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Severe acromioclavicular joint osteoarthritis is associated with acromial stress fractures after reverse shoulder arthroplasty

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A R T I C L E I N F O

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Level of evidence: Level III; Retrospective Case-control Design; Prognosis Study

Background: Little is known about the role of disorders of the acromioclavicular joint (ACJ) and how they relate to complications after reverse shoulder arthroplasty (RSA). The purpose of this study is to compare the severity of ACJ osteoarthritis in patients undergoing RSA with and without postoperative acromial and scapular spine fractures.

Methods: A retrospective review was performed to identify all patients who underwent primary RSA between 1/1/2007 and 10/31/2019 with a postoperative acromial or scapular spine stress fracture from a single institution. Patients who underwent RSA with a fracture were compared with an age-, sex-, and preoperative diagnosis-matched control group (1:4 controls) with a minimum 2-year follow-up. We compared demographics, medical comorbidities, and ACJ osteoarthritis between the 2 groups. Preoperative radiographs and 3-dimensional computed tomography scans were evaluated for ACJ osteoarthritis in all patients. The Petersson classification, a modified Petersson classification, location of the osteophytes, subchondral cysts, ACJ space, and size of the largest osteophyte were recorded and compared between the 2 groups.

Results: The study included 11 patients who underwent primary RSA (8 women and 3 men) with acromial (6) and scapular spine (5) fractures confirmed radiographically and 44 matched controls (average follow-up 3.1 vs. 4.3 years, $P = .17$). Average age at surgery was similar between study and control groups (69.6 vs. 70.0 years, $P = .86$). ACJ osteoarthritis with osteophytes larger than 2 mm was common and similar between the 2 groups (91% of patients with acromial fracture and 66% of controls, $P = .15$). There was no significant difference in the size or location of the ACJ osteophytes. The Petersson classification was similar between groups. However, the percentage of patients with subchondral ACJ cysts was higher in the fracture group (91% vs. 50%, $P = .02$), and the percentage of patients with large spanning or fused osteophytes was significantly higher in the fracture group (55% vs. 14%, $P = .008$).

Conclusion: Radiographic ACJ osteoarthritis is common in patients undergoing RSA. Severe ACJ osteoarthritis with completely spanning or fused osteophytes may predispose patients to acromial or scapular spine fractures after RSA.

Acromial stress fractures (ASFs) and scapular spine stress fractures (SSFs) are complications that are largely unique to reverse shoulder arthroplasty (RSA), as the change in shoulder biomechanics due to the implant design places greater stresses on the acromion and scapular spine.[6,18] These fractures have a reported incidence up to 15% and can lead to markedly poor outcomes.[8,10,14,20] Nonoperative management often leads to nonunion and persistent disability of the shoulder.[5] Although surgical fixation may lead to improvement, outcomes after open reduction internal fixation remain modest at best, and rates of nonunion and other complications after operative fixation are high.[4,9] Many studies have investigated and identified risk factors for development of an ASF or SSF after RSA, such as female gender, older age, chronic dislocation, osteoporosis, inflammatory osteoarthritis, and rotator cuff disease.[8,12,15,21] We speculate that decreased motion at the acromioclavicular (AC) joint due to

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osteoarthritis may also be a risk factor for ASF or SSF, as biomechanical studies have consistently shown a significant contribution of the AC joint and scapulothoracic articulation to overall shoulder motion, especially during arm elevation.[11,19] Therefore, we theorize that severe AC joint osteoarthritis causing stiffness and decreased motion through the AC joint would increase the amount of stress seen by the acromion and scapular spine during shoulder motion.

AC joint osteoarthritis is a common degenerative condition typically seen beginning in middle-aged patients.[13] AC joint osteoarthritis, especially with inferior osteophytes, has been well documented to be associated with rotator cuff disease.[2,7,17] Brown et al reported that 86% of patients over 50 years old with AC joint osteoarthritis had concomitant rotator cuff disease, with 57% of those patients having full-thickness tears.[1] Therefore, as commonly patients who undergo RSA are also over the age of 50, AC joint arthritis should be common in this population.

There have been few reports looking at the relationship between AC joint osteoarthritis and ASFs after RSA.[3] Therefore, we performed a retrospective case-control study to assess if there is an association between the extent of AC joint osteoarthritis assessed radiographically and the development of an ASF or SSF. We hypothesized that patients diagnosed with an ASF or SSF would have more severe AC joint osteoarthritis.

Materials and methods

Institutional review board approval was obtained before beginning this study. A retrospective review was performed of all patients who underwent primary RSA at our institution from 1/1/2007 to 10/31/2019. All patients diagnosed with a postoperative ASF or SSF were identified. These were diagnosed with either X-ray or computed tomography (CT) after the patient presented with pain and tenderness over the acromion or scapular spine. Exclusion criteria included diagnosis of an unstable preacromial os acromiale involving the AC joint articulation, preoperative ASF or SSF, revision RSAs, and patients whose primary RSA was performed for an acute fracture as these patients may have had confounding injuries of the suspensory complex that were not identified at the time of the original injury. Twelve patients with postoperative ASF or SSF were identified out of 1046 total RSAs performed during the study period. One patient was excluded from analysis because of having an arthritic preacromial os acromiale involving the AC joint, leaving 11 patients with ASF or SSF included in the fracture group.

Patients in the fracture group were compared with an age- (within 3 years), sex-, and preoperative diagnosis-matched control group (1:4 controls). Control patients were selected as the first 4 patients chronologically who underwent surgery beginning in January of the same year as the fracture group subject who met the match criteria. All patients included in this study had their surgeries performed by 1 of 4 board-certified and shoulder and elbow fellowship-trained orthopedic surgeons at a single academic institution.

Demographic information, past medical history, and surgery information for both groups were obtained from medical records. Preoperative radiographs and CT scans were evaluated by study investigators to characterize the extent of AC joint osteoarthritis. Radiographic variables collected included the following: acromial erosion (defined as any amount of acromial acetabularization seen on preoperative imaging), AC joint subchondral cysts, distal clavicular osteolysis, size of the largest osteophyte, narrowest AC joint width, AC joint subluxation, Petersson classification of AC joint degeneration,[16] location of large osteophytes, coracoacromial ligament ossification, and evidence of prior AC joint surgery. The Petersson classification of AC joint degeneration was developed in 1983 and consists of 3 grades: grade I (superficial degenerative signs with blister formation and some fragmentation), grade II (deep degeneration with cartilage fragmentation, blister formation, and penetrating ulceration of the joint surface in irregularly shaped areas), and grade III (full-thickness cartilage degeneration denuding the subchondral bone of more than 50% of the joint surface, with osteophytes on the inferior joint margins >2 mm). As the Petersson classification was originally developed based on gross anatomic assessment of cadavers, a modified Petersson classification was developed by study investigators and utilized in this study to allow for more differentiation between grades for the severity of AC joint osteoarthritis (6 grades rather than 3, see Table II).

A standard deltopectoral approach was used for all RSAs included in our study. All implants used a medial glenoid/lateral humeral design (Exactech Equinox Shoulder System, Gainesville, FL, USA). There were no notable differences in surgical technique or initial rehabilitation protocol used between the cases and control cohorts.

Continuous data were summarized with means and compared with an independent t-test. Categorical data were summarized with counts and percentages and analyzed with one-tailed Fisher's exact test and chi-square Testing. Univariate analysis was performed given the low number of study patients precluding multivariate analysis. Statistical significance was set at $P < .05$.

Results

Fifty-five (11 in the fracture group and 44 in the control group) primary RSAs were included in final analysis, consisting of 15 men (27%) and 40 women (73%). The average age of all patients was 69.9 years old (range 53-79 years), with a mean follow-up time of 4.0 years (range 0.5-9.7 years). The 11 patients with postoperative fracture consisted of 6 ASFs and 5 SSFs, and the fractures occurred at an average of 2.0 years (range 0.3-6.9 years) after surgery. There were no statistical differences between the fracture group and the control group in regard to patient body mass index, laterality of procedure, past medical history, tobacco use, previous shoulder surgery, or length of follow-up ($P > .05$). (Table I)

All but 1 patient (54/55, 98%) in this study were found to have some level of radiographic evidence of AC joint osteoarthritis preoperatively. The fracture cohort was found to have a significantly greater proportion of patients with AC joint subchondral cysts seen on XR (91% vs. 50%; $P = .01$) and large spanning or fused AC joint osteophytes (55% vs. 14%; $P = .02$) than the control cohort (Fig. 1). However, the mean size of the largest osteophyte (3.5 mm vs. 3.2 mm; $P = .73$) and the narrowest acromioclavicular joint (ACJ) width (1.4 mm vs. 1.2 mm; $P = .72$) measured by CT scan were similar between the fracture and control groups. The fracture cohort was also found to have significantly more acromial erosion than the control group (91% vs. 50%; $P = .01$). Of the 6 patients with fracture who were found to have the highest level of AC joint disease with large spanning or fused AC joint osteophytes, 3 (50%) were diagnosed with an ASF, and 3 (50%) were diagnosed with an SSF. There were no statistical differences between the fracture and control groups for any other radiographic parameters, including presence of pre-os acromiale ($P = .60$), presence of distal clavicle osteolysis ($P = .51$), AC joint subluxation ($P = .36$), Petersson classification (.56), location (superior, inferior, or both) of large osteophytes ($P = .67$), coracoacromial ligament ossification ($P = .64$), or evidence of prior distal clavicle excision surgery for AC joint osteoarthritis ($P = .26$) (Table II).

Table I
Demographic data.

Variable	Control group (N = 44)	Study group (N = 11)	*P* value
Age (SD)	70.0 (6.0)	69.6 (6.6)	.86
Gender (%)			.658
Males	12 (27.3)	3 (27.3)	
Females	32 (72.7)	8 (72.7)	
BMI (SD)	31.7 (7.6)	29.9 (12.5)	.544
Laterality (%)			.312
Left	14 (31.8)	2 (18.2)	
Right	30 (68.2)	9 (81.8)	
Hypertension (%)	25 (56.8)	7 (63.6)	.478
Diabetes (%)	10 (22.7)	1 (9.1)	.292
Inflammatory arthritis (%)	0 (0)	1 (9.1)	.200
Current tobacco use (%)	3 (6.8)	2 (18.2)	.259
Previous shoulder surgery (%)	18 (40.9)	3 (27.3)	.319
Preoperative diagnosis (%)			1.000
Rotator cuff arthropathy	36 (81.8)	9 (81.8)	
Massive rotator cuff tear	4 (9.1)	1 (9.1)	
Osteoarthritis	4 (9.1)	1 (9.1)	
Follow-up in years (SD)	4.3 (2.7)	3.1 (2.3)	.174

SD, standard deviation; *BMI,* body mass index.

Table II
Radiographic data.

Variable	Control group (N = 44)	Study group (N = 11)	*P* value
Os acromiale (%)	3 (6.8)	1 (9.1)	.602
Acromial erosion (%)	22 (50)	10 (90.9)	**.013**
Subchondral cysts (%)	22 (50)	10 (90.9)	**.013**
Osteolysis (%)	3 (6.8)	0 (0)	.505
Largest osteophyte in mm (SD)	3.2 (2.3)	3.5 (1.5)	.728
Narrowest AC joint width in mm (SD)	1.2 (0.7)	1.4 (1.3)	.724
ACJ subluxation (%)			.363
Stable (also mild or questionable subluxation)	43 (97.7)	10 (90.9)	
Obvious subluxation but <100% subluxation (type II separation)	1 (2.3)	1 (9.1)	
At least 100% subluxation (type III, IV, V, VI separation)	0 (0)	0 (0)	
Modified Petersson classification (%)			**.018**
None or only capsular distention on advanced imaging	1 (2.3)	0 (0)	
Mild joint space narrowing with or without small osteophytes (<1 mm)	1 (2.3)	1 (9.1)	
Moderate joint space narrowing with or without moderate-sized osteophytes (1-2 mm)	14 (31.8)	1 (9.1)	
Large osteophytes or large HO/loose bodies (>2 mm up to 3 mm)	8 (18.2)	3 (27.3)	
Large osteophytes or large HO/loose bodies (>3 mm), but not spanning	14 (31.8)	0 (0)	
Large spanning osteophytes or irregular joint borders on both sides of the AC joint, complete fusion/ankylosis	6 (13.6)	6 (54.5)	
Petersson classification[20] (%)			.545
Grade I	10 (22.7)	1 (9.1)	
Grade II	9 (20.5)	2 (18.2)	
Grade III	25 (56.8)	8 (72.7)	
Large osteophytes (%)			.668
None or not large osteophytes (2 mm or less)	14 (31.8)	2 (18.2)	
Inferior osteophytes	4 (9.1)	1 (9.1)	
Superior osteophytes	14 (31.8)	3 (27.3)	
Both inferior and superior osteophytes	12 (27.3)	5 (45.5)	
CA ligament ossification (%)			.637
None	42 (95.5)	11 (100)	
Mild or moderate	2 (4.5)	0 (0)	
Severe or near spanning	0 (0)	0 (0)	
Spanning CA ligament ossification/fusion	0 (0)	0 (0)	
Evidence of Prior ACJ surgery (%)			.261
None	35 (79.5)	11 (100)	
Partial inferior distal clavicle excision	8 (18.2)	0 (0)	
Complete distal clavicle excision/Mumford	1 (2.3)	0 (0)	
Aggressive distal clavicle resection or severe M-L joint space widening (iatrogenic instability due to aggressive resection).	0 (0)	0 (0)	

SD, standard deviation; *AC*, acromioclavicular; *ACJ*, acromioclavicular joint; *HO*, heterotopic ossification; *CA*, coracoacromial.

Discussion

Radiographic evidence of AC joint osteoarthritis in patients undergoing RSA is very common and rarely symptomatic. In patients undergoing primary RSA, severe AC joint osteoarthritis was associated with postoperative ASF and SSF compared with the control cohort. Specifically, patients with subchondral cysts and large spanning or fused AC joint osteophytes were at significantly increased risk of developing a postoperative ASF or SSF. These findings suggest a possible association between severe AC joint

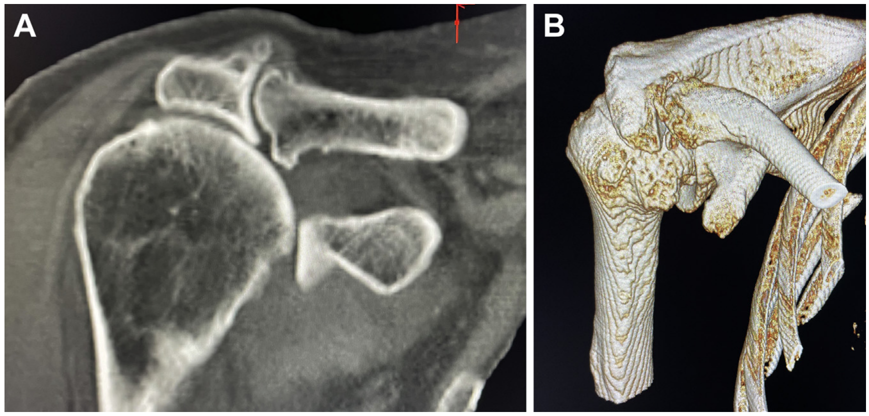

Figure 1 (**A**) Coronal view of right shoulder CT of a study patient illustrating large spanning AC joint osteophytes, with acromial acetabularization. (**B**) Right shoulder CT 3D reconstruction of the same patient, illustrating severe AC joint osteoarthritis with large spanning osteophytes. *CT*, computed tomography; *AC*, acromioclavicular; *3D*, 3-dimensional.

osteoarthritis, resulting in loss of motion through the joint and potential transferring strain through the scapula, and sustaining a postoperative ASF or SSF after RSA.

The AC joint and scapulothoracic articulation play a large role in overall shoulder range of motion. During arm elevation, scapulothoracic motion consists of scapular internal rotation, upward rotation, and posterior tilting relative to the clavicle, and the AC joint contributes to each of these motions.[11,19] In an in vivo biomechanical study, Ludewig et al found that the AC joint is almost solely responsible for scapulothoracic posterior tilting, providing an average of 19 degrees of the total 21 degrees of scapulothoracic motion during arm elevation.[11] Given these data, it can be inferred that a stiff AC joint might limit the amount that the scapulothoracic articulation contributes to overall shoulder motion, thereby requiring more motion at the glenohumeral articulation for shoulder function and resulting in increased stress at the acromion and scapular spine. Our findings support this theory, as the fracture group was found to be significantly more likely to have large spanning or fused osteophytes with complete AC joint ankylosis (54.5% vs. 13.6%, $P = .018$) than the control group. Of note, however, our results showed no difference between other radiographic measures of AC joint osteoarthritis (largest osteophyte size, location of osteophytes, narrowest AC joint width) between fracture and control groups, suggesting that the increased risk of ASF or SSF may not occur until the AC joint develops markedly severe stiffness or ankylosis.

Our results contrast with a previous study by Dubrow et al in 2014 that also reported on the prevalence of AC joint osteoarthritis in 125 patients who underwent RSA and who developed an ASF (N = 14, 11.2%) vs. those who did not (N = 111, 88.8%).[3] They reported no significant difference in the prevalence of AC joint osteoarthritis between the fracture group (11/14; 77.3%) and no fracture group (71/111; 64.1%) ($P = .23$). However, that study did not attempt to grade the severity of the AC joint osteoarthritis. We also found similar rates of AC joint osteoarthritis between fracture and nonfracture cohorts; however, severe disease with bony ankylosis was significantly more common in the fracture group (54.5% vs. 13.6%; $P = .02$). Together, these studies support that AC joint osteoarthritis is common in patients who undergo RSA and suggest that AC joint osteoarthritis may not be a contributing factor to an ASF or SSF until it is severe enough to lead to significant loss of AC joint motion.

Interestingly, approximately 1 in 5 control patients in our study had radiographic evidence of a prior distal clavicle excision or coplaning procedure, whereas no fracture patients had any previous AC joint surgeries. Although this difference was not statistically significant, distal clavicle excision could possibly represent a protective factor to developing an ASF or SSF postoperatively, although our control group was just a small sample of all patients undergoing RSA at our institution. In patients undergoing RSA who have large spanning or fused AC joint osteophytes, consideration of a distal clavicle excision at the time of RSA may be warranted. Doing this could possibly reduce the likelihood of sustaining an ASF or SSF by improving motion through the AC joint and scapulothoracic articulation postoperatively.

We recognize that this study has several limitations. First, our data show that, in additional to severe AC joint osteoarthritis, acromial erosion from a high-riding humeral head was also significantly correlated with postoperative ASF or SSF, and this may be a confounding variable. Unfortunately, as 10 of 11 patients with fracture were found to have acromial erosion, multivariate analysis could not be performed to account for the unique contributions of acromial erosion compared with AC joint osteoarthritis on the risk of having a postoperative fracture. Future studies will be needed to assess this. However, it should be noted that acromial erosion typically affects the anterolateral acromion, but 5 of 10 patients with acromial erosion had fractures of the scapular spine in a portion of the bone that was not affected by erosion, so we feel that the erosion is likely a correlated rather than a causative factor. In addition, the case-control study design also has inherent limitations, and although we attempted to match patients to controls of similar age, sex, and preoperative diagnosis (known risk factors for ASF or SSF after RSA), there may be other confounding variables that we did not account for. Finally, because of the rarity of ASF and SSF after RSA,[8,12] our study represents only a small cohort of patients, which limits the conclusions that can be drawn from the data.

Conclusions

This study found that while radiographic evidence of AC joint osteoarthritis is present in most patients undergoing RSA, severe AC joint osteoarthritis with large spanning AC joint osteophytes may predispose patients to sustaining an ASF or SSF after RSA. Patients with severe AC joint osteoarthritis with large spanning or fused osteophytes should be counseled preoperatively on their potentially increased risk of developing an ASF or SSF postoperatively. Future studies with larger sample sizes would be helpful to further characterize the association between AC joint ankylosis and sustaining an ASF or SSF after RSA and to investigate if distal clavicle resection at the time of surgery may be protective.

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References

1. Brown JN, Roberts SN, Hayes MG, Sales AD. Shoulder pathology associated with symptomatic acromioclavicular joint degeneration. J Shoulder Elbow Surg 2000;9:173-6.
2. Cuomo F, Kummer FJ, Zuckerman JD, Lyon T, Blair B, Olsen T. The influence of acromioclavicular joint morphology on rotator cuff tears. J Shoulder Elbow Surg 1998;7:555-9.
3. Dubrow S, Streit JJ, Muh S, Shishani Y, Gobezie R. Acromial stress fractures: correlation with acromioclavicular osteoarthritis and acromiohumeral distance. Orthopedics 2014;37:e1074-9. https://doi.org/10.3928/01477447-20141124-54.
4. Gutman MJ, Joyce CD, Baruch DE, Horvath YM, Zmistowski B, Harding ML, et al. Outcomes of nonoperative management of acromial stress fractures after reverse shoulder arthroplasty. Semin Arthroplasty 2021. https://doi.org/10.1053/j.sart.2021.03.010.
5. Hamid N, Connor PM, Fleischli JF, D'Alessandro DF. Acromial fracture after reverse shoulder arthroplasty. Am J Orthop (Belle Mead Nj) 2011;40:E125-9.
6. Kerrigan AM, Reeves JM, Langohr GDG, Johnson JA, Athwal GS. The influence of reverse arthroplasty humeral component design features on scapular spine strain. J Shoulder Elbow Surg 2021;30:572-9. https://doi.org/10.1016/j.jse.2020.06.011.
7. Kessel L, Watson M. The painful arc syndrome. Clinical classification as a guide to management. J Bone Joint Surg Br 1977;59:166-72. https://doi.org/10.1302/0301-620x.59b2.873977.
8. King JJ, Dalton SS, Gulotta LV, Wright TW, Schoch BS. How common are acromial and scapular spine fractures after reverse shoulder arthroplasty?: a systematic review. Bone Joint J 2019;101-b:627-34. https://doi.org/10.1302/0301-620x.101b6.Bjj-2018-1187.R1.
9. Lau SC, Large R. Acromial fracture after reverse total shoulder arthroplasty: a systematic review. Shoulder Elbow 2020;12:375-89. https://doi.org/10.1177/1758573219876486.
10. Levy JC, Anderson C, Samson A. Classification of postoperative acromial fractures following reverse shoulder arthroplasty. J Bone Joint Surg Am 2013;95:e104. https://doi.org/10.2106/jbjs.K.01516.
11. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. J Bone Joint Surg Am 2009;91:378-89. https://doi.org/10.2106/jbjs.G.01483.
12. Mahendraraj KA, Abboud J, Armstrong A, Austin L, Brolin T, Entezari V, et al. Predictors of acromial and scapular stress fracture after reverse shoulder arthroplasty: a study by the ASES Complications of RSA Multicenter Research Group. J Shoulder Elbow Surg 2021. https://doi.org/10.1016/j.jse.2021.02.008.
13. Mall NA, Foley E, Chalmers PN, Cole BJ, Romeo AA, Bach BR Jr. Degenerative joint disease of the acromioclavicular joint: a review. Am J Sports Med 2013;41:2684-92. https://doi.org/10.1177/0363546513485359.
14. Mayne IP, Bell SN, Wright W, Coghlan JA. Acromial and scapular spine fractures after reverse total shoulder arthroplasty. Shoulder Elbow 2016;8:90-100. https://doi.org/10.1177/1758573216628783.
15. Miller M, Chalmers PN, Nyfeler J, Mhyre L, Wheelwright C, Konery K, et al. Rheumatoid arthritis is associated with increased symptomatic acromial and scapular spine stress fracture after reverse total shoulder arthroplasty. JSES Int 2021;5:261-5. https://doi.org/10.1016/j.jseint.2020.10.010.
16. Petersson CJ. Degeneration of the acromioclavicular joint. A morphological study. Acta Orthop Scand 1983;54:434-8. https://doi.org/10.3109/17453678308996597.
17. Petersson CJ, Gentz CF. Ruptures of the supraspinatus tendon. The significance of distally pointing acromioclavicular osteophytes. Clin Orthop Relat Res 1983:143-8.
18. Shah SS, Gentile J, Chen X, Kontaxis A, Dines DM, Warren RF, et al. Influence of implant design and parasagittal acromial morphology on acromial and scapular spine strain after reverse total shoulder arthroplasty: a cadaveric and computer-based biomechanical analysis. J Shoulder Elbow Surg 2020;29:2395-405. https://doi.org/10.1016/j.jse.2020.04.004.
19. Teece RM, Lunden JB, Lloyd AS, Kaiser AP, Cieminski CJ, Ludewig PM. Three-dimensional acromioclavicular joint motions during elevation of the arm. J Orthop Sports Phys Ther 2008;38:181-90. https://doi.org/10.2519/jospt.2008.2386.
20. Teusink MJ, Otto RJ, Cottrell BJ, Frankle MA. What is the effect of postoperative scapular fracture on outcomes of reverse shoulder arthroplasty? J Shoulder Elbow Surg 2014;23:782-90. https://doi.org/10.1016/j.jse.2013.09.010.
21. Zmistowski B, Gutman M, Horvath Y, Abboud JA, Williams GR Jr, Namdari S. Acromial stress fracture following reverse total shoulder arthroplasty: incidence and predictors. J Shoulder Elbow Surg 2020;29:799-806. https://doi.org/10.1016/j.jse.2019.08.004.