Original Article
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Clavicular Tunnel Complications after Coracoclavicular Reconstruction in Acute Acromioclavicular Dislocation: Coracoid Loop versus Coracoid Tunnel Fixation

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Background: The purpose of this study was to compare clavicular tunnel complications after coracoclavicular (CC) reconstruction between a coracoid loop fixation group and a coracoid tunnel fixation group. We hypothesized that clavicular tunnel complications would be more common in the coracoid loop group.

Methods: This retrospective study evaluated 24 patients who underwent CC reconstruction using coracoid tunnel fixation (n = 14) and coracoid loop fixation (n = 10). Radiographic measurements included the CC distance and clavicular tunnel diameter. Clavicular tunnel complications such as tunnel widening and clavicular tunnel fractures were investigated. Clinical outcomes were assessed using the American Shoulder and Elbow Surgeons Shoulder score and the University of California at Los Angeles Shoulder score.

Results: The mean follow-up period was 17.5 months (range, 11–38 months). The final clavicular tunnel diameter and the increase in the clavicular tunnel diameter in millimeter and percentage were significantly greater in the coracoid loop group than in the coracoid tunnel group (all $p < 0.05$). Clavicular tunnel widening more than 100% was found in 5 patients, all belonging to the coracoid loop group. Clavicular tunnel fractures occurred in 3 patients (all in the coracoid loop group). Fracture was associated with severe tunnel widening (more than 100% increase). The mean value of the final clavicular tunnel diameter in patients with fractures was significantly larger than that in patients without (12.7 ± 3.3 mm vs. 8.4 ± 1.5 mm, $p = 0.016$).

Conclusions: Clavicular tunnel complications such as significant tunnel widening and fractures after CC reconstructions in acromioclavicular dislocations were common with the coracoid loop fixation technique. A greater clavicular tunnel widening and resultantly enlarged tunnel diameter might increase the risk of fracture through the clavicular tunnel.

Keywords: *Acromioclavicular joint, Dislocation, Coracoclavicular, Reconstruction, Complication*

Surgical management of acromioclavicular (AC) joint dislocation remains contentious because of the lack of consensus regarding the optimal surgical technique. A recent systematic review with 821 citations in the literature revealed there were 120 studies describing 151 techniques for reconstruction of the AC joint.[1] Many of the current techniques focus on reconstruction of the coracoclavicular (CC) ligaments in reference to anatomic studies that have emphasized the biomechanical importance of the CC

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ligaments for vertical stability in reconstruction of the AC joints.[2-4] Therefore, CC ligament reconstruction is gaining popularity and accepted as a viable option in achieving successful reduction and good clinical outcomes.[3-6]

However, the postoperative complication rate after the procedure has been reported to be greater than 20%.[5-8] Complications include loss of reduction, clavicle or coracoid fractures through the bone tunnel, osteolysis of the distal clavicle tunnel, and infection that might result in reoperations. Among them, fractures through the bone tunnel are a unique complication related to the surgical technique. Since CC reconstruction typically involves tunnel preparation in the clavicle and/or the coracoid, it must carry a risk of fracture during tunnel preparation intraoperatively and even in the postoperative period. On the other hand, several authors have reported on clavicular tunnel widening after CC reconstruction.[9,10] Clavicular tunnel widening is also related to bone tunnel preparation in the clavicle, although its clinical significance remains unclear.

CC reconstruction can be performed either with or without a coracoid bone tunnel. Therefore, there are two surgical methods to fix the graft on the coracoid side: one, coracoid tunnel fixation, and the other, coracoid loop fixation. Coracoid tunnel fixation involves tunnel placement both in the clavicle and the coracoid, and sutures or tendon grafts are passed through two bone tunnels and then fixed over the clavicle. In coracoid loop fixation, sutures or tendon grafts are looped around below the coracoid process without making a bone tunnel in the coracoid. Although both techniques have been widely used, complications specifically related to bone tunnels in the clavicle or coracoid process have not been much highlighted in the literature. Therefore, the purpose of this study was to compare clavicular tunnel complications after CC reconstruction between a coracoid loop fixation group and a coracoid tunnel fixation group. We hypothesized that clavicular tunnel complications would be more common in the coracoid loop group.

METHODS

The approval of Institutional Review Board of Nowon Eulji Medical Center was obtained (IRB No. 2019-09-007) for this study. All patients were offered detailed information about this study by examining orthopedic surgeons and signed informed consent forms.

Patient Selection

This study retrospectively evaluated a consecutive series of 24 patients who underwent CC ligament reconstructions for acute AC dislocation that were performed by two shoulder surgeons (NHC and TKL) in Nowon Eulji Medical Center. Between 2006 and 2013, one surgeon (NHC) performed CC ligament reconstruction with an autogenous semi-tendinous tendon graft using an open approach. For fixation, the tendon graft was passed below the coracoid process looping around it. One limb was passed through a single bone tunnel, which was made with a 4.5-mm reamer in the clavicle 3.0 cm medial from the AC joint, and the other limb was routed anterior to the clavicle. Then, the graft was fixed over the clavicle using the tendon square knot tying technique (coracoid loop group, n = 14) (Fig. 1A). Between 2014 and 2015, the other surgeon (TKL) performed CC ligament reconstruction with cortical buttons and sutures using an arthroscopic approach. In this technique, suture tapes were passed through a single bone tunnel with a 4.0-mm diameter in the clavicle, as well as the coracoid process, and fixed with cortical buttons (coracoid tunnel group, n = 13) (Fig. 1B). Detailed description of the surgical technique for both procedures and some patients presented in this paper had been previously reported by one of the authors.[11,12] The indication for surgery was the same for both surgeons: disruption of the CC ligaments accompanied by AC dislo-

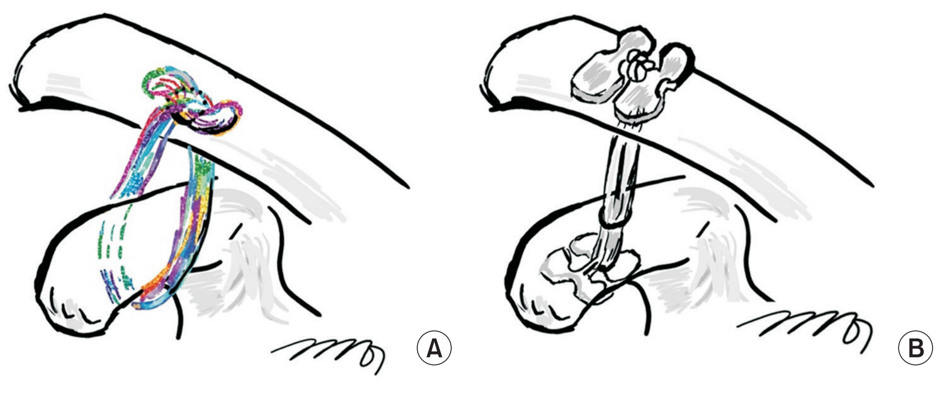

Fig. 1. Illustrations showing coracoid loop fixation (A) and coracoid tunnel fixation (B).

cation (Rockwood grade III, IV, or V). For grade III injury, surgical options were offered in young and active patients after careful discussion about nonsurgical or surgical options between the patient and the treating surgeon. The inclusion criterion of this study was reconstruction for acute AC joint dislocation performed using one of the two techniques. We excluded patients with a follow-up period less than 12 months, previous history of fracture or infection, and injury on the ipsilateral shoulder or arm.

Radiographic Evaluations

Plain radiography for anteroposterior and axial images of the clavicle without weight-bearing was performed on both clavicles preoperatively, immediately postoperatively, and at the final follow-up in all patients. Radiographic measurements with these images included the CC distance and the diameter of the clavicular bone tunnel. In the anteroposterior images of both clavicles, the closest vertical distance between the superior cortex of the coracoid process and the inferior cortex of the clavicle was defined as the CC distance. The tunnel diameter was measured as the widest mediolateral diameter of the clavicular bone tunnel in millimeter using the anteroposterior radiograph of both clavicles in the immediate postoperative period and at the final follow-up. The increase in tunnel diameter (tunnel widening) at the final follow-up compared to immediately after surgery was calculated in millimeter (mm) and percentage (%). All measurements were performed on the picture archiving and communication system (PACS; General Electric, Chicago, IL, USA) by use of a point mouse cursor with automated calculation of the distance by one orthopedic resident who did not participate in the diagnosis or surgery (JHH). Measurement was performed twice for each patient, and the mean values were used for analysis.

Clinical Evaluations

We evaluated shoulder functions using the American Shoulder and Elbow Surgeons Shoulder (ASES) score, the University of California at Los Angeles (UCLA) shoulder score, and range of shoulder motion (active forward elevation, external rotation at side, and internal rotation at back). We also collected data of complications and reoperations through a review of operation records and by clinical and radiographic examinations at the final follow-up.

Statistical Analysis

A paired *t*-test was used to compare the CC distance and tunnel diameter measured preoperatively, immediately after surgery, and at the final follow-up. Independent *t*-tests were used to statistically evaluate the differences in the measured values between the coracoid tunnel group and coracoid loop group, groups with and without clavicle tunnel widening, and groups with and without distal clavicle fractures. Chi-square test was performed to observe the factors related to clavicle fractures through the bone tunnel. A *p*-value of 0.05 was set as the level of statistical significance.

RESULTS

Patients

In the coracoid loop group, there were 13 men and 1 woman with a mean age of 40 years (range, 19–70 years). The mechanism of trauma was a simple fall in 4 patients, cycling or biking accident in 4, motor vehicle accident in 3, ski or snowboard injury in 1, and slip down during sports activity (hiking and tennis) in 2. According to Rockwood classification, 11 type V and 3 type III were included. The right shoulder was involved in 7 patients. The mean follow-up period was 17.5 months (range, 11–38 months). In the coracoid tunnel group, there were 8 men and 2 women with a mean age of 45 years (range, 22–75 years). The cause of injury included a simple fall in 4 patients, cycling or biking accident in 3, motor vehicle accident in 2, and pedestrian traffic accident in 1. There were 8 type V and 2 type III according to Rockwood classification. The mean follow-up period was 17.3 months (range, 12–48 months). Baseline demographic data and mean follow-up period were not significantly different between groups (Table 1).

Radiographic and Clinical Outcomes

In the coracoid loop group, the CC distance was 16.3 ± 4.2 mm (CC percentage, 86.6% ± 52.9%) preoperatively, 8.9 ± 2.6 mm (7.9% ± 47.2%) in the immediate postoperative period, and 10.8 ± 4.0 mm (28.1% ± 54.5%) at the final follow-up. In the coracoid tunnel group, the CC distance was 17.4 ± 4.8 mm (CC percentage, 130.8% ± 47.5%) preoperatively, 10.2 ± 4.5 mm (19.0% ± 23.4%) in the immediate postoperative period, and 13.8 ± 3.4 mm (71.0% ± 55.5%) at the final follow-up. As shown in Table 1, there were no statistically significant differences in CC distance between groups at each time point (all in $p > 0.05$). As for clinical outcomes, the UCLA Shoulder Score and ASES at the final follow-up in the coracoid loop group were 31.2 (range, 23–35) and 90.0 (range, 60–99), respectively, and those scores in the coracoid tunnel group were 30.6 (range, 20–35) and 94.7 (range, 80–100), respectively. There were no significant differences in clinical outcomes between

Table 1. Comparison of Clinical and Radiographic Outcomes between Groups

Variable	Coracoid loop group (n = 14)	Coracoid tunnel group (n = 10)	*p*-value
Age (yr)	40 (19–70)	45 (12–48)	0.441
Sex (male)	13	8	0.841
Site (right side)	7	5	1.000
Follow-up (mo)	17.5 (11–38)	17.3 (12–48)	0.841
CC distance (preoperative, mm)	16.3 ± 4.2	17.4 ± 4.8	0.637
CC distance (immediately after surgery, mm)	8.9 ± 2.6	10.2 ± 4.5	0.330
CC distance (final follow-up, mm)	10.8 ± 4.0	13.8 ± 3.4	0.093
UCLA score	31.2 (23–35)	30.6 (20–35)	0.709
ASES score	90.0 (60–99)	94.7 (80–100)	0.056

Values are presented as mean (range), number, or mean ± standard deviation.
CC: coracoclavicular, UCLA: University of California at Los Angeles Shoulder, ASES: American Shoulder and Elbow Surgeons Shoulder.

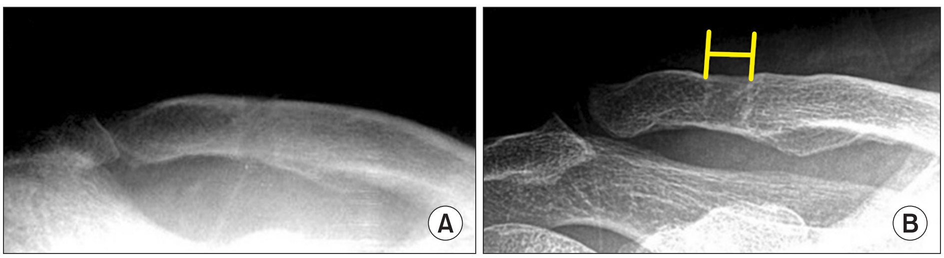

Fig. 2. (A) Immediate postoperative radiograph of a 41-year-old male patient in the coracoid loop group with a tunnel diameter of 5.5 mm in measurement. (B) At 2 years postoperatively, the tunnel was enlarged to 11.6 mm with 112% tunnel widening.

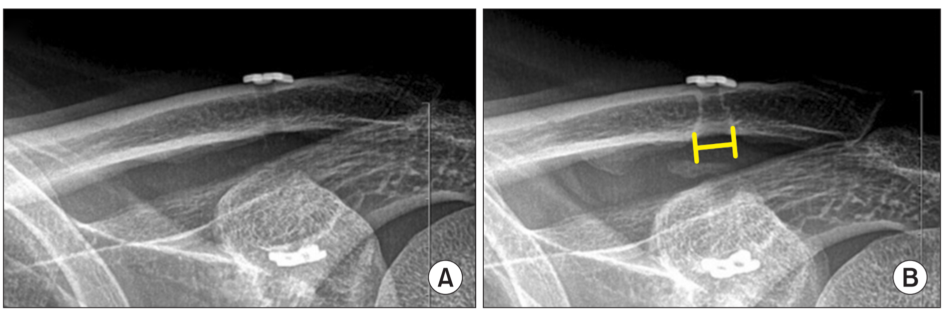

Fig. 3. (A) Immediate postoperative radiograph of a 34-year-old male patient in the coracoid tunnel group with a tunnel diameter of 4.6 mm in measurement. (B) At 2 years postoperatively, the tunnel was enlarged to 7.5 mm with 65% tunnel widening.

groups (Table 1).

Clavicular Tunnel Widening

In the coracoid loop group, the mean value of the clavicular tunnel diameter was 5.2 ± 0.4 mm in the immediate postoperative period and it significantly increased to 10.0 ± 2.4 mm at the final follow-up with tunnel widening increase of 4.8 ± 2.3 mm (93.3% ± 46.0% increase, $p = 0.001$) (Fig. 2). More than 50% increase in tunnel widening was found in 12 patients (86%), and more than 100% increase was also found in 5 patients (35%) in the coracoid loop group. On the other hand, in the coracoid tunnel group, the clavicular tunnel diameter was 4.8 ± 0.3 mm in the immediate postoperative period and 7.6 ± 0.8 mm at the final follow-up with tunnel widening of 2.8 ± 0.9 mm (59.6% ± 21.9% increase, $p < 0.001$) (Fig. 3). More than 50% increase in tunnel widening was found in 7 patients (70%), while more than 100% increase was not found in the coracoid tunnel group (Table 2).

Comparing the outcomes between groups, the final clavicular tunnel diameter and the increase of clavicular tunnel diameter in millimeter and percentage were significantly greater in the coracoid loop group than in the coracoid tunnel group (all $p < 0.05$) (Table 2). As a result,

Table 2. Comparison of Clavicular Tunnel Complications between Groups

Variable	Coracoid loop group (n = 14)	Coracoid tunnel group (n = 10)	*p*-value
Initial tunnel diameter (immediately after surgery, mm)	5.2 ± 0.4	4.8 ± 0.3	0.382
Final tunnel diameter (follow-up, mm)	10.0 ± 2.4	7.6 ± 0.8	0.003
Increase of tunnel diameter (tunnel widening, mm)	4.8 ± 2.3	2.8 ± 0.9	0.019
Increase of tunnel diameter (tunnel widening, %)	93.3 ± 46.0	59.5 ± 21.8	0.044
Tunnel widening (> 50% increase)	7	7	0.437
Tunnel widening (> 100% increase)	5	0	0.154
Clavicular tunnel fracture	3	0	0.431

Values are presented as mean ± standard deviation.

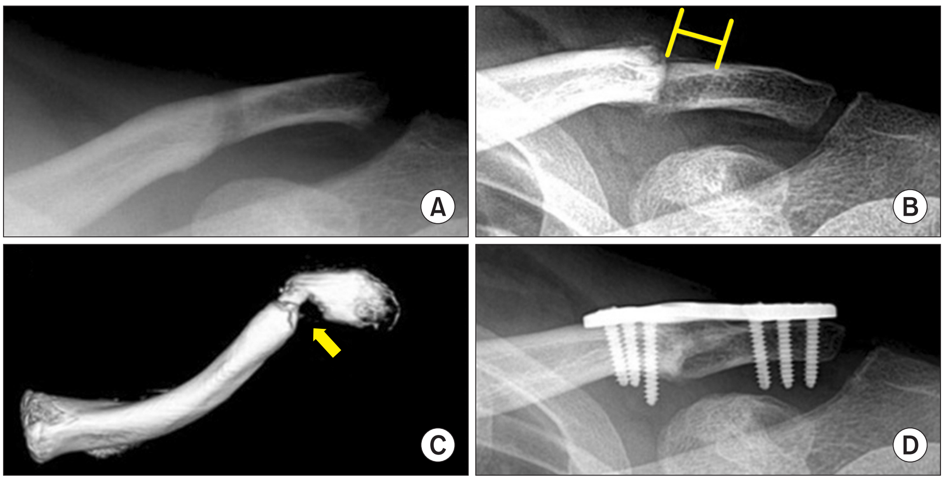

Fig. 4. (A) Immediate postoperative radiograph of a 37-year-old male patient in the coracoid loop group with a tunnel diameter of 4.7 mm in measurement. (B) At 11 months postoperatively, a clavicular fracture occurred with the tunnel was enlarged to 11.3 mm (144% tunnel widening). (C) Three-dimensional computed tomography showed a clavicular fracture through the bone tunnel (arrow), in which the enlarged tunnel was more than 50% of the anteroposterior width of the distal clavicle. (D) The fracture was treated with osteosynthesis and healed.

the amount of tunnel widening during the follow-up was much greater in the coracoid loop group than in the coracoid tunnel group.

Clavicular Tunnel Fracture

Fracture through the clavicular bone tunnel developed in 3 patients, all belonging to the coracoid loop group (Fig. 4). Fracture in the coracoid process was not found. However, the difference in the incidence of clavicular tunnel fractures did not reach the significant level (p = 0.431). All fractures were associated with severe tunnel widening more than 100%. The mean value of final clavicular tunnel diameter in patients with fractures was significantly larger than that in patients without (12.7 ± 3.3 mm vs. 8.4 ± 1.5 mm, p = 0.016). Two clavicular fractures were treated with open reduction, plate fixation, and bone grafting and eventually healed, and the remaining one was treated nonoperatively, resulting in fibrous nonunion. Clinical scores were not significantly different between patients with fracture and those without fracture (UCLA Shoulder Score, 33.0 ± 1.7 and 30.7 ± 4.4, respectively, p = 0.401, and ASES Score, 94.6 ± 0.5 and 91.6 ± 9.2, respectively, p = 0.890).

DISCUSSION

This study demonstrated that clavicular bone tunnel complications after CC ligament reconstruction were common when it was performed with a single tunnel in the clavicle. Notably, clavicular tunnel fractures occurred only in the coracoid loop group. Although clavicular tunnel widening was found in both groups, more severe widening was found in the coracoid loop group, which might have resulted in clavicular fractures through the widened bone tunnels in this group. We emphasize that such complications must be acknowledged by surgeons because they are related to surgical techniques for creating bone tunnels in the clavicle for CC ligament reconstruction. Clavicular tunnel complications are clinically relevant, given that they resulted in reoperations in this series.

Clavicular fractures after CC ligament reconstruction have been reported by several authors.[13-17] The incidence of clavicular fractures was estimated ranging from 4% to 43%, suggesting this complication was not uncommon in the literature, as shown in our series. Despite previous reports of clavicular fractures through bone tunnels, this complication has been rarely discussed in the context of methods used for coracoid side fixation. In the current study, clavicular fractures were found only in coracoid loop fixation, not in coracoid tunnel fixation. Furthermore, clavicular tunnel widening was greater than 100% in fracture cases. This could suggest that the clavicular bone tunnel is enlarged during the follow-up period, and it might result in a clavicular fracture through the bone tunnel. Given the mean 19.2 ± 2.8 mm anteroposterior width in distal clavicle osseous anatomy,[18] the mean final tunnel diameter of 12.6 ± 3.3 mm in our fracture cases reached 66% of the anteroposterior width of the clavicle, which would definitively increase the risk of fracture. Although the etiology of this complication is still unknown, we postulated that mechanical stress of the tendon graft on the clavicular bone tunnel in this construct might be the possible cause of tunnel widening and resultant fracture. Looped tendon grafts below the coracoid base could suffer from significant motions according to scapular movements during arm activity, in which it might increase stress concentration in the clavicular bone tunnel, resulting in clavicular tunnel widening and fracture. This is similar to a windshield-wiper or bungee cord effect, as well known in anterior cruciate ligament reconstruction. This phenomenon was previously suggested as a possible mechanism of clavicular tunnel widening by Yoo et al al.[9] Our study findings support this theory and further demonstrate that severe clavicular tunnel widening could result in a clavicular fracture through the bone tunnel and must be a clinically important factor in evaluating postoperative outcome after CC ligament reconstruction.

On the other hand, the construct of coracoid tunnel fixation would be less vulnerable to this stress because the graft fixation point and its line of action are centered within the coracoid bone tunnel. Interestingly, previous studies also support this assumption because clavicular fractures were found in studies comparing the outcomes after CC reconstruction using coracoid loop and tunnel fixations. Milewski et al.[14] reviewed 27 surgically treated patients with AC dislocations. Of them, 10 were treated with the coracoid tunnel technique and the remaining 17 with the coracoid loop technique as in the current study. Among the complications, 3 clavicle fractures (18% of the coracoid loop group) occurred only in the coracoid loop group. Martetschlager et al.[13] performed 59 anatomic CC ligament procedures including 13 primary fixation using the cortical fixation button technique (coracoid tunnel fixation) and 46 primary reconstruction using the tendon graft (coracoid loop fixation). Their result was similar because they encountered 2 clavicle fractures through the drill holes only in the coracoid loop group.

Other authors reported no clavicle fractures with use of similar reconstruction constructs. Baran et al.[19] evaluated outcomes of 17 patients after CC reconstructions with hamstring allografts. Tendon was passed under the coracoid and fixed over the clavicle through double tunnels, unlikely in our study. They claimed that the reason for no development of fractures was attributed to the use of coracoid loop fixation instead of drilling through the coracoid and the use of 5 mm bone tunnels in the clavicle. Banffy et al.[20] presented outcomes of 17 patients after arthroscopic single-tunnel CC reconstruction using an arthroscopic technique and cortical button fixation (the same technique as in our cortical tunnel group) and reported that there was no clavicle or coracoid fracture. They discussed that the reason for no fracture in their series was attributed to restoration of both the CC ligaments and superior AC joint capsule. The above two studies were challenged by our study outcomes. Double-tunnel reconstruction seems to be the major difference from our surgical technique, although it is unknown whether the late occurrence of clavicular tunnel fractures depends on the single-tunnel and double-runnel construct. This issue would require further investigation. To reduce the risk of clavicle and coracoid fractures, Millett et al.[15] recommended looping the tendon graft around both the coracoid base and distal clavicle, thereby avoiding the use of bone tunnels altogether for graft passage. Milewski et al.[14] also suggested the technique of minimizing the clavicle tunnel diameter, allowing at least 25 mm between two clavicular tunnels, placing the lateral clavicle tunnel at least 10 to 15 mm from the lateral edge of the clavicle, when double-tunnel reconstruction is used.

Several limitations must be mentioned regarding the current study. First, clavicular fractures and tunnel widening in this study pertain to our surgical techniques involving a single tunnel in the clavicle. Therefore, it should not be extrapolated to other techniques, such as double-tunnel reconstructions. Second, the small sample size of this study and small differences in some positive outcome variables between groups can be problematic. The final clavicular tunnel diameter and the increase of tunnel diameter were significantly larger in the coracoid loop group than in the coracoid tunnel group, but the group differences were only marginal (final diameter, 2.4 mm and the increase, 2.0 mm) (Table 2). However, post hoc analysis showed sufficient powers for both outcomes (93.6% and 84%, respectively). On the other hand, the power was low for the final clavicular tunnel diameter that was significantly greater in patients with clavicular tunnel fractures than those without fractures (the difference of 4.3 mm between groups and 57.3% of power). This low statistical power may be due to the small sample size of the fracture group (n = 3) or the small difference (4.2 mm) being investigated, or both. Third, the horizontal instability was not evaluated in this study with use of axial stress X-ray (Alexander view).[21] Whether successful healing of the AC ligament was achieved or not is unknown in our series. Fourth, the operating surgeons, as well as the detailed surgical techniques in both groups, were different in terms of approach (open versus arthroscopic) and fixation materials (autogenous tendon graft versus sutures and cortical buttons). Fifth, we did not perform intra- or interobserver reliability test for our measurements. Finally, the short-term follow-up and retrospective design are another weakness.

In conclusion, our findings suggest that clavicular tunnel complications such as significant tunnel widening and fracture after CC reconstructions in AC dislocations are common in the coracoid loop fixation technique. Great clavicular tunnel widening and resultantly enlarged tunnel diameter might increase the risk of fracture through the clavicular tunnel.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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