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Biomechanical evaluation of internal fixation techniques for unstable meso-type os acromiale

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Background: Several internal fixation surgical techniques have been described for the treatment of symptomatic os acromiale. The purpose of this study was to compare the biomechanical characteristics of different internal fixation techniques for the operative treatment of unstable meso-type os acromiale in a cadaveric model.
Methods: Testing was performed on 12 matched pairs of cadaveric acromia with simulated meso-type os acromiale. Twelve specimens were prepared with 2 cannulated 4.0-mm screws only (SO group), inserted in the anterior-posterior direction. Contralateral specimens were repaired with screws and a tension band (TB group). An inferiorly directed load to the anterior acromion was applied at a rate of 60 mm/min until failure. Ultimate failure load, stiffness, and fracture pattern were recorded and analyzed.
Results: Ultimate failure load was significantly higher for the TB group (mean, 336 N ± 126 N; range, 166-623 N; $P = .01$) than for the SO group (mean, 242 N ± 57 N; range, 186-365 N). In contrast, no significant difference in stiffness was found between the SO group (mean, 22.1 N/mm ± 4.7 N/mm; range, 13.0-33.3 N/mm; $P = .94$)) and the TB group (mean, 22.2 N/mm ± 2.9 N/mm; range, 18.2-26.6 N/mm).
Conclusion: Surgical repair of simulated unstable meso-type os acromiale by a combination of cannulated screws with a tension band leads to significantly higher repair strength at time zero in a cadaveric model compared with cannulated screws alone.
Level of evidence: Basic Science Study, Biomechanics.

Keywords: Tension band; cannulated screws; os acromiale

DePuy Synthes provided unrestricted in-kind donations of the surgical tools used in this study.
Investigation performed at the Department of BioMedical Engineering, Steadman Philippon Research Institute, Vail, CO, USA.

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Fusion of the acromial apophysis across the 4 distinct ossification centers typically occurs between the ages of 15 and 18 years.[7] Os acromiale is described as a failure of osseous union between 2 of the apophyses, most commonly between the meso-acromion and meta-acromion.[17,22] The frequency ranges from 1% to 15%.[6,12,17] Commonly, os acromiale is a nonsymptomatic condition that is identified incidentally during radiographic examination of the shoulder.[6,22] However, several clinical studies

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have reported symptomatic cases of os acromiale, with symptoms such as pain at the site of nonunion, decreased range of motion, pain during abduction, weakness, and pain during hypermobility.[1-3,5,10,16,18,21,22] In addition, rotator cuff tears and impingement have been associated with this pathologic process.[6,10,15,22]

In cases of failed conservative treatment of symptomatic os acromiale, a surgical approach is recommended, including fragment excision[10,14,22] or surgical repair consisting typically of resection of the pseudarthrosis, reduction, and internal fixation.[7] Fragment excision can be performed arthroscopically or through an open approach, although excision of larger types can result in deltoid impairment.[22] Poor results have frequently been reported after open excision.[10,22] Pagnani et al[14] reported promising results after arthroscopic fragment resection in a young and athletic population with os acromiale at the junction between meso-type and meta-type. Larger fragments need to be preserved to prevent deltoid weakness, particularly in active individuals. Internal fixation has been the method of choice, although fixation techniques vary between studies, from fixation with tension wiring to cannulated screws inserted from anterior-posterior (A-P) or posterior-anterior.[2,5,15,19,22] The biomechanical characteristics of different internal fixation modalities have not been compared.

Therefore, the purpose of this study was to compare the strength and stiffness of different internal fixation techniques at time zero for the operative treatment of unstable and symptomatic meso-type os acromiale in a cadaveric biomechanical model. The investigated techniques were cannulated screw fixation vs. cannulated screw fixation augmented with a tension band. The tension band technique was hypothesized to provide higher repair strength compared with isolated cannulated screw fixation.

Materials and methods

Specimen preparation

In this time zero biomechanical study, a total of 12 matched pairs ($n = 24$) of fresh frozen human cadaveric shoulders (8 male, 4 female; mean age ± standard deviation, 55.3 ± 6.3 years; range, 45-64 years) were tested. Specimens were thawed at room temperature 24 hours before testing, and all soft tissues were dissected. The acromion was visually inspected for preexisting injury or os acromiale. One right shoulder was excluded because of its exceptionally small acromion size, which was not amenable to repair. The inferior region of the scapulae was removed by cutting in parallel with the inferior border of the scapula spine 1 cm inferior to the glenoid root. In addition, the anterior medial angle was removed. Specimens were then potted in polymethyl methacrylate (PMMA; Fricke Dental International, Inc., Streamwood, IL, USA) in a custom-made cylindrical mold with the glenoid fossa in parallel with the base of the mold. PMMA was poured 1 cm medial to the root of the acromion. Before potting, 3 screws were drilled circumferentially into the spine of the scapulae to ensure rigid fixation in the PMMA. Dual-energy x-ray absorptiometry bone mineral density (BMD) testing was performed on all specimens to assess potential BMD biases (mean BMD, 0.487 g/mm^2; range, 0.345-0.605 g/mm^2). Acromia were randomly distributed between the 2 repair groups; half of the specimens were repaired with internal fixation with cannulated screws only (SO group), inserted in the A-P direction without a tension band, and the contralateral specimens were treated with cannulated screws inserted in the A-P direction in combination with a tension band (TB group). The senior author's (P.J.M.) preference for fixation with cannulated screws, either alone or in combination with a tension band, is to place the screws in the A-P direction because of technical ease, anatomic preference given the size of the anterior fragment, and suspected biomechanical superiority. Therefore, the A-P insertion direction was used for the comparison of the SO group vs. the TB group.

Surgical techniques

Biomechanical testing was performed on cadaveric scapulae to reproduce time zero internal fixation of a simulated os acromiale between the meso-acromion and meta-acromion. The simulated os acromiale was created in each specimen through a superior to inferior osteotomy performed in the frontal plane on the lateral border of the acromion. Os acromiale is most prevalent between the meso-acromion and meta-acromion[10]; however, this location is difficult to locate in an intact shoulder. Sammarco[17] described the average position of meso-type os acromiale as a distance 42% of the A-P length of the acromion from the anterior tip. All osteotomies were performed consistent with this proportion, parallel to the dorsal border of the spine of the scapulae.

To fix the acromion for loading, a 1.25-mm hole was drilled parallel to the dorsal acromion border 1 cm from the anterior tip just superior to the inserted screws. Two-mm-wide suture tape composed of braided ultrahigh-molecular-weight polyethylene and polyester (FiberTape; Arthrex, Naples, FL, USA) was inserted, and the 2 ends were tied over a 10-cm-diameter cylinder, secured by 10 alternating half-hitches each (Fig. 1).

Cannulated screw fixation

With reduction forceps, the acromion was reduced and fixed anatomically. A 1.25-mm Kirschner wire (K-wire) was inserted (parallel to the lateral and upper acromion borders) in an A-P direction between the lateral and middle thirds of the acromion. A second 1.25-mm K-wire was inserted parallel to the first, between the medial and middle thirds of the acromion. Both K-wires were drilled through the acromion by a cannulated 2.7-mm drill. Two 4.0-mm cannulated screws (DePuy Synthes, West Chester, PA), the first a short threaded screw to gain compression and the second a long threaded screw to increase stability, were inserted over the K-wires. Both K-wires were then removed (Fig. 2).

Combination cannulated screw with tension band fixation

As described before, screws were first inserted into the acromion in the A-P direction. In accordance with the AO guidelines, a

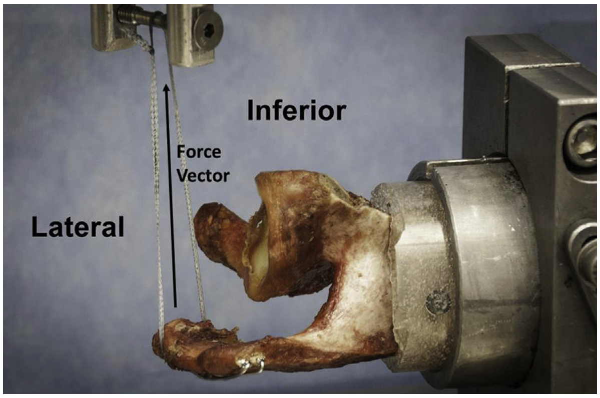

Figure 1 Biomechanical test setup. A high-strength suture tape (FiberTape; Arthrex, Naples, FL, USA) was inserted into the acromion 1 cm from the anterior tip. The 2 ends were tied around a 10-cm-diameter cylinder and looped around a rod fixed to the actuator of the tensile testing machine. The testing jig was positioned so the pull vector was perpendicular to the surface of the acromion.

1.25-mm tension band was placed through the screws around the superior acromion, forming a figure-of-8 with twists on both loops in accordance with the technique described for an osteosynthesis after patella fracture.[4] Both loops were tightened simultaneously and in the same direction to achieve equal tension throughout (Fig. 2).

Biomechanical testing

Testing was performed with a dynamic tensile testing machine (ElectoPuls E10000; Instron Systems, Norwood, MA, USA). The accuracy for this system has been calibrated to be equal to or better than ±0.25% of the indicated force and ±30 μm of the indicated position. The medial aspect of the acromion was clamped in an inverted orientation so that the acromion was perpendicular to the actuator and parallel to the base of the test frame with a custom steel apparatus and rigidly fixed to the base. Position of the acromion was confirmed with a box level (Empire Level; Empire Level Manufacturing Corporation, Mukwonago, WI, USA). The suture tape loop was passed around a 10.0-mm-diameter rod that was rigidly fixed to the actuator. This test setup allowed perpendicular tensile forces to be applied in the superior to inferior direction to the anterior acromion (Fig. 1). This is in accordance with anatomic studies that have described the function of the deltoid muscle and its estimated loading of the lateral acromion.[8,9] The large middle portion of the deltoid muscle reportedly inserts at the lateral acromion and acts as an abductor.[9] The deltoid muscle provides most of the required force to initiate elevation of the humeral head, resulting in an inferiorly directed force on the lateral acromion.[8] This setup simulated the situation in which the middle portion of the deltoid exerts force on the lateral acromion to elevate the humerus in a neutral position. Because of a lack of existing biomechanical literature on the acromion, the load protocol was modeled off previous biomechanical studies of the clavicle,[20] which experiences similar bending forces through the action of the deltoid muscle. The suture tape provided a distributed load on the acromion, which more accurately reproduced the deltoid attachment. Specimens were then loaded to failure at a displacement controlled rate of 60 mm/min. The failure mechanism and ultimate failure load were recorded. Stiffness of the repair constructs was calculated from the linear region of the force-displacement data.

Statistical analysis

A power analysis was performed with data from the first 6 specimens in the SO and TB groups, which determined that 12 matched pairs would be sufficient to detect a 20% difference between the ultimate failure strengths of the repair constructs with 80% power. Two-sample Wilcoxon signed rank tests were used to compare central tendency of relevant measurements between SO and TB groups. Kendall's τ was used to assess correlations between the ultimate failure loads with BMD, gender, age, acromion length, and side of the repair. Statistical significance was declared for $P < .05$. All statistical analyses were performed with statistical analysis software (SPSS version 20; IBM, Armonk, NY, USA). The fracture pattern was recorded descriptively.

Results

Ultimate failure load

Ultimate failure load and stiffness data for all specimens are reported in Table I and Table II. Ultimate failure load was significantly higher for the TB group (mean, 336 N ± 126 N; range, 166-623 N; $P = .01$) than for the SO group (mean, 242 N ± 57 N; range, 186-365 N) (Fig. 3). There was no significant correlation between ultimate failure load and BMD, gender, age, acromion length, or side of the repair.

Stiffness

There was no significant difference between stiffness of the SO group (mean, 22.1 N/mm ± 4.7 N/mm; range, 13.0-33.3 N/mm; $P = .94$) and that of the TB group (mean, 22.2 N/mm ± 2.9 N/mm; range, 18.2-26.6 N/mm) (Fig. 4).

Failure mechanism

All specimens in the SO group failed because of displacement of the anterior aspect of the acromion without dislocation of the inferior cortex (Fig. 5). In contrast, most TB specimens (10 of 12) fractured at the posterior exit of the medial screw, while the repair remained intact (Fig. 4).

Discussion

The most important finding of this study was the significantly higher repair strength of meso-type os acromiale with cannulated screws in combination with tension band than with cannulated screws alone. The SO repair allowed

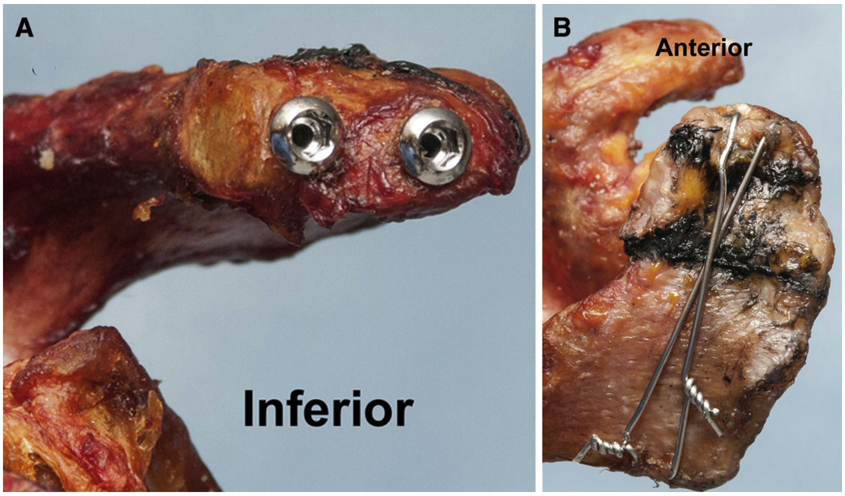

Figure 2 Surgical techniques. (**A**) Screws-only repair (SO). The screws were inserted in the anterior to posterior (A-P) direction on a left acromion. (**B**) Repair with a combined screw and tension band technique (TB). A tension band was placed around the screws (in the A-P direction), forming a figure-of-8 with twists on both loops on a right acromion.

Table I Ultimate failure load and stiffness of all matched pair specimens treated with screws only or screws in combination with tension band

Specimens	Age	Gender	Group 1: SO			Group 2: TB			Load to failure difference (%)
			Side	Failure (N)	Stiffness (N/mm)	Side	Failure (N)	Stiffness (N/mm)	
Pair 1	62	Male	Left	239	25.3	Right	243	21.5	1.6
Pair 2	64	Male	Right	339	20.8	Left	441	23.4	23.1
Pair 3	45	Female	Left	196	21.8	Right	349	18.2	43.8
Pair 4	56	Female	Left	217	13.0	Right	386	22.4	43.8
Pair 5	63	Male	Left	229	20.2	Right	206	21.1	−11.2
Pair 6	55	Male	Left	275	33.3	Right	410	25.2	32.9
Pair 7	56	Male	Right	365	23.6	Left	623	26.6	41.4
Pair 8	50	Female	Left	186	20.2	Right	283	23.6	34.3
Pair 9	54	Male	Right	217	23.3	Left	166	19.0	−30.7
Pair 10	52	Male	Right	235	23.5	Left	392	26.5	40.1
Pair 11	60	Male	Right	192	19.0	Left	309	19.1	37.9
Pair 12	46	Female	Right	209	20.3	Left	224	20.3	6.7
Mean	55.3	—	—	242	22.0	—	336	22.2	22.0
SD	6.3	—	—	57	4.7	—	126	2.9	24.7

SO, screws only; *TB*, screws in combination with tension band; *Load to failure difference*, percentage difference in ultimate failure load between paired specimens; *SD*, standard deviation.

considerable displacement of the anterior component as the construct approached failure. In contrast, no displacement of the repair site was observed for the TB group, which concentrated stresses at the posterior-medial screw hole and resulted in longitudinal fractures of the acromion.

No significant difference in stiffness was found between the repair techniques. An explanation for this finding is that no further compression force acting on the repair site can be expected by adding a tension band through cannulated screws. Therefore, the initial stiffness of the repairs is a result of the initial compression force caused by both screws. However, the tension band will give biomechanical support as soon as the screws start to fail and the stiffness of the construct decreases. Thus, the repair stiffness will be improved by adding a tension band once the screw repair begins to fail.

The clinical relevance of this finding remains unclear as the loading that acts on the repair site due to the deltoid muscle contraction is unknown. However, a wide range of union rates after surgical repair of os acromiale (25% to 100%) has been reported,[1,13,21] perhaps indicating that some techniques were not able to produce sufficient biomechanical stability. Furthermore, more stable fixation would theoretically permit a more aggressive postoperative rehabilitation protocol. Surgical intervention options for symptomatic os acromiale and failed conservative therapy include acromioplasty, fragment excision, and internal fixation.

Table II Ultimate failure load, stiffness, and *P* values for repair technique comparisons

Repair technique	Load to failure (N)	*P* value	Stiffness (N/mm)	*P* value
SO	242 ± 57	.01	22.1 ± 4.7	.94
TB	336 ± 126		22.2 ± 2.9	

SO, screws only; *TB*, screws in combination with tension band.
Data reported as mean ± standard deviation.

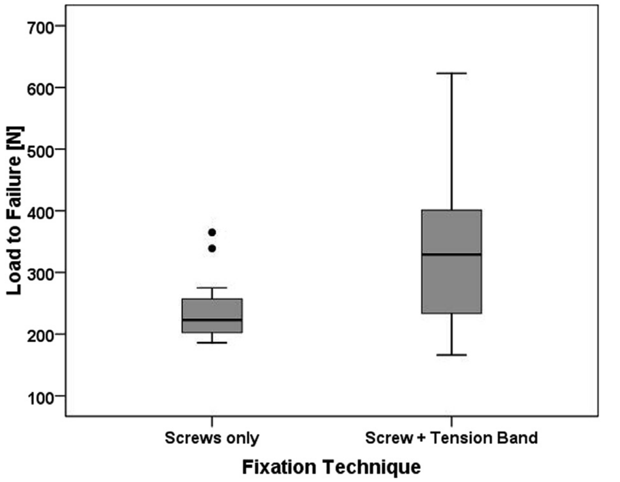

Figure 3 Box plot comparing the ultimate failure loads of the simulated os acromiale fixed with screws only (SO group) vs. screws in combination with a tension band (TB group). The TB group failed at significantly higher loads ($P = .01$) than the SO group. *Dots* represent positive outliers in the SO group with ultimate failure loads of 339 N and 365 N.

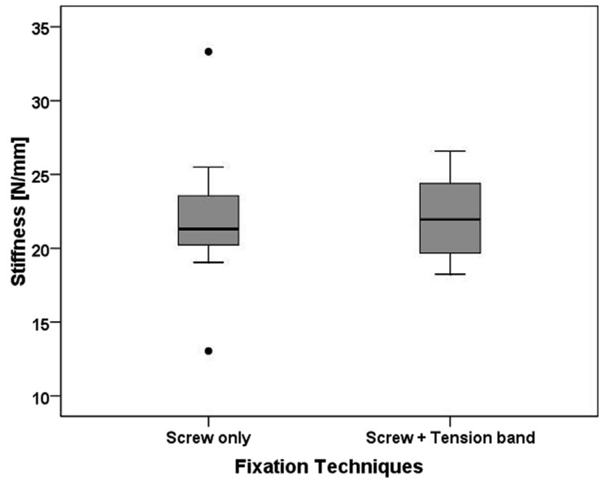

Figure 4 Box plot comparing the stiffness of the simulated os acromiale fixed with screws only (SO group) vs. screws in combination with a tension band (TB group). There were no significant differences between both groups. Both *dots* represent outliers in the SO group with stiffness of 13.0 N/mm and 33.3 N/mm.

Several case reports have described the treatment of unstable meso-type os acromiale with various techniques. Warner et al[22] reported that initial treatment of unstable meso-type os acromiale with tension wiring resulted in successful union in only 1 of 4 cases. The authors believed the failure was due to an inability to achieve rigid fixation and modified the technique by using cannulated screws inserted in the A-P direction in combination with a tension band. After treatment modification, 6 of the 7 patients had consolidated fusion. In contrast, Peckett et al[15] reported consolidated fusions in all patients treated with tension wiring only or with a combination of screws and tension band. Two patients, treated with screws inserted in the A-P direction in combination with a tension suture, had a nonunion. Atoun et al[1] used absorbable screws inserted in the posterior-anterior direction under arthroscopic control of intraoperative reduction and observed an osseous union in 8 of 9 patients. The higher rate of osseous fusion in patients treated with a combination of screws and tension band, compared with a tension wiring–only or screws-only approach, may be explained by the higher fixation strength after repair with screws and tension band compared with the screws-only technique observed in the present study at time zero.

In addition, poor surgical technique may be responsible for inferior results. In particular, an incomplete resection of the pseudarthrosis influences the rate of osseous consolidation negatively, regardless of the fixation technique. Furthermore, the use of bone grafts might be beneficial. On the basis of the clinical literature, no conclusion can be drawn about which surgical repair technique for the treatment of symptomatic meso-type os acromiale should be the preferred technique because of the limited number of cases described and the large variety of surgical techniques being used.[1,11,15,22] Therefore, the results of this study will provide surgeons with biomechanical data to make more informed decisions about which surgical repair to use to gain sufficient stability.

The authors acknowledge the limitations of this study. First, this study used a time zero cadaveric biomechanical model and did not account for the biologic restoration processes. Next, no tension band–only study group was included. However, Warner et al[22] reported consolidation in only 1 of 4 patients after tension band–only repair. Therefore, poor stability of the tension band–only repair can be inferred and was not included. The decision to use the A-P insertion direction was based on pilot results and experience of the senior author. However, increased

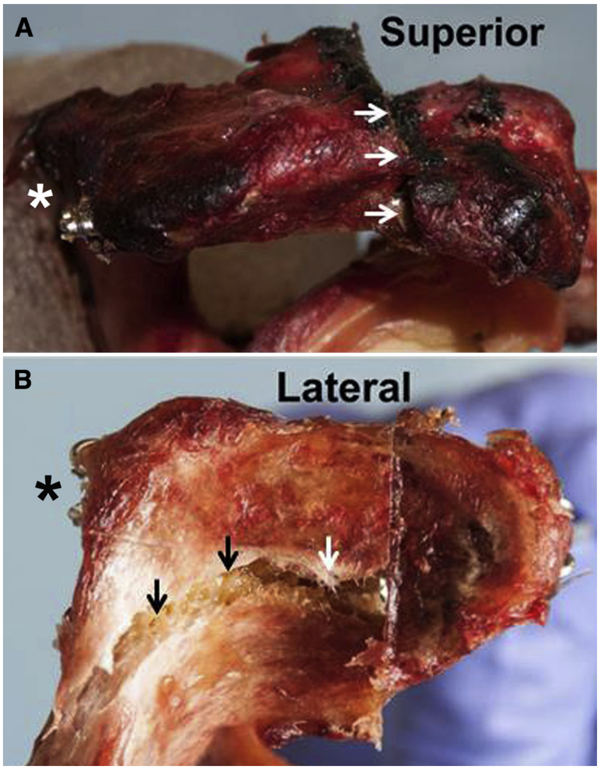

Figure 5 (**A**) Inferior bending of the anterior aspect of the acromion without dislocation of the inferior cortex. The location of failure is marked by *arrows*. The screw ends are marked by an *asterisk*. This fracture pattern was seen in all specimens treated with cannulated screws only. (**B**) Fracture along the medial screw with unaffected repair construct. This was seen in 10 of 12 of the specimens treated with screws in combination with a tension band. The failure pattern of the other 2 specimens was consistent with screw-only repair (**A**). A rupture of the tension band was seen for both specimens.

ultimate failure strength after A-P insertion is reasonable to expect, considering the larger bone stock at the posterior part of the acromion in cases of meso-type os acromiale, which may allow more stable screw thread fixation. Furthermore, the testing setup and loading conditions were a simplification of the complex loading conditions acting on the anterior aspect of the acromion. Specifically, we attempted to simulate bending induced from tension in the deltoid but did not account for forces from the humerus acting on the inferior surface of the acromion as the arm elevates or abducts. In addition, the specimens were loaded to failure to simulate a worst-case scenario rather than a cyclic loading protocol to simulate the small repetitive forces experienced by the acromion. However, the authors believe that the load to failure protocol was most appropriate for this time zero model because cyclic loading simulates loading over time and would neglect the subsequent healing that would occur over that time. No precedent for an os acromiale biomechanical model exists. Therefore, the model used in this study was determined through internal pilot investigations to provide a consistent, reproducible, and clinically relevant model to compare biomechanical fixation characteristics at time zero.

The strengths of this study are its matched pair study design; inclusion of specimens with much lower age than is common in cadaveric studies (mean, 55 years), which is a realistic representation of the patient population; and exclusion of osteoporotic specimens. Clinical studies are necessary to determine if the improved biomechanical stability at time zero observed in this study for a combination of screws inserted in the A-P direction and tension band translates into improved fusion rates and patient outcomes. In addition, the more stable fixation construct may favor a more aggressive postoperative protocol. However, irritation and pain due to the tension band need to be considered. In some settings, screws alone may be sufficient to minimize the risk for hardware irritation, but if the surgeon has concerns about fixation after the screws have been inserted, the tension band should certainly be added.

Conclusions

Surgical repair of a simulated, unstable meso-type os acromiale by a combination of cannulated screws inserted in the A-P direction with a tension band leads to significantly improved repair strength at time zero compared with cannulated screws alone. These results will provide surgeons with biomechanical data to make more informed decisions about which surgical repair to use to gain optimal stability in symptomatic and unstable meso-type os acromiale.

Disclaimer

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