

Anatomic Coracoclavicular Ligament Reconstruction for the Treatment of Acute Acromioclavicular Joint Dislocation

Minimum 10-Year Follow-up

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Background: The long-term clinical and radiographic outcomes following coracoclavicular (CC) ligament reconstruction for the operative treatment of acute acromioclavicular (AC) joint dislocation remain uncertain. The purpose of the present study was to determine the long-term clinical and radiographic outcomes of CC ligament reconstruction and to identify risk factors for unfavorable outcomes.

Methods: We reviewed 20 cases of AC joint dislocation in 19 patients (18 male and 1 female; mean age, 32.3 years) that were treated with single-bundle reconstruction. The mean duration of follow-up was 12.7 years. We measured the CC vertical distance (CCD) on the anteroposterior view and compared the affected and unaffected sides (CCD ratio). We divided the patients into those with a CCD ratio of <25% (Group 1) and those with a CCD ratio of \geq 25% (Group 2). We radiographically investigated the clavicular tunnel anteroposterior (CTAP) angle, clavicular tunnel ratio, and coracoid tunnel orientation on the basis of the entry and exit points at the base of the coracoid. For the coracoid tunnel orientation, we compared center-center orientation and noncenter-center orientation.

Results: Group 1 comprised 17 cases (85%), and Group 2 comprised 3 cases (15%). At the time of the latest follow-up, Group 1 had a significantly higher mean Constant score than Group 2 (98.2 compared with 90.7; $p = 0.038$). Of the 3 radiographic parameters, only the CTAP angle was significantly different between the 2 groups ($p < 0.0001$). Two (67%) of the 3 cases in Group 2 were associated with posterior AC joint displacement.

Conclusions: CC ligament reconstruction for the treatment of acute AC joint dislocation resulted in successful long-term clinical and radiographic outcomes. It is important to decrease the CTAP angle and to ensure proper anatomic placement of the clavicular and coracoid tunnels at the time of surgery.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Many nonanatomic procedures for the operative treatment of acute acromioclavicular (AC) joint dislocation have been proposed, including coracoclavicular ligament transfer and Bosworth screw or pin fixation^{1,2}. However, these procedures are performed less frequently than they had been in the past because of their high complication rates^{1,2}. More recently, anatomic coracoclavicular (CC) ligament reconstruction has become popular in the hope of decreasing complication rates and improving patient outcomes. Some

studies have demonstrated higher clinical success rates and superior biomechanical outcomes when CC ligament reconstruction has been compared with other techniques¹⁻⁵. However, the detailed operative techniques, complication rates, and follow-up periods have differed among studies⁶⁻¹³. To our knowledge, the longest mean duration of follow-up for this procedure was 5.2 years, as reported by Struhl and Wolfson⁶. The long-term (>10-year) clinical and radiographic outcomes of this procedure remain uncertain⁶⁻¹³.

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TABLE 1 Demographic Data and Radiographic Variables of the Single-Bundle Group*†

Case	Sex, Age (yr)	Interval Between Injury and Surgery (d)	Side	Rockwood Type	Injury Mechanism	Duration of Follow-up (mo)	Constant Score (points)	ASES Score (points)
Group 1								
Group 1A								
1	M, 21	5	L	V	Sport	186	100	100
2	M, 20	4	R	V	Sport	160	98	100
3	F, 75	5	R	V	Motor-vehicle accident	153	87	100
4§	M, 16	2	L	V	Sport	154	100	100
5	M, 18	10	R	V	Sport	145	100	100
6§	M, 18	12	R	V	Sport	135	100	100
7	M, 25	5	R	V	Sport	129	100	100
8	M, 20	4	L	V	Sport	125	100	100
9	M, 17	3	L	V	Sport	156	100	100
10	M, 19	6	L	III	Sport	124	98	96.7
Group 1B								
11	M, 22	12	L	V	Sport	165	100	100
12	M, 43	12	L	V	Sport	203	98	100
13	M, 36	19	R	V	Motor-vehicle accident	186	98	100
14	M, 44	5	L	IV	Sport	174	96	100
15	M, 31	11	R	III	Sport	151	100	100
16	M, 38	17	R	IV	Sport	140	95	95
17	M, 55	11	R	V	Motor-vehicle accident	130	100	100
Group 2								
18	M, 48	6	R	V	Motor-vehicle accident	126	84	90
19	M, 53	8	R	V	Fall from height	149	100	100
20	M, 26	34	L	V	Sport	145	88	95

*ASES = American Shoulder and Elbow Surgeons, CCD = coracoclavicular distance, CTR = clavicular tunnel ratio, CTAP = clavicular tunnel anteroposterior, and CCL = coracoclavicular ligaments. †Postoperatively, patients were only allowed to perform passive range-of-motion exercises up to a flexion and abduction of 90° in the first 4 weeks postoperatively. Free passive range of motion was allowed from postoperative Week 5, and strengthening exercises were started at postoperative Week 6. After 6 weeks, no further restrictions were applied to the range of motion and strengthening exercises. ‡Ossification radiographically visible in coracoclavicular interspace. §The same patient underwent index surgery on the left side at 16 years of age, and on the right side at 18 years of age. #CCD value in millimeters.

We developed an anatomic CC ligament reconstruction technique involving the use of artificial ligaments for the treatment of acute high-grade AC joint dislocation and unstable distal clavicular fractures, applying the principles of anterior cruciate ligament reconstruction described in 1998^{14,15}. The purposes of the present study were to determine the long-term clinical and radiographic outcomes of CC ligament reconstruction and to identify risk factors for unfavorable outcomes.

Materials and Methods

The local institutional review board approved the study protocol. All patients provided informed consent before inclusion in the study.

Patients

Twenty-four patients with acute AC joint dislocation were managed with anatomic CC ligament reconstruction with use of the

rectangular ENDOBUTTON device (12 × 4 mm) (Smith and Nephew) and a Trevira-hochfest artificial ligament (2.5 × 1 × 250 mm) (Telos, SARL) by 1 senior surgeon (F.Y.) at our institution from September 1998 to December 2004¹⁴. We contacted all 24 patients by telephone to request their inclusion in the present study. One patient had moved to another country, and another patient declined inclusion because of the absence of shoulder symptoms. We followed the remaining 22 patients, 1 of whom was managed with the single-bundle technique but declined radiographic reassessment and 2 of whom were managed with the double-bundle technique (see Appendix). One patient was managed with the single-bundle technique bilaterally. Consequently, the cohort comprised 20 shoulders in 19 patients who were managed with the single-bundle technique and were available for clinical and radiographic assessments at the time of the latest follow-up (Table 1). The indication for surgery was acute

TABLE 1 (continued)

CCD Ratio (%)	CTR	Coracoid Tunnel Orientation (Entry-Exit)	CTAP Angle (deg)	Posterior Displacement	Implant Pullout	Ossification†	Osteoarthritis	Suture of Torn CCL
-2.1	0.17	Lateral-lateral	4.0	-	-	-	+	-
-3.2	0.17	Center-center	3.0	-	-	-	+	-
-52.1	0.14	Center-center	1.5	-	-	+	+	-
8.1#	0.19	Center-center	3.2	-	+	-	+	-
-13.7	0.17	Center-lateral	2.5	-	-	-	+	+
10.1#	0.12	Lateral-lateral	1.3	-	-	+	+	-
4.5	0.15	Lateral-lateral	0.8	-	-	-	+	+
9.4	0.17	Center-center	1.0	-	-	+	+	-
-21.7	0.14	Lateral-lateral	0.5	-	-	-	+	-
2.4	0.16	Center-lateral	2.7	-	-	-	+	+
22.0	0.22	Center-center	2.2	-	-	-	+	-
24.3	0.16	Lateral-lateral	2.2	-	-	-	+	-
22.8	0.17	Center-center	1.0	-	-	-	+	-
11.9	0.25	Center-center	2.0	-	-	-	-	-
13.4	0.17	Center-center	0.8	-	-	-	-	-
18.1	0.17	Lateral-lateral	1.5	-	-	-	+	-
11.7	0.15	Center-center	1.8	-	+	-	+	+
56.9	0.16	Center-lateral	11.2	+	-	-	+	-
55.4	0.15	Center-center	21.2	+	-	+	+	-
87.2	0.17	Center-center	4.0	-	-	-	+	-

Rockwood type-IV or VAC joint dislocation or Rockwood type-III dislocation among athletes and high-demand manual laborers^{1,2,16}. The preoperative clinical scores could not be determined because the patients had post-injury pain and discomfort¹².

Single-Bundle Technique

Highlights of the operative techniques are shown in Figs. 1-A through 1-H. The goals of the procedure were to heal the freshly ruptured soft tissue and to reduce complications such as recurrent AC instability and postoperative fracture of the coracoid and/or clavicle^{1,2,17,18}. The patient was placed in the beach-chair position. A vertical skin incision was made from approximately 3 cm medial to the AC joint line toward the coracoid process. The delto-trapezial fascia was split in the coronal plane, and the deltoid muscle was released from the anterior edge of the distal aspect of the clavicle. The surgeon identified the coracoid process and the ruptured CC ligaments before drilling from superior to inferior through both cortices of the central portion of the coracoid base with a 3.5-mm drill-bit. The surgeon then drilled the same coracoid tunnel with a 4.5-mm drill-bit in the same direction to avoid blowout of the coracoid process (Fig. 1-E). The artificial ligament was passed through the medial 2 holes of the ENDOBUTTON

(Fig. 1-H) and was attached with a polydioxanone traction suture through a lateral hole of the button. The traction suture was introduced through the coracoid tunnel. The surgeon pulled the traction suture to introduce the distal button through the coracoid hole, and then the button was flipped into the horizontal position (Fig. 1-B). While maintaining anatomic reduction of the AC joint, the surgeon pulled the 2 ends of the ligament vertically to determine the optimal position of the clavicular tunnel approximately 25 mm medial to the lateral end of the clavicle (Fig. 1-F)¹⁹. The surgeon drilled the identified point with a 3.5-mm drill-bit, aiming for the coracoid tunnel (Fig. 1-G). With use of a wire loop, the free ends of the ligament were then shuttled through the 3.5-mm clavicular tunnel. The 2 ends of the ligament were consecutively passed through the button holes (Fig. 1-C). Before reduction, the prevalently ruptured AC joint disc was resected or sutured. While reduction of the AC joint was maintained, the 2 ends were tied via a surgeon's knot and 3 square knots (Fig. 1-D). The surgeon then checked the AC stabilization by testing passive shoulder motion; no shoulder required additional Kirschner wire transfixation in the AC joint. When possible (4 shoulders), the stumps of the torn CC ligaments were sutured with 2-0 Prolene (Ethicon) (Fig. 1-D). The delto-trapezial fascia and the superior

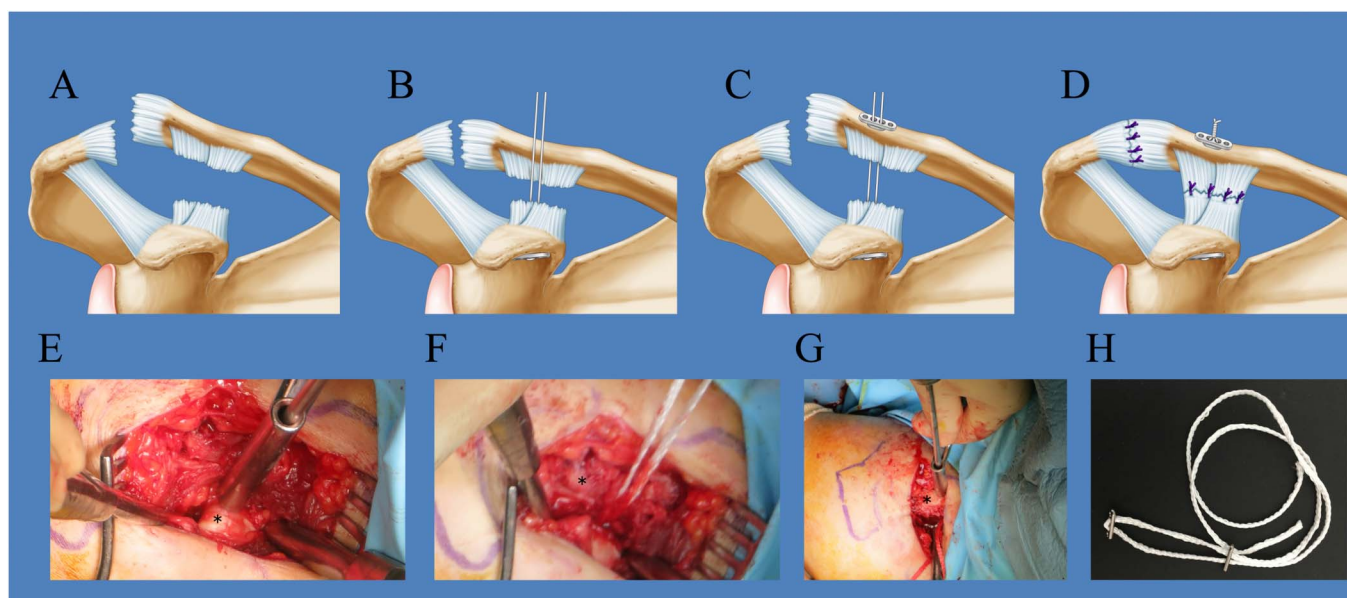


Fig. 1
Figs. 1-A through 1-H Illustrations and photographs showing the anatomic coracoclavicular ligament reconstruction technique. **Fig. 1-A** Dislocated AC joint. **Fig. 1-B** The ENDOBUTTON is placed centrally under the coracoid base. **Figs. 1-C and 1-D** The free ends of the ligament are introduced through the clavicular tunnel and are secured by means of a surgeon's knot. **Fig. 1-E** The 3.5-mm coracoid tunnel is drilled with a 4.5-mm drill-bit in the same direction. * = coracoid process. **Fig. 1-F** The surgeon determines the optimal portion of the clavicular tunnel at approximately 25 mm medial to the lateral end of the clavicle by pulling the artificial ligament vertically. * = distal end of the clavicle. **Fig. 1-G** The optimal portion is drilled with a 3.5-mm drill-bit, aiming for the coracoid tunnel. * = distal end of the clavicle. **Fig. 1-H** Telos artificial ligament and 2 ENDOBUTTONS.

capsule were imbricated, skin closure was performed, and the arm was placed in a sling for 3 weeks. Active range of motion could be started at 6 weeks postoperatively. Return to full activity was allowed 4 months postoperatively (Table I).

Functional Outcome Measures at Latest Follow-up

Shoulder function was assessed with use of the Constant score and the American Shoulder and Elbow Surgeons (ASES) score. One author (not a member of the surgical team) measured the range of motion in all shoulders with use of a hand-held goniometer.

Radiographic Assessment at Latest Follow-up

The shoulders were evaluated with radiographs and computed tomography (CT), including 3-dimensional (3D) re-

constructed CT scanning with an Activion 16 scanner (Toshiba) (spiral scan, 0.5-mm slice thickness, 1.0 pitch, 0.4-mm reconstruction, 3-dimensional [3D] edit mode). We also assessed the radiographic parameters reported in previous studies^{1,12,19-26}.

Displacement of AC Joint

We measured the CC vertical distance (CCD) between the uppermost border of the coracoid process and the opposing clavicular surface on the anteroposterior radiograph and then compared the lengths of the affected and unaffected sides (CCD ratio) (Fig. 2)^{1,12,21-23}. In patients who had undergone bilateral shoulder surgery, we defined a normal CCD as 10 to 13 mm^{1,20}.

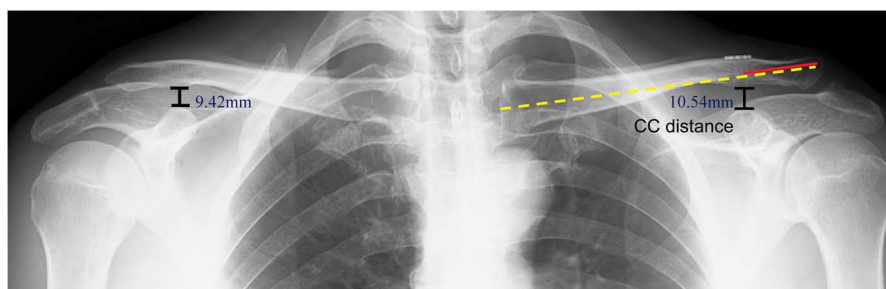


Fig. 2
 The coracoclavicular (CC) distance is measured between the uppermost border of the coracoid process and the opposing clavicular surface. A yellow dashed line is drawn from the medial border of the clavicle to the lateral border. A red solid line is drawn from the lateral border to the center of the bone tunnel. The clavicular tunnel distance is divided by the clavicular length to obtain the clavicular tunnel ratio.

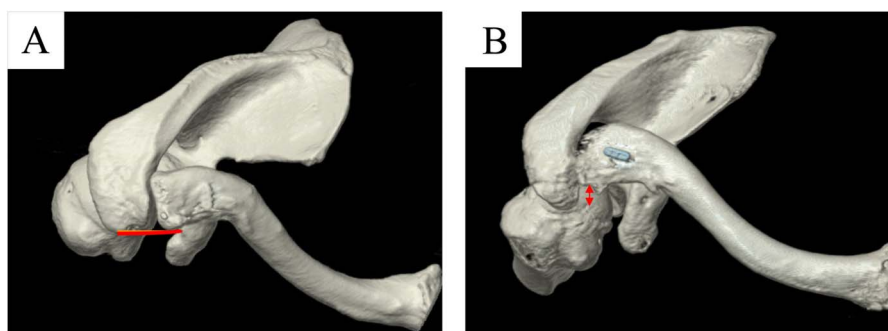


Fig. 3

Figs. 3-A and 3-B 3D reconstructed CT images of the AC joint. **Fig. 3-A** The clavicle is in line with the acromion (red line), indicating a horizontally stable AC joint. **Fig. 3-B** The clavicle is posteriorly displaced (red arrow), indicating a horizontally unstable AC joint.

Clavicular Length

We measured the clavicular length from the midpoint of the sternal border to the midpoint of the lateral margin of the clavicle. From the end point used on the lateral aspect of the clavicle, distances were measured to the midpoint of the bone tunnel (Fig. 2)²³. The distance from the lateral border of the clavicle to the center of each bone tunnel (DCTP) was divided by the total clavicular length to obtain the clavicular tunnel ratio (CTR)²³.

Posterior Displacement

We evaluated posterior displacement on radiographs and 3D CT images (Figs. 3-A and 3-B). Reduction was defined as a

clavicle that was in line with the acromion (Fig. 3-A)²⁴, and displacement was defined as a clavicle that was not in line with the acromion (Fig. 3-B)²⁴.

Coracoid Tunnel

We assessed the entry and exit points of the coracoid tunnel at the base of the coracoid on 3D and axial CT images²⁵. We divided the coracoid base into 3 regions (medial, center, and lateral) for the tunnel placement (Figs. 4-A and 4-B). Center-center orientation was taken to represent perfect coracoid tunnel orientation; we compared center-center orientation and noncenter-center orientation²⁵.

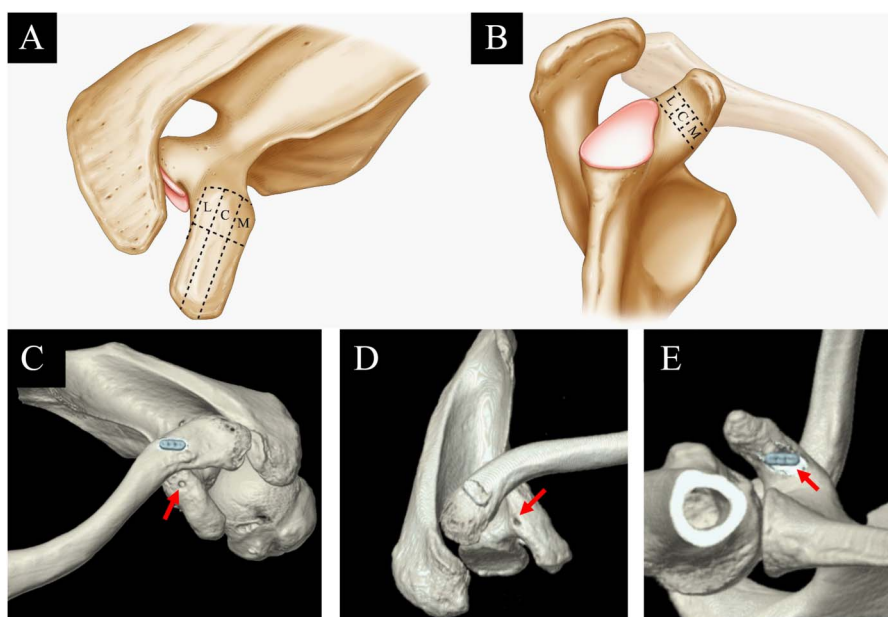


Fig. 4

Figs. 4-A through 4-E Illustrations and 3D reconstructed CT images showing the divided markings for the entry and exit points of the coracoid tunnel on the coracoid base. C = center, L = lateral, M = medial. **Fig. 4-A** The superior aspect of the coracoid base. **Fig. 4-B** The undersurface of the coracoid base. **Fig. 4-C** Left shoulder. The entry point of the coracoid tunnel (red arrow) is located in the center portion. **Fig. 4-D** Right shoulder. The entry point (red arrow) is located in the lateral portion. **Fig. 4-E** Right shoulder. The button (exit point, red arrow) is located in the center portion.

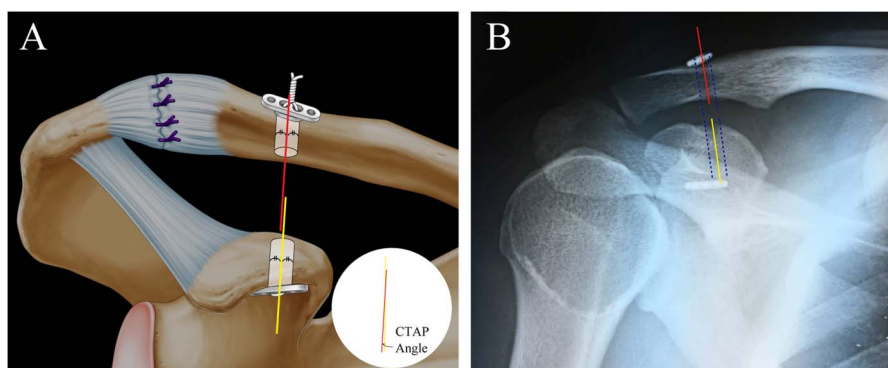


Fig. 5

Figs. 5-A and 5-B Illustration and radiograph showing the clavicular tunnel anteroposterior (CTAP) angle, which is the acute angle between the radiographic midline (red and yellow solid lines) of the clavicular and coracoid tunnels (cylinders in **Fig. 5-A** and blue dotted lines in **Fig. 5-B**).

Clavicular Tunnel Anteroposterior Angle

We assessed the clavicular tunnel anteroposterior (CTAP) angle (the angle between the radiographic midline of the bone tunnel formed in the clavicle and the coracoid process) on anteroposterior radiographs that were made immediately postoperatively (Figs. 5-A and 5-B)²⁶.

ENDOBUTTON Pullout

We investigated pullout of the ENDOBUTTONs at the attachment sites^{8,9,12}. Three orthopaedic surgeons (D.M., K.K., N.F.) who had not been involved in the earlier treatments measured the mean CCD, DCTP, and clavicular length in millimeters and the mean CTAP angle in degrees with use of digital calipers in the Picture Archiving and Communication System (PACS), resulting in satisfactory intraclass correlation reliability test results (Table II)²⁷. The diagnosis of radiographic appearance in terms of coracoid tunnel orientation, posterior displacement of the clavicle, ENDOBUTTON pullout, ossification in the CC interspace, and osteoarthritis of AC joint was determined by consensus among the 3 surgeons.

Classification of Patients According to CCD Ratio

Considering the inconsistency of successful clinical and radiographic outcomes in previous studies^{1,2,20-22,24,26} and our operative purpose of narrowing the CC interspace, we established an approach based on the operative indication (Rockwood type-III to V dislocation) to investigate the relationship between clinical and radiographic outcomes. We divided the patients into 2 groups on the basis of the CCD ratio: Group 1 (CCD ratio of <25%, resembling Rockwood type-I or II partial dislocation) and Group 2 (CCD ratio of ≥25%, resembling Rockwood type-III, IV, or V dislocation)¹. We then further divided Group 1 into two subgroups: Group 1A (CCD ratio of <10%, resembling Rockwood type I) and Group 1B (CCD ratio of 10% to 25%, resembling Rockwood type II) because our ultimate operative purpose was to maintain the AC joint as it was in Group 1A.

Statistical Analysis

We used the unpaired t test with Bonferroni correction to independently compare postoperative clinical scores, the interval from injury to surgery, age, and radiographic parameters such as the CTR and the CTAP angle. The Fisher

TABLE II Intraobserver and Interobserver Reliability of Radiographic Parameters*

Parameter	Reliability (95% Confidence Interval)	
	Intraobserver	Interobserver
CCD ratio	0.992 (0.980 to 0.997)	0.931 (0.839 to 0.972)
CTR	0.985 (0.962 to 0.994)	0.909 (0.820 to 0.959)
CTAP angle	0.993 (0.982 to 0.997)	0.980 (0.959 to 0.991)

*CCD = coracoclavicular distance, CTR = clavicular tunnel ratio, and CTAP = clavicular tunnel anteroposterior.

TABLE III Variables and Clinical Scores in the Study Cohort

Variable	Total Cohort (N = 20)
Constant score* (points)	97.1 ± 4.9
ASES score*† (points)	98.8 ± 2.7
Male:female ratio† (no. of patients)	18:1
Age* (yr)	32.3 ± 16.3
Dominant-side surgery (no. of shoulders)	11 (55.0%)
Interval between injury and surgery* (d)	9.6 ± 7.4 (2 to 34)
Duration of follow-up* (mo)	151.8 ± 22.2
Sports injury (no. of shoulders)	15 (75.0%)

*The values are given as the mean and the standard deviation, with or without the range in parentheses. †ASES = American Shoulder and Elbow Surgeons. ‡One male patient underwent the index surgery bilaterally.

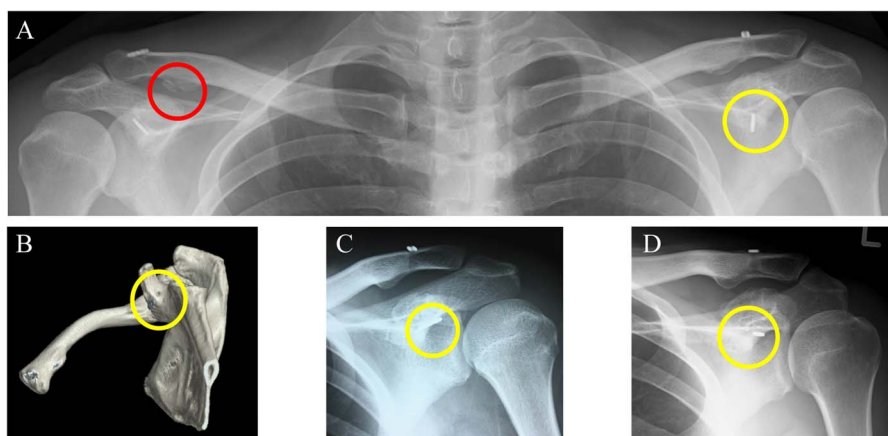


Fig. 6

Figs. 6-A through 6-D Radiographs and 3D reconstructed CT image for the 1 patient who underwent single-bundle coracoclavicular ligament reconstruction of both shoulders (Cases 4 and 6). **Fig. 6-A** Anteroposterior radiograph made at the time of the latest follow-up. The red circle shows ossification in the coracoclavicular interspace, and the yellow circle shows pullout of the distal ENDOBUTTON. **Fig. 6-B** 3D reconstructed CT image made at the time of the latest follow-up. The yellow circle shows pullout of the distal ENDOBUTTON. **Fig. 6-C** Anteroposterior radiograph made 12 months postoperatively. The yellow circle shows the distal ENDOBUTTON seated on the undersurface of the coracoid. **Fig. 6-D** Anteroposterior radiograph made 132 months postoperatively. The yellow circle shows pullout of the distal ENDOBUTTON.

exact test with Bonferroni correction was used to independently compare posterior displacement, coracoid tunnel orientation (center versus noncenter), and Rockwood classification (type III versus type IV or V). We used 1-way analysis of variance to calculate intraobserver and interobserver reliability correlations of repeated interval scale mea-

asures. The level of significance was set at $p < 0.05$. Statistical analyses were performed with SAS software (version 9.13).

Results

The cohort consisted of 20 shoulders in 19 patients (18 male and 1 female) with a mean age of 32.3 years at the time of

TABLE IV Comparison of Multiple Variables Between Groups*								
Variable	CCD Ratio <25%			CCD Ratio ≥25%	P Value			
	Group 1 (CCD Ratio <25%) (N = 17)	Group 1A (CCD Ratio <10%) (N = 10)	Group 1B (10% ≤ CCD Ratio <25%) (N = 7)	Group 2 (N = 3)	Group 1 vs. Group 2	Group 1A vs. Group 1B	Group 1A vs. Group 2	Group 1B vs. Group 2
Constant score† (points)	98.2 ± 3.3	98.3 ± 4.1	98.1 ± 2.0	90.7 ± 8.3	0.038†	>0.999	0.177	0.174§
ASES score† (points)	99.5 ± 1.4	99.7 ± 1.0	99.3 ± 1.9	95.0 ± 5.0	0.013†	>0.999	0.045†	0.285§
CTR†	0.17 ± 0.03	0.16 ± 0.02	0.18 ± 0.04	0.16 ± 0.01	>0.999	0.356	>0.999	>0.999§
CTAP angle† (°)	1.9 ± 1.0	2.1 ± 1.2	1.6 ± 0.5	12.1 ± 8.6	<0.001†	>0.999	0.008†	0.032†§
Coracoid tunnel orientation (center vs. noncenter)‡ (no. of shoulders)	9 vs. 8	4 vs. 6	5 vs. 2	2 vs. 1	>0.999	>0.999	>0.999	>0.999**
Posterior displacement (no. of shoulders)	0	0	0	2	0.063	—	0.154	0.267**
Rockwood type III vs. IV or V (no. of shoulders)	2 vs. 15	1 vs. 9	1 vs. 6	0 vs. 3	>0.999	>0.999	>0.999	>0.999**
Interval between trauma and surgery† (d)	8.4 ± 5.0	5.6 ± 3.1	12.4 ± 4.5	16.0 ± 15.6	0.408	0.009†	0.205	>0.999§
Age† (yr)	30.5 ± 16.3	24.9 ± 17.8	38.4 ± 10.5	42.3 ± 14.4	>0.999	0.370	0.608	>0.999§

*CCD = coracoclavicular distance, ASES = American Shoulder and Elbow Surgeons, CTR = clavicular tunnel ratio, and CTAP = clavicular tunnel anterior posterior. †The values are given as the mean and the standard deviation. ‡Significant. §Unpaired t test with Bonferroni correction. #“Center” indicates that both the entry and the exit point of the coracoid tunnel were located in the center portion of the coracoid base. **Fisher exact test with Bonferroni correction.

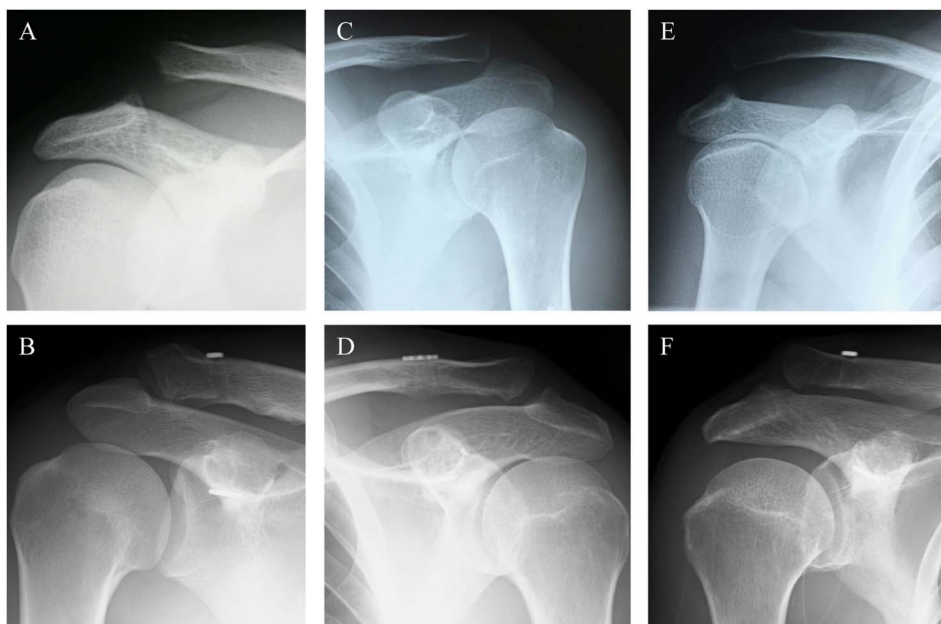


Fig. 7

Figs. 7-A through 7-F Preoperative (**Figs. 7-A, 7-C, and 7-E**) and postoperative (**Figs. 7-B, 7-D, and 7-F**) anteroposterior radiographs. **Figs. 7-A and 7-B** Case 15 (Rockwood type III; CCD ratio, 13.4%). **Figs. 7-C and 7-D** Case 14 (Rockwood type IV; CCD ratio, 11.9%). **Figs. 7-E and 7-F** Case 18 (Rockwood type V; CCD ratio, 56.9%).

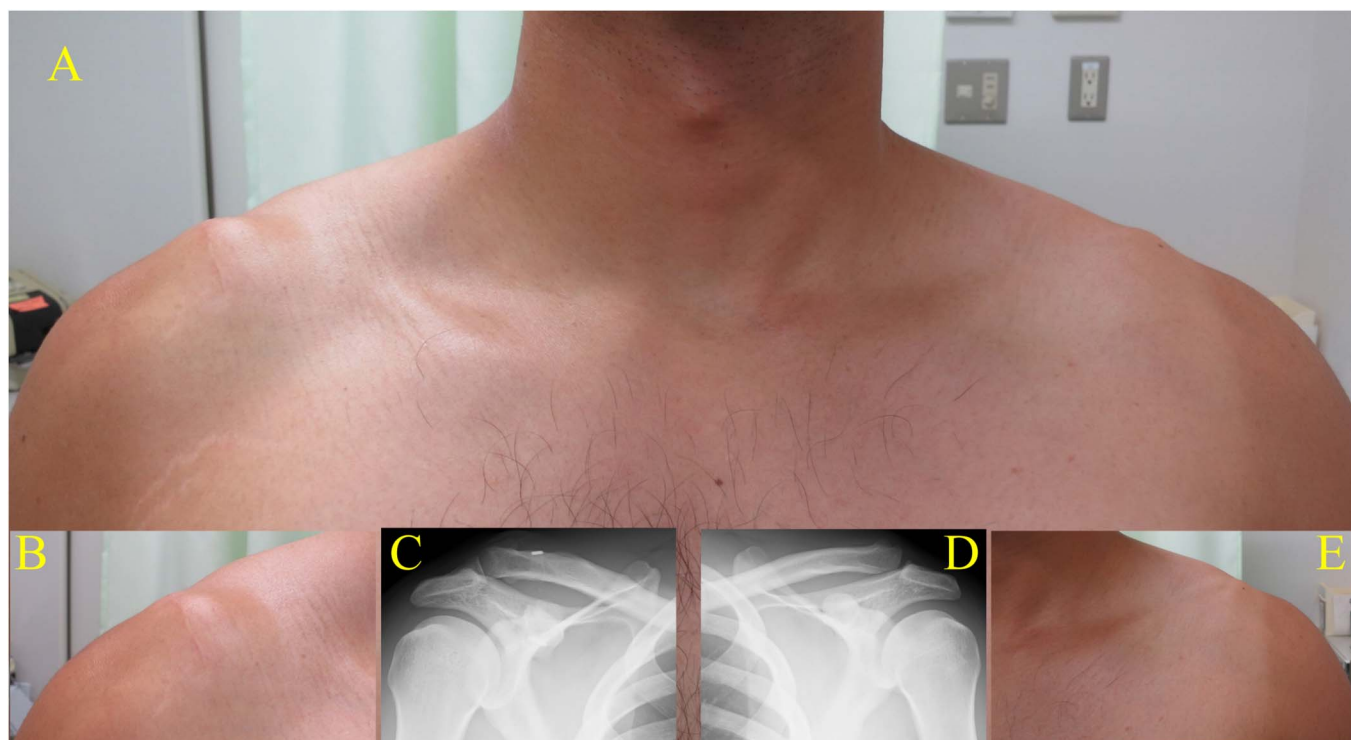


Fig. 8

Figs. 8-A through 8-E Case 5. Follow-up photographs and radiographs. **Fig. 8-A** Postoperative photograph of both shoulders. **Fig. 8-B** Postoperative photograph of the right shoulder, showing a slight protrusion around the AC joint. **Fig. 8-C** Postoperative anteroposterior radiograph of the right shoulder, showing osteoarthritic changes of the AC joint. **Fig. 8-D** Postoperative anteroposterior radiograph of the left shoulder. **Fig. 8-E** Postoperative photograph of the left shoulder.

surgery. The dominant shoulder was involved in 11 cases. The mean interval between the injury and surgery was 9.6 days. The mean duration of postoperative follow-up was 12.7 years (151.8 months; range, 124 to 203 months). The mechanism of injury was sports-related for 14 patients, a fall from a height for 1 patient, and a motor-vehicle accident for 4 patients. According to the Rockwood classification, there were 2 type-III, 2 type-IV, and 16 type-V dislocations. The mean Constant and ASES scores were 97.1 and 98.8, respectively (Tables I and III).

Radiographic and Clinical Outcomes and Complications in Multiple Groups

In the 1 patient who underwent the procedure bilaterally, the CCD and CTR were 10.1 mm and 0.12, respectively, on the right side and 8.1 mm and 0.19, respectively, on the left side at the time of the latest follow-up (Fig. 6); hence, both shoulders in this patient were included in Group 1. There were 10 shoulders in Group 1A, 7 in Group 1B, and 3 in Group 2 (Table IV). The mean CTR ranged from 0.16 to 0.18 in all groups. The mean Constant and ASES scores and CTAP angles were significantly different between Groups 1 and 2 (98.2 compared with 90.7 [$p = 0.038$], 99.5 compared with 95.0 [$p = 0.013$], and 1.9° compared with 12.1° [$p < 0.001$], respectively) (Table IV and Fig. 7). Of the radiographic variables that were related to the operative technique (CTR, CTAP angle, and coracoid tunnel orientation), only the CTAP angle significantly differed between Groups 1 and 2. There were no significant differences in clinical scores or the 3 radiographic variables between Groups 1A and 1B. There were 11 cases of center-center coracoid tunnel placement, 6 of lateral-lateral tunnel placement, and 3 of center-lateral tunnel placement. Two of the 3 shoulders in Group 2 had posterior displacement of the AC joint (Table I). Only 2 shoulders (Cases 4 and 17) had pullout of the coracoid button with reduction of the AC joint (Fig. 6). Four shoulders showed postoperative ossification in the CC interspace (Fig. 6-A). Eighteen shoulders showed radiographic signs of AC joint osteoarthritis (Fig. 8). No patient had intraoperative or postoperative clavicular or coracoid fracture, infection, or any form of osteolysis around the ENDOBUTTONS.

Discussion

To our knowledge, the mean duration of follow-up in the present study (12.7 years) is the longest reported follow-up for anatomic CC ligament reconstruction. The overall results of this CC ligament reconstruction technique were very successful, with high mean Constant and ASES scores (97.1 and 98.8, respectively) that were comparable with those in previous studies: the mean Constant and ASES scores were both 98.0 at a mean of 5.2 years as reported by Struhl and Wolfson⁶, and the mean Constant score was 96.6 at a mean of 17 months as reported by Yoo et al.²⁸. Furthermore, there were no complications such as coracoid and/or clavicular fractures related to the index procedures, and no revision procedures had been performed after a minimum duration of follow-up of 10 years. Interestingly, 2 shoulders (Cases 4 and 17) had pullout of the coracoid button with maintenance of AC joint reduction. This

finding suggests that this technique potentially can result in AC stabilization with complete soft-tissue healing even if the artificial ligament is disrupted. Seventeen shoulders (85%) had a CCD ratio of $<25\%$ and no posterior AC displacement in conjunction with significantly higher clinical scores compared with those for the shoulders with a CCD ratio of $\geq 25\%$; however, degenerative changes still developed in the AC joint.

The satisfactory radiographic results may have been achieved for the following reasons. First, our choice of operative drill diameter (3.5 mm for the clavicular tunnel, 4.5 mm for the coracoid tunnel) and ENDOBUTTON size (4×12 mm) were supported by previous studies. A 4.5-mm coracoid tunnel is reportedly superior to a 6-mm coracoid tunnel for biomechanically rigid fixation after CC ligament reconstruction²⁹, the Telos ligament has good mechanical properties (ultimate tensile strength, 1,866 N; stiffness, 68.3 N/mm) compared with natural ligament³⁰ (ultimate tensile strength, 1,730 N; stiffness, 182 N/mm), and the pullout strength of a metallic button is $>1,150$ N^{31,32}. Hence, our choices of implant and ligament were appropriate for rigid intraoperative fixation of the CC interspace and avoidance of implant migration into the clavicular and/or coracoid tunnel.

Second, the clavicular tunnel could have been located inside the anatomic insertion of the CC ligaments in the present study, considering that the mean CTR ranged from 0.16 to 0.18 in all groups (Table IV). In 1 anatomic study, the ratio of the distance from the lateral clavicular edge to the conoid center to clavicular length was 23.8% and the ratio of the distance from the lateral clavicular edge to the trapezoid center to clavicular length was 17.6%³³; in another study, these ratios were 25.5% and 15.6%, respectively³⁴. Those reports support the location of our clavicular tunnel placement inside the attachment of the CC ligaments as an anatomically proper position^{33,34}, even allowing for anatomic variance of the CC ligaments³⁵.

Third, the placement of the coracoid tunnel was located at the base of the coracoid in all shoulders, although not all shoulders had center-center coracoid tunnel orientation. The coracoid tunnel orientation did not significantly influence radiographic outcomes among the groups (Table IV). The entry point of the coracoid tunnel was located at the base of the coracoid in all shoulders, although only 11 shoulders (55%) had center-center coracoid tunnel orientation. A previous cadaveric study demonstrated no significant difference between a base-centered and distal-centered 4.5-mm tunnel at the base of the coracoid with respect to the mean ultimate load and energy at ultimate load²⁹. Additionally, Yi and Kim²⁶ investigated the influence of specific radiographic parameters on radiographic results following the use of the single TightRope (Arthrex) technique and found no significant difference in the tunnel-to-medial coracoid ratio between dissociated and nondissociated groups. Our results are consistent with the results of those 2 studies^{26,29} because the location of the coracoid tunnel did not significantly differ between the 2 groups.

Fourth, the mean CTAP angle in Group 1 (1.9°) had a more perpendicular placement compared with that in Group 2

(12.1°). The CTAP angle in patients with dissociation is reportedly more acute than the angle in patients with non-dissociation, indicating better clinical outcomes in the latter patients²⁶. In the present study, only the CTAP angle significantly differed between Groups 1 and 2. The clinical results in Group 2 were significantly inferior to those in Group 1. Given these clinical and radiographic results, a lower CTAP angle seems to be desirable for a good outcome. Surgeons should intraoperatively monitor the direction of the coracoid and clavicular tunnels to produce a lower CTAP angle^{10,26}. This monitoring is reportedly facilitated during arthroscopically assisted surgery with use of a transclavicular-transcoracoid drilling guide and fluoroscopy despite longer operation times and the risk of coracoid fracture³⁶.

The present study had several limitations. First, it had a small sample size, especially in Group 2. The limited statistical power meant that the CTAP angle was not conclusively determined to be a significant predictive factor of an unfavorable outcome, despite the fact that the CTAP angle significantly differed between Groups 1 and 2²⁶. Nevertheless, we believe that the CTAP angle is an important operative factor affecting outcome. Previous studies have indicated that the interval between trauma and surgery and the age at the time of trauma significantly influence clinical and radiographic outcomes^{3,10}; however, in the present study, these 2 factors did not significantly influence the outcomes in either group, possibly because of the small sample size. Second, the present study was retrospective and had no control group. Third, using clinical scores and classifying patients on the basis of the CCD ratio have not yet been validated for the assessment of AC joint dislocations. Indeed, considering the small sample sizes in the groups, the statistical results could not demonstrate the superiority of Group 1A over 1B. However, we consider that reduction of the AC joint by <25% of the CCD ratio is desirable for better long-term outcomes on the basis of the comparative results between Groups 1A and 1B and between Groups 1 and 2. Fourth, 2 of the 3 patients in Group 2 (Cases 18 and 20) had lower clinical

scores because of pain than did the patients in Group 1, whereas 1 patient (Case 19) had maximum clinical scores. One possible explanation is that the latter patient (Case 19) achieved full range of motion and strength without pain because of comprehensive scapulothoracic functionality^{2,6,37}.

In conclusion, the present study showed successful clinical and radiographic outcomes at a minimum of 10 years after anatomic CC ligament reconstruction for the treatment of acute AC joint dislocation. Longer-term successful outcomes may be achieved by ensuring the proper direction of drill-holes to create a lower CTAP angle and anatomically proper placement of the clavicular and coracoid tunnels intraoperatively.

Appendix

eA A table showing baseline variables and clinical scores for 1 patient who declined radiographic examinations and 2 patients who were managed with the double-bundle technique as well as radiographs of Case 2 are available with the online version of this article as a data supplement at <http://links.lww.com/JBJSOA/A17>. ■

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