Effect of Quadriceps Tendon Autograft Preparation and Fixation on Graft Laxity During Suspensory Anterior Cruciate Ligament Reconstruction

A Biomechanical Analysis

Asheesh Bedi,* MD, Benjamin L. Smith,† MS, Justin J. Mitchell,‡ MD, Rachel M. Frank,§ MD, Oliver L. Hauck,† MS, and Coen A. Wijdicks,†‖ PhD, MBA
Investigation performed at Arthrex Inc, Naples, Florida, USA

Background: Favorable collagen fibril density and thickness combined with advances in graft preparation and fixation have significantly increased interest in the quadriceps tendon (QT) autograft for anterior cruciate ligament (ACL) reconstruction. While various suspensory techniques have been described, the biomechanical profile of these constructs is largely undefined.

Purpose: To compare the biomechanics of suspensory techniques for soft tissue QT autograft fixation in an in vitro model of ACL reconstruction.

Study Design: Controlled laboratory study.

Methods: Full-thickness QT grafts were harvested using a 9-mm graft blade. Adjustable-loop devices (ALDs) were secured to the graft (n = 6 per group) with a combination implant containing the ALD and suture tape-reinforced whipstitching (tape-reinforced [TR] group), tethered superficially to the graft with a whipstitch (onlay [OL] group), luggage-tagged through and around the graft (luggage tag [LT] group), or staggered behind superficial suturing (staggered [SG] group). Grafts were tested on an electromechanical testing machine following a validated in vitro reconstruction model of intraoperative workflow and postoperative ACL kinematics, cyclic loading, and load to failure.

Results: The TR group had significantly less postcyclic tension loss (mean, 24%) compared with the OL (56%; $P = .002$), LT (69%; $P < .001$), and SG (90%; $P < .001$) constructs. Cyclic elongation was below the 3.0-mm threshold defined as clinical failure for TR (1.6 mm), but not for OL (3.3 mm), LT (7.9 mm), and SG (11.3 mm). All constructs were within native ACL stiffness limits (220 ± 72 N/mm) without significant differences. Ultimate loads significantly exceeded a normal ACL loading limit of 454 N for TR (739 N; $P = .023$), OL (547 N; $P = .020$), and LT (769 N; $P = .001$), but not for SG (346 N; $P = .236$).

Conclusion: The TR ALD construct demonstrated the most favorable time-zero biomechanical properties of modern soft tissue QT suspensory constructs, with 32% less tension loss and 52% less cyclic elongation versus the closest construct. Failure loading of all constructs was acceptable with respect to the native ACL except for the SG group, which had suboptimal ultimate load.

Clinical Relevance: TR ALD implants may protect soft tissue QT autografts before graft-bone healing in ACL reconstruction by minimizing time-zero laxity and fixation failure.

Keywords: quadriceps tendon; soft tissue autograft; tape reinforcement; suspensory fixation; anterior cruciate ligament

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The lower failure rates of autograft compared with allograft for young and active patients undergoing anterior cruciate ligament (ACL) reconstruction have been well-documented in the literature.[9,11,45] While bone–patellar tendon–bone (BTB) and hamstring tendon autografts

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have been the most commonly utilized and reported upon, technical advancements in graft preparation and fixation have significantly increased interest in the use of the quadriceps tendon (QT) autograft. A recent systematic review by Heffron et al[15] reported that >60% of the publications (115 of 187) focusing on QT for ACL reconstruction were published within the past 10 years, and 30% (56 of 187) were published within the past 3 years. Multiple authors have demonstrated greater thickness, greater collagen fibril density, and higher load to failure, with a stiffness more closely resembling the native ACL, for QT compared with patellar tendon grafts.[36,40] Low complication rates and similar or superior functional and patient-reported outcomes compared with BTB and hamstring tendon autografts are also documented in clinical studies of ACL reconstruction with QT autografts.[16,18,41]

Grafts are often prepared on 1 or both sides utilizing suspensory fixation when bone-QT or all–soft tissue QT (ASTQT) autograft is chosen for ACL reconstruction. Early cadaveric biomechanical studies of different soft tissue QT suspensory fixation strategies have shown premature failures during cyclic loading, substantial cyclic elongation, and suboptimal failure loads (<454 N).[4,20,32,35] A recent biomechanical study by Lamplot et al[25] found promising biomechanical improvements when using a novel, adjustable-loop cortical button implant with tape-reinforced suturing. Other suspensory techniques exist in the market by leading sports medicine manufacturers[46]; however, the biomechanical properties and modes of failure of these constructs have yet to be characterized. Time-zero biomechanics should be optimized to reduce laxity (ie, creep, cyclic elongation, and displacement) and increase construct stiffness and failure load (ie, ultimate failure or clinical failure threshold). These data, in conjunction with clinical findings, may help surgeons select the best construct to reduce the risk of premature graft failure.

The purpose of the study was to compare the biomechanics of suspensory techniques for soft tissue QT autograft fixation in an in vitro model of ACL reconstruction. We hypothesized that a tape-reinforced adjustable-loop device (ALD) would best minimize laxity while meeting or exceeding ranges of native ACL stiffness and loading.

METHODS

Specimen Preparation

A total of 24 fresh-frozen human cadaveric extensor mechanisms were harvested from 16 male and 6 female cadaveric donors (mean age, 58 years; range, 20-87 years). All specimens were required to be without gross evidence of degenerative joint disease or other diseases affecting tissue quality. Deidentified donor tissue was provided by registered tissue banks for research purposes and did not require institutional review board approval by our institution. One of the tissue banks sent patella-quadriceps tissue. For consistency, we also isolated the same complex from full knees in the same manner before graft harvest to eliminate any confounding variables. Bilateral knees were used and randomized.

The specimens were thawed to room temperature and were dissected free of subcutaneous tissue. ASTQT grafts were meticulously harvested from the central third of the QT by a single author (B.L.S.) under clinical supervision. Using a 9-mm graft knife (Arthrex), the QT was harvested in a full-thickness fashion and sharply transected from the superior pole of the patella using a sharp scalpel. Each test group had a median graft diameter of 10.0 mm (pooled range, 9.5-10.5 mm), measured with a graft sizing block; the minor variance was attributed to natural anatomic differences in tendon thickness.[8] Grafts were kept frozen at –20°C and thawed to room temperature for preparation and testing, where they were kept moist with 1× phosphate-buffered saline throughout all phases.

Suspensory Fixation Techniques

The investigated suspensory fixation techniques utilized ALDs integrated with the distal (patellar) aspect of the QT in various manners (Figure 1). Grafts were randomly assigned to 1 of 4 techniques, with 6 samples per group, where ALDs were either (1) secured to the graft with a combination implant containing the ALD and suture tape-reinforced whipstitching (tape-reinforced [TR] group), (2) tethered superficially to the graft with a whipstitch (onlay [OL] group), (3) luggage-tagged through and around the

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[‖] Address correspondence to Coen A. Wijdicks, PhD, MBA, Department of Orthopedic Research, Arthrex Inc, 1370 Creekside Boulevard, Naples, FL 34108, USA (email: coen.wijdicks@arthrex.com).

[*] NorthShore Orthopedic and Spine Institute, Chicago, Illinois, USA.

[†] Department of Orthopedic Research, Arthrex, Inc, Naples, Florida, USA.

[‡] Orthopaedic Surgery and Sports Medicine, Gundersen Health System, Onalaska, Wisconsin, USA.

[§] Department of Orthopedic Surgery, University of Colorado School of Medicine, Aurora, Colorado, USA.

A.B. and B.L.S. contributed equally to this article.

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Ethical approval was not sought for the present study.

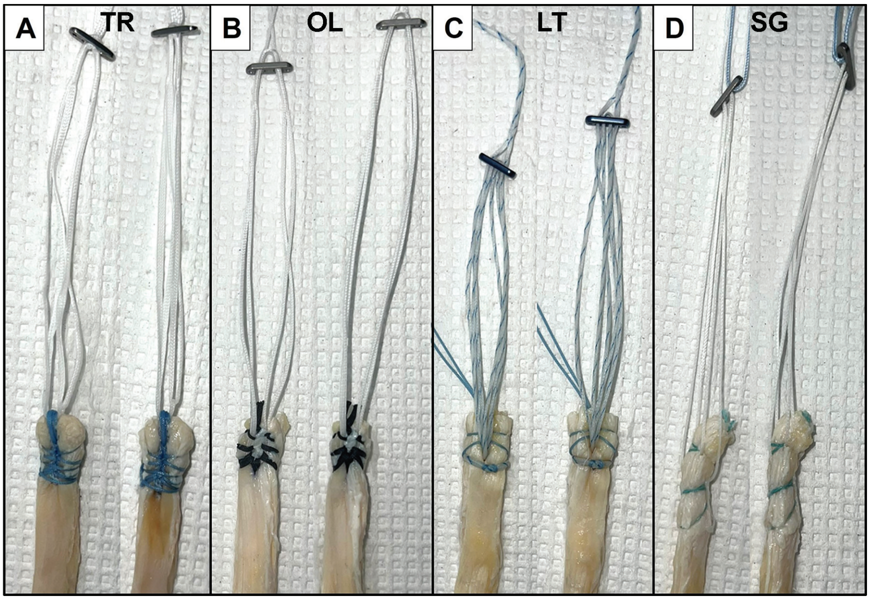

Figure 1. The investigated quadriceps tendon autograft techniques consisted of adjustable-loop cortical button implants fixated in various manners, including (A) tape-reinforced (TR), (B) onlay (OL) with whipstitches, (C) luggage tag (LT), and (D) staggered (SG) behind superficial graft sutures. Each graft is shown before (left) and after (right) pretensioning at 80 N for 5 minutes to visualize initial deformation and lengthening patterns.

graft (luggage [LT] tag group), or (4) created in a staggered manner behind superficial suturing (staggered [SG] group). Constructs were chosen to represent the latest state-of-the-art techniques for QT autograft fixation reported by orthopaedic medical device manufacturers, using identical or similar devices.

The TR group utilized a combination implant containing No. 2 round looped suture and a suture tape tag holding an ALD (FiberTag TightRope II; Arthrex). Grafts were prepared following the described QuadLink technique (Arthrex), in which the tag was laid 20 mm proximal to the end of the graft and secured with 4 looped whipstitches at approximately 5-mm intervals in both directions before final knot tying just proximal to the tag with 5 alternating half hitches.[1] The OL group consisted of an ALD (ProCinch RT; Stryker) laid superficially on the graft 20 mm proximal to its end. An LT was created around the apex of the ALD using 1.4-mm suture tape (XBraid; Stryker) and passed through the graft to tightly secure it. Thereafter, 4 conventional whipstitches were looped over each side of the ALD at 3- to 4-mm intervals, with a rip-stop between passes 3 and 4, before final knot tying at the graft end with 5 alternating half hitches.[6] For the LT group, a No. 2 suture (FiberWire; Arthrex) was looped around the ALD (ULTRABUTTON; Smith & Nephew) and used to pull it through and around the graft, creating an LT, at the 15-mm mark. The No. 2 suture limbs were passed 1 mm behind the implant, followed by 2 looped whipstitch passes and a final locking stitch deep to the superficial implant.[46] For the SG group, a whipstitch was applied to the exterior of the graft using a preloaded delivery device (SPEEDTRAP Graft Preparation System; DePuy Synthes). The ALD (BTB TightRope; Arthrex) was created proximally in an SG manner behind whipstitches to create a rip-stop effect, replicating the RIGIDLOOP BTB Adjustable Cortical System (DePuy Synthes) for QT graft preparation.[10] The choice of ALD implant for this technique was because of access and availability of implants to achieve adequate statistical power.

Reconstruction Technique

Acrylic blocks were used to model femoral sockets, consistent with previous studies, to simulate in vivo applied radial forces and observe the reconstruction throughout testing.[22,25,34] The blocks contained a 20 mm-long socket terminating in a 15-mm tunnel, measuring 4.0 mm in diameter, extending to the cortex. Socket diameters were sized in 0.5-mm increments and matched closest to the prepared graft's diameter to create a press-fit.

For each construct, before advancing the graft, it was pretensioned on a graft preparation board (GraftPro; Arthrex) at 80 N for 5 minutes to eliminate initial creep. The cortical buttons of the ALD were then shuttled through the socket and flipped onto the cortex. Grafts were advanced 10 to 15 mm into the sockets by pulling on the shortening strands of the ALD, leaving room for retensioning during later testing. The proximal, musculotendinous aspect of the graft was secured in a clamp (Figure 2) to simulate secure fixation from a tibial socket.

Biomechanical Testing

Biomechanical testing was performed on an electromechanical test machine (ElectroPuls E3000; Instron)

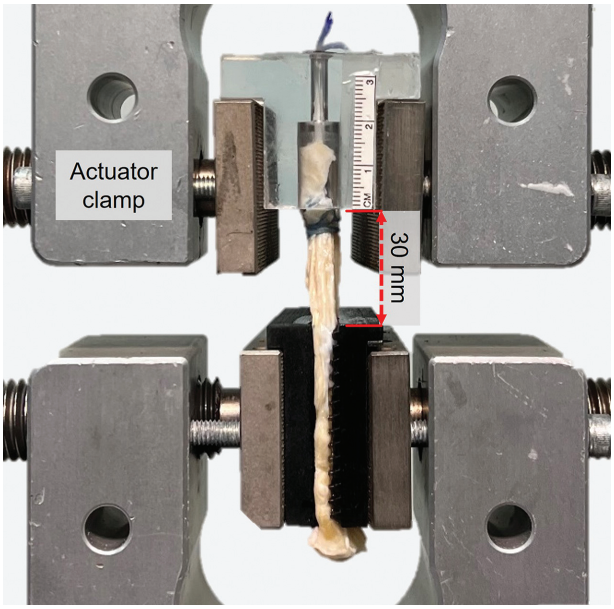

Figure 2. The biomechanical testing setup utilized an acrylic block to model a femoral socket for suspensory fixation. The proximal musculotendinous aspect of the quadriceps tendon graft was rigidly fixed in a tissue grip, simulating secure tibial fixation in line with the femoral socket.

following a previously validated model of intraoperative workflow for tensioning, fixation, and loading.[22,25,42] Acrylic blocks were rigidly clamped in a vise secured to the actuator, while the soft tissue clamp was secured directly beneath at the base of the machine (Figure 2). The length from the bottom of the acrylic block to the top of the tissue clamp (ie, the joint space) was 30 mm and represented the native ACL length at 30° of flexion in this study.

Tensile loading was applied in line with the graft to create a "worst-case" scenario, consistent with other studies.[4,20,25,32] Grafts were tested in a sequence consisting of 10 position-controlled precycles simulating intraoperative conditioning, manual retensioning of the ALD, 1000 position-controlled cycles simulating ACL kinematics during weightbearing knee flexion,[26] 1000 force-controlled cycles simulating ACL weightbearing force,[12] and load to failure at 50 mm/min (Figure 3). Manual retensioning was performed by alternating pulling on the shortening strands of the ALD to a maximum achievable load of 200 N, confirmed by monitoring the live force data from the testing machine. The 200-N limit was consistent with previous studies and reflected a common amount of tension applied by surgeons.[22,25,42] Position-controlled cycling ranged from +1-mm to −2-mm displacement to reflect ACL length changes during weightbearing knee flexion.[26] Force-controlled cycling ranged from 10 N to 250 N, consistent with peak loads of previous ACL reconstruction studies.[3,13]

The initial and final peak load levels from position-controlled cycling were used to compute tension loss (%) for each construct ([1 – *final load/initial load*] × 100). Cyclic elongation (mm) quantified plastic elongation (ie, laxity) and was calculated as the difference in elongation between the first 50-N preload and the 10-N valley of the last force-controlled cycle. Ultimate stiffness (N/mm) was measured as the slope of the linear 200-N to 300-N region of the load-displacement curve. Ultimate load and mode of failure were also recorded.

Statistical Analysis

All statistical analyses were performed with $\alpha = 0.05$ and $\beta = 0.20$ in SigmaPlot Version 14.0 software (Systat Software). A 1-way analysis of variance (ANOVA) a priori power analysis using differences in QT cyclic elongation between a No. 2 whipstitch (Arthrex) and TR whipstitching ($\Delta = 7.70$ mm; SD = 2.63 mm; levels = 4) revealed a minimum sample size of 4 to reach a power of 0.8; the sample size of the current study was expanded to 6 to further increase power.[22,32] Parametric outcomes for tension loss, cyclic elongation, and ultimate stiffness were compared using 1-way ANOVA. A Kruskal-Wallis 1-way ANOVA on ranks was performed for ultimate load due to failed equal variance. Post hoc pairwise multiple comparisons procedures were performed for parametric and nonparametric data via the Holm-Sidak or Tukey method, respectively. Parametric 1-sample *t* tests were used to compare the ultimate load of each group to 454 N, the hypothesized maximum load of the ACL during daily normal activities.[35]

RESULTS

Position-Controlled Cycling

As mentioned, pretensioning was critical in releasing initial construct creep before reconstruction, particularly in OL, LT, and SG preparations (Figure 1). Despite this, sizable tension losses and elongation were still observed during testing. The TR group had the least tension loss (mean ± SD, 24% ± 11%), followed by the OL (56% ± 15%), LT (69% ± 16%), and SG (90% ± 9%) constructs (Table 1 and Figure 4). Significant differences in tension loss were found when comparing the TR group with the OL ($P = .002$), LT ($P < .001$), and SG ($P < .001$) groups. A significant difference was also found when comparing the LT and SG constructs ($P = .023$) and the OL and SG constructs ($P < .001$). One sample from the SG group failed during retensioning due to amputation of the ALD against the taut superficial whipstitch sutures; this sample was documented and analyzed as 100% tension loss.

Force-Controlled Cycling

Cyclic elongation was the lowest in the TR group (1.6 ± 0.3 mm), followed by OL (3.3 ± 1.2 mm), LT (7.9 ± 1.7 mm), and SG (11.3 ± 2.6 mm) (Table 1 and Figure 5). Significant differences were found in cyclic elongation when comparing the TR to the OL ($P = .032$) and LT groups

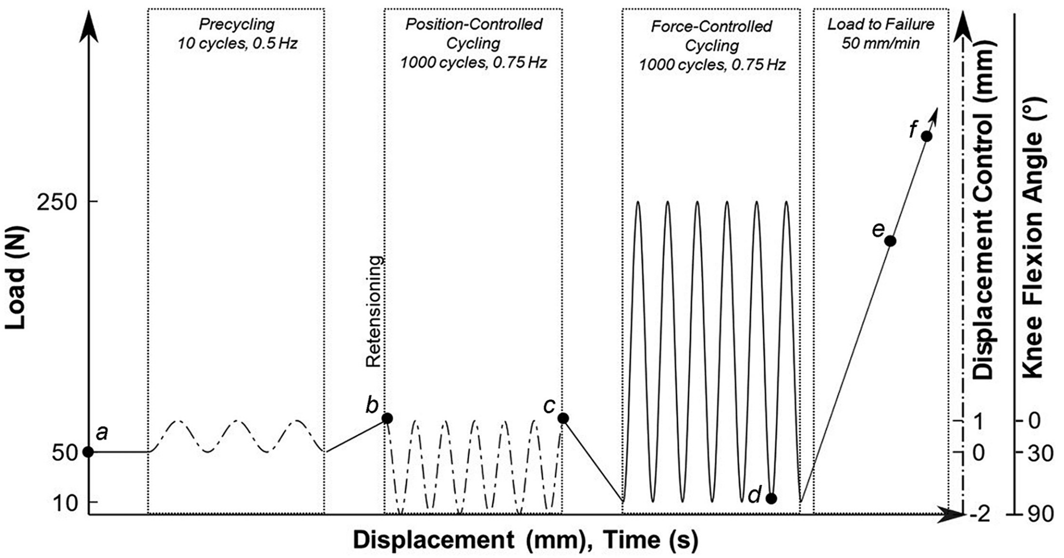

Figure 3. Biomechanical testing protocol. Cyclic elongation (mm) (Δad); initial load (N) (b); final load (N) (c); ultimate stiffness (N/mm) (Δef); (1 – c/b) × 100 = tension loss (%).

TABLE 1
Results of Biomechanical Testing of the Different Quadriceps Graft Preparation Techniques[a]

Suspensory Technique	Tension Loss (%)	Cyclic Elongation (mm)	Ultimate Stiffness (N/mm)	Ultimate Load (N)
TR	24 ± 11	1.6 ± 0.3	217 ± 21	739 ± 216
OL	56 ± 15[b]	3.3 ± 1.2[b]	203 ± 24	547 ± 67
LT	69 ± 16[b]	7.9 ± 1.7[b,c]	197 ± 18	769 ± 122
SG	90 ± 9[b,c,d]	11.3 ± 2.6[e]	208 ± 11[e]	346 ± 197[b,d]

[a] Data are presented as mean ± SD. LT, luggage tag; OL, onlay; SG, staggered; TR, tape reinforced.
[b] Significant difference versus TR ($P < .05$).
[c] Significant difference versus OL ($P < .05$).
[d] Significant difference versus LT ($P < .05$).
[e] Excluded from statistical analysis due to 50% sample loss during cyclic loading.

($P < .001$) and when comparing the OL and LT groups ($P < .001$). Two additional samples from the SG construct failed while cycling, 1 by amputation of the ALD at the graft interface (cycle 1) and 1 by pullout of an ALD strand from the graft (cycle 752). Due to the resulting unequal sample sizes in the SG group (n = 3), it was excluded from statistical comparisons for cyclic elongation.

Pull to Failure

No significant differences were found regarding ultimate stiffness ($P = .294$), and all samples surviving cyclic loading were within the native ACL stiffness range of 220 ± 72 N/mm reported by Woo et al[48] (Table 1 and Figure 6). The ultimate load significantly exceeded the established threshold of 454 N for the TR ($P = .023$), OL ($P = .020$), and LT ($P = .001$) groups but not for the SG group ($P = .236$) (Table 1). Significant differences in ultimate load were found between the TR and SG constructs ($P = .044$) and the LT and SG constructs ($P = .005$). The maximum load reached before failure was used for the SG group to account for early failures.

The modes of failure varied. For the TR group, 3/6 samples failed by breakage of the ALD, while the other 3/6 samples failed by suture pullout. For the OL group, all 6 samples failed by suture pullout. For the LT group, 4/6 samples failed by suture pullout, while the remaining 2/6 samples failed by breakage of the ALD. It was observed that the samples in the LT group strangled and tore the graft under considerable tension. For the SG group, the 3 specimens surviving cycling failed by ALD and suture pullout with observed graft shredding.

DISCUSSION

The principle finding of this study was that QT autograft prepared utilizing a TR suture fixation construct for ACL reconstruction demonstrated the least amount of tension

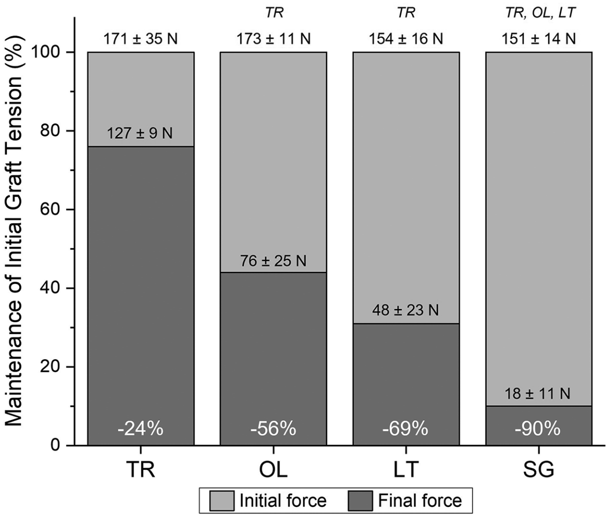

Figure 4. Initial and final graft tension at full extension in the position-controlled cycling block for different quadriceps tendon autograft preparation techniques. Italicized letters indicate comparative significant differences ($P < .05$). LT, luggage tag; OL, onlay; SG, staggered; TR, tape reinforced.

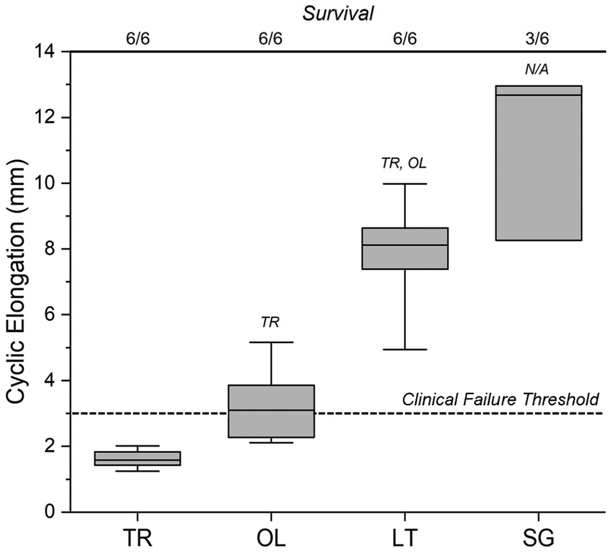

Figure 5. Cyclic elongation for different quadriceps tendon autograft preparations. Values are presented in box plots comprising the IQR (box), median (line), and range (whiskers). The number of samples that survived cyclic loading is listed. Italicized letters indicate comparative significant differences ($P < .05$). The SG was not included for statistical analysis because of 50% failure during cycling (3 out of 6 survival). A commonly used 3.0-mm threshold for clinical failure[39] is provided for reference. LT, luggage tag; N/A, not applicable; OL, onlay; SG, staggered; TR, tape reinforced.

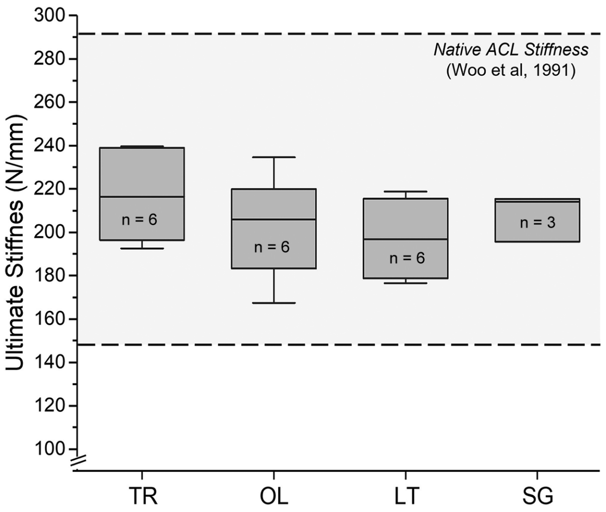

Figure 6. Ultimate stiffness for different quadriceps tendon autograft preparations in relation to native anterior cruciate ligament (ACL) tensile stiffness (220 ± 72 N/mm) reported by Woo et al.[48] Values are presented in box plots comprising the IQR (box), median (line), and range (whiskers). LT, luggage tag; OL, onlay; SG, staggered; TR, tape reinforced.

loss and cyclic elongation (ie, laxity) when compared with other modern, commercially available graft preparations. All constructs reaching the pull-to-failure step were within native ACL stiffness ranges (220 ± 72 N/mm)[48] and exceeded the upper limit of ACL loading for normal activities (454 N),[35] except for the SG construct, which had early cyclic loading failures and suboptimal failure load.

Understanding optimal graft preparation for QT autograft in ACL reconstruction is becoming more critical as the use of this graft increases in both primary and revision reconstruction procedures.[27,30,47] The ASTQT autograft preparation in particular has been adopted for its reduced risks of donor-site morbidity from bone-block harvesting, including anterior knee pain and patellar fracture associated with bone-plug harvesting, and similar clinical outcomes to bone-QT autografts.[2,28,33] Compared with hamstring tendon autograft, QT autograft has shown decreased pivot-shift laxity, lower failure rates, similar patient-reported outcomes, and a higher hamstring-to-quadriceps muscle strength ratio, which may have a protective effect on the ACL reconstruction by limiting hyperextension moments and quadriceps dominance.[23,24,29,31,37,44]

Despite promising findings, suspensory fixation of the QT autograft has been challenging and requires suture passage through a multilaminar structure, as compared with traditional looped-tissue constructs found in hamstring graft fixation or transosseous preparations seen in BTB graft fixation. Unlike hamstring tendon autograft, which has shown nonsignificant clinical differences between various fixation methods,[19] single-stranded QT autograft depends on the strength of the graft preparation technique to resist suture pullout or rupture.[25,32] Suspensory techniques that resist creep and are stiffer may limit graft laxity and the "bungee-cord effect" contributing to tunnel enlargement during rehabilitation.[14] To that end, a variety of options for QT autograft preparation and fixation have been proposed, with the optimal technique yet to be established.

Previous cadaveric biomechanical studies of ASTQT graft suspensory fixation have examined different construct preparations with and without looped cortical button implants. Michel et al[32] showed that graft suturing with a doubled No. 2 Krackow stitch tied over a metal button had the least cyclic elongation (mean, 10.59 mm) and greatest ultimate load (553 N) versus No. 2 and No. 5 whipstitches and baseball stitches. However, the methodology of knot tying over a cortical button has become less common with advancements in looped cortical button implants. Kamada et al[20] evaluated various fixed continuous-loop cortical button preparations, either tied using a baseball suturing construct, incorporated into a pass of baseball suturing or stitched directly to the graft with 8 simple sutures. These authors found significantly less cyclic elongation (4.1 mm) and the greatest ultimate load (386 N) when directly stitching the fixed-loop device to the graft. Both studies stressed grafts to peak loads of 100 N for 500 cycles, which is less aggressive than several other protocols that cyclically load to 250 N.[3,13,22] Despite this, constructs still had cyclic elongation surpassing commonly documented clinically acceptable limits of 3 to 5 mm or ultimate loads <454 N, which are frequently utilized criteria in time-zero ACL reconstruction studies.[5,17,35,38]

Lamplot et al[25] built upon these studies using more contemporary fixation with adjustable-loop cortical button devices in a full-construct model of ACL reconstruction, with a more aggressive cyclic loading protocol of 2000 total cycles and peak loads of 250 N. In their biomechanical study, the authors found that ALD constructs, when retensioned, were biomechanically superior to fixed-loop device constructs, with 73% greater graft tension and 46% less elongation after cyclic loading. They also found that a combination implant containing the ALD and TR whipstitching improved biomechanics, with 83% less total cyclic elongation and 44% greater stiffness versus an equivalent construct that lacked tape reinforcement. These findings validated the use of ALD devices for ACL graft fixation compared with fixed-loop devices and served as the basis for the current study, which compared the next-generation version of the combination TR implant with various other modern ALD ASTQT preparations.

The results of the current study confirm the findings of Lamplot et al[25] using an identical loading protocol, and it demonstrates that TR suture fixation has significantly less tension loss and cyclic elongation when compared with other ALD fixation techniques. Less tension loss indicates greater graft load retention, which describes the maintenance of initial graft tension following exposure to repeated biomechanical stresses. Graft load retention is thought to be critically important in the clinical setting, given the stresses under which the graft may be placed as patients return to higher-impact activities. The TR construct retained 76% of its initial load, while the other groups fell <50%, reaching 10% in the SG construct. Cyclic elongation quantifies the permanent lengthening of a construct under repeated loading (ie, laxity). Minimizing laxity is crucial in restoring adequate ACL function in patients, and side-to-side differences of 3 to 5 mm with KT arthrometer testing are often used as clinical criteria for ACL reconstruction failure.[5,7,39] Cyclic elongation was only found to be below this limit for the TR construct (1.6 mm), while the OL (3.3 mm), LT (7.9 mm), and SG (11.3 mm) constructs were not. It should be noted that the SG construct had a concerning 50% failure rate preceding load to failure; and thus, the authors advocate caution in clinical adoption of this technique.

Among all constructs, load-to-failure testing revealed no significant differences in ultimate stiffness, with all surviving samples within the native ACL stiffness range of 220 ± 72 N/mm.[48] Ultimate load significantly exceeded 454 N for all constructs except the SG construct (346 N). Failure modes collectively favored suture pullout (16 of 24 grafts), though unique attributes were observed in the LT construct, where the LT progressively strangled the graft, and the SG group, where the ALD strands shredded the graft. The modes of failure are important when considering graft-to-bone healing, as graft shape distortion or disruption may destabilize early healing. Gap formation between the graft and socket could enable the influx of synovial fluid with elevated deleterious cytokines, impairing tendon-to-bone healing.[21,43]

Overall, the quality of ACL graft fixation is important for maintaining time-zero graft position and minimizing graft laxity or failure during rehabilitation. The current study is the first to compare the clinically relevant biomechanical properties of several commonly used methods for QT autograft preparation. The results of this study demonstrated significant differences between commercially available QT autograft preparation constructs in terms of fixation and construct behavior during cyclic and ultimate failure testing, with TR suture fixation demonstrating the most stable biomechanical profile.

Limitations

There are notable limitations in the present study. This cadaveric study evaluated biomechanical properties of the graft constructs only at time zero. Like all cadaveric time-zero studies, there was no ability to account for graft healing, dynamic or bony stabilization of the knee, and changes in activity or strength over time. Because of this, these testing modes may not necessarily reflect in vivo biomechanics and, ultimately, clinical performance. In addition, acrylic blocks were utilized in place of human cadaveric bone to simulate bone tunnels, and forces were pulled directly in line with the tissue, which does not absolutely approximate the rotational and dynamic forces experienced in vivo by the ACL or ACL graft. Testing was not performed in a full-construct model; rather, the proximal, musculotendinous aspect of the QT graft was rigidly clamped, which may consequently overestimate construct stiffness and underestimate elongation, as it does not account for less secure methods of tibial fixation. Preparation of the proximal QT graft may yield outcomes different from those in the current study, particularly increased elongation, reduced stiffness, and lower failure loads.[25] While graft preparation was performed using techniques that mirror those performed in the operative setting, relative experience with the new techniques could play a minor role in the outcomes. In addition, the loading protocol in this study likely exceeds what is experienced during the early rehabilitation process. Loading the graft to this extent at time zero could result in graft elongation beyond what would typically be experienced in the early postoperative period. Although this study demonstrated significant differences between the graft fixation techniques, nonsignificant outcomes may be correlated with a type II error secondary to relatively small sample sizes. The catastrophic early failure of 3 SG samples may have, in part, contributed to the underreporting of significance between graft fixation options for select outcomes.

CONCLUSION

The TR ALD construct demonstrated the most favorable time-zero biomechanical properties of modern soft tissue QT suspensory constructs, with 32% less tension loss and 52% less cyclic elongation versus the closest construct. Failure loading of all constructs was acceptable with respect to the native ACL except for the SG group, which had suboptimal ultimate load.

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