Semitendinosus vs Gracilis Grafts With 1- vs 2-Tunnel Techniques for Coracoclavicular Ligament Reconstruction

A Biomechanical Study

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Background: Despite the evolution of acromioclavicular joint surgery to a more anatomic coracoclavicular (CC) ligament reconstruction, no definitive guidance regarding the number and position of bone tunnels in the clavicle, as well as the ideal graft choice, is established.

Purpose/Hypothesis: The purpose of this study was to biomechanically compare the reconstruction of the CC ligament complex between gracilis- and semitendinosus-tendon grafts in 1- and 2-tunnel techniques. It was hypothesized that the gracilis tendon graft will provide comparable primary stability in both tunnel techniques while utilizing a smaller tunnel diameter.

Study Design: Controlled laboratory study.

Methods: A total of 24 cadaveric shoulders (13 men, 11 women; 66 $\pm$ 7.5 years) were randomly allocated to 4 repair groups: gracilis with 1 tunnel (GT-1), gracilis with 2 tunnels (GT-2), semitendinosus with 1 tunnel (ST-1), and semitendinosus with 2 tunnels (ST-2). First, specimens were tested for native anterior, posterior, and superior translations. Then, specimens were randomly assigned to 1 of the 4 CC reconstruction groups before undergoing the same testing, followed by cyclic loading and load to failure (LTF).

Results: The GT-2 reconstruction demonstrated significantly less translation when compared with ST-2 in anterior (P = .024) and posterior (P = .048) directions. GT-1 and ST-2 both showed significantly less translation than ST-1 in anterior and superior directions ($P < .001$). All reconstructions demonstrated less superior translation compared with native testing, with GT-1 and ST-2 significantly less than ST-1 ($P < .001$). There were no significant differences for peak displacement and LTF between groups.

Conclusion: Gracilis tendon grafts using a 1- or 2-tunnel technique for CC ligament reconstruction provided comparable translation, displacement, and LTF as corresponding semitendinosus grafts. Therefore, the gracilis tendon should be considered as a biomechanical equivalent graft choice for the reconstruction of the CC ligament complex.

Clinical Relevance: In a cadaveric model, the gracilis tendon demonstrated adequate fixation with minimal translation in CC ligament reconstruction while utilizing smaller diameter bone tunnels, which may help minimize the risk of complications such as loss of reduction and fracture.

Keywords: acromioclavicular separation; anatomic tunnels; coracoclavicular reconstruction; gracilis graft

Acromioclavicular (AC) joint separation accounts for a large number of traumatic shoulder injuries. These injuries are more common in men and in contact and collision athletes. For low-grade injuries, classified by Rockwood[19] as type I or II, nonoperative management is typically the treatment of choice; however, high-grade AC separations (type IV, V, and VI) and chronic symptomatic injuries often require surgery.[1,18,20] Type III injury treatment remains controversial and has been a subject of debate regarding nonoperative or operative treatment for more than 50 years.[9,21]

From the first report of AC separation surgery in 1861 by Cooper[6] to one of the most well-known techniques today described by Weaver and Dunn[25] in 1972, an array of procedures have emerged using wires, screws, hardware, and soft tissue grafts to reduce and hold the AC joint in place.[3,6,25] Many failures occurred because of loss of

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reduction, as it was thought that the coracoacromial ligament was not strong enough to mimic the coracoclavicular (CC) ligament complex.[12] Therefore, more recent studies have focused on the reconstruction of the CC ligaments themselves using tendon grafts. Lee et al[13] expanded on the Modified Weaver-Dunn procedure by comparing different types of graft options to reconstruct the CC ligaments compared with the native CC ligament and found no differences between the semitendinosus, gracilis, and extensor hallucis longus tendons with a 1-tunnel reconstruction technique. Many studies have investigated a variety of other techniques and grafts, most commonly using a semitendinosus graft.[2,10,23] Yoo et al[26] demonstrated good results with single-tunnel reconstruction using a semitendinosus graft. However, a study by Choi et al[5] showed that a large percentage of patients experienced a loss of reduction (47%) using a single-tunnel technique. Mazzocca et al[15] evaluated an anatomic reconstruction with 2 tunnels in a biomechanical study and reported that this construct provided more stability to the AC joint. This technique was further supported by Hou et al[11] who also compared 1-tunnel versus 2-tunnel reconstruction in 23 patients and found that 2-tunnel reconstruction provided satisfying radiographic and clinical results. A common concern of drilling tunnels is the potential postoperative complication of a clavicular fracture.[17] Several studies have focused on tunnel location, diameter, and fixation methods in an attempt to minimize this complication.[8,22] Despite an abundance of literature on different surgical techniques, controversy still exists on the best method to provide adequate fixation with minimal complications. To our knowledge, no study has focused on comparing 2 common hamstring tendon graft options—gracilis and semitendinosus—with both the 1-tunnel and the 2-tunnel techniques.

The purpose of this study was to biomechanically compare the reconstruction of the CC ligament complex between gracilis- and semitendinosus-tendon grafts in 1- and 2-tunnel techniques. Since the gracilis tendon has a smaller diameter than the semitendinosus, the tunnel sizes are smaller, which may minimize the risk of clavicular fracture. We hypothesized that even though the semitendinosus is a more widely used graft, a gracilis tendon will provide a similar reduction without significant translation in both tunnel models while utilizing a smaller tunnel diameter.

METHODS

A total of 24 (8 paired, 16 unpaired) fresh-frozen cadaveric shoulders (MedCure Inc) were allocated into 4 groups. The groups consisted of the following graft and tunnel combination: (1) gracilis tendon with 1 tunnel (GT-1); (2) gracilis tendon with 2 tunnels (GT-2); (3) semitendinosus with 1 tunnel (ST-1); and (4) semitendinosus with 2 tunnels (ST-2). The specimens were randomly assigned to a testing sequence, starting with either the anterior-posterior or superior-inferior direction, then subcategorized into the order of direction (Figure 1). All specimens underwent a complete bone mineral density analysis before any biomechanical testing (Lunar EXPERT-XL image densitometer; GE Healthcare).

Specimen preparation and biomechanical testing were executed in the same manner as previously published protocols using a servohydraulic materials testing system (MTS Systems Corp).[15] Each shoulder specimen underwent testing of the native ligaments.

First, the specimens were preconditioned with 10 cycles of 25 N in anterior, posterior, and superior directions to eliminate creep, and then tested in all directions according to the preassigned sequence with 70 N of force. Net displacement values were recorded in anterior, posterior, and superior directions. Next, conoid and trapezoid ligaments of the CC complex were marked at their attachments on the clavicle and measured. The AC and CC ligaments were transected, and the assigned reconstructions were performed on each specimen. A 3.5-mm drill was used to create the tunnel(s) for a gracilis tendon graft while a 5-mm drill was used to make the tunnel(s) for a semitendinosus graft. These drill sizes were chosen because they represented the smallest diameter hole that the respective grafts reliably fit through.

For every specimen, the native ligament attachments were used as a guide for tunnel placement rather than a standard distance due to the variability in the anatomy. If the specimen was assigned to receive 1 tunnel, then the tunnel was drilled halfway between the previously marked attachment points of the 2 CC ligaments. If the specimen was assigned 2 tunnels, then each anatomic mark was drilled. For a single-tunnel reconstruction, the selected graft and a suture tape (FiberTape; Arthrex) were passed

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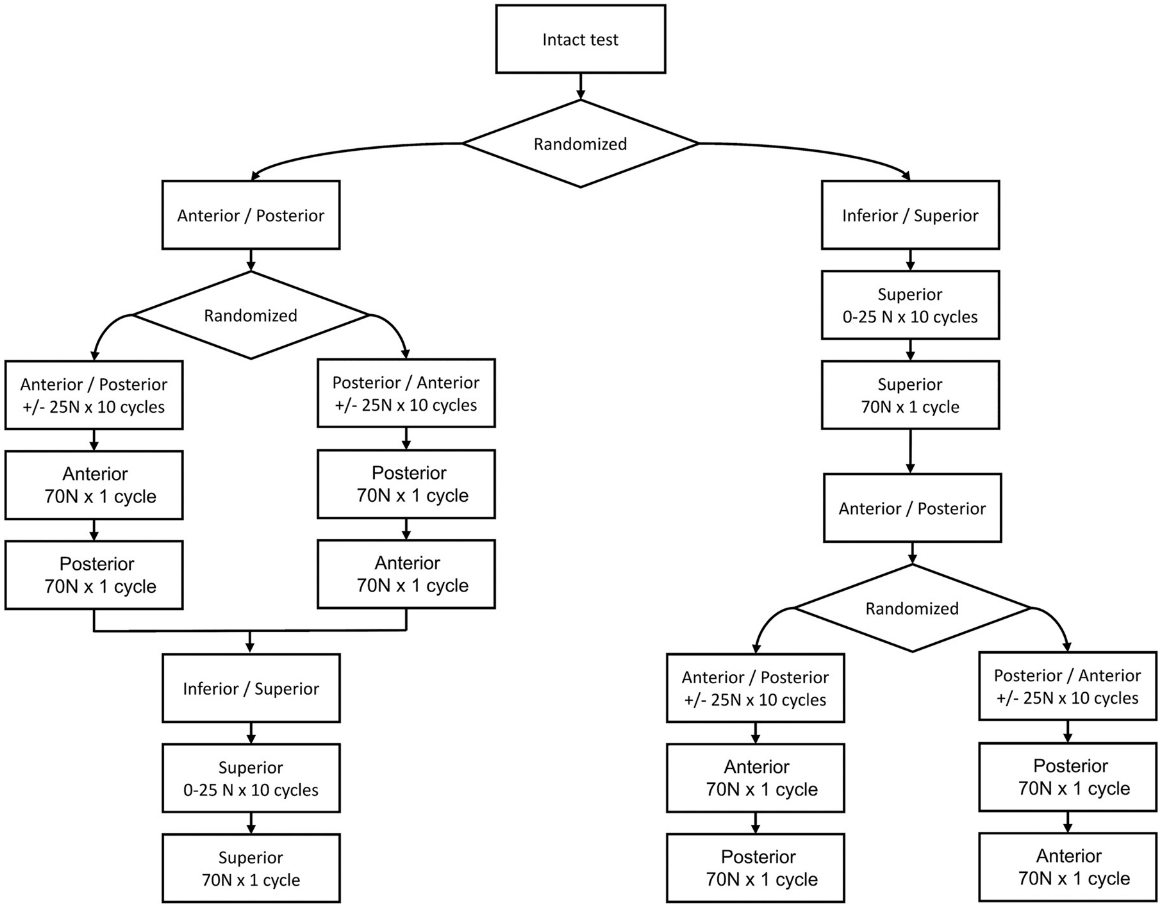

Figure 1. Testing sequence adapted from Mazzocca et al.[15]

through the tunnel together from superior to inferior, wrapped around the coracoid, then posterior to the clavicle before being tied over the top of the clavicle and reinforced with high-strength suture (No. 2 FiberWire; Arthrex) through the graft and a 3 × 8–mm (gracilis) or 5.5 × 8–mm (semitendinosus) tenodesis polyetheretherketone (PEEK) interference screw (Arthrex) into the tunnel (Figure 2).

For a 2-tunnel reconstruction, the selected graft and suture tape were passed through either tunnel from superior to inferior, wrapped around the coracoid toward the other tunnel, then passed up through the second tunnel, and tied over the top of the clavicle with the high-strength suture reinforcement through the graft and a 3.5 × 8–mm (gracilis) or 5.5 × 8–mm (semitendinosus) tenodesis PEEK interference screw into each tunnel (Figure 3).

After reconstruction, the specimens were returned to the materials testing machine in the previously marked position and again conditioned for 10 cycles at 25 N in all directions to eliminate creep of the graft and suture material. The same protocol was repeated in the assigned order while recording displacement values. At the end of the matched testing, each specimen underwent 3000 cycles of 70 N in the superior-inferior direction at a rate of 1 Hz while displacement was recorded. Finally, a load to failure (LTF) tensile test at 120 mm/min was completed in the superior direction, and this was recorded along with the mode of failure.

Statistical Analysis

Descriptive statistics, including mean and standard deviation, were calculated to characterize the study groups. A mixed-effects linear regression model was used to examine differences in the change in translation from the native and reconstructed specimens, peak translation during cyclic loading, LTF, and failure mode among the 4 study groups. This approach accounts for the dependency introduced with the inclusion of the right and left shoulder from the same donor. Results are presented as mean differences with corresponding 95% CIs. To account for multiple comparisons, P values were adjusted using the Holm-Bonferroni method. All statistical analyses were conducted with Stata 15 software (StataCorp). Statistical significance was set at .05.

RESULTS

A total of 24 cadaveric specimens were included in this study (13 men and 11 women; mean age, 66 years [±7.5;

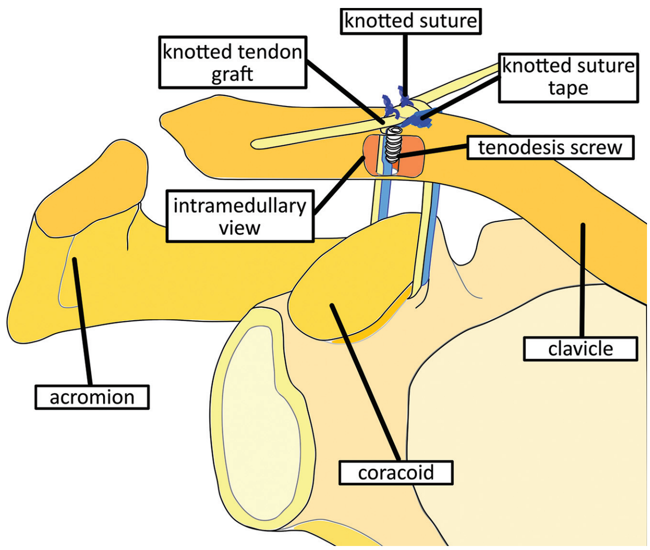

Figure 2. One-tunnel configuration (intramedullary view only for illustration).

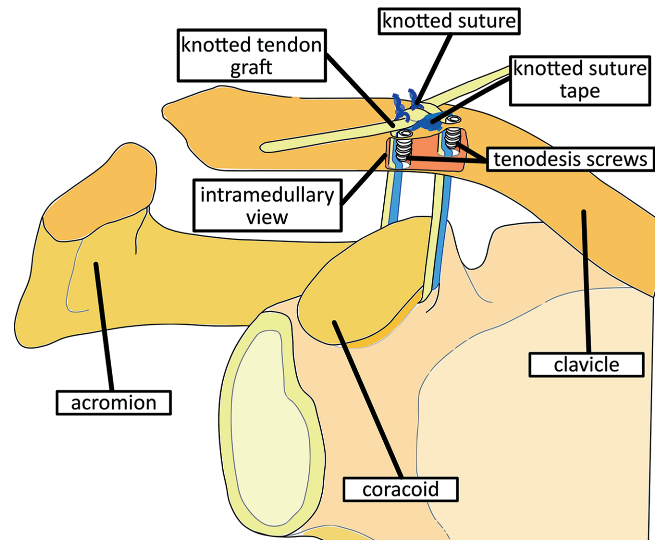

Figure 3. Two-tunnel configuration (intramedullary view only for illustration).

TABLE 1
Comparison of Anterior Translation Between Groups[a]

	Anterior Translation at 70 N			
Comparison	Difference, mm	95% CI		*P*
GT-1 vs ST-1	−3.96	−4.03	−3.90	**<.001**
GT-1 vs GT-2	1.14	−1.21	3.49	.343
GT-1 vs ST-2	−1.88	−1.92	−1.84	**<.001**
ST-1 vs GT-2	5.10	2.75	7.46	**<.001**
ST-1 vs ST-2	2.08	2.02	2.14	**<.001**
ST-2 vs GT-2	−3.02	−5.38	−0.67	**.024**

[a]Bold values indicate significance GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

TABLE 2
Comparison of Posterior Translation Between Groups[a]

	Posterior Translation at 70 N			
Comparison	Difference, mm	95% CI		*P*
GT-1 vs ST-1	−0.63	−5.04	3.78	>.999
GT-1 vs GT-2	3.93	−0.49	8.34	.243
GT-1 vs ST-2	−2.03	−6.32	2.26	>.999
ST-1 vs GT-2	4.56	0.14	8.97	.215
ST-1 vs ST-2	−1.40	−5.75	2.95	>.999
ST-2 vs GT-2	−5.96	−10.37	−1.55	**.048**

[a]The bold value indicates significance GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

range, 52-75 years]). There was no significant difference in bone mineral density between groups. There were no significant differences among cadaveric data, including side, sex, or age between the 4 groups. All surgical reconstructions demonstrated increased anterior translation compared with the native ligaments, but GT-2 was the closest to the native shoulder, with a mean difference of only 0.29 mm (Figure 4). Each group demonstrated less superior translation compared with the native specimens (Figure 4). The differences in the translation in the native state to each corresponding repair were used to compare the gracilis and semitendinosus 1- and 2- tunnel techniques in anterior, posterior, and superior directions. The GT-1 reconstruction showed significantly less translation in both anterior ($P < .001$) and superior ($P < .001$) directions compared with the ST-1 technique. A significantly ($P < .001$) lower anterior translation was also observed when comparing GT-1 to ST-2. The GT-2 group demonstrated significantly less anterior ($P = .024$) and posterior ($P = .048$) translation compared with the ST-2 group as well as significantly ($P < .001$) less anterior translation when compared with ST-1. When comparing both ST groups, significantly ($P < .001$) less anterior and superior translation was found for ST-2 (Tables 1-3).

There were no statistically significant differences in peak displacement (GT-1, .31 ± .36 mm; GT-2, .74 ± .91 mm; ST-1, .56 ± .34 mm; ST-2, 1.17 ± 2.02 mm; Table 4, Figure 5) during superior-inferior cyclic loading or LTF (GT-1, 558.77 ± 297.69 N; GT-2, 492.33 ± 230.10 N; ST-1, 508.24 ± 78.93 N; ST-2, 675.36 ± 123.36 N; (Table 5, Figure 6) between all 4 groups.

Clavicular fractures occurred in 13 of 24 specimens (54%) during LTF testing with no significant difference between groups ($P = .999$). Other modes of failure were coracoid fracture in 6 specimens, graft slippage in 4 specimens, and a scapular body fracture in 1 specimen. These failures occurred across all groups with no obvious trend.

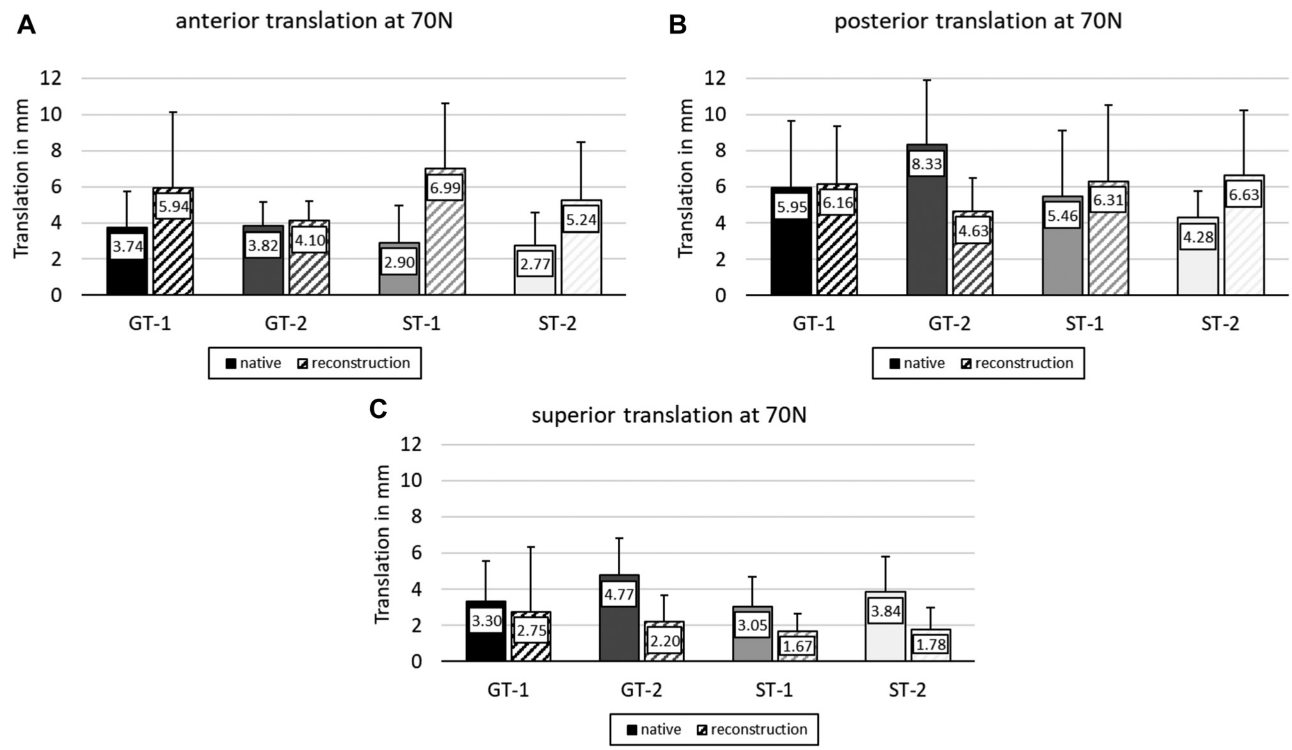

Figure 4. Translation of the native CC ligament (left column of the column pair) and the reconstructed CC complex (right column of the column pair) in (A) anterior, (B) posterior, and (C) superior directions for each group. CC, coracoclavicular; GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

TABLE 3
Comparison of Superior Translation Between Groups[a]

	Superior Translation at 70 N			
Comparison	Difference, mm	95% CI		*P*
GT-1 vs ST-1	−2.96	−3.38	−2.53	**<.001**
GT-1 vs GT-2	0.11	−2.88	3.09	>.999
GT-1 vs ST-2	−0.01	−0.25	0.24	.939
ST-1 vs GT-2	3.06	0.08	6.05	.176
ST-1 vs ST-2	2.95	2.60	3.29	**<.001**
ST-2 vs GT-2	−0.12	−3.10	2.86	>.999

[a]Bold values indicate significance GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

TABLE 4
Comparison of Peak Displacement Under Cyclic Loading[a]

	Peak Displacement After 3000 Cycles			
Comparison	Difference, mm	95% CI		*P*
GT-1 vs ST-1	0.28	−0.90	1.45	.645
GT-1 vs GT-2	0.45	−0.72	1.62	.449
GT-1 vs ST-2	0.88	−0.28	2.05	.137
ST-1 vs GT-2	0.18	−0.99	1.34	.766
ST-1 vs ST-2	0.61	−0.56	1.77	.308
ST-2 vs GT-2	0.43	−0.74	1.60	.472

[a]GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

DISCUSSION

The most important finding was that gracilis tendon grafts, using either a 1- or 2-tunnel technique for CC ligament reconstruction, resulted in comparable translation, displacement, and LTF as corresponding semitendinosus tendon grafts. It was also observed that the gracilis graft demonstrated less translation in certain directions compared with the semitendinosus graft.

The smaller size of the gracilis tendon compared with traditionally used semitendinosus makes it an attractive option for CC ligament reconstruction by allowing for the use of smaller bone tunnels. Our technique consisted of one or two 3.5-mm tunnels, which are 30% smaller than our tunnel diameter for semitendinosus (5 mm). Dumont et al[7] published a study examining the effect of tunnels as well as tenodesis screws used for CC ligament reconstruction. Their study used sawbones and demonstrated that tunnels drilled into the clavicle reduced the amount of force it took to fracture. They found no difference in the use of tenodesis screws; however, using sawbones does not necessarily correlate with the strength of actual

TABLE 5
Comparison of LTF Between Groups[a]

Comparison	LTF at 120 mm/min			
	Difference (N)	95% CI		P
GT-1 vs ST-1	57.18	−264.45	150.08	.589
GT-1 vs GT-2	61.47	−269.09	146.16	.562
GT-1 vs ST-2	95.80	−105.63	297.23	.351
ST-1 vs GT-2	4.28	−208.89	200.33	.967
ST-1 vs ST-2	152.98	−51.32	357.29	.142
ST-2 vs GT-2	157.26	−50.08	364.61	.137

[a]GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; LTF, load to failure; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

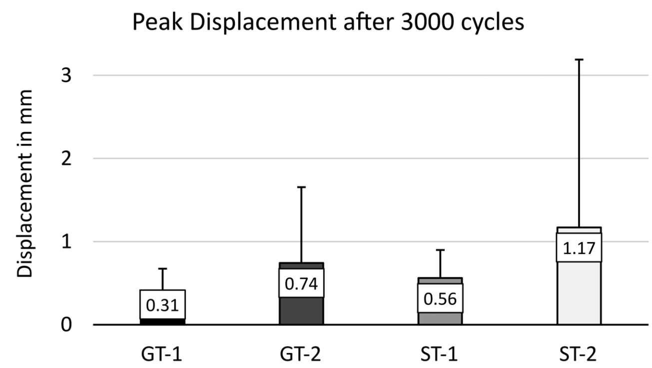

Figure 5. Peak displacement (mm) under cyclic loading after 3000 cycles per group. GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

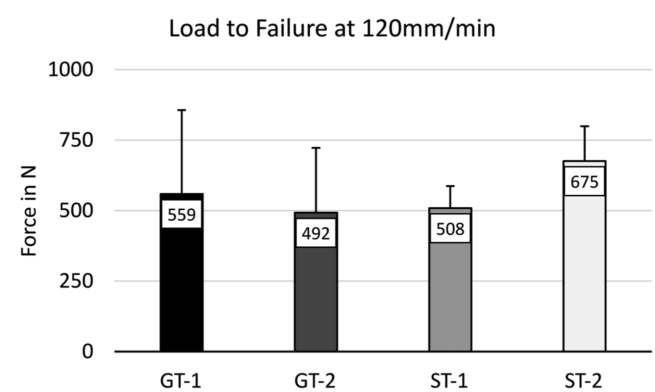

Figure 6. Load to failure (N) at 120 mm/min per group. GT-1, gracilis with 1 tunnel; GT-2, gracilis with 2 tunnels; ST-1, semitendinosus with 1 tunnel; ST-2, semitendinosus with 2 tunnels.

bone. The study by Spiegl et al[22] used cadaveric specimens during their biomechanical study of clavicular fractures after CC ligament reconstruction. They performed anatomic, 2-tunnel fixation with a cortical button using 2.4-mm tunnels versus a semitendinosus graft using 6-mm tunnels. They found that the smaller tunnels did not significantly decrease clavicular strength compared with the native specimen. However, the larger tunnels did significantly decrease the clavicular strength. According to their study, when the width of the clavicle was <17.4 mm, it was weakened by approximately 30%.

In 2006, Mazzocca et al[15] described the anatomic reconstruction of the conoid and trapezoid ligaments in a biomechanical study. Although anatomic reconstruction has shown superior results compared with traditional surgical techniques (eg, Weaver-Dunn),[15] one of the feared complications of an anatomic technique is the risk of clavicular fracture, especially in contact athletes. Reports in the literature have not fully quantified the incidence of fracture, as it is likely underreported. Turman et al[24] reported a case series of clavicular fractures after CC reconstruction with 6-mm tunnels. Another study reported clavicular fractures in 18% of patients undergoing an anatomic CC ligament reconstruction,[16] while another reported fractures in 2 of 46 patients.[14] Recommendations for preventing a clavicular fracture in a 2-tunnel technique include spacing bone tunnels 20 to 25 mm apart and not placing lateral tunnels closer than 10 to 15 mm from the lateral edge of the clavicle.[4] Since a clavicular fracture is a serious concern after CC ligament reconstruction, we explored the use of a smaller graft—the gracilis tendon—to provide an adequate reduction while using smaller bone tunnels in both 1- and 2-tunnel techniques.

There have been many studies discussing the advantages and disadvantages of 1- versus 2-tunnel reconstruction. One tunnel may be technically easier, especially in a small clavicle, and theoretically, there is less risk of fracture. However, anatomic reconstruction of the CC ligament complex has been shown to have fewer failures of reduction both biomechanically and clinically.[10,13] Since the number of tunnels to use is still controversial, both 1- and 2-tunnel techniques were utilized. In our study, gracilis tendon 1-tunnel reconstruction demonstrated less translation in anterior and superior directions, while gracilis tendon in the 2-tunnel configuration demonstrated less translation in anterior and posterior directions compared with 1- and 2-tunnel semitendinosus reconstructions, respectively. Therefore, regardless of the number of tunnels utilized for CC ligament reconstruction, our study showed that a gracilis tendon is a promising option for fixation without loss of reduction. One possible reason for increased stability with the gracilis tendon reconstruction may have been the fixation technique. Since the grafts were tied over the top of the clavicle, a smaller graft may have allowed for a tighter knot, preserving tension across the construct. Another explanation may be less micromotion within the smaller tunnels. Last, it may be technically easier to tension a 1-limb construct. Further biomechanical testing is needed to fully understand this phenomenon.

There are several limitations to our study. As with all biomechanical studies, these results represent a time-zero stability without any interval healing that would occur in an in vivo reconstruction. The mean cadaveric age of 66 years is considerably older than the typical patient population who sustain AC joint injuries. The forces created by the materials testing machine approximate the mechanical stress of daily living and have been used in other studies, but this does not simulate the increased stresses from more rigorous activities such as sports. Also, the specimens were removed from the materials testing machine between the native and graft testing to perform the reconstruction. Our gracilis tendon reconstruction appeared to have less translation than the semitendinosus tendon reconstruction, which would not be expected given the difference in graft size. However, we believe that the smaller tendon was easier to maneuver through the tunnels and tie over the top of the clavicle, resulting in a stronger fixation method. Last, the failures noted during testing—including coracoid fracture, graft slippage, and scapular body fracture—occurred across all groups without an obvious trend.

Future studies could use a similar biomechanical technique to test a gracilis tendon graft through small diameter tunnels accompanied by AC reconstruction. Clinical use of a gracilis tendon graft for the treatment of high-grade AC joint injuries is necessary to determine patient outcomes and the possible decreased risk of clavicular fracture.

CONCLUSION

Gracilis tendon grafts used with either a 1- or 2-tunnel technique for CC ligament reconstruction resulted in comparable translation, displacement, and LTF as corresponding semitendinosus tendon grafts in a cadaveric model. Therefore, the gracilis tendon should be considered as a biomechanical equivalent graft choice for the reconstruction of the CC ligament complex.

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