J Shoulder Elbow Surg (2020) 29, 2556–2563

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

The risk of postoperative scapular spine fracture following reverse shoulder arthroplasty is increased with an onlay humeral stem

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Background: The purpose of this study was to assess the effects of lateralization and distalization on scapular spine fracture (SSF) after reverse shoulder arthroplasty (RSA). The hypothesis was that postoperative distalization would increase the risk of SSF, whereas lateralization would not.

Methods: A multicenter retrospective review was performed at a minimum of 1 year postoperatively on primary RSAs with 3 different implants, 2 with an inlay design (n = 342) and 1 with an onlay design (n = 84). Functional outcome, range of motion, stem design, and radiographic measurements, including acromiohumeral distance and lateralization, were compared between groups with and without fracture.

Results: The incidence of SSF in the onlay group (11.9%) was significantly higher compared with the inlay group (4.7%; $P = .043$). Postoperative acromiohumeral distance was approximately 4 mm higher in the SSF group (37.5 mm) compared with the control group (33.7 mm; $P = .042$), whereas lateralization was similar between the 2 groups (52.8 mm vs. 53.9 mm; $P = .362$). Higher return to activity (92.1% vs. 71.4%; $P < .001$) as well as postoperative forward flexion was observed in the group without fracture (135° vs. 120°; $P = .009$).

Conclusion: Increased postoperative distalization is associated with an increased risk of SSF after RSA. An onlay stem resulted in a 10 mm increase in distalization compared with an inlay stem, and a 2.5 times increased risk of SSF. Lateralization, however, does not appear to increase the risk of SSF.

Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Reverse shoulder arthroplasty; scapular spine fracture; acromial fracture; inlay stem; onlay stem; acromiohumeral distance; humeral offset; humeral lateralization

Institutional Review Board approval was received from CCER of Geneva (14-277).

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1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2020.03.036

Table I Baseline demographics and function

	No fracture (n = 400)	Scapular spine fracture (n = 26)	*P* value
Age	72.5 (range, 49-90)	72.5 (range, 48-86)	.971
Sex	229 females (58%)	17 females (65%)	.117
	171 males (42%)	9 males (35%)	
Dominant arm	225 (56%)	11 (42%)	.165
Smoking history	148 (37%)	11 (42%)	.609
Osteoporosis	23 (6.2%)	0 (0%)	.191
ASES score	36.1 (±17.5)	32.15 (±17.2)	.267
SANE score	32.9 (±21.2)	29.83 (±22.8)	.435
VAS pain score	6.2 (±2.4)	6.3 (±2.4)	.712
Forward flexion	83° (±43)	75° (±38)	.310
External rotation	23° (±28)	20° (±30)	.309
Internal rotation	L5	L4	.239

ASES, American Shoulder and Elbow Surgeons; *SANE*, Single Assessment Numeric Evaluation; *VAS*, visual analog scale.

Reverse shoulder arthroplasty (RSA) is an increasingly common procedure,[8] constituting around one-third of the total shoulder replacements performed in the USA in 2011.[28] It is a versatile procedure that was initially used for the treatment of rotator cuff arthropathy[24] and is now being offered as a treatment option for various pathologies, such as proximal humerus fractures[5] and primary osteoarthritis with severe glenoid bone loss,[4,9] among others. Although this procedure leads to improved outcomes especially at mid-term follow-up,[2] it is not one without complications.[3,11]

One complication unique to RSA is postoperative scapular spine fracture (SSF). The incidence of SSF after RSA is approximately 4%.[22] When fractures occur, they lead to a decrease in functional outcomes.[1,20,22] It is therefore important to identify risk factors for the development of this complication. Recently, it has been suggested that prosthesis design may contribute to SSF.[16,18] However, previous studies have only evaluated 1 prosthesis design per study. Moreover, different RSA designs lead to variable amounts of postoperative lateralization and distalization. Therefore, these studies were not likely able to fully evaluate the relationship between lateralization and distalization and postoperative SSF.

The purpose of this study was to assess the effects of lateralization and distalization on SSF, by comparing the incidence of this complication with different prosthetic designs. The hypothesis was that postoperative distalization would be associated with an increased risk of SSF, but that increasing lateralization would not be associated with SSF.

Materials and methods

A retrospective comparative study was conducted on prospectively collected data on RSAs performed at 3 different institutions between July 2015 and July 2018. Inclusion criteria included a primary RSA performed for the diagnoses of rotator cuff arthropathy, primary osteoarthritis, or failed cuff repair, and a minimum follow-up of 1 year or identification of a postoperative SSF before 1 year. Exclusion criteria included revision RSA and preoperative acromial fracture. Seven hundred and forty-six RSAs were performed during the study period, of which 676 met the study criteria. Two hundred and fifty were lost to follow-up, leaving 426 (63%) available for follow-up at a mean of 12.9 months (range, 3-32 months).

Three fellowship-trained shoulder surgeons (PJD, MAF, AL) at 3 different centers performed the surgeries. A deltopectoral approach was used in all cases. Implant choice was based on surgeon preference and included 143 Univers Revers (Arthrex, Inc., Naples, FL, USA), 199 Altivate Reverse (DJO, Inc., Dallas, TX, USA), both of which have an inlay humeral stem design, and 84 Aequalis Ascend Flex (Tornier, Inc., Bloomington, MN, USA), which have an onlay humeral stem design. Baseline demographics of the cohort are presented in Table I.

Radiographic evaluation

Grashey (true glenohumeral anteroposterior view), scapular Y, and axillary radiographs were obtained preoperatively, immediately after surgery, and at a final follow-up. Radiographs were reviewed by an independent examiner (GH) in DICOM (digital imaging and communications in medicine) format using Echoes (Medstrat, Downers Grove, IL, USA) and Horos (Pixmeo, Bernex, Switzerland). The radiographs were reviewed for the presence of an acromial fracture, followed by a chart review for the presence or absence of fractures. If present, the fracture was classified according to the Levy classification into types I, II, and III.[17]

Immediate postoperative x-ray anteroposterior views were used to measure distalization, humeral offset, and lateralization (Fig. 1). Distalization was based on the acromiohumeral distance (AHD) in millimeters. Humeral lateralization in millimeters was measured according to Levy et al.[17] In addition, the center of rotation (COR) offset was measured as the perpendicular distance between the COR of the original humeral head and the COR of the humeral cup (Fig. 1).[12]

Clinical evaluation

Clinical outcome was assessed preoperatively and at the final follow-up. Function was determined with patient-reported

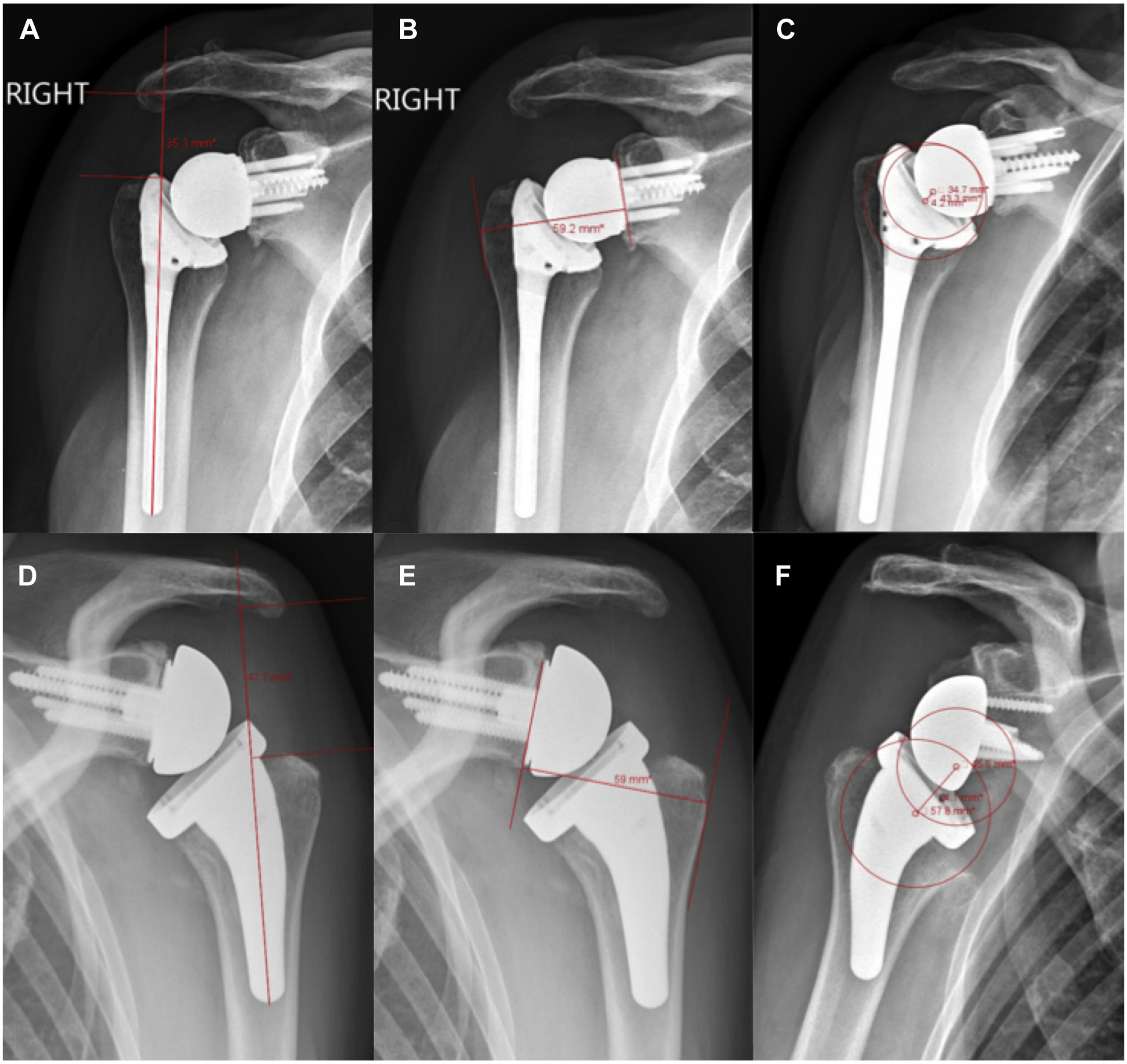

Figure 1 Radiographic examples of measurements obtained for analysis in the inlay (**A**-**C**) and onlay components (**D**-**F**). (**A**, **D**) Acromiohumeral distance measured perpendicular to the long axis of the humerus. (**B**, **E**) Lateralization of the humerus relative to the glenoid. (**C**, **F**) Center of rotation offset.

outcomes using the American Shoulder and Elbow Surgeons (ASES) score, visual analog scale (VAS) pain score, and Single Assessment Numeric Evaluation (SANE) score. Range of motion (ROM) was assessed by the treating surgeon at each site to determine forward flexion, external rotation with the arm at the side, and internal rotation, and was estimated to the nearest spinal level. Patient satisfaction (yes or no) and return to activity (yes or no) were recorded at the final follow-up.

Information on age, sex, smoking history, diagnosis, and hand dominance on all patients was also collected. The diagnosis of osteoporosis was made based on a chart review of their patient problem list. This was then confirmed by the presence or absence of any osteoporosis drug therapy in the medication list. If present, data on the onset of the SSF, time to fracture diagnosis, and treatment were also obtained.

Statistical analysis

Mean and standard deviations were used to describe continuous data. To examine the difference in radiographic measurements, pre- and postoperative ROM, and functional outcome scores, a paired *t*-test, sign test, or Wilcoxon rank sum test was conducted according to variable distribution. χ^2 tests were performed for the incidence of acromial fracture per surgeon, per stem design (inlay vs. onlay), and for return to activity and satisfaction. Two-tailed *P* values of $<.05$ were considered significant. Statistical analyses were carried out by a trained statistician.

Results

Radiographic results

Of the 426 patients in the cohort, 26 (6.1%) were diagnosed with SSF, the most common being Levy type I (n = 12), followed by type II (n = 9), and then type III (n = 5) (Fig. 2). All type III fractures occurred adjacent to or at the tip of one of the baseplate screws. One patient in the SSF group with a type III fracture was treated surgically with internal fixation; all other fractures were managed conservatively.

There was no difference between the SSF and the no fracture groups with regard to age, sex, arm dominance, and smoking history. No patients with SSF had a diagnosis of osteoporosis. Postoperative AHD was approximately 4 mm higher in the SSF group (37.5 mm) compared with the no fracture group (33.7 mm; $P = .042$). There was no difference in lateralization between the 2 groups (52.8 vs. 53.9; $P = .362$). Furthermore, there was no difference in the COR offset between the 2 groups (14.1 vs. 13.2; $P = .489$) (Table II).

When the incidence of SSFs was categorized according to the stem design, the 2 stems with an inlay design had an incidence of 4.7%, compared with 11.9% with the onlay stem ($P = .043$). Postoperative AHD was 10 mm higher in the onlay stems as compared with the inlay stems (41.9 mm vs. 31.5 mm; $P < .001$). Humeral lateralization was slightly higher in the onlay group (57.0 mm vs. 53.1 mm; $P < .001$), whereas the COR offset was approximately 2 times higher in the onlay group (23.2 mm vs. 10.2 mm; $P < .001$) (Table III).

Clinical results

In the overall cohort, ROM and functional outcome scores improved from preoperative to postoperative follow-up with significant differences in all categories ($P < .001$).

In both the SSF and control groups, overall ROM and functional outcome scores improved from preoperative to postoperative follow-up ($P > .05$). Higher return to activity (95.9% vs. 71.4%; $P < .001$) as well as higher postoperative forward flexion was observed in the no fracture group (135° vs. 120°; $P = .009$). All other categories (ASES score, VAS pain score, SANE score, satisfaction, and ROM) did not show a statistically significant difference between the 2 groups (Table IV).

Discussion

The aim of this study was to compare the effect of lateralization and distalization on SSF after RSA. The major findings are that distalization was higher in the SSF group and that the incidence of SSF was 2.5 times higher with an onlay stem compared with an inlay stem. These findings support our hypothesis and may have important implications for both prosthetic design and component placement.

SSFs were generally considered to be a rare complication of RSA,[6] and their risk factors have been poorly understood. Nonetheless, some risk factors such as osteoporosis,[21] acromial thickness,[27] inflammatory arthritis, and glenoid lateralization[13] have been shown to be associated with these fractures. There is still no consensus in the literature about the rate of SSF; whereas some studies have reported a rate as low as 0.8%,[26] others have reported a rate of around 11%.[10] In recently published systematic reviews, Patterson et al[22] found a rate of 4.1%, whereas King et al[13] found a rate of 2%. These mixed results could be attributed to the fact that these studies combined different types of implants that had different stem designs (ie, inlay and onlay).

Previous studies have suggested that humeral stem design may influence the rate of SSF. Ascione et al[1] evaluated 485 onlay RSAs and found a rate of 4.3%, whereas Neyton et al[20] showed a rate of 1.3% in a multicenter retrospective study on 1035 inlay RSAs. Further evidence comes from 2 other studies that compared 2 stems head-to-head. In a retrospective

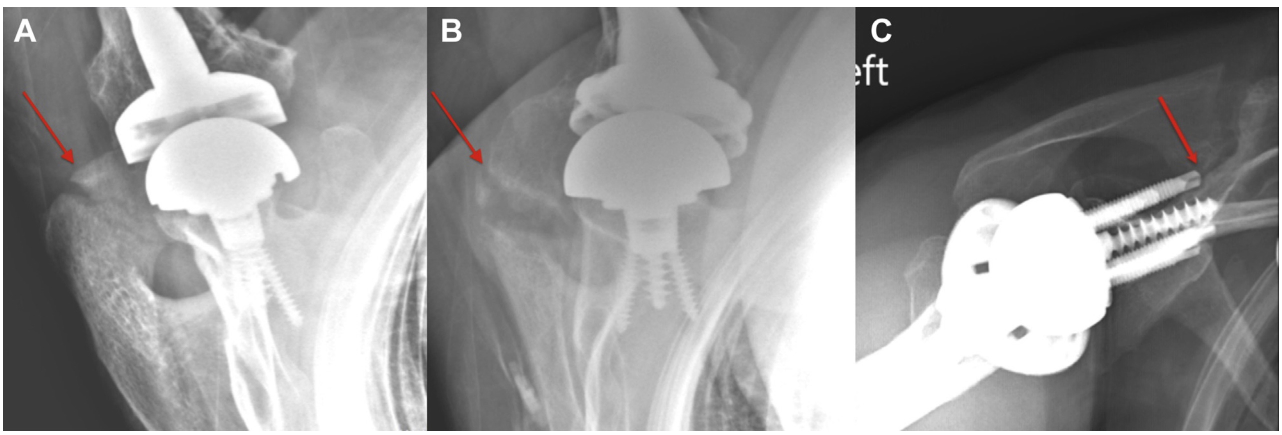

Figure 2 Radiographs showing examples of the different types of scapular spine fractures (←): (**A**) Levy type I, (**B**) Levy type II, and (**C**) Levy type III.

Table II Postoperative radiographic measurements of the groups

	No fracture (n = 400)	Scapular spine fracture (n = 26)	*P* value
AHD (mm)	33.7 (±9.1)	37.4 (±8.7)	**.021**
Center of rotation offset (mm)	13.2 (±6.6)	14.1 (±6.8)	.489
Humeral lateralization (mm)	53.9 (±7.0)	52.8 (±8.0)	.362

AHD, acromiohumeral distance.

Table III Radiographic measurements for the inlay stems vs. the onlay stem

	AHD (mm)	Lateralization (mm)	Center of rotation offset (mm)
Inlay stem 1	31.4 ± 7.8	53.2 ± 6.2	12.5 ± 3.3
Inlay stem 2	31.5 ± 7.6	53.2± 7.4	8.6 ± 3.8
P value	.749	.869	**<.001**
Overall inlay	31.5 ± 7.7	53.1 ± 6.9	10.2 ± 4.0
Onlay stem	41.9 ± 9.9	57.0 ± 6.1	23.2 ± 3.8
P value	**<.001**	**<.001**	**<.001**

AHD, acromiohumeral distance.
Inlay stem 1 (Univers Revers; Arthrex, Inc.); Inlay stem 2 (Altivate Reverse; DJO, Inc.).

Table IV Postoperative outcome

	No fracture (n = 400)	Scapular spine fracture (n = 26)	*P* value
Forward flexion	135° (±33°)	120° (±29°)	**.009**
External rotation	42° (±30.1°)	33° (±33°)	.125
Internal rotation	L4	L3	.464
ASES score	36.1 (±17.5)	32.2 (±17.2)	.267
SANE score	32.9 (±21.2)	29.8 (±22.8)	.435
VAS pain score	6.2 (±2.4)	6.3 (±2.4)	.712
Return to activity	92.1%	71.4%	**.001**
Satisfaction	92.1%	90.1%	.569

ASES, American Shoulder and Elbow Surgeons; *SANE*, Single Assessment Numeric Evaluation; *VAS*, visual analog scale.

comparative study, Merolla et al[18] evaluated 68 patients with rotator cuff arthropathy that had received either a Grammont (inlay) design or an onlay design, and found that SSFs only occurred in patients who had received the latter (0% vs. 7.9%). LeDuc et al[16] evaluated 109 RSAs performed by 2 different surgeons and observed that the onlay cohort had an SSF rate of 12.07%, which was 3.33 times higher than the inlay cohort (3.92%; *P* = .23). Although this difference did not reach statistical significance based on the power of the cohort, the magnitude of difference is consistent with our findings. In the current study, the rate of postoperative SSF was 2.5 times higher in the RSAs with an onlay design (11.1%) as compared with an inlay design (4.7%; *P* = .042). Combined with the previous studies, this suggests that the risk of SSF is higher with an onlay humeral design.

To better understand the differences in rates of SSFs between the inlay and onlay stems, it is important to highlight the characteristics of each, as they lead to differences in postoperative lateralization and distalization. The original Grammont design used a medialized glenosphere with a 155° inlay humeral component. Following this, there were 2 primary divergences in prosthetic design. The first was the development of a 135° humeral component with increased glenoid lateralization. This design was developed to decrease scapular notching and improve on limited internal and external rotation observed with the classic Grammont design. The second was the development of convertible humeral stems, which provided conversion at the level of the humeral cut and thus provided an onlay humeral design. These design features lead to marked differences in postoperative arm position. A computer modeling study comparing the 155° Grammont stem with the onlay stem showed that, by altering the stem design from Grammont to onlay, humeral offset can change by up to 7 mm and AHD can change by up to 4 mm.[14] Another study examining the radiographic differences in humeral position according to an RSA design showed that, compared with the inlay design, the onlay design resulted in a statistically significant increase in humeral offset (28.1 mm vs. 20.8 mm; *P* = .001), as well as distalization measured by acromio-epiphyseal distance (26.0 mm vs. 19.9 mm; *P* = .001).[7] Furthermore, Roche et al[23] showed that a 145° onlay stem resulted in a 10 mm increase in AHD and a 3 mm increase in offset when compared with a 135° inlay stem. In the current study, distalization was 10 mm greater and the COR offset was twice as high with the onlay design.

Arm lengthening, frequently reported as an increase in AHD, has been considered by some to be an important factor in the restoration of function and stability after RSA.[15] An excess amount, however, may increase the risk of neurologic injury.[15] Increased arm lengthening has also been thought of as a potential risk factor for acromial fractures, due to the increased pull by the deltoid muscle on the acromion.[10,27] In a study evaluating the use of RSA in patients with preoperative acromial pathologies such as os acromiale, Mottier et al[19] showed the effect of arm lengthening on the acromion when they reported that 87.5% of these lesions were displaced as a result of increased traction by the deltoid postoperatively. Although other reports have failed to show a significant association between SSF and AHD,[10,27] one study showed that their SSF group had shorter preoperative arm lengths (*P* < .004) due to increased upward migration of the humeral head compared with the control group, which in turn meant more elongation of the arm after surgery.[27] Our study showed that the

SSF group had a higher postoperative AHD (37.4 mm) compared with the control group (33.7 mm; $P = .042$). Although this difference may seem minor, a computer modeling study showed that by altering implant design, a 4.6 mm increase in AHD may be associated with double the increase in the mid deltoid muscle length especially during abduction ROM.[23] In addition, the magnitude of this difference might be affected by the fact that inlay and onlay implants, which result in different amounts of distalization, were pooled together in both fracture and non-fracture groups. Nevertheless, the AHD difference remained statistically significant underlining the association between increased risk of SSF and distalization. We also found that the onlay stem increased the arm length by 10 mm as compared with the inlay stem, which could possibly lead to excessive stresses on the acromion. This difference could in part explain the increased incidence of SSF in the onlay design. However, AHD only evaluates the position in 1 plane. Notably, the COR increase with the onlay group, which reflects both the distal and lateral position, was higher than the AHD increase.

Based on finite element analysis, acromial stress increases with lateralization.[29] Wong et al analyzed stress distribution over the acromion resulting from deltoid muscle forces required to achieve an abduction arc of motion (0-120°) with varying humeral and glenosphere configurations. Humeral medialization decreased stress on the acromion by 1.4% ($P = .038$), whereas glenosphere lateralization increased stress by 17.2%.[29] They suggested that lateralization could increase the risk of SSF. In addition, this and other studies have suggested that a decrease in deltoid force lowers the risk of SSF.[27] Theoretically, this can be accomplished with a medialized COR with a lateralized humerus that increases the deltoid moment arm, thereby decreasing joint reaction force as well as stress on the scapular spine. Our data, however, did not show any statistically significant difference in lateralization (52.8 mm vs. 53.9 mm; $P = .362$) between the SSF and no fracture groups. Roche et al[23] showed that lateralization increased the cuff muscle length but had no effect on the deltoid muscle length when they controlled for distalization by using the same stem design and implant features. This, along with the above findings, may indicate that deltoid lengthening affected by distalization rather than by lateralization increases the risk for SSF. Moreover, the group of patients with the greatest increase in the deltoid moment arm (ie, the onlay group had a 2× increase in COR), had the highest incidence of SSF. This suggests that the theoretical model of deltoid moment is flawed and that the more nonanatomic position increases the postoperative force on the scapula.

It is interesting to note that no patients in the SSF group had documented osteoporosis in our study. Osteoporosis and acromial thickness are 2 risk factors that have been previously linked to SSFs.[21,27] Otto et al[21] showed that osteoporosis was a significant risk factor for SSF but were unable to find a correlation between SSF and anteromedial acromial thickness, as measured on an anteroposterior view. Furthermore, Werthel et al[27] supported these findings and were able to show a correlation between SSF and acromial thickness at its mid portion on a Y-view ($P = .008$). However, although the difference in acromial thickness was statistically significant, the magnitude of the difference was minimal (1.1 mm), which could be difficult to appreciate both clinically and radiographically.

The analysis of ROM and functional data revealed that patients with SSF showed a significantly lower return to activity as compared with the control group ($P = .005$). The SSF group also had a 16° limitation of postoperative forward flexion (120°) vs. the no fracture group (135°; $P = .009$). Other studies have demonstrated that the final postoperative ROM decreases after SSF.[20,22] We did not observe statistically significant differences in satisfaction, ASES, VAS pain, and SANE scores, or internal and external rotation in the SSF group compared with the no fracture group. Similarly, Werthel et al[27] showed that these measures did not exhibit a significant difference between the groups, although the SSF group was less satisfied. On the other hand, other reports have shown that patients with SSF had inferior functional outcomes compared with those with no fracture.[20,22]

The most common fracture in our study was the Levy type I, which occurred in 12 patients, followed by type II in 9 patients and type III in 5. Evidence on the difference between the type I and II fractures that occur in the acromial region comes from a study by Voss et al,[25] who evaluated the acromial morphology and bone mineral density. They showed that the posterior medial acromion close to the acromioclavicular joint (Levy type II region) had the highest bone mineral density, whereas the lateral part (Levy type I region) had the lowest.[25] This in turn could make this region more susceptible to fractures. On the other hand, type III fractures were thought to occur as a result of a stress riser effect by the superior baseplate screw. Otto et al[21] have shown that 14 of 16 of type III fractures occurred at the tip of the screw. Our results support these findings with all of the type III fractures occurring adjacent to or at the screw tip. In the setting of adequate stability, strong consideration should therefore be given to limiting the length of the superior baseplate screw and/or directing it away from the scapular spine.

The strengths of this study are the cohort size and variety of implants that provided a range of lateralization and distalization to be evaluated. At the same time, there are several limitations. First, the follow-up period was short, and only some fractures that occurred later may have been missed. However, previous studies have demonstrated that the vast majority of fractures occur within the first year postoperatively.[1,10,22,27] Second, the radiographic evaluation was carried out using plain radiographs only, whereas more advanced imaging such as computed tomography or single photon emission computed tomography scan was reserved for patients with pain over the acromion and negative radiographs, and it is thus possible that some fractures (ie, asymptomatic fractures) were missed. Third, the study design was retrospective with only 63% available for follow-up, and it is not known how those lost to follow-up would affect the incidence. Finally, although we attempted to evaluate lateralization and distalization independent of design by providing measurements, it should be noted that these measurements can also be impacted by component position, which may differ based on surgeon preference (ie, glenosphere position or thickness of the humeral head cut).

Conclusion

Increased postoperative distalization is associated with an increased risk of SSF after RSA. An onlay humeral stem design resulted in a 10 mm increase in distalization compared with an inlay humeral stem and a 2.5 times increased risk of SSF. On the other hand, lateralization does not appear to increase the risk of postoperative SSF.

Disclaimer

This study was supported by a grant from DJO, Inc.

Patrick J. Denard reports that he is a paid consultant for and receives royalties from Arthrex, Inc.

Mark A. Frankle reports that he is a paid consultant for and receives royalties from DJO, Inc.

Alexandre Lädermann reports that he is a paid consultant for Arthrex, Wright, and Medacta and receives royalties from Wright.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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