inc) design. Glenoid components were all-polyethylene components designed for use without an additional metal baseplate. The study comprised a nonconsecutive series of all patients who underwent TSA with successful placement and reading of tantalum markers for RSA at a minimum follow-up of 3 years.

Eleven patients underwent TSA and had completed clinical and radiographic follow-up at a minimum of 3 years postoperatively. All had successfully completed 3-year follow-up RSA examinations at the time of data analysis. Nine patients received a keeled glenoid component, and 2 patients received a pegged component. Mean age of these patients at surgery was 61.5 years (range, 50-80 years). Four patients were male and 7 were female. Six TSAs were performed on the right side and 5 were performed on the left side. Osteoarthritis was the indication for surgery in all cases.

At surgery, the glenoid reamer was centered over the bare spot, and reaming proceeded in neutral version until subchondral bone was encountered. One patient demonstrated severe posterior wear and retroversion on preoperative computed tomography (CT) scan (24.9°), and it was determined that this would not permit stable placement of the component. The anterior glenoid was reamed until adequate bone stock could be engaged and stable fixation was achieved. All other glenoids were reamed symmetrically.

For the purposes of monitoring component stability using RSA, the authors followed the traditional method described for lower extremity arthroplasty,[14] with modifications similar to what has been used in RSA studies of the shoulder performed to date.[6-9] Eight tantalum beads, 0.8 mm in diameter, were implanted into the nonarticular edge of the glenoid component, and 11 beads, 1.0 mm in diameter, were implanted into the bone of the humerus and into the glenoid and coracoid processes of the scapula. Postoperative care consisted of sling immobilization in the immediate postoperative period, followed by progressive passive, active-assisted, and active range of motion (ROM) exercises performed with the guidance of a physical therapist.

Patient outcomes were measured prospectively using the American Shoulder and Elbow Surgeons (ASES) score, visual analog scale (VAS) pain score, and active ROM in forward flexion (FF), external rotation (ER), and internal rotation (IR). These were recorded preoperatively and at clinical follow-up examinations. To investigate the importance of the radiographic signs of glenoid component loosening, Grashey and axillary radiographs were evaluated at each follow-up appointment for the appearance of radiolucencies. Radiolucencies surrounding the glenoid component were graded by 3 orthopedic surgeons (J.J.S., H.M., R.G.) independently according to the system of Lazarus et al,[3] and interobserver reliability was calculated.

Radiostereometric analysis was performed using the UmRSA 6.0 program (RSA Biomedical, Umeå, Sweden). The authors obtained a 3-dimensional reconstruction of the components and bone segments using stereoradiography with a calibration cage (Cage 43; RSA Biomedical) positioned under the patient. Using this technique, 2 radiographic views of the shoulder joint were taken from the superior and inferior directions. Segment motion and point motion were used to compare each patient's baseline component positioning to that shown in subsequent radiographs (**Figure 1**). The authors' initial study protocol called for the use of immediate postoperative RSA, but postoperative pain limited their ability to position patients properly; thus, protocol was changed and baseline RSA was conducted 6 months postoperatively. Glenoid component migration was defined as motion between the component segment and the glenoid and coracoid bone segment (each segment defined by at least 3 beads). Translational movement was defined about 3 axes, such that translation from caudad (+) to cephalad (-) was designated as the x-axis, translation from medial (+) to lateral (-) was designated as the y-axis, and translation from anterior (+) to posterior (-) was designated as the z-axis. Similarly, rotational movement was defined about these same axes, such that clockwise motion about each axis was positive rotation (**Figure 2**). The precision of the radiographic setup was determined using double examinations, and 95% confidence intervals (CIs) were calculated. Measured motion found to be within this interval was considered undetectable due to the error of the radiographic setup. The maximum mean error of rigid body fitting for RSA kinematics was 0.25. The maximum acceptable condition number was 300 due to the challenge of distribution and visualization of beads in the shoulder.

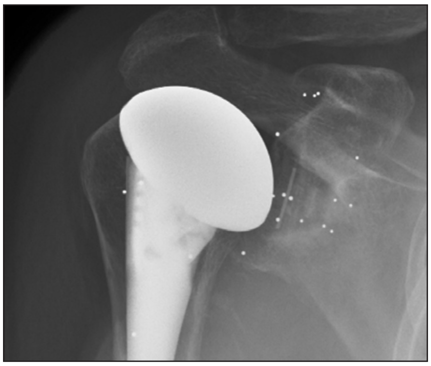

Figure 1: Radiostereometric analysis may be performed by obtaining stereoradiographs after implantation of tantalum metal beads into bone or polyethylene at the time of surgery.

Component motion in translation and rotation was assessed using the thresholds for significant motion proposed by Rahme et al,[6] with 1 mm of translational motion and 2° of rotational motion used as indicators of motion being possibly clinically significant. To determine whether patients with higher levels of motion displayed differences in clinical outcomes and the appearance of radiolucencies, the authors' cohort was divided into 2 groups based on whether the glenoid component had either not reached (low motion) or surpassed (high motion) these thresholds. Clinical outcomes were compared using an independent-samples Student's *t* test ($P<.05$), and observations were made about the appearance of radiolucencies in each group. Reliability in the detection of radiolucencies between observers was measured using the intraclass correlation coefficient for exact measures and using Cronbach's alpha.

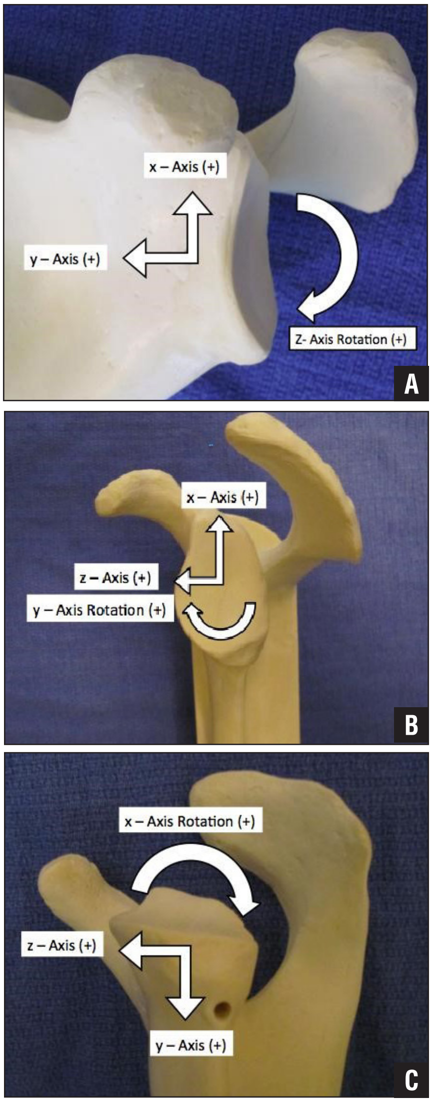

Figure 2: Motion of the glenoid components in translation and rotation was measured about 3 axes: z-axis, anterior-to-posterior translation (A); y-axis, medial-to-lateral translation (B); and x-axis, cephalad-to-caudad translation (C).

Results

For the group as a whole, mean translational motion measured using RSA at 3 years was 0.51±0.46 mm along the x-axis, 0.44±0.27 mm along the y-axis, and 0.42±0.29 mm along the z-axis. Mean rotational motion was 2.63°±2.48° around the x-axis, 1.55°±0.77° around the y-axis, and 3.31°±2.5° around the z-axis (**Table 1**). One component had translated more than 1 mm along each of the 3 axes at 3 years. More than 2° of rotational motion around at least 1 axis was detected in 1 component at 1 year, 3 components at 2 years, and 6 components at 3 years. The component that experienced the greatest translational motion also experienced the greatest rotational motion, and this component was implanted in the patient who underwent preferential

Table 1

Summary of Glenoid Component Motion in Translation and Rotation After 3 Years

Glenoid Component Range of Motion	No.	Mean±SD	Range
In translation, mm			
x-axis	11	0.51±0.46	0.1-1.68
y-axis	11	0.44±0.27	0.1-1.02
z-axis	11	0.42±0.29	0.11-1.05
In rotation			
x-axis	11	2.63°±2.48°	0.26°-7.56°
y-axis	11	1.55°±0.77°	0.18°-2.67°
z-axis	11	3.31°±2.5°	1.01°-8.54°

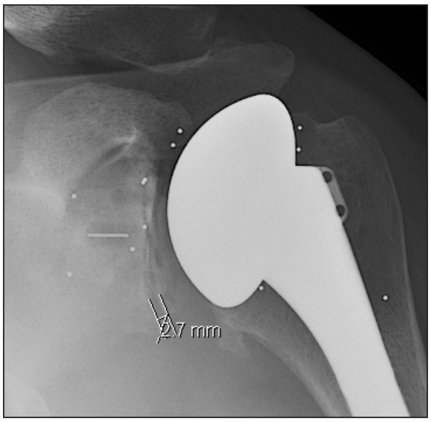

Figure 3: Radiolucencies detected around the glenoid components were graded by 3 authors independently according to the system of Lazarus et al.[3] The presence of radiolucencies was found to be associated with early rotational motion of the glenoid components in this study.

reaming of the anterior glenoid (patient 6). The CI of the RSA setup to detect translational motion was -0.07 to -0.01 mm for the x-axis, 0 to 0.04 mm for the y-axis, and -0.02 to 0.07 mm for the z-axis. The CI for the detection of rotational motion was -0.33° to 0° for the x-axis, -0.32° to 0.08° for the y-axis, and -0.11° to 0.42° for the z-axis.

At a mean follow-up of 50.2 months (range, 41-55 months), this group of patients demonstrated good clinical outcomes. Mean ASES score had improved from 30.3 to 81.3 (*P*<.001), mean VAS pain score had improved from 8 to 1 (*P*<.001), mean active FF had improved from 109° to 155° (*P*=.001), mean active ER had improved from 28° to 54° (*P*=.003), and mean IR had improved from the level of the sacrum to L3 (*P*=.002). Radiolucencies were detected around no components at 1 year, 6 components at 2 years, and 5 components at 3 years (**Figure 3**). The intraclass correlation coefficient for agreement in the detection of radiolucencies was 0.961, and Cronbach's alpha was 0.986, demonstrating excellent agreement between observers. **Table 2** lists the number of radiolucencies for each patient in relation to the motion detected by RSA at 3 years.

After 3 years, 5 glenoid components were found to have not surpassed the 1 mm/2° threshold for motion in any plane and were placed in the low-motion group, whereas 6 glenoid components had surpassed this threshold and were placed in the high-motion group. Mean VAS score was significantly lower in the low-motion group (0±0) than in the high-motion group (2.0±2.9; *P*=.04). Other differences between groups were not statistically significant. Mean ASES score in the low-motion group was 76.2±37.2, compared with 71.0±13.7 in the high-motion group (*P*=.76). Mean active FF in the low-motion group was 156°±25°, compared with 136°±48° in the high-motion group (*P*=.42). Mean active ER was 48°±22° in the low-motion group, compared with 53°±22° in the high-motion group. Mean IR was to the level of L3 in the low-motion group and reached the L2 level in the high-motion group (*P*=.21; **Table 3**). Four of the 6 patients in the high-motion group showed radiolucencies around the glenoid component at 3 years, whereas radiolucencies were only visible around 1 of the 5 components in the low-motion group.

Discussion

Early glenoid component motion is of interest to the practicing shoulder surgeon because aseptic loosening is an important cause of TSA revision.[1,2] Radiostereometric analysis is an effective way to measure component motion following arthroplasty,[11,14,18] and its use in the measurement of glenoid component motion after TSA is important because of recognized issues related to the stability of these components following implantation.[2,19,20] The current authors' results indicate that early glenoid component motion is greatest in rotation and that early low-level pain and the persistent appearance of radiolucent lines may be early indicators of this motion. To the best of the authors' knowledge, this study represents the largest and longest-term RSA analysis of TSA glenoid components in the literature to date.

Based on this study's findings, it appears that early glenoid component motion occurs primarily in rotation, and this is in agreement with a prior RSA study by Nuttall et al,[7] who found that anteversion was the most common movement in their study cohort. Such a finding is not surprising because humeral head motion would be expected to rotate a component that is loose or still in the process of settling, rather than to translate it. One particular area of interest was medialization of a glenoid component over time, which would have represented settling or subsidence and possible loss of glenoid bone stock.

Table 2

Individual Component Motion in Translation and Rotation in Relation to the Appearance of Radiolucent Lines on Postoperative Radiographs[a]

Patient No./Sex/ Age, y	Side	RL Zone 1 y	RL Zone 2 y	RL Zone 3 y	Final Trans, mm x-axis	Final Trans, mm y-axis	Final Trans, mm z-axis	Final Rotation x-axis	Final Rotation y-axis	Final Rotation z-axis
1/F/66	R	0	0	0	-0.26	-0.03	-0.12	0.60°	-0.02°	-2.39°
2/M/50	L	0	0	1	-0.26	-0.36	0.10	2.14°	2.20°	2.45°
3/F/78	L	0	1	3	-0.25	-0.05	0.36	0.88°	-1.86°	0.85°
4/F/52	L	0	0	0	-0.15	-0.13	-0.16	-1.25°	-1.79°	1.8°
5/F/64	L	0	1	0	-0.29	-0.24	-0.74	2.71°	-2.14°	1.13°
6/M/52	R	0	1	1,2	1.51	-1.01	-1.09	4.63°	-1.70°	-8.54°
7/F/80	R	0	0	0	0.69	0.21	0.39	1.61°	0.08°	-1.32°
8/M/61	L	0	1	0	-0.08	-0.27	0.32	-0.14°	-0.83°	1.52°
9/M/52	R	0	3	0	-0.19	0.50	-0.15	0.45°	-1.54°	-1.98°
10/F/53	R	0	0	1	-0.15	-0.14	0.02	-3.76°	-0.07°	-0.42°
11/F/68	R	0	1	3	-0.55	-0.09	0.46	0.86°	0.11°	-7.45°

Abbreviations: F, female; L, left; M, male; R, right; RL, radiolucent lines; Trans, translation.
[a]All but one of the patients with radiolucencies at 3 years demonstrated rotation of greater than 2° at 3 years. The 5 greatest measured rotations from baseline at 3 years all occurred in patients with radiolucencies.

Medial-to-lateral motion was measured along the y-axis in the current study, and positive motion would have represented medialization. Most components experienced very little motion along the y-axis; 2 components had translated medially after 3 years, and both translations were rather small (**Table 3**). This finding helps to add to our understanding of the early behavior of cemented, all-polyethylene glenoid components, and such data can only be obtained from studies that use RSA.

Table 3

Comparison of Clinical Outcome Measures Between Low- and High-Motion Groups[a]

Outcome Measure	Mean±SD Low-Motion Group (n=5)	Mean±SD High-Motion Group (n=6)	*P*
ASES	76.2±37.2	71±13.7	.76
VAS	0±0	2±2.9	.04
AFF	156±25.1	136±47.8	.42
ER	48±22	52.5±21.6	.74
IR	L3	L2	.21

Abbreviations: AFF, active forward flexion; ASES, American Shoulder and Elbow Surgeons score; ER, external rotation; IR, internal rotation; VAS, visual analog scale pain score.
[a]After 3 years, 5 glenoid components were found to have not surpassed the 1-mm/2° threshold for motion in any plane and were placed in the low-motion group, whereas 6 glenoid components had surpassed this threshold and were placed in the high-motion group. Mean VAS pain score was found to be different between groups, but no other differences in clinical parameters were identified.

The significance of radiolucent lines after TSA has been a matter of debate for many years, and many surgeons feel that these may be normal postoperative radiographic findings. The current authors' finding of early micromotion in 66% of patients with radiolucencies, compared with only 20% of patients without radiolucencies, indicates that persistent radiolucencies may be cause for concern. In particular, the patient who required asymmetric glenoid reaming demonstrated radiolucencies in 2 zones, as well as very high rotation in 2 planes. Four studies of glenoid component motion using RSA have been published with 2-year data, and whereas the earlier studies generally demonstrated excellent stability of the components, a more recent investigation into the stability of partially cemented, fluted, pegged glenoid components found that some of these showed early migration and that the presence of a radiolucency around the central peg could be a marker of this early motion.[8] The incidence of radiolucent lines around the glenoid component has been reported to be between 28.4% and 90%,[21-25] and their presence has traditionally been attributed to first-generation cementing techniques, especially for keeled implants.[26] Many of the current authors' patients demonstrated these lines despite the use of bone compaction, cement pressurization, and modern implant designs that theoretically should decrease their incidence. The current authors' data should alert surgeons to the possibility of early micromotion when radiolucent lines are noted postoperatively.

Incomplete pain relief following TSA was the only clinical sign that the current authors found to be correlated with early glenoid component micromotion. Although the patient cohort was small, the VAS pain score for patients who did not exceed 1 mm of translation or 2° of rotation was 0 in every case. However, patients with higher degrees of motion had VAS pain scores ranging from 0 to 4. Unfortunately, the absence of pain is not completely reliable: The patient with the highest levels of motion and radiolucencies in 2 zones was pain free at final follow-up. This patient has required no additional procedures, and he is satisfied with his outcome. Shoulder pain, even after TSA, may be multifactorial, and the current authors' results should therefore be interpreted with caution when attempting to determine whether glenoid component loosening is present. Although a large-scale study using RSA is likely to be cost prohibitive, further study of how the incomplete relief of pain following TSA correlates with later need for revision due to loosening may be beneficial.

The results of this study must be viewed in light of certain limitations. First, the baseline RSA examinations were taken 6 months postoperatively due to patient discomfort with the radiographic setup, which limited the quality of these early films and necessitated a change in the study's protocol. However, the current authors feel that the data are valuable because measurement of the progression of motion over time was still possible. If motion occurred in the first 6 months but did not progress after that, the authors feel it is unlikely to have been important and could represent an early period of settling, which would be of limited clinical significance. Second, the authors' threshold for high motion was somewhat arbitrary, although it was taken from a previously published study of TSA using stereoradiography.[6] At this time, there are no data to support the assumption that 1 mm of translation or 2° of rotation is truly predictive of early loosening and the eventual need for revision. Finally, there was an additional limitation due to the RSA setup: The limit for acceptable condition numbers was increased from 200 to 300 for the study group due to the small size of the polyethylene glenoid component. The condition number indicates how well the beads were distributed within the segment, and a greater distribution and number of beads is ideal for RSA measurements. The size of the glenoid component made it challenging to insert a large number of well-distributed beads into the limited amount of non-articulating surface, and condition numbers for the glenoid component were higher due to this challenge, with several of the patients having only 3 beads visible for migration measurements. However, the authors do not feel that this adversely affected the data, and the CIs based on double examinations were small.

Conclusion

Despite good short-term clinical outcomes, early glenoid component motion occurs and is greatest in rotation. Persistent low-grade pain and the persistent appearance of radiolucent lines may be early indicators of this motion. It is the authors' recommendation and current practice to raise concern for early loosening if a patient demonstrates both pain and radiolucent lines on routine follow-up, and they have chosen to monitor these patients on a yearly basis to intervene early, if necessary, before bone loss becomes substantial.

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