Biomechanical Analysis of Single-, Double-, and Triple-Bundle Configurations for Coracoclavicular Ligament Reconstruction Using Cortical Fixation Buttons With Suture Tapes: A Cadaveric Study

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Purpose: To compare the acromioclavicular (AC) joint stability of single-bundle (SB), double-bundle with an anterolateral limb (DBa), double-bundle with a posterolateral limb (DBp), and triple-bundle (TB) coracoclavicular (CC) ligament reconstructions using cortical fixation buttons with suture tapes. **Methods:** Eight cadaveric shoulders were used. AC joint translation and rotational stability were tested for intact and following 4 different CC reconstruction techniques: SB, DBa, DBp, and TB configurations using cortical fixation buttons with suture tapes. For each reconstruction and native AC joint as control, anteroposterior (AP) and superoinferior translations were quantified using 10- and 15-N translational loads and anterior and posterior rotations were measured using 0.16- and 0.32-Nm rotational torque. **Results:** DBp reconstruction showed significantly better AP stability compared with SB and DBa reconstruction at 10 and 15 N (DBp: 4.1 ± 0.6 mm, SB: 7.8 ± 1.1 mm, $P < .001$; DBa: 6.5 ± 0.7 mm, $P = .02$ at 10 N; DBp: 5.5 ± 0.8 mm, SB: 10.1 ± 1.0 mm, $P = .003$; DBa: 9.1 ± 0.7 mm, $P = .02$ at 15 N). The degree of total rotation showed tendency to decrease according to increasing number of bundles; however, there were no significant differences (SB: 43.1 ± 9.2°, DBa: 37.9 ± 7.3°, DBp: 33.9 ± 6.8°, TB: 32.2 ± 6.6°, $P = .37$ at 0.32 Nm). **Conclusions:** An additional posterolateral clavicular hole for CC ligament reconstruction using cortical fixation buttons with suture tapes resulted in better AP stability compared with SB reconstruction, whereas use of additional anterolateral clavicular hole did not show any improvement compared with SB reconstruction. Reconstruction using both anterolateral and posterolateral clavicular holes did not guarantee better stability compared with SB reconstruction. There was an increasing tendency of rotational stability with number of bundle increases, although they did not reach statistical difference. **Clinical Relevance:** When surgeons consider double-bundle CC ligament reconstruction using cortical fixation buttons with suture tapes, it is better to position the lateral clavicular hole posteriorly to restore AP stability.

See commentary on page 2992

The coracoclavicular (CC) ligament consists of the trapezoid and conoid bundles that provide anteroposterior (AP) and superoinferior (SI) stability in the acromioclavicular (AC) joint, respectively.[1] It is important to restore both bundles because patients usually have not only SI but also AP instability after AC joint injury; therefore, surgical techniques for AC injuries have attempted to reconstruct these 2 different bundles to

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restore their functions.[2,3] Double-bundle reconstructions using tendon grafts or cortical button fixation methods with variable configurations have been used and generally result in superior biomechanical properties to conventional single-bundle (SB) reconstruction.[4-6] In clinical situations, SB reconstruction of the CC ligament using a cortical button fixation method is associated with up to 23% to 50% loss of reduction on radiologic images, whereas double-bundle reconstruction has shown only a 4.8% reduction loss after 2 years' follow-up.[3,7-9]

The lateral and medial bundles of a double-bundle reconstruction represent the trapezoid and conoid ligaments, respectively; therefore, the location of the lateral clavicular hole is important to restore the function of trapezoid ligament, which provides resistance to AP displacement of the distal clavicle.[1] Based on the anatomic insertion area of the trapezoid tuberosity, the lateral clavicular hole in double-bundle CC ligament reconstruction has been described as 2.5 cm medial from the lateral clavicular edge and at the midpoint in the AP plane.[4,10,11] In the situation of arthroscopic CC reconstruction using cortical fixation buttons with suture tapes, however, it is uncertain whether the native location of the trapezoid insertion is the optimal site for lateral bundle reconstruction because of distorted anatomy after AC joint dislocation. In the AC-CC ligament injured condition, making the lateral clavicular hole more posteriorly than the anatomic insertion position may better restore AC joint stability because the dislocated distal clavicle usually located superoposterior to the coracoid process.[12] No studies have reported the biomechanical stability of CC reconstruction using cortical fixation buttons with suture tape with different locations of the lateral clavicular hole, however.

The purpose of this study was to compare the biomechanical properties including AP and SI translation as well as anterior and posterior rotation after CC reconstruction using cortical fixation buttons with suture tape of SB, double-bundle with an anterolateral limb (DBa), double bundle with a posterolateral limb (DBp), and triple-bundle (TB) CC ligament reconstructions. We hypothesized that double-bundle and TB reconstructions would result in better translational and rotational stability compared with SB reconstruction and that DBp reconstruction would demonstrate better stability, especially AP translation compared with DBa reconstruction.

Methods

Specimen and Preparation

Eight fresh frozen cadaveric shoulders 5 men and 3 women with an average age of 58 ± 10 years were used in this study. Specimen preparation was carried out following previously established methods.[5,13] All specimens were thawed overnight at room temperature 1 day before dissection. The humerus was disarticulated from the glenohumeral joint capsule, and all soft tissues were removed except the AC ligament and CC ligament. The scapula was potted with plaster of Paris in an aluminum box, aligning the AC joint with the box in both the sagittal and axial planes. The clavicle was secured in a polyvinyl chloride pipe with 4 screws, keeping its long axis centered within the pipe.

The scapula was mounted to a custom testing system with an X-Y translational plate to allow for AP and SI translation of the AC joint. The clavicle was mounted to the top arc of the jig in a cylinder that allows for anterior and posterior rotation (Fig 1). The neutral position was set with the AC joint anatomically reduced. Two metallic screws were inserted into the acromion and distal clavicle at the AC joint for consistent, 3-dimensional digitization using the MicroScribe system (Revware, Raleigh, NC). Three small indents were drilled into the polyvinyl chloride pipe to measure the degree of clavicle rotation with the MicroScribe.

Mechanical Testing

Mechanical testing was first performed on each specimen with the intact AC and CC ligaments. AP translation testing was performed after applying 5-N tension loads to the CC ligaments inferiorly and locking the SI translation plate. After preconditioning in the AP direction with 10 N for 10 cycles, AP translation was measured using 10- and 15-N translational loads. These loads were chosen based on previous biomechanical study.[13] For SI translation testing, the AP translation plate was locked with the AC joint reduced in the neutral position without any tension load. The ligaments were preconditioned with 10 N for 10 cycles in the SI direction; the SI translation was then measured using 10- and 15-N loads. During anterior and posterior rotation testing, the SI translation plate was locked with a 5-N tension load applied to the CC ligaments inferiorly and the AP translation plate was locked at the

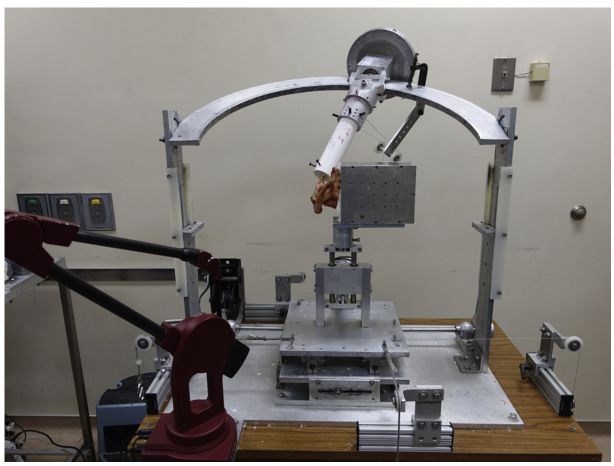

Fig 1. A customized testing system was used to test translational and rotational movement of the acromioclavicular joint.

neutral position without any tension load. Inferiorly directed 5-N tension on scapula was needed for angular control, as described by Kippe et al.[14] Preconditioning was performed with 0.16 Nm for 10 cycles, and then anterior and posterior rotations were measured using 0.16 and 0.32 Nm, respectively. For rotation loads, these loads were chosen based on pilot testing. The loads were adequate to give a consistent endpoint for rotation while not damaging the ligaments or repairs.

The MicroScribe was used to evaluate translational and rotational movement of the AC joint. To ensure reproducible measurements, the neutral position was digitized after each tension loading, and all measurements were taken twice by a single orthopedic surgeon (I.P.). If the difference between 2 measurements was >1 mm, the measurement was repeated. The averages of the 2 consecutively repeatable measurements were used for analysis.

For the CC reconstruction, the AC and CC ligaments were transected after all translation and rotation movements were locked. The SI translation plate was locked after a 5-N tension load was applied to the CC ligaments inferiorly, and the AP translation and rotation degree of freedom were locked in the neutral position. The CC interval distance was measured between the lateral aspect of the conoid tubercle and the upper border of the coracoid process after each reconstruction procedure using the MicroScribe. The CC interval distance was maintained consistently for each specimen to avoid overtightening during reconstruction experiments. In this study, 4 configurations of reconstruction were tested according to different numbers and locations of lateral clavicular holes. All reconstructions were conducted by single orthopedic surgeon (S-J.S.) using a commercially available cortical fixation button (Dog Bone; Arthrex, Naples, FL) and 2-mm-wide suture tape (Fiber Tape; Arthrex).

SB Reconstruction

SB reconstruction was conducted with 2 cortical fixation buttons and 1 suture tape. A 2.4-mm clavicular hole was created at the point perpendicular to the center of the coracoid base in the SI plane and the posterior one-third in the AP plane. A 4.0-mm central bone hole was created at the base of the coracoid, and 1 suture tape was passed through the coracoid and clavicle. Once the cortical fixation buttons were applied to the clavicle and coracoid base, the suture tape was tied over the clavicular cortical button (Fig 2A).

Double-Bundle Reconstruction

The double-bundle reconstruction used 3 cortical fixation buttons and 2 suture tapes. Two clavicular holes were used (lateral and medial clavicular holes), and based on the location of the lateral clavicular hole, 2 configurations of double-bundle reconstruction were performed (DBa and DBp). The coracoid hole and the medial clavicle hole created in the SB reconstruction were used for the medial limb reconstruction. In the DBa reconstruction, a lateral clavicular hole was created 2 cm lateral to the medial clavicular hole and in the anterior one-third in the AP plane (Fig 2B). In the DBp reconstruction, a lateral clavicular hole was located 1 cm lateral to the medial clavicular hole and in the posterior one-third in the AP plane (Fig 2C). All bone holes were made using a 2.4-mm cannulated drill bit. Two suture tapes were passed through the coracoid and 2 clavicular holes, respectively, and the suture tape on the lateral clavicular hole was tied first over one cortical button, and then the suture tape on the medial was tied over the other cortical button.

TB Reconstruction

The TB reconstruction used the same 3 clavicular holes and coracoid hole created during the other reconstructions and used 2 cortical buttons and 2 suture tapes. One suture tape was passed through the coracoid and medial clavicular hole. Two limbs of another suture tape were passed through the coracoid and 2 lateral clavicular holes, respectively. Two cortical fixation buttons were applied to the coracoid base and medial clavicular hole. The lateral suture tape was tied first over the clavicular bone without the cortical button and then the medial suture tape was tied over the cortical button (Fig 2D).

Statistical Analysis

A sample size calculation was performed based on the average and standard deviation from the first 3 specimens tested and our primary hypothesis that the double-bundle reconstruction with a posterolateral limb would result in less AP translation than a double-bundle reconstruction with an anterolateral limb. The differences between the 2 techniques were found to be 3.0 mm with a standard deviation of 2.5 mm, resulting in 8 specimens needing to be tested for a power of 0.8 and an alpha of 0.05. A descriptive evaluation was performed based on the mean and standard error. A 1-way repeated measures analysis of variance was used to compare the translational, rotational stability, and CC interval distance according to reconstruction configurations. Significance was set at $P < .05$. When a significant difference was detected, a Tukey post hoc test was used for pairwise multiple comparisons. All statistical analyses and tests were conducted using the SigmaPlot (Systat Software, Germany).

Results

Locations of Clavicular Holes and CC Interval Distance

Average distances from the lateral edge of the clavicle to the anterolateral clavicular hole, posterolateral

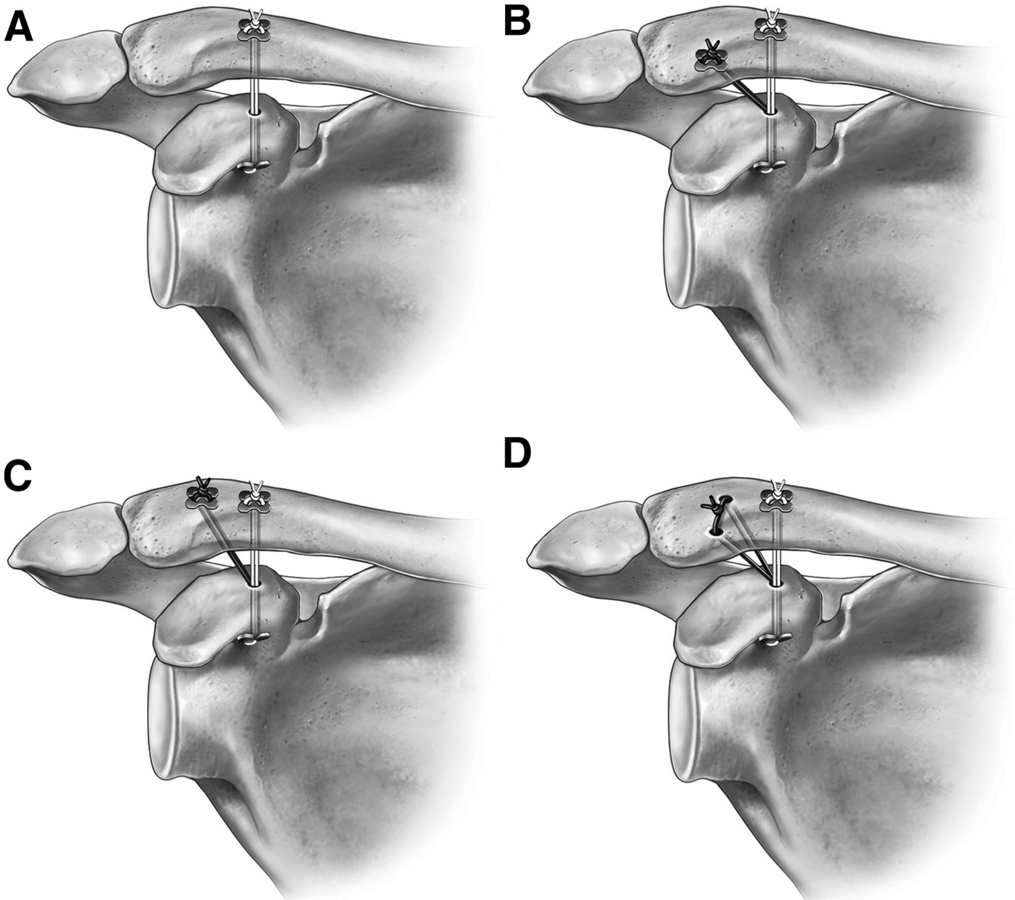

Fig 2. Four configurations of coracoclavicular ligament reconstruction. (A) Single-bundle reconstruction. (B) Double-bundle with an anterolateral limb reconstruction. (C) Double-bundle with a posterolateral limb reconstruction. (D) Triple-bundle reconstruction.

clavicular hole, and medial clavicular hole were 24.7 ± 2.8 mm, 32.0 ± 2.7 mm, and 45.2 ± 5.4 mm, respectively (Fig 3). None of the reconstruction configurations showed any significant differences of CC interval distance compared with intact (intact: 22.3 ± 1.7 mm, SB: 24.6 ± 1.9 mm, DBa: 23.7 ± 1.6 mm, DBp: 22.9 ± 1.5 mm, TB: 22.6 ± 1.6 mm, $P = .84$).

AP Translation

DBp reconstruction had a significant decrease in anterior translation compared with SB reconstruction at 10- and 15-N translational loads (SB: 3.9 ± 1.0 mm, DBp: 2.3 ± 0.6 mm, $P = .04$ at 10 N; SB: 5.2 ± 0.9 mm, DBp: 3.1 ± 0.7 mm, $P = .02$ at 15 N). DBp reconstruction also had a significant decrease in posterior translation compared with DBa and SB reconstructions (DBp: 1.8 ± 0.3 mm, SB: 3.9 ± 0.8 mm, $P = .02$; DBa: 3.9 ± 0.6 mm, $P = .02$ at 10 N; DBp: 2.4 ± 0.5 mm, SB: 4.9 ± 0.8 mm, $P = .002$; DBa: 5.4 ± 0.7 mm, $P < .001$ at 15 N). DBp reconstruction showed a significant improvement in total AP stability compared with SB and DBa reconstructions at both 10 and 15 N (DBp: 4.1 ± 0.6 mm, SB: 7.8 ± 1.1 mm, $P < .001$; DBa: 6.5 ±

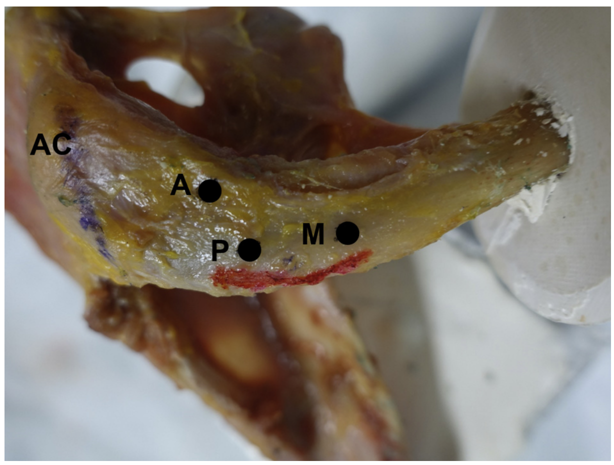

Fig 3. Locations of clavicular holes. A medial clavicular hole (M) was created at the point perpendicular to the center of coracoid base in the superoinferior plane and the posterior one-third in the AP plane. An anterolateral clavicular hole (A) was created 2 cm lateral to the medial clavicular hole and anterior one-third in the AP plane. A posterolateral clavicular hole (P) was located 1 cm lateral to the medial clavicular hole and posterior one-third in the AP plane. (AC, acromioclavicular joint; AP, anteroposterior.)

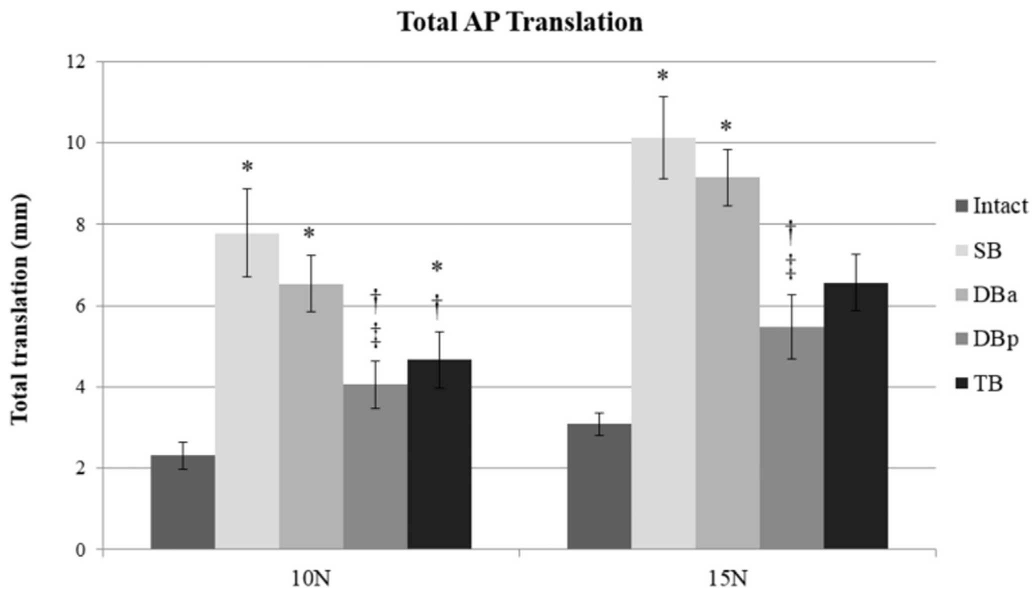

Fig 4. Total AP translations according to variable coracoclavicular ligament reconstruction configurations. *Significantly different in comparison to intact specimens (SB: $P < .001$, DBa: $P < .001$, TB: $P = .04$ at 10 N, SB: $P < .001$, DBa: $P = .001$ at 15 N). †Significantly different in comparison to SB reconstruction (DBp: $P < .001$, TB: $P = .003$ at 10 N, DBp: $P = .003$ at 15 N). ‡Significantly different in comparison to DBa reconstruction (DBp: $P = .02$ at 10 N, $P = .02$ at 15 N). (AP, anteroposterior; DBa, double bundle with an anterolateral limb; DBp, double bundle with a posterolateral limb; SB, single bundle; TB, triple bundle.)

0.7 mm, $P = .02$ at 10 N; DBp: 5.5 ± 0.8 mm, SB: 10.1 ± 1.0 mm, $P = .003$; DBa: 9.1 ± 0.7 mm, $P = .02$ at 15 N) (Fig 4). The mean values with 95% confidence intervals of total translational and rotational movements are summarized in Table 1.

SI Translation

SB reconstruction had greater superior translation than other reconstructions; however, there were no significant differences (SB: 2.5 ± 2.0 mm, DBa: 0.2 ± 0.1 mm, DBp: 0.6 ± 0.2 mm, TB: 0.2 ± 0.1 mm, $P = .20$ at 10 N; SB: 2.7 ± 2.1 mm, DBa: 0.4 ± 0.0 mm, DBp: 0.6 ± 0.2 mm, TB: 0.3 ± 0.1 mm, $P = .42$ at 15 N). All reconstructions had significantly greater total SI translation than intact specimens at 15 N; however, there were no significant differences between reconstruction groups (Fig 5).

Rotational Stability

All reconstructions had significantly greater anterior rotation than intact specimens at 0.32 Nm; however, there were no significant differences according to reconstruction configurations (intact: 4.7 ± 1.4°, SB: 16.0 ± 4.3°, $P = .002$; DBa: 15.9 ± 4.0°, $P = .002$; DBp: 14.1 ± 3.4°, $P = .01$; TB: 14.0 ± 4.0°, $P = .01$ at 0.32 Nm). SB reconstruction had the largest amount of posterior rotation compared with the other reconstructions at 0.32 Nm; however, there were no significant differences (SB: 27.1 ± 11.7°, DBa: 22.1 ± 7.7°, DBp: 19.8 ± 7.1°, TB: 18.2 ± 6.2°, $P = .45$ at 0.32 Nm). Total AP rotation showed a tendency to decrease according to increasing number of suture limbs at 0.16 and 0.32 Nm; however, there were no significant differences (SB: 43.1 ± 9.2°, DBa: 37.9 ± 7.3°, DBp: 33.9 ± 6.8°, TB: 32.2 ± 6.6°, $P = .37$ at 0.32 Nm) (Fig 6).

Table 1. Total AP, SI, and Rotational Stability of Each Experimental Condition

	AP Translation (mm)		SI Translation (mm)		Total Rotation (°)	
	10 N	15 N	10 N	15 N	0.16 Nm	0.32 Nm
Intact	2.3 ± 0.3 (1.5-3.1)	3.0 ± 0.3 (2.4-3.7)	1.2 ± 0.3 (0.6-1.8)	1.5 ± 0.3 (0.8-2.2)	5.4 ± 1.6 (1.8-9.1)	11.2 ± 2.1 (6.3-16.0)
SB	7.8 ± 1.1 (5.1-10.3)	10.1 ± 1.0 (7.7-12.5)	6.4 ± 2.4 (0.7-12.0)	10.4 ± 1.9 (5.9-14.9)	26.5 ± 8.3 (6.9-46.1)	43.1 ± 9.2 (21.3-64.8)
DBa	6.5 ± 0.7 (4.9-8.1)	9.1 ± 0.7 (7.4-10.7)	3.1 ± 1.3 (0-6.2)	7.1 ± 1.4 (3.8-10.4)	19.3 ± 3.5 (11.1-27.5)	37.9 ± 7.3 (20.7-55.2)
DBp	4.1 ± 0.6 (2.6-5.4)	5.5 ± 0.8 (3.6-7.3)	4.6 ± 1.4 (1.4-7.8)	7.1 ± 1.1 (4.5-9.6)	18.5 ± 5.0 (6.6-30.4)	33.9 ± 6.8 (17.7-50.0)
TB	4.6 ± 0.7 (3.0-6.3)	6.5 ± 0.7 (4.9-8.2)	3.2 ± 1.3 (0.1-6.3)	7.3 ± 1.2 (4.4-10.2)	17.1 ± 4.9 (5.4-28.8)	32.2 ± 6.6 (16.6-47.6)

NOTE. All values were described as mean ± standard error (lower and upper 95% confidence intervals).

AP, anteroposterior; DBa, double bundle with an anterolateral limb; DBp, double bundle with a posterolateral limb; SB, single bundle; SI, superoinferior; TB, triple bundle.

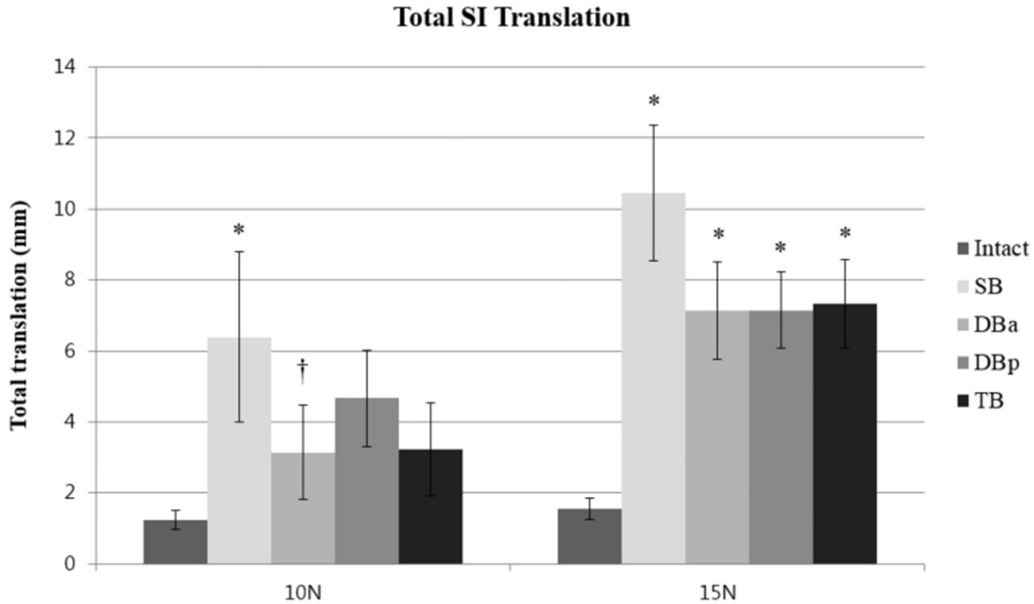

Fig 5. Total SI translations according to variable coracoclavicular ligament reconstruction configurations. *Significantly different in comparison to intact specimens (SB: $P = .04$ at 10 N, SB: $P < .001$, DBa: $P = .006$, DBp: $P = .006$, TB: $P = .005$ at 15N). †Significantly different in comparison to SB reconstruction (DBa: $P = .04$ at 10 N). (DBa, double bundle with an anterolateral limb; DBp, double bundle with a posterolateral limb; SB, single bundle; SI: superoinferior; TB, triple bundle.)

Discussion

The principal finding of this study was that CC reconstruction using an additional posterolateral clavicular hole resulted in greater AP stability compared with SB reconstruction or CC reconstruction using an additional anterolateral clavicular hole. Regarding

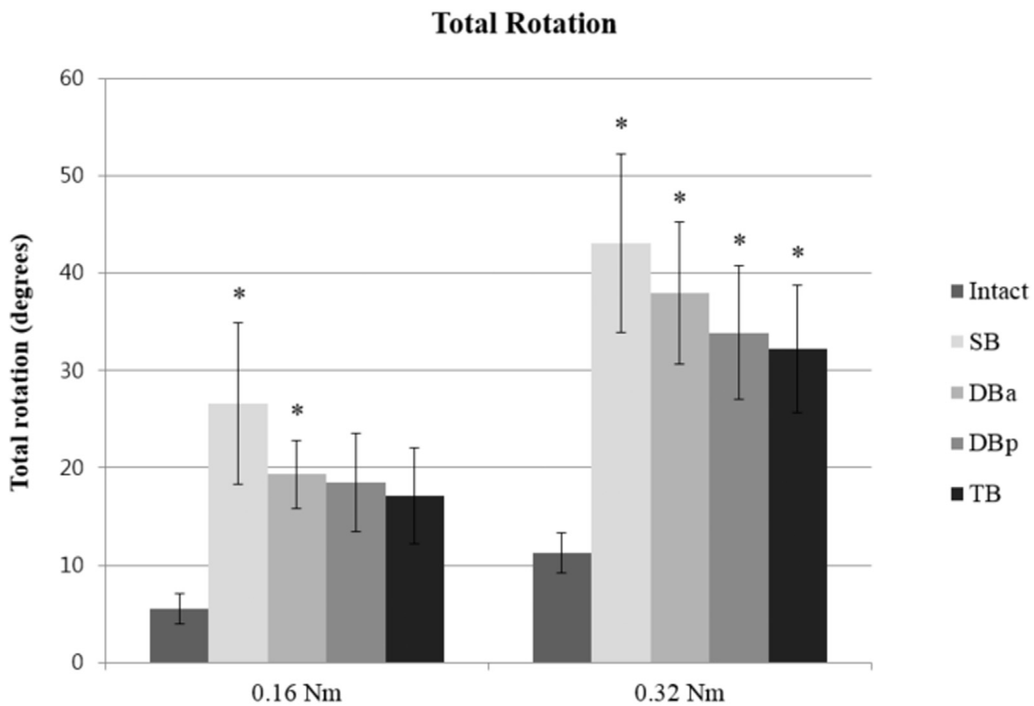

Fig 6. Total rotational stability according to variable coracoclavicular ligament reconstruction configurations. *Significantly different in comparison to intact specimens (SB: $P = .001$, DBa: $P = .04$ at 0.16 Nm, SB: $P < .001$, DBa: $P = .001$, DBp: $P = .006$, TB: $P = .01$ at 0.32 Nm). (DBa, double bundle with an anterolateral limb; DBp, double bundle with a posterolateral limb; SB, single bundle; TB, triple bundle.)

rotational stability, there was an increasing tendency with number of bundle increases; however, they did not reach statistical differences.

SB CC reconstruction using a cortical button fixation method for acute AC dislocations has been shown to have satisfactory biomechanical and clinical outcomes.[15-17] Beitzel et al.[15] reported satisfactory biomechanical characteristics of a single clavicular tunnel technique using an adjustable-loop-length suspensory fixation device for CC reconstruction compared with double clavicular tunnel or the intact AC joint. In the present study under the consistent maintenance of the CC interval as the level of native shoulder after each reconstruction to avoid overtightening, SB reconstruction showed significantly inferior AP stability compared with DBp reconstruction or the intact AC joint. Furthermore, some clinical studies reported variable complications, such as clavicular bone erosion and fixation failure during long-term follow up, after SB CC reconstruction using a cortical button fixation method.[8,9,18] These unsatisfactory clinical outcomes could have numerous causes, including technical errors or inappropriate fixation. In the cadaveric condition, however, the nonanatomic 1-plane fixation of an SB reconstruction could be 1 of the most important reasons to make differences in the stability when compared with double-bundle fixation. The native CC ligament has 2 different bundles that provide resistance in 2 different planes. SB reconstruction only provides resistance in 1 plane, which leads to AP translational or rotational instability. Moreover, in the SB reconstruction, focal stress concentration on the single clavicular button could lead to clavicular bone erosion or fixation failure; postoperative complications related to button fixation on the clavicular side have been reported in up to 27.8% of patients.[3,8] In a previous clinical study evaluating shoulder functional outcomes after double-bundle CC reconstruction using 3 cortical fixation buttons with suture tapes, satisfactory clinical and radiological outcomes without increase of >5 mm in horizontal displacement have been reported.[3] That report did not compare outcomes with those of SB reconstruction or double-bundle reconstruction with other locations of the lateral clavicular hole, however.

The location of the clavicular holes for double-bundle CC reconstruction is important to restore normal AC joint stability, especially in the AP plane.[6,10,15,19] Many previous studies have attempted to make clavicular holes at anatomic locations during double-bundle CC reconstruction[4,10,11]; however, the CC ligaments are inserted broadly under the clavicle, and it is unclear which point is the optimal location of the clavicular hole within a broad footprint of the CC ligament. In a 3-dimensional mapping study, Chahla et al.[20] demonstrated that the clavicular footprint of the CC ligament spans up to a length of 2.56 cm in the mediolateral dimension. Only a few previous biomechanical studies have evaluated AP stability of anatomic double-bundle CC reconstruction using a cortical button fixation method. Walz et al.[6] reported that anatomic double-bundle CC reconstruction using 2 adjustable-loop-length suspensory fixation devices showed comparable AP and SI stability with the native CC ligaments; however, their study used a transected AC ligament as the control group, despite the AC ligament having the important role of AP restraint of the distal clavicle.[21] In our study, an additional posterolateral clavicular hole in DBp reconstruction provided better AP stability compared with SB reconstruction, whereas use of an additional anterolateral clavicular hole did not. One possible explanation is that the clavicle is naturally located posterior to the coracoid process.[12] An imaginary line connecting the base of coracoid process and the center of the medullary canal of the distal clavicle shows a sloping line in the sagittal plane; therefore, the line would pass the posterosuperior cortex of the distal clavicle. To make reduction vector parallel to this imaginary line, the clavicular hole should be located at the posterior portion of the distal clavicle.

The clavicle allows not only AP and SI translational movement but also anterior and posterior rotational movement against the acromion. There is 15° to 20° of posterior rotation of the clavicle along its long axis during shoulder abduction, resulting in a much more complex movement at the AC joint.[22,23] In patients with AC dislocation, rotational movement of the clavicle significantly increases even after surgical reconstruction, which might lead to surgical failure from abrasive wear by sutures during repetitive rotation.[14,24] Therefore, it is important to know which reconstruction methods could supply satisfactory stability of the AC joint regarding both translational and rotational aspects. In the present study, there was an increased tendency toward rotational stability by increasing the planes of clavicular fixation; however, they did not reach statistical differences. During double-bundle reconstruction, a method using 2 coracoid holes was expected to show more stability than 1 coracoid hole because of more divergent planes between different bundles.[25] In the present study, however, only a single coracoid hole was created during double-bundle and TB reconstruction, because making ≥2 holes in the coracoid process is technically challenging with a greater possibility of coracoid fracture.

Limitations

There are some limitations in the present study. First, the lateral clavicular hole locations were kept a constant distance from the medial clavicular hole, not by ratio of the total clavicle length. The relation between lateral and medial clavicular holes would be somewhat different between clavicles with different lengths. In this study, however, distances from the lateral clavicular edge to each clavicular hole were similar to those of previous anatomic studies. According to previous studies, the trapezoid insertion point is represented as 17% of the total clavicle length, approximately 2.5 cm medial from the lateral clavicular edge, and the conoid insertion point is positioned as 30% of the total clavicle length, approximately 4.5 cm medial from the lateral clavicular edge.[10,26] Second, there may be some measurement errors in rotational testing because of challenges defining the long axis of the clavicle. In addition, during rotational movement, the distal clavicle was sometimes translated as well as rotated, especially in the SB reconstruction model, because it was highly unstable without the AC ligaments. To reduce unexpected translation, inferior directed 5-N tension was placed on the scapula during rotational testing. Third, all muscles and ligaments except the AC and CC ligaments were dissected for this biomechanical study, although the periclavicular muscles contribute to stability of the distal clavicle. This cadaveric biomechanical study does not completely reflect normal clinical situations, only the time zero stability of the reconstruction itself. Furthermore, this study compared variable clavicular holes using only suture tapes. In cases of graft reconstruction, results could be different from those of our study. Fourth, we did not use cortical fixation buttons on lateral clavicular holes during TB reconstruction, which could be some biomechanical differences according to use of cortical fixation buttons. We tried to demonstrate biomechanical characters when both lateral clavicular holes were used simultaneously in CC reconstruction, but it was impossible to use 2 cortical fixation buttons on different lateral clavicular bone holes because of their close locations. Last, the sample size of cadaveric shoulder was relatively small. The results of small number of cadavers may not be truly representative, and the true clinical implications of the outcomes are doubtful. Further study with a large sample size is needed to document more representative outcomes.

Conclusions

An additional posterolateral clavicular hole for CC ligament reconstruction using cortical fixation buttons with suture tapes resulted in better AP stability compared with SB reconstruction, whereas use of an additional anterolateral clavicular hole did not show any improvement compared with SB reconstruction. Reconstruction using both anterolateral and posterolateral clavicular holes did not guarantee better stability compared with SB reconstruction. There was an increasing tendency of rotational stability with increases in the number of bundles, although they did not reach statistical differences.

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