PODCAST In-Depth

Medialized Clavicular Bone Tunnel Position Predicts Failure After Anatomic Coracoclavicular Ligament Reconstruction in Young, Active Male Patients

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Background: Recent radiographic data have suggested that medialized conoid tunnel placement greater than 25% of absolute clavicular length is correlated with early failure after anatomic coracoclavicular ligament reconstructions. A comparison with a larger active duty military cohort of clinical and radiographic outcomes can serve as a basis for standardizing surgical technique.

Purpose: To establish the ideal radiographic tunnel position for anatomic coracoclavicular ligament reconstruction and to elucidate variables associated with early loss of reduction and ability to return to active-duty military service.

Study Design: Case series; Level of evidence, 4.

Methods: A retrospective review of the military's electronic medical record between the years 2000 and 2013 was performed. All anatomic coracoclavicular reconstructions at a single institution were included for analysis, and nonanatomic or revision reconstructions were excluded. Radiographic failure was defined as 6 mm of superior clavicle displacement on immediate postoperative films.

Results: A cohort of 38 patients underwent 39 anatomic coracoclavicular reconstructions. Average follow-up time was 26 months (range, 1.2-92 months). A total of 20 radiographic failures were identified, with an average conoid tunnel ratio of 0.27. When conoid tunnel ratios were compared with a reference ratio of 0.20 to 0.25, increased risk of failure was statistically significant with lateralization greater than 0.20 (P = .018; odds ratio [OR] = 40 [95% CI, 1.05-999.06]) or with medialization of 0.251 to 0.30 (P = .002; OR = 39 [95% CI, 1.58-944.36]) or greater than 0.30 (P = .029; OR = 21 [95% CI, 0.77-562.15]). Medialization of the trapezoid position greater than 0.16 (vs a range of 0.13-0.16) was also found to be significant for failure ($P < .023$; OR = 8 [95% CI, 1.33-48.18]). However, these significant findings did not correlate with symptoms or ability to return to duty ($P > .05$).

Conclusion: The optimal technique for treating acromioclavicular separations has yet to be determined. Recently, anatomic coracoclavicular reconstruction has demonstrated biomechanical superiority to previously described methods. The findings of optimal tunnel positioning in anatomic reconstructions from this large active-duty military cohort can assist preoperative planning to reduce failure rates when treating these difficult injuries.

Keywords: shoulder; AC joint; general sports trauma; imaging and radiology; general military training

Acromioclavicular (AC) joint separations are common injuries in an active population, accounting for up to 40% of injuries in those participating in contact sports.[17] Rockwood types 1 and 2 AC joint separations, and a notable number of type 3 AC joint separations, can be successfully treated without operative intervention.[14,19-21,26] However, some refractory type 3 injuries and most high-energy (types 4-6) injuries require surgical treatment to restore normal mechanics and function of the shoulder.

More than 60 procedures for treatment of AC joint separations have been reported in the literature.[6,7,10] While early techniques had mixed results, more modern anatomic techniques have decreased failure rates to <10% in some studies (compared with a >20% loss of reduction in more historical techniques such as Weaver-Dunn or dynamic muscle transfer procedures) and have improved clinical outcomes.[4,5,11,15,23,24] Biomechanical studies comparing various reconstruction techniques have demonstrated increased construct strength when compared with

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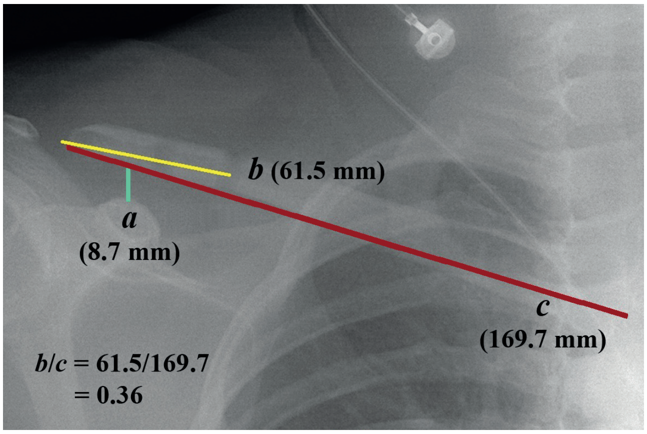

Figure 1. Immediate postoperative shoulder radiograph. Line *a* represents the coracoclavicular distance (used to define radiographic failure). Line *b* indicates the distance from the lateral edge of the clavicle to the middle of the conoid tunnel, and line *c* indicates total clavicular length. The conoid tunnel ratio was calculated as *b/c*.

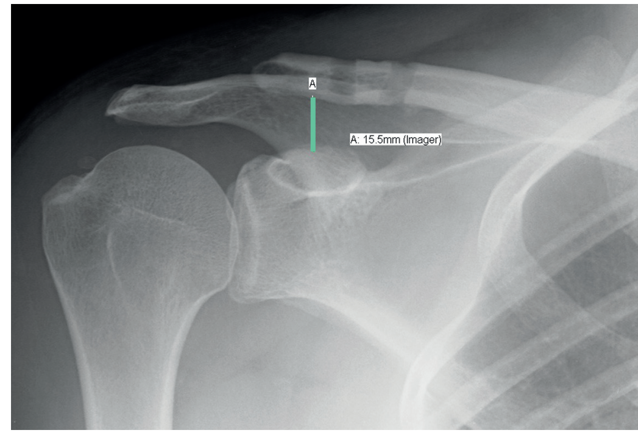

Figure 2. Radiograph of a shoulder that had failed at postoperative follow-up. The vertical line indicates >6 mm displacement.

nonanatomic constructs and equivalent loads to failure as found in the native state.[12-14,27] Multiple studies using an anatomic approach, synthetic or biological grafts, and single- or 2-tunnel techniques have demonstrated favorable results for patients.[5,6,22,24,28] However, the outcomes reported are based on small cohorts, and only 1 study was specifically dedicated to a young, active-duty military population (28 patients; average age, 26.5 years; range, 19-40 years).[5] In this cohort, conoid and trapezoid tunnel positions were evaluated based on a ratio to total clavicular length (conoid tunnel ratio, trapezoid tunnel ratio).[5,18] No failures were found when the conoid tunnel was placed lateral to 25% of the total clavicle length.

The purpose of the current study was to evaluate a series of coracoclavicular (CC) ligament reconstructions in an active-duty military population at a single institution and to examine the ability of patients to return to duty. Given the results of previous investigations evaluating the effect of clavicular tunnel position and failure during CC ligament reconstruction, we sought to evaluate the role of tunnel position on subsequent radiographic failure and ability to perform tasks required for active-duty military service. We hypothesized that (1) medialization of conoid tunnel placement will result in increased failure rates for CC ligament reconstruction and (2) positioning the trapezoid tunnel medially will result in increased failure rates.

METHODS

Data Collection

After receiving institutional review board approval, we performed a retrospective review using the electronic Surgery Scheduling System at a single tertiary military referral center for procedures listed as "Shoulder, AC joint reconstruction or repair" between the years 2000 and 2013. This initial data set was further analyzed to include only anatomic CC reconstructions. Reasons for exclusion were the following: nonanatomic reconstructions such as ligament (eg, Weaver-Dunn procedure) or dynamic muscle transfer procedures; the use of hardware such as plates, screws, or isolated suture button fixation without concomitant reconstruction of the native conoid and trapezoid ligaments; and revision CC ligament reconstructions. The electronic medical record was reviewed for all clinical documentation, including physical therapy, primary care physician, and orthopaedic encounters, to evaluate different variables: demographics, concomitant distal clavicle resection, return to duty, symptoms, and radiographic failure. Radiographic failure was defined as a superior clavicle displacement (increased coracoclavicular distance) of at least 6 mm from immediate postoperative films (Figures 1 and 2).[5] This distance was chosen based on previous studies.[5,11] All images in an electronic imaging system (Phillips iSite Enterprise, version 4.3.37.00) were reviewed, including shoulder, clavicle, and chest radiographs. For some patients, we performed measurements on different views when comparing initial postoperative radiograph and subsequent follow-up films.

Types of injury were classified by use of the Rockwood type of AC joint separation.[9,17] All images were reviewed by an orthopaedic surgery resident and were validated by a sports medicine fellowship–trained surgeon. The surgeries were performed by 1 of 11 different board-certified orthopaedic surgeons, 4 of whom were fellowship-trained in sports medicine. The electronic software measurement tools were used to measure postoperative clavicular tunnel position as follows: The lateral edge of the clavicle was measured to the middle of the conoid and trapezoid tunnel, and the entire length of the clavicle was measured from the lateral edge of the native clavicle to the medial edge at the sternoclavicular joint.[5] Operative reports were used to determine the amount of distal clavicle resection, if performed. If these data were unavailable, chest radiographs or Zanca views were used to measure the contralateral native clavicle to determine any differences in clavicle length. The distance to each tunnel was divided by the length of the native clavicle to calculate a ratio (Figure 1).

Surgical Techniques

All anatomic CC reconstructions were performed with a technique similar to the techniques described by Carofino and Mazzocca[4] and Cook and Tokish.[6] All patients were positioned in the beach-chair position, and either an open or arthroscopically assisted procedure was performed. Either a semitendinosus autograft or allograft was used. Two bone tunnels, located at positions to recreate native anatomic features of the CC ligaments, were placed in the clavicle at the discretion of the operating surgeon. AC joint reconstruction was included based on surgeon preference. Measurements were made before distal clavicle resection in cases where the distal clavicle was removed or were compared with the native contralateral clavicle on chest radiograph or Zanca views. Interference screws were used to achieve fixation within the clavicular tunnels. Supplementary fixation with a cortical suture button or cerclage suture fixation was used at the discretion of the surgeon.

In the majority of cases, the limb of the graft exiting the lateral tunnel was used to reconstruct the posterior and superior AC ligaments. Early in the study, this was done by suturing the graft to the AC joint capsule and acromial periosteum. Later, the graft was placed through a third tunnel in the acromion, fixed with a tenodesis screw, and wrapped anteriorly and sutured to itself over the AC joint.

Postoperative Rehabilitation

Rehabilitation followed a standardized protocol. Patients were placed in an abduction sling and were instructed to wear the sling with the arm supported and without tension on the reconstructed ligaments. The sling was worn full-time for 6 weeks, with only pendulum exercises allowed. At 6 weeks postoperatively, range of motion exercises were initiated in physical therapy per protocol. At approximately 3 months, strengthening exercises were begun, and return to full duty was based on individual progression.

Statistical Analysis

The statistical analysis was performed by an independent biostatistician using SAS version 9.4 (SAS Inc). The threshold for statistical significance was set at $P < .05$. We performed univariate or chi-square analysis with logistic regression to find statistical significance for the influence of risk factors associated with failure, and we performed the Fisher exact test to compare failure rates across the categories for conoid tunnel ratio and trapezoid tunnel ratio. When significance was found across categories, additional Fisher exact tests for pairwise comparisons were performed to determine where the differences in rates lay. For continuous variables, the 2-tailed, 2-sample t test was performed to compare means between the failed and successful reconstructions. Three additional predictor categorical variables were also tested: the absolute position, in millimeters, of both the conoid and trapezoid tunnels based on the median value from our data set, and a conoid position of greater than 25% (ratio, 0.25) of the total clavicle length based on the prior study by Cook et al.[5]

RESULTS

Our initial query of the Surgery Scheduling System yielded 111 patients for review. After we applied exclusion criteria and evaluated the operative reports, clinical notes, and radiographic examinations, we selected for further review a subset of 38 patients undergoing 39 procedures. One patient underwent 2 surgeries; this patient required a revision of an acutely failed reconstruction, performed by the same surgeon, which ultimately also failed. This revision case was excluded from statistical analysis. All patients in the study were male. The cohort consisted of 36 active-duty members, 1 active-duty retiree, and 1 civilian. Of the active-duty personnel, 34 were Army members, 1 was a Navy member, and 1 was an Air Force member. Average follow-up time was just over 2 years (784 days). The majority of patients were junior enlisted (n = 25); there were 11 senior enlisted or officers. The mean age of the patients (±SD) was 31.3 ± 8.5 years (range, 21-50 years) (Table 1). Twenty-six cases were Rockwood type 5, and 12 cases were type 3.

Fifteen patients underwent distal clavicle resection as part of the reconstructive procedure. The average time to failure was 122 days. When 2 outliers were excluded (797 and 642 days), the time to failure was 55 days. One of these patients failed atraumatically during deployment and was identified during routine postdeployment screening. The other patient was found to have failed during routine Veterans Affairs or military separation physical examination. Twenty-eight patients were able to return to military duty (82.4%), while 6 patients were unable to return to duty. The 1 civilian member and 1 retiree member were excluded in this variable, and 2 additional patients had unknown status at the time of data collection. Of the 6 patients who were unable to return to duty, 4 had continued shoulder pain and inability to perform the duties required of their military occupational specialty. One of these patients had a concomitant Lisfranc open reduction internal fixation and was unable to run or march with a ruckasack. One patient retired, and the other patient did not return to duty because of mental health comorbidities. With regard to graft type, only 35 patients had clear documentation of the use of autograft or allograft in their medical record.

When the data were examined for radiographic tunnel placement as a source of failure, 20 reconstructions met our definition of radiographic failure (53%). Three of 4 patients with a conoid tunnel ratio of less than 0.20 had radiographic failure (P = .018; odds ratio [OR] = 40 [95% CI, 1.05-999.06]). Eight patients had a conoid ratio of 0.20 to 0.25, with no failures in this group (Table 2), whereas 12 of 17 patients with a conoid ratio of 0.251 to 0.30 and 5 of 9 patients with a ratio of greater than 0.30 had radiographic failure (P = .002; OR = 39 [95% CI, 1.58-944.36] and P = .029; OR = 21 [95% CI, 0.77-562.15],

TABLE 1
Patient Demographics[a]

Characteristic	Value	No. of Patients
Age, y, mean ± SD	31.3 ± 8.5	38
Male sex	38 (100)	38
Rank		36
Junior enlisted	25 (69.4)	
Senior rank	11 (30.6)	
Laterality		38
Left	21 (55.3)	
Right	17 (44.7)	
Distal clavicle resection		38
Yes	15 (39.5)	
No	23 (60.5)	
AC reconstruction		33
Yes	23 (69.7)	
No	10 (30.3)	
AC joint separation, Rockwood type		38
3	12 (31.6)	
5	26 (68.4)	
Conoid tunnel, mm, average ± SD	46.8 ± 7.9	38
Trapezoid tunnel, mm, average ± SD	28.5 ± 7.8	38
Clavicle length, mm, average ± SD	173.3 ± 17.3	38
Conoid tunnel ratio, average ± SD	0.272 ± 0.050	38
Trapezoid tunnel ratio, average ± SD	0.166 ± 0.047	38
Augmentation		38
Yes (cortical fixation button)	6 (15.8)	
No	32 (84.2)	
Graft type		35
Autograft	9 (25.7)	
Allograft	26 (74.3)	
Radiographic failure		38
Yes	20 (52.6)	
No	18 (47.4)	
Return to duty		34
Yes	28 (82.4)	
No	6 (17.6)	

[a]Data are reported as n (%) unless otherwise indicated. AC, acromioclavicular.

respectively) (Table 2). Regarding the trapezoid tunnel ratio, 4 of 7 patients with a ratio less than 0.13 failed, 2 of 10 with a ratio of 0.13 to 0.16 failed, and 14 of 21 with a ratio of greater than 0.16 failed (Table 3). The average (±SD) conoid tunnel ratio in failures was 0.28 ± 0.055, while successful reconstructions had an average ratio of 0.262, demonstrating no statistically significant difference (P = .271) (Table 4).

When univariate or chi-square analysis with logistic regression was performed to determine the influence of risk factors, no variables, including presence of distal clavicle excision, concomitant AC reconstruction, or augmentation with a cortical button, were found to be statistically significant for radiographic failure or inability to return to duty (Table 5). A total of 11 surgeons performed the procedures in this study, and only 4 were fellowship trained. Of the 20 failures, 8 were patients of the fellowship-trained surgeons. Fellowship training and/or surgeon had no statistically significant effect on failure. Three additional categorical predictor variables were chosen based on previous data by Cook et al.[5] In their investigation, the authors reported no failures when the conoid tunnel was placed lateral to 25% of the total clavicular distance. Additionally, they demonstrated that a trapezoid tunnel position lateral to 12.7% of the total clavicle was significantly associated with decreased failure. However, given biomechanical studies that have shown the conoid ligament to be the main contributor of stability to the CC ligament complex, the trapezoid tunnel position was deemed less important than the conoid position.[5] Thus, we chose to look at medialization based on absolute position of both tunnels using the median value of our data set as a reference and the previously described value of medialization greater than 25% (ratio, 0.25) of the conoid tunnel. When the 3 additional categorical predictor variables were tested as risk factors for radiographic failure, medialization of the conoid tunnel greater than 47 mm and a ratio greater than 0.25 were found to be statistically significant, whereas medialization of the trapezoid tunnel was not found to be statistically significant (Table 6). Failures, on average, were medialized 5.088 and 5.129 mm compared with successful reconstructions of both the conoid and trapezoid tunnel, respectively ($P < .05$) (Table 4).

TABLE 2
Outcomes Analyzed by Conoid Tunnel Ratio[a]

Conoid Tunnel Ratio	Failure, n (%)	*P* Value	Return to Duty, n (%)	*P* Value
<0.20	3/4 (75)	**.018**	3/4 (75)	.555
0.20-0.25	0/8 (0)	—	8/8 (100)	
0.251-0.30	12/17 (70.6)	**.002**	11/14 (79)	
>0.30	5/9 (55.6)	**.029**	6/8 (75)	

[a]Bolded *P* values indicate statistically significant difference compared with conoid tunnel ratio of 0.20 to 0.25 ($P < .05$).

TABLE 3
Outcomes Analyzed by Trapezoid Tunnel Ratio[a]

Trapezoid Tunnel Ratio	Failure, n (%)	*P* Value	Return to Duty, n (%)	*P* Value
<0.13	4/7 (57.1)	.162	6/7 (85.7)	.171
0.13-0.16	2/10 (20)	—	10/10 (100)	
>0.16	14/21 (66.6)	**.023**	12/17 (71)	

[a]Bolded *P* value indicates statistically significant difference compared with trapezoid tunnel ratio of 0.13 to 0.16 ($P < .05$).

TABLE 4
Comparison of Failed and Successful Reconstructions by Bone Tunnel Ratios[a]

	All Failures (n = 20)	All Successes (n = 18)	*P* Value	Absolute Difference, mm	*P* Value
Trapezoid tunnel ratio	0.177 ± 0.054	0.154 ± 0.036	.135	5.129 ± 7.408	**.040**
Conoid tunnel ratio	0.28 ± 0.055	0.262 ± 0.042	.271	5.088 ± 7.533	**.045**

[a]Data are reported as average ± SD. Bolded *P* values indicate statistically significant difference compared with successful reconstructions.

We performed the Fisher exact test to compare the failure rates across the subgroups of conoid and trapezoid placement based on ratio and found statistical significance in both groups ($P < .05$) (Tables 2 and 3). When analyzing the conoid tunnel ratio, we found significant differences in the radiographic failure rates for each group compared with the 0.20 to 0.25 conoid ratio group ($P < .05$) (Table 2). Return to duty based on conoid ratio placement was not found to have significance. Comparing the failure rates across the 3 groups of trapezoid tunnel position, using pairwise testing, we found a significant difference in failure rates for medialization greater than 0.16 versus the range of 0.13 to 0.16 (Table 3). Again, no significant difference was found in the return to duty rates across these 3 trapezoid tunnel position groups ($P = .171$) (Table 3).

DISCUSSION

On the basis of the current findings, the hypothesis was accepted. Significantly increased failure rates were associated with medialization of both the conoid and trapezoid tunnels. In contrast with previous studies, the existing research establishes a statistically significant range for placement of both the conoid and trapezoid tunnels with decreased incidence of radiographic failure.

A study of CC ligament reconstructions previously correlated radiographic outcomes with clavicular tunnel position. Cook et al[5] reported that medialization of the conoid bone tunnel was significantly associated with early radiographic failure of the reconstructions. The investigators found that those reconstructions with a conoid tunnel ratio of greater than 0.3 (ie, 30% of total clavicle length) had a significantly higher failure rate than those with a conoid ratio of less than 0.3. None of their reconstructions with a conoid ratio of less than 0.25 failed. Therefore, they recommended placing the conoid tunnel at 25% of the total clavicle length.[5]

Our findings support those of Cook et al[5] but contribute greater clarity and precision to the data on ideal tunnel placement. We found that the reconstructions with a conoid ratio of greater than 0.25 had a significantly higher failure rate than those with a ratio less than 0.25. Further, we noted a significantly higher failure rate in reconstructions with a ratio less than 0.2. This indicates that the reconstructions with conoid tunnels placed more lateral than 20% and more medial than 25% of total clavicle length had significantly higher failure rates. Therefore, the optimal position of the conoid bone tunnel is between 20% and 25% of total clavicle length. These results not only support the clinical findings and suggested surgical technique of tunnel placement by Cook et al[5,6] but also compare

TABLE 5
Results of Univariate or Chi-Square Analyses for the Influence of Risk Factors on Rates of Radiographic Failure and Non–Return to Duty[a]

Characteristic	Radiographic Failure, OR (95% CI)	*P* Value	Non–Return to Duty, OR (95%CI)	*P* Value
Age	1.05 (0.97-1.14)	.200	1.00 (0.89-1.12)	.987
Rank: junior enlisted vs senior rank	1.30 (0.31-5.39)	.718	0.95 (0.15-6.17)	.955
Distal clavicle resection: yes vs no	0.67 (0.18-2.49)	.553	1.55 (0.26-9.08)	.630
Fellowship-trained surgeon: yes vs no	1.05 (0.29-3.86)	.944	0.27 (0.03-2.59)	.255
Acromioclavicular reconstruction: yes vs no	1.95 (0.43-8.83)	.386	1.88 (0.18-19.68)	.597
Preoperative Rockwood type: 3 vs 5	0.52 (0.13-2.10)	.361	0.90 (0.14-5.81)	.912
Conoid tunnel	1.10 (1.00-1.21)	.056	1.03 (0.92-1.15)	.632
Trapezoid tunnel	1.10 (1.00-1.22)	.052	1.05 (0.94-1.19)	.393
Ratio conoid tunnel	1.08 (0.94-1.24)	.267	1.05 (0.88-1.25)	.570
Ratio trapezoid tunnel	1.12 (0.96-1.30)	.140	1.09 (0.91-1.32)	.349
Augmentation (cortical fixation button): yes vs no	0.39 (0.06-2.44)	.313	0.92 (0.09-9.69)	.945
Graft type: allograft vs autograft	0.80 (0.17-3.67)	.774	1.84 (0.18-18.66)	.605

[a]Logistic regression revealed no significant surgeon effect regarding radiographic failure or return to duty (P = .883 and .905, respectively). OR, odds ratio.

TABLE 6
Categorical Predictor Variables as Risk Factors for Failure

Characteristic[a]	Radiographic Failure Odds Ratio (95% CI)	*P* Value
Conoid tunnel categorical: >47 mm vs ≤47 mm	4.67 (1.19-18.35)	**.028**
Trapezoid tunnel categorical: >27 mm vs ≤27 mm	2.92 (0.78-10.92)	.112
Ratio conoid tunnel categorical: >25% vs ≤25%	5.67 (1.22-26.33)	**.027**

[a]For the conoid tunnel, we used categorical variable >47 mm vs ≤47 mm, where the cutoff, 47 mm, is the median conoid tunnel. For the trapezoid tunnel, we used categorical variable >27 mm vs ≤27 mm, where the cutoff, 27 mm, is the median trapezoid tunnel. For the ratio conoid tunnel, we used categorical variable >25% vs ≤25%, where the cutoff, 25%, is based on prior studies by Cook et al.[5] Bolded *P* values indicate statistical significance.

favorably to the cadaveric study by Boehm et al.[3] In that study, 36 clavicles (18 male) were dissected to find the anatomic locations of both the conoid and trapezoid ligaments in order to determine the optimal amount of distal clavicle that could be resected in the treatment of AC joint arthrosis without destabilizing the joint. In the data reported by Boehm et al, the average position of the middle of the conoid tunnel was 39.5 mm from the lateral edge of the clavicle in male specimens. When this number is divided by the average reported male clavicle length of 160 mm, the ratio of 0.25 anatomically supports our proposed range.

We found an association between medial placement of the trapezoid tunnel and a higher incidence of failure. Cook et al[5] noted that the ratio of the distance from the end of the clavicle to the center of the trapezoid tunnel was significantly higher in failed reconstructions, but the investigators did not further stratify the reconstructions. Upon stratifying our data, we found a significantly higher failure rate in reconstructions with a trapezoid tunnel ratio of greater than 0.16. We were unable, however, to find an optimal lateral position of the trapezoid tunnel as we did for the conoid tunnel, as the range of 0.13 to 0.16 was not found to be statistically significant compared with a ratio of less than 0.13. This finding, similar to the conoid tunnel position, is in concordance with the cadaveric study by Boehm et al[3]; the calculated trapezoid ratio based on their findings is 0.13. The optimal ranges for trapezoid and conoid tunnel placement based on a ratio proposed in our study equate to a 3% and 5% distance of the total clavicle length for tunnel drilling. When taking the average clavicle length of 173.3 mm in our study and multiplying by the percentage of total clavicle occupied by the proposed range for each tunnel, we find the trapezoid tunnel to have a 5.2-mm distance for proper placement, with the conoid having a slightly longer distance of 8.7 mm. Applying this same principle to the average clavicle length reported by Boehm et al,[3] a distance of 4.8 and 8 mm are available for proper tunnel placement of the trapezoid and conoid tunnel, respectively. When we consider the typical reamer and tunnel size of 5 mm,[4,6] as well as the statistically significant finding that both the trapezoid and conoid tunnels were medialized 5.12 and 5.08 mm, respectively, the margin of error is essentially the diameter of the reamer. Thus, when tunnels are drilled, focus should be placed on ensuring that the radius of the reamer is within the defined range. Depending on total clavicle length, to ensure appropriate intertunnel distance to decrease the risk of clavicle fracture, tunnels may need to be drilled with the center of the tunnel at the most lateral aspect of one range and the most medial aspect of the other, instead of being drilled at the midpoint of the range itself.[4,5] Another biomechanical cadaveric study found that the bone mineral density of the clavicle decreases as one moves from medial to lateral and the optimal density is found between 20 and 50 mm from the lateral edge of the clavicle.[10] Although total average clavicle length was not provided in the article, it would be interesting to calculate a ratio and compare with our findings. The decreased bone mineral density at the lateral edge of the clavicle may explain the increased risk of radiographic failure associated with a lateralized tunnel position.

When looking at different surgical techniques that include augmentation with a cortical button or concomitant AC joint reconstruction, biomechanical studies have suggested that augmented states and reconstructed states (specifically when the tail of the graft is incorporated into the AC joint, as in our study) achieve stability comparable with the native clavicle.[1,2,25] In our series, however, whether cortical button augmentation or concomitant AC joint reconstruction was performed did not influence radiographic or clinical success. Further research is required to articulate the relative benefits of adjunctive button fixation with pertinent risks associated with transcoracoid drilling, primarily coracoid fracture.[8] Additionally, the utility of a third acromial tunnel in preventing superior or anterior-posterior displacement has been underinvestigated, and this area may benefit from further biomechanical analysis.

The current study demonstrates several strengths. As with the study by Cook et al,[5] our demographic represents a young, extremely active military population. This study corroborates previous findings and correlates the radiographic success of CC ligament reconstructions with the relative medial or lateral positioning of the clavicular tunnels.

However, this study has several limitations. First, despite serving as a consecutive series of all anatomic reconstructions performed at a single institution, this is a retrospective study with multiple operating surgeons and nonstandardized surgical technique. Second, validated outcome scores were not collected pre- and postoperatively. The only clinical outcome score included in this study was return to duty rate. The importance of return to duty rate, however, cannot be overstated. For military personnel, this is a composite indication of their functional capacity to perform to standard despite the high demands placed on their shoulders. In addition, with only 2 exceptions, the radiographic failures in this study occurred early in the postoperative period—before full activity would be normally resumed. The radiographic failure rate in our cohort, as well as the average time to failure, is consistent with previous reports.[5,11,15]

Another weakness of the study is that nonstandardized images were used for all quantitative measurements. Not all patients had postoperative Zanca views, so a mixture of chest, shoulder, and clavicle films were used for subsequent analysis. This may contribute to measurement error; however, the concept of a ratio instead of an absolute position allows comparison between different films because the ratio remains constant. Finally, the surgery itself was not standardized given that 11 different surgeons performed the procedure, with each surgeon likely incorporating a slight variation in technique. An example is the different AC joint reconstruction techniques, which ranged from imbricating the capsule to adding an acromial tunnel; these were grouped together and studied as one on the basis of whether an AC joint reconstruction was performed, regardless of technique used. However, this did not affect radiographic or clinical outcomes.

CONCLUSION

This study confirms that medial bone tunnel placement is significantly associated with radiographic failure of anatomic CC ligament reconstructions. Preoperative measurement of total clavicle length is recommended to place the medial (conoid) tunnel at a point between 20% and 25% of total clavicle length and the lateral (trapezoid) tunnel at a point less than 16% of total clavicle length. As with prior studies, radiographic failure has not been shown to influence clinical outcome.[5,8,11,15,16] Despite a high rate of radiographic failure in our cohort, anatomic CC ligament reconstructions resulted in a high return-to-duty rate in a military population. The high rate of failure and loss of reduction may not truly be considered a failure of the surgery, as most patients are able to return to active duty, which requires high upper extremity demands.

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REFERENCES

1. Beitzel K, Obopilwe E, Apostolakos J, et al. Rotational and translational stability of different methods for direct acromioclavicular ligament repair in anatomic acromioclavicular joint reconstruction. *Am J Sports Med*. 2014;42(9):2141-2148.
2. Beitzel K, Obopilwe E, Chowaniec DM, et al. Biomechanical properties of repairs for dislocated AC joints using suture button systems with integrated tendon augmentation. *Knee Surg Sports Traumatol Arthrosc*. 2012;20:1931-1938.
3. Boehm TD, Kirschner S, Fischer A, Gohlke F. The relation of the coracoclavicular ligament insertion to the acromioclavicular joint. *Acta Orthop Scand*. 2003;74(6):718-721.
4. Carofino BC, Mazzocca AD. The anatomic coracoclavicular ligament reconstruction: surgical technique and indications. *J Shoulder Elbow Surg*. 2010;19(2 suppl):37-46.
5. Cook JB, Shaha JS, Rowles DJ, Bottoni CR, Shaha SH, Tokish JM. Clavicular bone tunnel malposition leads to early failures in coracoclavicular ligament reconstructions. *Am J Sports Med*. 2013;41(1): 142-148.
6. Cook JB, Tokish JM. Surgical management of acromioclavicular dislocations. *Clin Sports Med*. 2014;33(4):721-737.
7. DeBerardino TM, Pensak MJ, Ferreira J, Mazzocca AD. Arthroscopic stabilization of the acromioclavicular joint dislocation using the AC Graftrope system. *J Shoulder Elbow Surg* 2010;19(2 suppl):47-52.
8. Dunn JC, Waterman BR. Successful nonoperative management of coracoid fracture associated with suture-button fixation of acromioclavicular separation. *Mil Med*. 2015;180(1):e138-141.

9. Galatz LM, Williams GR. AC joint injuries. In: Rockwood CA, Bucholz RW, eds. *Fractures in Adults*. New York, NY: Lippincott Williams & Wilkins; 2006:1332-1364.
10. Geaney LE, Beitzel K, Chowaniec DM, et al. Graft fixation is highest with anatomic tunnel positioning in acromioclavicular reconstruction. *Arthroscopy*. 2013;29(3):434-439.
11. Martetschläger F, Horan MP, Warth RJ, Millett PJ. Complications after anatomic fixation and reconstruction of the coracoclavicular ligaments. *Am J Sports Med*. 2013;41(12):2896-2903.
12. Mazzocca AD, Arciero RA, Bicos J. Evaluation and treatment of acromioclavicular injuries. *Am J Sports Med* 2007;35(2):316-329.
13. Mazzocca AD, Santangelo SA, Johnson ST, Rios CG, Dumonski ML, Arciero RA. A biomechanical evaluation of an anatomical coracoclavicular ligament reconstruction. *Am J Sports Med*. 2006;34(2):236-246.
14. Michlitsch MG, Adamson GJ, Pink M, et al. Biomechanical comparison of a modified Weaver-Dunn and a free-tissue graft reconstruction of the acromioclavicular joint complex. *Am J Sports Med*. 2010;38(6):1196-1203.
15. Milewski MD, Tompkins M, Giugale JM, Carson EW, Miller MD, Diduch DR. Complications related to anatomic reconstruction of the coracoclavicular ligaments. *Am J Sports Med*. 2012;40(7):1628-1634.
16. Muller T, Stuyck J, Fabry G. Conservative treatment of acromioclavicular dislocation: evaluation of functional and radiological results after six years follow-up. *Acta Orthop Belg*. 1993;59(3):255-262.
17. Pallis M, Cameron KL, Svoboda SJ, Owens BD. Epidemiology of acromioclavicular joint injury in young athletes. *Am J Sports Med*. 2012;40(9):2072-2077.
18. Rios CG, Arciero RA, Mazzocca AD. Anatomy of the clavicle and coracoid process for reconstruction of the coracoclavicular ligaments. *Am J Sports Med*. 2007;35(5):811-817.
19. Salzmann GM, Walz L, Buchmann S, et al. Arthroscopically assisted 2-bundle anatomical reduction of acute acromioclavicular joint separations. *Am J Sports Med* 2010;38(6):1179-1187.
20. Schlegel TF, Burks RT, Marcus RL, Dunn HK. A prospective evaluation of untreated acute grade III acromioclavicular separations. *Am J Sports Med*. 2001;29(6):699-703.
21. Simovitch R, Sanders B, Ozbaydar M, Lavery K, Warner JJP. Acromioclavicular joint injuries: diagnosis and management. *J Am Acad Orthop Surg*. 2009;17(4):207-219.
22. Sobhy MH. Midterm results of combined acromioclavicular and coracoclavicular reconstruction using nylon tape. *Arthroscopy*. 2012; 28(8):1050-1057.
23. Takase K, Yamamoto K. Changes in surgical procedures for acromioclavicular joint dislocation over the past 30 years. *Orthopedics*. 2013;36(10):e1277-1282.
24. Tauber M, Gordon K, Koller H, Fox M, Resch H. Semitendinosus tendon graft versus a modified Weaver-Dunn procedure for acromioclavicular joint reconstruction in chronic cases: a prospective comparative study. *Am J Sports Med*. 2009;37(1):181-190.
25. Thomas K, Litsky A, Jones G, Bishop JY. Biomechanical comparison of coracoclavicular reconstructive techniques. *Am J Sports Med*. 2011;29:804-810.
26. Tibone J, Sellers R, Tonino P. Strength testing after third-degree acromioclavicular dislocations. *Am J Sports Med*. 1992;20(3):328-331.
27. Wellmann M, Kempka JP, Schanz S, et al. Coracoclavicular ligament reconstruction: biomechanical comparison of tendon graft repairs to a synthetic double bundle augmentation. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(5):521-528.
28. Yoo JC, Ahn JH, Yoon JR, Yang JH. Clinical results of single-tunnel coracoclavicular ligament reconstruction using autogenous semitendinosus tendon. *Am J Sports Med* 2010;38(5):950-957.