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Scapula fracture incidence in reverse total shoulder arthroplasty using screws above or below metaglene central cage: clinical and biomechanical outcomes

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Background: Reverse total shoulder arthroplasty (RTSA) is a viable treatment option for rotator cuff tear arthropathy but carries a complication risk of scapular fracture. We hypothesized that using screws above the central glenoid axis for metaglene fixation creates a stress riser contributing to increased scapula fracture incidence. Clinical type III scapular fracture incidence was determined with screw placement correlation: superior screw vs. screws placed exclusively below the glenoid midpoint. Cadaveric RTSA biomechanical modeling was employed to analyze scapular fractures.
Methods: We reviewed 318 single-surgeon single-implant RTSAs with screw correlation to identify type III scapular fractures. Seventeen cadaveric scapula specimens were matched for bone mineral density, metaglenes implanted, and fixation with 2 screw configurations: inferior screws alone (group 1_{INF}) vs. inferior screws with one additional superior screw (group 2_{SUP}). Biomechanical load to failure was analyzed.
Results: Of 206 patients, 9 (4.4%) from the superior screw group experienced scapula fractures (type III); 0 fractures (0/112; 0%) were identified in the inferior screw group. Biomechanically, superior screw constructs (group 2_{SUP}) demonstrated significantly ($P < .05$) lower load to failure (1077 N vs. 1970 N) compared with constructs with no superior screws (group 1_{INF}). There was no significant age or bone mineral density discrepancy.
Conclusion: Clinical scapular fracture incidence significantly decreased ($P < .05$) for patients with no screws placed above the central cage compared with patients with superior metaglene screws. Biomechanical modeling demonstrates significant construct compromise when screws are used above the central cage, fracturing at nearly half the ultimate load of the inferior screw constructs. We recommend use of inferior screws, all positioned below the central glenoid axis, unless necessary to stabilize the metaglene construct.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Reverse total shoulder; arthroplasty; scapula fracture; complication; metaglene; clinical; biomechanical; outcomes

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Reverse total shoulder arthroplasty (RTSA) has gained popularity since its reintroduction to the US market following Food and Drug Administration approval in 2003. Although RTSA is still in the minority of arthroplasties performed in the United States, this procedure accounted for one-third of all shoulder arthroplasty procedures in 2011.[11] Whereas it is an accepted treatment for older patients with rotator cuff tear arthropathy, it has also shown utility in rotator-deficient patients, failed hemiarthroplasty, failed total shoulder arthroplasty, and proximal humerus fractures.[5] However, with major complication rates as high as 26% reported in studies, RTSA is not without its challenges.[13] Complications including scapular notching, postoperative hematoma, periprosthetic infection, glenosphere dissociation, and acromial/scapular fracture are well documented.[1]

Scapular spine fracture is a serious complication of RTSA often caused by a fall on an outstretched arm or a forced movement to the shoulder, or it can be of insidious onset with no explicit trauma. The incidence of scapular fractures occurring after RTSA was reported to be between 5.8% and 10.2% in previous studies.[3,12] In 1 study, 400 RTSA patients were analyzed and 3 discrete scapular fracture patterns were described: avulsion fractures of the anterior acromion (type I); fractures of the acromion posterior to the acromioclavicular joint (type II); and fractures of the scapular spine (type III).[3] Levy later classified these fractures on the basis of the deltoid muscle origin but again acknowledged the complication's existence and variable clinical outcomes.[6] The metaglene component of the reverse shoulder implant in our study is secured with cortical compression screws, and the fixation pattern is left to the choice of the surgeon. Some implants are secured with a central compression screw and peripheral locking screws. Certainly, osteoporosis, implant design, and surgical technique may influence scapular spine fracture risk; however, evidence from 3-dimensional CT scans of type III fractures suggests that these fractures may also be a result of a stress riser formed at the tip of superior screws in the glenoid (Fig. 1), which prompted our investigation.[3,9]

Scapular fracture patients often necessitate revision procedures, which can be difficult without removal of the superior screw causing the displacement.[3] Oftentimes, an open reduction of this fracture complication involves removing the superior screw to gain an adequate displacement reduction and to achieve fixation. Secondary procedures increase morbidity, and outcomes have been unpredictable. The sequelae from this complication prompted our clinical and biomechanical investigation into metaglene fixation techniques and their impact on scapular fracture incidence in RTSA. We hypothesized that a fixation configuration with all screws directed below the central cage of the metaglene plate would decrease the incidence of type III scapular fractures without any loss of metaglene fixation.

Materials and methods

Clinical scapular fracture incidence

Between 2009 and 2015, patients were treated at a single institution with RTSA for various indications including rotator cuff disease with concomitant glenohumeral arthritis, previous failed arthroplasty/resurfacing, and post-traumatic disease. A single surgeon performed all procedures with an RTSA implant (Equinoxe Reverse Total Shoulder Arthroplasty; Exactech, Gainesville, FL, USA) through a deltopectoral approach. Recruitment and participation of the patients were in accordance with Institutional Review Board protocols. Informed consent and permission to enroll in the RTSA clinical database were obtained from all patients. Demographic data of the patients were entered into a database and updated at yearly postoperative follow-up visits to capture any complications and to record functional outcomes. Standard shoulder radiographs were obtained preoperatively, postoperatively, and at subsequent 1-year follow-up intervals.

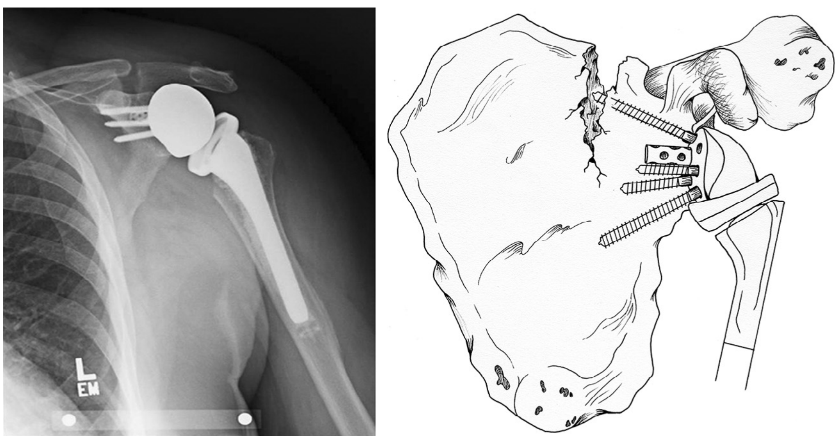

Figure 1 Radiographic anteroposterior view and illustration of 4-screw construct demonstrating scapular spine fracture (type III). Reverse total shoulder arthroplasty implant demonstrates a fixation pattern of inferior screws and a single superior screw placed above the central glenoid axis with fracture propagation from superior screw tip.

All patient records were reviewed by an orthopedic surgery resident, a research associate, and the primary surgeon. Data bank records including initial radiographs, computed tomography (CT) scans, patient demographics, surgical and perioperative notes, implants logs, and follow-up radiographs were reviewed for all patients who received RTSA. The number and location of screws used for metaglene plate fixation were recorded on the basis of intraoperative and postoperative imaging in conjunction with implant log and operative note entries. The location, size, trajectory, and number of screws used were determined on the basis of the patient's anatomy with the goal of fixation into solid bone. Our standard technique was initially to use 3 inferior compression screws placed bicortically, plus 1 to 3 superior screws with the superiormost screw aimed at the coracoid. This technique of using an additional 1 to 3 superior screws was abandoned in 2013 in favor of an inferior-only screw construct for most of our patients because of our concern for type III scapula fracture increase related to superior screw stress risers noted on CT. Any radiographic or clinical evidence of scapular compromise was recorded. Scapular fractures that were identified on clinical examination or radiographs were further evaluated by CT and classified for treatment purposes. Any patient with continued pain beyond the expected postoperative recovery course was evaluated with radiographs and CT to assess for scapular compromise. The primary surgeon determined the definitive scapular fracture treatment plan.

Statistical analysis was performed with 2 cohorts based on metaglene fixation configuration. The first cohort was patients with screws placed only below the horizontal axis of the glenoid and no superior screws (group 1_{INF}). The second cohort was patients implanted with screws placed inferiorly and anywhere from 1 to 3 screws placed superior to the horizontal glenoid axis (group 2_{SUP}). Analyses were performed to assess the differences between the surgery groups for potential confounders of the outcome of fracture (age, gender, and side of surgery). Data from surgeries in which the primary outcome was type III scapular fracture were analyzed for group differences using a Fisher exact test. Group differences for continuous descriptive statistics were analyzed using Satterthwaite *t*-tests, and categorical descriptive statistics were analyzed using χ^2 tests or Fisher exact tests when needed. SAS software 9.3 (SAS Institute, Cary, NC, USA) was used for all analyses, and statistical significance was determined at a type I error rate of .05.

Biomechanical scapular fracture model

For the biomechanical arm of our study, 23 right shoulder joints were harvested from embalmed cadaveric donors by glenohumeral disarticulation and used for biomechanical testing. All cadavers were embalmed in routine fashion by a standardized protocol in place at our institution. All soft tissues were removed from the scapula by sharp dissection, and labral remnants were excised to prepare the glenoids. Bone mineral density (BMD) was quantified at the inferior angle of each scapula using a cabinet densitometry system (Digimus; Kubtec Technologies, Milford, CT, USA). Seventeen cadaveric specimens were included in the study (mean age ± standard deviation [SD], 82.8 ± 10.3 years); the remaining harvested specimens were structurally unfit for inclusion. Six specimens were excluded from testing because of either inability to complete BMD measurements (1/6) or structural compromise of the glenoid or scapula rendering specimens unsuitable for metaglene implantation (5/6). Compromised glenoids with complete erosion necessitating an augment were excluded along with 3 specimens that sustained acromion or scapular body fractures during harvest, which precluded specimen potting. The specimens were matched for BMD and randomized to receive inferior screws only or inferior screws plus a single superior screw. Eight specimens received inferior screw placement constructs, whereas 9 specimens received an additional superior screw placement construct after matching of the groups for BMD.

A standard RTSA humeral stem, humeral baseplate, and 11-mm polyethylene insert were assembled and mounted to the crosshead of a uniaxial materials testing system (model H5KS; Tinius Olsen, Horsham, PA, USA) through a stainless steel custom-fabricated adaptor. The glenoid aspect of the RTSA implant was prepared in standard fashion, and metaglenes were implanted per the manufacturer's recommendations using standard instrumentation and prostheses on each cadaveric specimen. Specimens were randomized and pair matched for BMD and distributed between groups testing the 2 implant approaches on the basis of metaglene fixation: group 1_{INF} (3 inferior screws with no superior screw; n = 8) or group 2_{SUP} (4-screw approach including 3 inferior screws plus 1 superior screw; n = 9). All metaglene implants were stabilized with appropriately sized 4.5-mm compression screws (range, 18-38 mm), placed bicortically with the assistance of a standard drill guide, on the basis of scapular geometry. Both 3- and 4-screw constructs employed 3 screws in the inferior half of the metaglene baseplate (Fig. 2, *A*). The 4-screw (superior screw) construct used a single fourth screw placed at the anterior screw hole in the superior half of the construct, with this screw directed superiorly into the glenoid neck and body (Fig. 2, *C*). Screw placement was confirmed under fluoroscopic guidance to ensure appropriate placement (Fig. 2, *B* and *D*). An appropriately sized glenosphere was implanted and secured in standard fashion.

Each scapula with implanted metaglene/glenosphere components was individually potted in dental stone (Microstone; Whip Mix, Louisville, KY, USA). On the basis of anatomic studies previously reported to loosely mimic a fall onto outstretched arm, the alignment of the humeral stem and glenoid implant was measured and consistently reproduced for testing; the specimens were potted so the medial border of the scapula was perpendicular to the floor and at 60° of glenohumeral abduction.[2,7] Specimens were loaded to failure with force being directed from the humerus directly to the scapula with the materials testing system (H5KS) using a 5000 N load cell. A compressive force was applied at a load rate of 10 mm/min in displacement control until a point of construct failure was reached. Fracture was identified both on the load-displacement curve (Horizon, Tinius Olsen), which represented bony scapular failure, and visually with fracture propagation into the scapular spine and body. Specimens were then analyzed to confirm resultant scapular fracture pattern after reaching the ultimate load to failure.

The load-displacement curves for each specimen were analyzed to assess ultimate load to failure and specimen stiffness. The results of these curves and data points were compared between group 1_{INF} (inferior screw) and group 2_{SUP} (superior screw) to identify any significant differences in the 2 constructs. Ultimate load to failure was identified by precipitous acute decline on the load-displacement curve along with visual construct compromise with fractures identified extending into the scapula body and spine; load was described in newtons. Construct stiffness was defined as the slope of the load-displacement curve and described in units of newton/millimeter. The 2 groups were compared by Student *t*-tests. SAS JMP 12 software

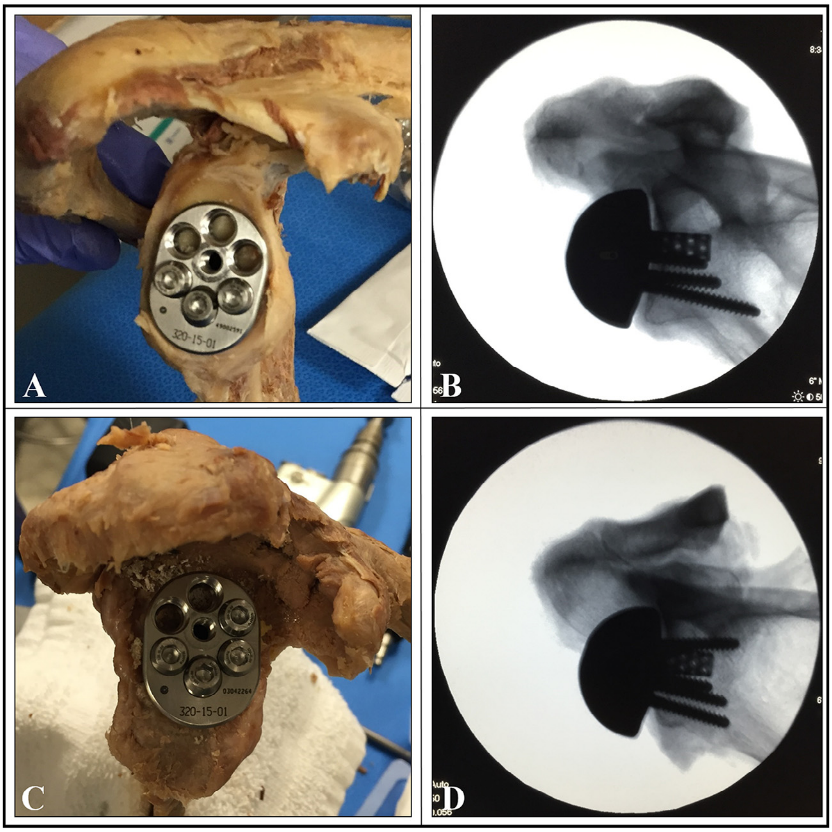

Figure 2 (**A**) Reverse total shoulder arthroplasty (RTSA) implant in cadaveric model and (**B**) fluoroscopic image demonstrating inferior screw metaglene plate fixation. (**C**) RTSA implant demonstrating superior screw metaglene plate fixation in cadaveric model and (**D**) fluoroscopic image.

was used for all biomechanical analyses, and statistical significance was determined at a type I error rate of .05.

Results

Clinical

Clinical records of 319 RTSA patients treated by a single surgeon from 2009 to 2015 were evaluated and included in the initial cohort analysis. A total of 318 patients met inclusion criteria and were included in the cohort study analysis; 1 patient was excluded because the index RTSA was performed by an outside provider. Of this group, 206 patients received metaglene fixation with at least 1 superior screw, whereas 112 patients received inferior screws only. In September 2013, the primary surgeon purposefully changed the screw construct used to eliminate all superior screws. Aside from superior screw exclusion, no other technique changes were implemented at this time with regard to alteration in deltoid/soft tissue tensioning, glenosphere or polyethylene liner size or position, screw trajectory, or humeral resection. This screw change was made secondary to the number of type III scapula fractures identified and CT evaluation demonstrating that all had superior screw involvement. For analysis purposes, the cohort was broken into 2 groups: inferior screw only (group 1_{INF}) and superior screw (group 2_{SUP}). Of 206 patients, 9 (4.4%) in the superior screw group experienced type III scapula body fractures (Table I), whereas 0 fractures (0/112; 0%) were identified in the inferior screw group ($P = .0295$, Fisher exact test) (Tables II and III). The superior screw cohort with 9 type III scapula fractures was composed of 22% (2/9) using 2 superior screws and 78% (7/9) using a single superior screw. The median number of days from surgery to fracture was 120 days. The mean time from surgery to fracture was 508.6 ± 676.4 days (SD). The days from surgery to fracture for the 9 patients were 32, 62, 62, 69, 120, 300, 692, 1353, and 1887. In the superior screw group with type III fractures, 5 of 9 (55.56%) experienced fracture within 3 months of surgery and 6 of 9 (66.67%) within the first year. The mean time from surgery was 1586 days for the superior screw group and 427 days for the inferior screw group; the disparity in follow-up time is due to an intentional technique change to avoid placement of superior screws because of scapular fracture risk.

There was not a significant difference in age between the 2 groups (mean ± SD, 65.3 ± 11.0 (superior) vs. 64.8 ± 10.9 (inferior); $P = .69$, Satterthwaite *t*-test). However, the patients who had fractures were significantly older than those who did not experience fractures (mean ± SD, 69.3 ± 9.8 vs. 65.1 ± 11.0; $P = .24$, Satterthwaite *t*-test). There were more

Table I Patient demographics and functional scores for the clinical type III scapular fractures

Clinical fracture patients—superior screw constructs

Sex	Age at surgery (years)	Operative side	Superior screw No.	Surgery complication	Time from surgery to fracture (days)	Scapula fracture treatment	Assessment point	Pain	Active forward flexion	Active abduction	Active external rotation	Internal rotation	ASES score	UCLA score	SST-12 score	Constant score
F	78	L	2	Type III scapular fracture	62	Nonoperative	Preoperative	10	60	30	–5	0 or unable	0	7	0	6
							1-year postoperative	2	80	60	35	L5	55	23	7	59
							2-year postoperative	0	110	90	20	Back pocket	78	30	9	74
							3-year postoperative	0	Unable	170	90	T10	87	29	11	81
							4-year postoperative	0	65	45	10	Back pocket	57	24	3	31
							5-year postoperative	0	100	90	35	Midline	72	28	7	67
F	77	R	1	Type III scapular fracture	120	Open reduction–internal fixation	Preoperative	10	90	45	0	0 or unable	0	7	0	12
							1-year postoperative	0	110	90	10	Back pocket	77	28	9	74
							3-year postoperative	0	90	90	20	Back pocket	67	26	7	53
F	71	R	2	Type III scapular fracture	1887	Open reduction–internal fixation	Preoperative	10	30	30	-5	0 or unable	0	6	0	2
							1-year postoperative	0	160	90	30	L5	95	35	11	90
							2-year postoperative	1	150	90	30	Midline	83	29	11	78
							3-year postoperative	2	130	90	35	L5	82	32	11	84
							4-year postoperative	0	170	90	35	T10	95	35	11	94
F	69	R	1	Type III scapular fracture	692	Open reduction–internal fixation	Preoperative	8	90	60	0	Greater trochanter	10	6	0	13
							1-year postoperative	0	160	90	30	Midline	95	35	10	86
							3-year postoperative	0	90	90	35	Back pocket	70	28	9	68
F	51	L	1	Type III scapular fracture	1490	Nonoperative	Preoperative	10	Unable to obtain—lost to follow-up and noncompliance							
M	61	R	1	Type III scapular fracture	300	Revision RTSA and open reduction–internal fixation	Preoperative	10	60	60	0	Greater trochanter	0	8	0	10
							2-year postoperative	2	160	90	20	Midline	85	30	11	88
							3-year postoperative	0	130	90	20	Back pocket	77	29	7	72
F	70	L	1	Type III scapular fracture	62	Open reduction–internal fixation	Preoperative	8	60	60	0	Greater trochanter	17	9	0	13
							2-year postoperative	0	90	90	35	Back pocket	70	28	9	70
							3-year postoperative	0	120	90	30	Back pocket	78	27	8	65
M	83	L	1	Type III scapular fracture	69	Nonoperative	Preoperative	2	30	0	0	0 or Unable	40	13	1	15
							2-year postoperative	0	100	60	30	Back pocket	78	28	10	47
M	70	R	1	Type III scapular fracture	32	Open reduction–internal fixation	Preoperative	10	90	60	10	Greater trochanter	8	10	0	12
							1-year postoperative	0	120	90	20	Back pocket	77	29	8	70
							2-year postoperative	0	160	90	35	Back pocket	95	35	11	86

ASES, American Shoulder and Elbow Surgeons; *UCLA*, University of California–Los Angeles; *SST-12*, 12-Item Simple Shoulder Test; *RTSA*, reverse total shoulder arthroplasty.

Table II Superior screws vs. inferior screws—clinical fracture incidence

Screw construct	Patient quantity	Mean age ± SD	Scapular fracture quantity	Fracture incidence (%)	Median days to fracture
Group 2_{SUP}	206	65.3 ± 11	9	4.4	120
Group 1_{INF}	112	65 ± 10.8	0	0	—

SD, standard deviation.
Superior screw vs. inferior screw construct comparison highlights the 4.4% fracture incidence in the superior screw cohort (Group 2_{SUP}) vs. 0% in the inferior screw–only cohort (Group 1_{INF}).

Table III Fisher exact test

Cell (1,1) frequency (F)	197
Left-sided Pr ≤ F	.0189
Right-sided Pr ≥F	1
Table probability (*P*)	.0189
Two-sided Pr ≤ P	.0295

Fisher exact test yields a *P* value < .05, indicating a statistically significant higher fracture incidence in superior screw constructs compared with inferior screw fixation.

female patients (59%), but there was not a significant difference in gender between the 2 groups (59% female in group 2_{SUP} vs. 61% female in group 1_{INF}; $P = .73$, χ^2 test). There were more operations performed on the right side (58%), but there was not a significant difference in side between the 2 groups (56% right side in group 2_{SUP} vs. 60% right side in group 1_{INF}; $P = .54$, χ^2 test).

Biomechanics

In our biomechanical model, we again observed a significant trend toward fracture propensity with superior screw constructs compared with inferior screw configurations. Group 2_{SUP} (4-screw constructs) demonstrated a significantly lower ultimate load by 45% (1077 ± 126.7 N vs. 1970 ± 191 N; $P = .001$, Student *t*-test) and decreased construct stiffness by 43% (178.5 ± 22 N/mm vs. 312.5 ± 44.1 N/mm; $P = .013$, Student *t*-test) compared with group 1_{INF} (inferior screw–only constructs) (Table IV). There was no significant age or BMD discrepancy identified between groups (Table IV).

Discussion

RTSA can provide a successful option for patients who cannot undergo anatomic total shoulder arthroplasty. However, serious complications from RTSA treatment include type III scapular spine fractures. Studies show scapular fracture incidence of all types between 0.8% and 10.2% for RTSA, and this complication is accepted to compromise functional results.[3,12,14] Whereas our clinical incidence of type III scapula fracture in this study was lower than in previous inclusive studies at 4.4%, our inferior screw construct has changed the fracture incidence and dropped it to 0%. In a previous study observing RTSA scapular fractures by Stevens et al, type III scapula fractures resulted in a quantifiable decrease in range of motion and functional outcomes during the course of a 48-month follow-up. It is critical to detect these fractures after the initial presentation of acute-onset postoperative pain.[6,9] It is estimated that the current accuracy of diagnosis of post-RTSA scapula fractures by plain radiographs alone is around 78.8%; hence, CT scan is frequently required to confirm the diagnosis.[6,9] The treatment of these fractures is recognized by many authors to be difficult both conservatively or operatively, and the incidence of nonunion is presumed to be high.[12] The associated increase in the patient's morbidity and the health care costs for operative interventions to handle these complications pose a substantial consideration in performing RTSA.

To our knowledge, this is the only clinical or biomechanical study to date that evaluates the scapular fracture incidence between the 2 metaglene fixation constructs and proposes a technique alteration that may lower the type III scapular fracture incidence. Our results suggest that screws in the superior portion of the metaglene, above the central cage of the implant, may create a stress riser and consequently increase type III scapular fracture risk. The most common cause of post-RTSA scapular fracture in our patients was found to be minor trauma to the upper extremity, typically a fall onto an outstretched hand, although several were of insidious onset based on history. Although they were unable to reach statistical significance or conclusions in their study, Otto et al postulated from imaging study review that scapula spine fractures may originate from or involve these screws; they witnessed that the majority (11/16) of their scapula spine fractures involved the tip of a posterior or superior screw.[9] Other hypotheses for the occurrence of these fractures include an increase in deltoid tension on the acromion and fatigue due to pre-existing strains on the deltoid or osteoporotic bone.[4,8,9] Comparatively reducing fracture incidence from 4.4% to 0%, our clinical data suggest a decrease in fracture incidence based on screw configuration and resultant stress risers. Furthermore, we experienced no evidence of metaglene plate loosening or complications related to use of only inferiorly placed screws for metaglene stabilization.

Consistent with our clinical data, our biomechanical model further demonstrated a significant decrease in construct strength when superior screws were employed in a single-direction load to failure model. The scapulae with a superior screw construct (group 2_{SUP}) fractured at approximately half the

Table IV Biomechanical RTSA scapula fracture model

Group No.	Metaglene fixation screw construct	Mean BMD (g/cm^2) ± SEM	Mean age (years) ± SEM	Mean load to failure (N) ± SEM	Mean stiffness (N/mm) ± SEM
1	Inferior only	0.158 ± 0.0111	81 ± 3.54	1970 ± 191	312.45 ± 44.07
2	Inferior + superior	0.151 ± 0.0092	84.4 ± 3.64	1077 ± 126	178.48 ± 21.98
P value		.615	.51	.001	.013

RTSA, reverse total shoulder arthroplasty; *BMD*, bone mineral density; *SEM*, standard error of the mean.
Cadaveric specimen results from biomechanical analysis with corresponding screw construct, BMD, age, maximum load to failure, and construct stiffness along with *P* values indicate significant decrease in construct load to failure and stiffness when superior screws are used. No statistically significant age or BMD was identified.

ultimate load needed to induce fracture in the specimens with inferior screw–only configurations (group 1_{INF}) and also demonstrated a significant decrease in construct stiffness, providing further evidence that a superior screw compromises biomechanical integrity. Our biomechanical model substantiates our original hypothesis that the inferior screw metaglene fixation technique decreases the incidence of type III scapula fractures in RTSA patients.

We recognize that our study has limitations. The RTSAs in our clinical study were performed by a single surgeon. Similarly, all RTSA prostheses used in our study were a single model by a single manufacturer, although previous reports in the literature demonstrate type III scapula fractures with implants of different manufacturers. Our clinical practice has included cases referred to us with type III scapular fracture complications with nearly all major RTSA prostheses implanted. Still, our study evaluates only 1 implant on the market, so definitive conclusions cannot be declared regarding other implants currently used, although it is fair to urge caution in the use of superior screws unless absolutely necessary for stabilization. The metaglene used in the study is unique in that it has 6 holes for locking screws, thus allowing 3 screws to be placed below the central cage. Other implants on the market have 2 to 4 screw holes total; thus, only 1 would be able to be placed below the central cage/screw/post. The biomechanical stability of such a construct with only 1 locking screw has not been studied.

Another limitation is that biomechanical testing was performed on embalmed cadaveric specimens, which may not represent the true mechanical behavior of fresh tissue. However, the relative comparison between inferior screw–only and superior screw approaches was performed in similar tissues that had been pair matched to similar BMDs, suggesting that the relative improvement in biomechanical strength using the inferior screw–only approach could translate to patient populations. Furthermore, other variables that may affect the risk of scapula fracture warrant further investigation, although these were outside the scope of our study; possible factors include glenosphere size, glenosphere lateral offset, position of baseplate/metaglene on glenoid, metaglene inferior tilt, length of screws, directionality of screws, polyethylene liner size, acromiotuberosity distance, acromial tilt, contact area of baseplate, and soft tissue tension.

In the clinical portion of the study, patients who experienced fractures were significantly older than patients who did not experience fracture. Previous studies noted that significant risk factors for scapular spine fracture after RTSA include age and bone quality.[12] BMD data were not collected for every clinical patient and therefore could not be included in this study. However, our cadaveric study scapulae were matched by BMD between the 2 groups before biomechanical evaluation to exclude this potentially confounding variable and still demonstrated a significant advantage of the 3-screw compared with the 4-screw fixation approach. Still, it is difficult to assess the extent of osteoporotic change, if any, in each cadaveric specimen. Osteoporosis is a significant clinical risk factor toward increased incidence of scapular fracture.[9,12] In a recent bone remodeling study, bone resorption in the scapula around the implant was increased significantly in osteoporotic bone.[10] Special care should be taken to counsel these patients about protecting against excessive load to prevent potential stress fractures, especially if superior screws are used in the construct.[9]

Because of the chronologic nature of our clinical study, there is a difference in follow-up time between patients who received inferior screw constructs and patients who received superior screw constructs. This discrepancy is due to a purposeful alteration in surgical technique and implementation of an inferior-only screw construct by the primary surgeon after noticing a common pattern of stress risers and fracture line propagation from the tip of superior screws. In the interest of patient safety and ethics, it would be difficult to justify reverting to a superior screw construct to allow a randomized controlled trial when our clinical and biomechanical data demonstrate a significant increase in scapular fracture incidence with this prior technique. Our median time to fracture was 120 days, although it could be argued on the basis of previous reports that the fracture risk exists at any point in the postoperative course. There is a difference in the time from surgery in the 2 clinical groups that is a limitation of the study as well. However, follow-up time in the inferior screw group will only increase as time advances, and we think our study subjects were sufficiently beyond the average time to fracture in the superior screw construct that our results are significant enough to warrant attention for those performing RTSA.

Conclusions

Our study has demonstrated that the previously accepted method of using superior screws for metaglene fixation leads to an increased clinical incidence of type III scapular fracture and resulted in significant construct compromise in our biomechanical model of the Equinoxe RTSA system. Radiographic and intraoperative examination of post-RTSA fractures reinforces the notion that the superior screw above the central cage used in superior screw constructs serves as a stress riser. In our patient follow-up experience, we did not witness any compromise in metaglene fixation stability by not using a superior screw. It is too early to apply these conclusions to all implants on the market, and we thought this would be beyond the scope of this study to examine all available implants. However, on the basis of our study with the chosen metaglene implant, we recommend use of only inferior compression screws, all positioned below the central cage of the metaglene, unless absolutely necessary to stabilize the metaglene construct.

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