

Adjustable Cortical Fixation Device for Quadriceps Tendon Repair

A Cadaveric Biomechanical Study

Heath P. Gould,* MD, William R. Rate IV,[†] MS, Pooyan Abbasi,* MSME, Katherine L. Mistretta,* MD, and Jason W. Hammond,*[‡] MD

Investigation performed at MedStar Union Memorial Hospital, Baltimore, Maryland, USA

Background: Adjustable cortical fixation devices have demonstrated utility in orthopaedic applications, such as ankle syndesmosis repair.

Purpose: To assess the cyclic gap formation of a quadriceps tendon repair technique using an adjustable cortical fixation device compared with repair with knotless suture anchors and suture tape, a modification of conventional suture anchor repair.

Study Design: Controlled laboratory study.

Methods: Eight fresh-frozen matched pairs of cadaveric knees were used. Specimens in each pair were randomized to undergo either modified suture anchor repair (control) or adjustable cortical fixation repair. The control repair was performed as previously described. The experimental repair was performed using 2 No. 2 FiberWire sutures placed into the quadriceps tendon in a running locked Krackow configuration and 2 adjustable loop devices passed through transosseous tunnels. The lagging strands of the devices were tensioned to seat the cortical fixation buttons at the inferior patellar pole and then tied to the free Krackow strands at the superior pole to complete the repair. The mean plastic gap (permanent tendon displacement that did not recover with cyclic extension) and mean maximum gap (peak displacement that occurred with cyclic knee flexion and partially recovered with extension) were evaluated during cyclic loading for 500 cycles of full knee extension to 90° of flexion.

Results: At all testing intervals, the mean plastic gap was significantly smaller for the cortical fixation group versus the suture anchor group ($P < .02$). Similarly, the mean maximum gap was significantly smaller for the cortical fixation specimens at all testing intervals ($P < .01$). After cyclic loading, the mean maximum gap was significantly smaller in the cortical fixation group (4.80 ± 1.56 mm) versus the suture anchor group (8.47 ± 1.47 mm; $P = < .001$). The mean plastic gap was also significantly smaller in the cortical fixation versus the suture anchor group (3.25 ± 1.10 mm vs 6.57 ± 1.62 mm, respectively; $P = < .001$).

Conclusion: Quadriceps tendon repair using an adjustable cortical fixation device demonstrated superior biomechanical properties in cyclic displacement testing compared with repair using the suture anchor technique.

Clinical Relevance: These results suggest that an adjustable cortical fixation device is a biomechanically viable alternative for quadriceps tendon repair.

Keywords: quadriceps tendon rupture; adjustable cortical fixation device; suture anchor repair; cadaveric; biomechanics

There is currently no consensus regarding the optimal surgical management of quadriceps tendon rupture.¹⁸ The 2 most common repair techniques are transosseous repair and suture anchor repair. Although both methods have demonstrated satisfactory biomechanical^{6,11,16,21} and clinical results overall,³ a substantial number of patients experience functional impediments postoperatively, such as extension lag, muscle atrophy, decreased range of motion, and

strength deficit.^{4,10,13,22,23} These repair techniques are further limited by the potential for tendon gap formation postoperatively, which can be a major concern as patients progress through their postoperative rehabilitation programs. A variant of the conventional suture anchor quadriceps tendon repair using knotless suture anchors and suture tape has been reported to have superior cyclic displacement, construct stiffness, and load to failure compared with that of transosseous and conventional suture anchor repair.^{7,15}

In the context of extensor mechanism injuries, adjustable cortical fixation may be an effective option because it allows the surgeon to retension the repair intraoperatively,

The Orthopaedic Journal of Sports Medicine, 9(1), 2325967120974393
DOI: 10.1177/2325967120974393
© The Author(s) 2021

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For article reuse guidelines, please visit SAGE's website at <http://www.sagepub.com/journals-permissions>.

thereby potentially maximizing tendon-bone compression at the repair site. A previous cadaveric study has demonstrated superior biomechanical properties of adjustable cortical fixation devices compared with conventional suture anchor repair and transosseous repair in the surgical management of patellar tendon rupture.¹² Adjustable cortical fixation devices have shown good clinical results in ankle syndesmosis repair, cruciate ligament reconstruction, and acromioclavicular joint dislocation.^{1,2,19} Results of adjustable cortical fixation for quadriceps tendon rupture have not been reported.

The purpose of this study was to compare biomechanical properties of an adjustable cortical fixation device (ACL TightRope; Arthrex) with knotless suture anchors and suture tape, a modification of the conventional suture anchor technique for quadriceps tendon repair. Cyclic gap formation was selected as the biomechanical outcome of interest because it simulates the effects of early functional rehabilitation after quadriceps tendon repair. We hypothesized that quadriceps tendon repair using an adjustable cortical fixation device would demonstrate smaller gap formation with cyclic loading compared with repair using the modified suture anchor repair method.

METHODS

Eight matched pairs of fresh-frozen cadaveric knees obtained from the state anatomy board donation program were used in this study (5 male and 3 female pairs; mean age, 73.0 years; age range, 55-89 years). Skin and subcutaneous tissues were removed. Specimens in each pair were randomly assigned to receive either the modified suture anchor technique^{7,15} or the adjustable cortical fixation repair technique. A biomechanical model of extensor mechanism cyclic loading, originally described by Ravalin et al¹⁷ and modified by Krushinski et al,⁸ was used as the test setup (Figure 1).

The femur was fixed to an MTS Mini Bionix load frame (MTS Systems) and oriented parallel to the floor using a custom-made clamp. The tibia was allowed to hang freely. The weight of an intact foot was simulated using a 2.3-kg (5-lb) weight fixed approximately 33 cm distal to the knee joint line using an external fixation device (Synthes). The quadriceps tendon was secured proximally using a custom soft tissue clamp, which was attached to a heavy-gauge steel cable passed through a pulley from its origin at the servohydraulic actuator.

A quadriceps tendon rupture was simulated by transecting the tendon along the osseotendinous junction at the superior pole of the patella, leaving the remaining

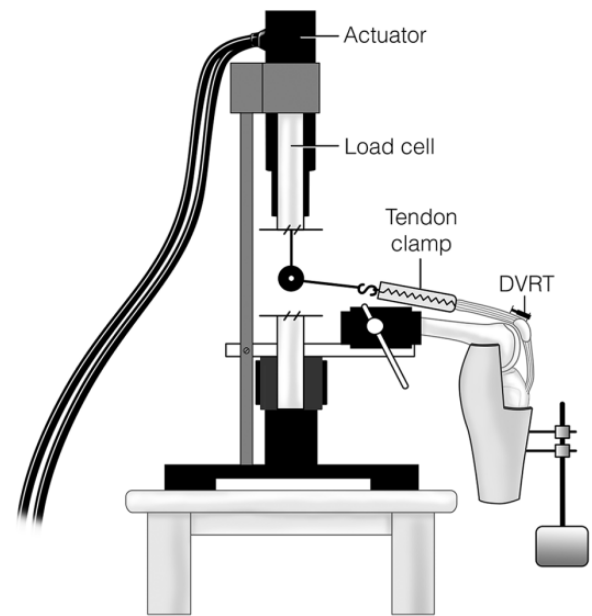


Figure 1. Schematic diagram of the biomechanical testing setup, depicting a left knee cadaveric specimen fixed to the testing jig and attached to the MTS Mini Bionix load frame (MTS Systems). DVRT, differential variable reluctance transducer.

retinaculum intact. The distal aspect of the quadriceps tendon and the superior pole of the patella were debrided. The control group was treated using a modification of the suture anchor and suture tape quadriceps tendon repair originally described by Kindya et al⁷ (Figure 2).

Two strands of high-strength suture tape (FiberTape; Arthrex) were used to place 2 running locked Krackow stitches in the medial and lateral portions of the quadriceps tendon. Firm tension was applied after each pass of suture tape to remove any slack from the running stitch. Drill holes were placed in the medial- and lateral-thirds of the patella using the drill for the 4.75-mm biocomposite knotless suture anchors (SwiveLock; Arthrex). The appropriate tap for the 4.75-mm anchors was then passed through each drill hole. The 2 medial Krackow strands were loaded into the medial anchor and then malleted and screwed into the medial drill hole while tension was held on the lateral strands with the knee maintained in full extension. After the medial anchor was fully seated, the lateral strands were loaded into the lateral anchor and reduced to the patella in the same manner.

The experimental repair was also performed with the knee in full extension using 2 adjustable cortical fixation

†Address correspondence to Jason W. Hammond, MD, c/o Lyn Camire, MA, ELS, Department of Orthopaedic Surgery, MedStar Union Memorial Hospital, 3333 North Calvert Street, Suite 400, Baltimore, MD 21218, USA (email lyn.camire@medstar.net).

*Department of Orthopaedic Surgery, MedStar Union Memorial Hospital, Baltimore, Maryland, USA.

†MedStar Georgetown University Hospital, Washington, DC, USA.

Final revision submitted July 12, 2020; accepted July 29, 2020.

One or more of the authors has declared the following potential conflict of interest or source of funding: Materials for this study were donated by Arthrex. J.W.H. has received educational support, consulting fees, and royalties from Arthrex and hospitality payments from Linvatec, Supreme Orthopaedic Systems, and Stryker. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

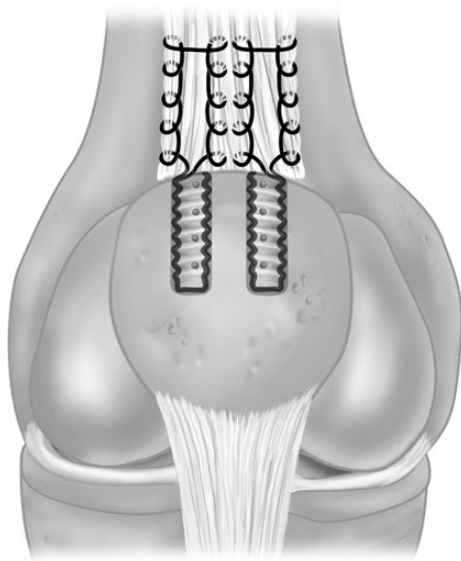


Figure 2. Schematic diagram of the control repair technique in a left knee. Two Krackow stitches are placed in the quadriceps tendon using 2 long strands of suture tape. The medial and lateral free ends of suture tape are then secured to the medial- and lateral-thirds of the patella, respectively, using knotless biocomposite suture anchors.

devices (ACL TightRope) (Figure 3). A 4-mm Beath pin was passed through the lateral-third of the tendon. The pin was introduced at the midsubstance of the transected tendon (Figure 4A) and angled superficially to exit through the tendon surface 1 cm proximal to the distal aspect of the tendon (Figure 4B). The adjustable loop portion of the device was loaded into the open eyelet of the Beath pin (Figure 5A) and passed through the tendon (Figure 5B).

A No. 2 high-tensile-strength suture (FiberWire; Arthrex) was passed through the midsubstance of the quadriceps tendon, entering just lateral to the entry point of the adjustable loop. The first (most distal) throw of the locked Krackow suture was passed through the adjustable loop (Figure 6A) to secure the loop to the tendon (Figure 6B). The running locked Krackow stitch proceeded in a standard fashion, with 4 additional throws passed in a distal-to-proximal direction and then 4 throws passed in a proximal-to-distal direction. Tension was pulled after each suture pass to remove any slack in the suture construct. The final locked throw of the Krackow stitch was then passed through the adjustable loop to provide a second point of fixation between the loop and the tendon (Figure 7). This technique was repeated at the medial-third of the tendon to secure an additional adjustable cortical fixation device to the tendon.

Two transosseous holes were created through the patella in a superior-to-inferior direction using the 4-mm Beath pin. One drill hole was placed in the medial-third of the patella, and the other was placed in the lateral-third (Figure 8). The leading strands attached to the cortical fixation buttons were drawn through the drill holes distally using a transosseous suture passer. The buttons then

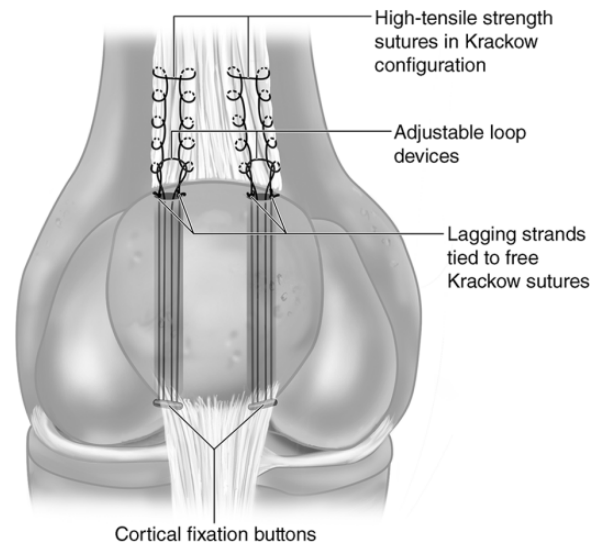


Figure 3. Schematic diagram of the experimental repair technique in a left knee. The adjustable loops are first passed through the midsubstance of the quadriceps tendon and secured to the superficial surface of the tendon using the most distal throws of the Krackow stitches medially and laterally. The loops are then passed through the patella, and the attached cortical fixation buttons are seated medially and laterally at the inferior pole of the patella. The tensioning strands of the adjustable cortical fixation device are tied proximally to the free limbs of the Krackow stitches at the superior pole of the patella.

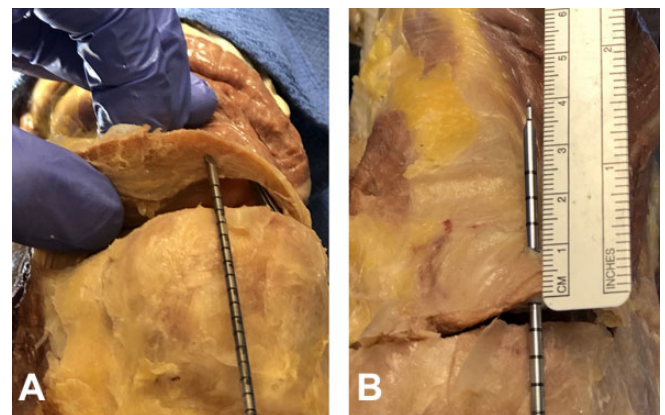


Figure 4. (A) Left knee, axial view. A 4-mm Beath pin is drilled into the lateral-third of the quadriceps tendon, entering at the midsubstance and angled superficially. (B) Left knee, anterior view. A 4-mm Beath pin is drilled into the lateral-third of the quadriceps tendon, exiting at the superficial aspect of the tendon 1 cm proximal to the rupture site.

followed through the holes in a similar fashion (Figure 9A). The lagging strands were not passed through the patella but were instead pulled proximally, allowing the buttons to seat at the inferior pole of the patella medially and laterally (Figure 9B).

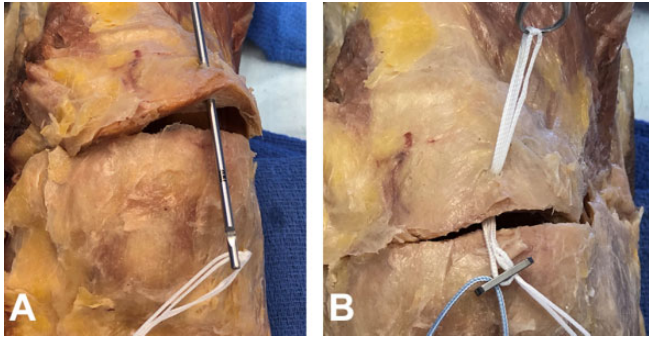


Figure 5. Left knee, anterior view. (A) Adjustable loop loaded into the open eyelet of the 4-mm Beath pin. (B) Adjustable loop passed through the quadriceps tendon.

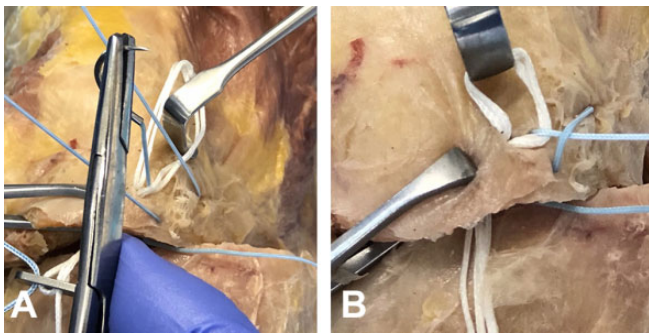


Figure 6. Left knee, anterior view. (A) No. 2 high-tensile-strength suture passed through the adjustable loop in a locked fashion. (B) Locked Krackow stitch securing the loop to the quadriceps tendon.

To prevent loosening of the Krackow stitch, tension was held on the free Krackow strands while the adjustable cortical fixation device was tightened. The repair construct was then pretensioned by cycling the knee 5 times from 0° to 90°. The lagging strands were again pulled proximally to retension the construct and then tied to the free Krackow strands at the superior patellar pole to complete the repair (Figure 10).

After the repair was completed, a 9-mm stroke length differential variable reluctance transducer (Microstrain Inc) was secured to the anterior surface of the tendon spanning the repair site. Its fixation points were augmented using a single simple, interrupted No. 2 high-tensile-strength suture (FiberWire) then placed proximally into the quadriceps tendon and distally into the soft tissue at the superficial surface of the patella. Each specimen was then cycled from 90° to 5° at a frequency of 0.25 Hz up to a maximum load of 250 N. Cyclic loading was stopped at 5° rather than full extension to avoid the potential of placing nonanatomical stress on the repair by attempting to achieve a position beyond physiologic extension.⁸ The initial cycle was performed manually to obtain actuator displacement parameters. Displacement values for that cycle were not included in the data. Gap displacement was recorded at 2, 5, 20, 50, 100, 200, and 500 cycles. Plastic



Figure 7. Left knee, anterior view. Running locked Krackow stitch in the lateral-third of the quadriceps tendon. The adjustable loop is secured to the tendon by the 2 most distal throws of the running locked Krackow stitch.

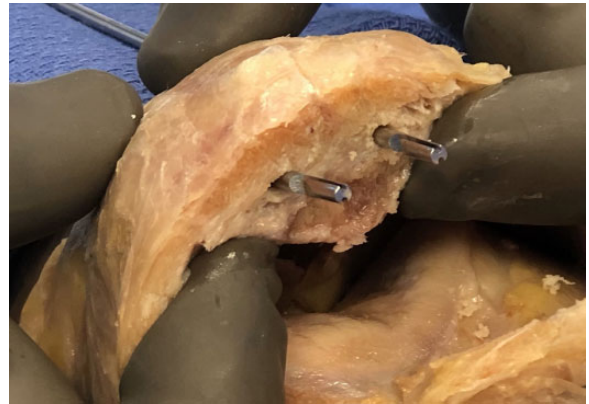


Figure 8. Left knee, axial view. Two 4-mm Beath pins drilled in a transosseous fashion through the medial- and lateral-thirds of the patella, respectively.

gap (permanent displacement in the tendon that did not recover with cyclic extension) and maximum gap (peak displacement that occurred with knee flexion and partially recovered with extension) were recorded at each testing interval. Load-to-failure testing was not performed because the quadriceps tendon could not be reliably clamped without tearing through the tendon tissue or slipping off the tendon before failure of the repair.

An a priori power analysis was performed based on the results of Kindya and colleagues.⁷ It was determined that 7 specimens per group would provide 80% power to detect a statistically significant difference ($\alpha < .05$) of 2.7 mm in plastic gap formation. An additional specimen pair was procured to ensure that any unforeseen technical or specimen complications would not affect the sample size required to obtain adequate power. Plastic and maximum gap formation were compared at various intervals of cyclic loading using paired *t* tests. Least-squares estimates were also generated for both plastic and maximum gap formation using a

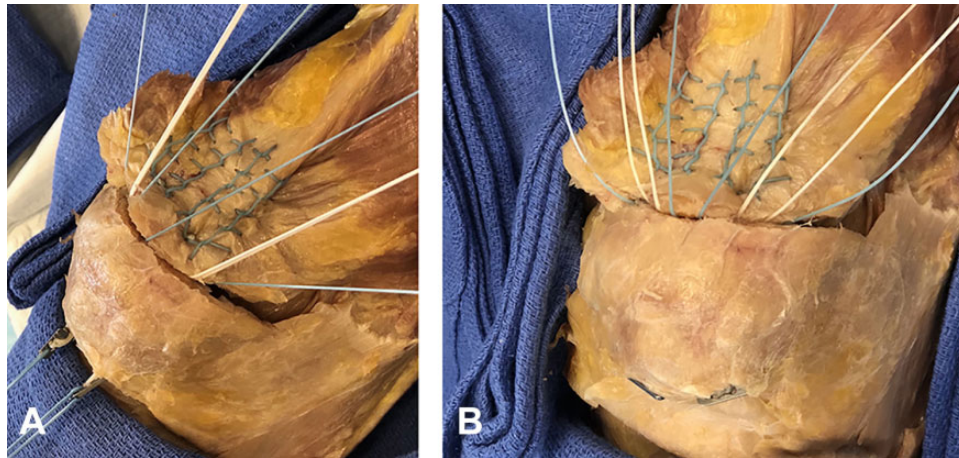


Figure 9. (A) Left knee, oblique view. Cortical fixation buttons passed through the transosseous drill holes using the leading strands (shown in blue) of the adjustable cortical fixation device. The lagging strands (shown in white) and the free limbs of the Krackow stitches (shown in blue) are not drawn through the tunnel and remain at the superior patellar pole. (B) Left knee, anterior view. Lagging strands (shown in white) have been tensioned proximally, allowing the cortical fixation buttons to settle at the inferior patellar pole.

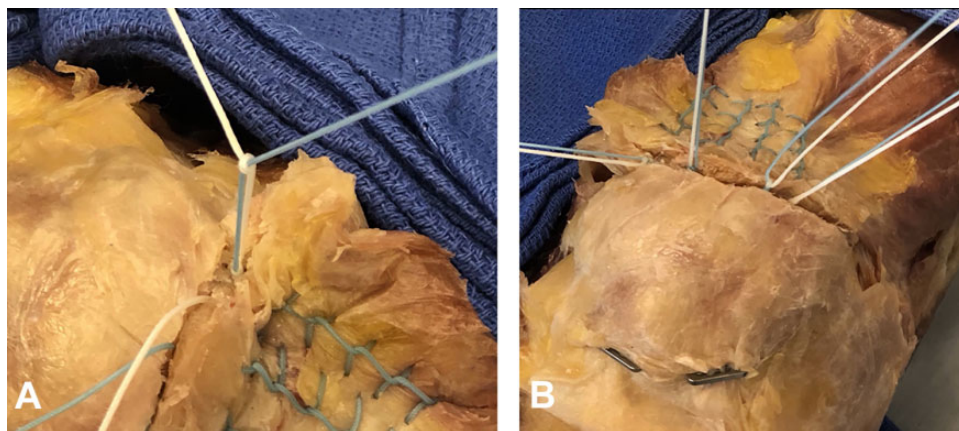


Figure 10. (A) Left knee, lateral view. Lagging strand of the adjustable cortical fixation device (shown in white) tied to the corresponding free Krackow strand (shown in blue) at the superior patellar pole. (B) Left knee, anterior view. Four lagging strands of the adjustable cortical fixation device (shown in white) have been tied to the 4 corresponding free Krackow strands (shown in blue) at the superior patellar pole. Surgical knots and suture tails have been intentionally left prominent for illustration purposes.

weighted linear mixed-effect model. The model residuals violated the principle of homoscedasticity, and therefore weighted regression modeling was used. Weights were created by regressing squared residuals on the fitted values and by calculating the reciprocal of the squared fitted values. Alpha level of .05 was used.

RESULTS

The mean maximum and plastic gap sizes were significantly smaller in the experimental repair group compared with the control repair group at all testing intervals from 2 through 500 cycles (all $P < .01$ and $P < .02$, respectively) (Table 1). After application of a weighted linear mixed-effect model, the difference in least-squares estimates between groups

remained statistically significant at all testing intervals from 2 through 500 cycles (all $P < .01$) (Table 2).

DISCUSSION

Compared with using a knotless suture anchor and suture tape repair technique, quadriceps tendon repair using adjustable cortical fixation demonstrated significantly smaller gap formation at all testing intervals. Tendon gap formation is a substantial concern during the early phases of postoperative rehabilitation after extensor mechanism repair. As a result, many surgeons employ an extensive period of immobilization before initiating range of motion exercises. These findings suggest that an adjustable cortical fixation technique is biomechanically effective for

TABLE 1
Comparison of Gap Size in Experimental and Control Groups^a

No. of Cycles	Gap Size, mm		P Value
	Experimental Repair	Control Repair	
Plastic gap			
1	N/A	N/A	N/A
2	0.52 ± 0.20	1.86 ± 1.16	.009
5	0.77 ± 0.27	2.23 ± 1.33	.013
10	1.04 ± 0.30	2.61 ± 1.34	.009
20	1.28 ± 0.40	3.02 ± 1.43	.008
50	1.77 ± 0.52	3.75 ± 1.48	.005
100	2.18 ± 0.68	4.32 ± 1.58	.005
200	2.62 ± 0.98	5.59 ± 1.65	.001
500	3.25 ± 1.10	6.57 ± 1.62	<.001
Maximum gap			
1	N/A	N/A	N/A
2	1.39 ± 0.45	3.37 ± 1.69	.009
5	1.68 ± 0.46	3.86 ± 1.80	.008
10	1.95 ± 0.48	4.34 ± 1.90	.006
20	2.26 ± 0.51	4.83 ± 2.04	.006
50	2.84 ± 0.79	5.69 ± 2.17	.005
100	3.40 ± 1.12	6.33 ± 2.31	.009
200	4.01 ± 1.57	7.65 ± 1.67	<.001
500	4.80 ± 1.56	8.47 ± 1.47	<.001

^aData are shown as mean ± SD. All differences were statistically significant, with $\alpha < .05$. N/A, not applicable.

protection against gap formation after quadriceps tendon repair. The goal of this technique is to allow the surgeon to intraoperatively cycle and retension the repair in order to determine the range of motion through which the knee can be moved without evidence of gapping. The patient could then be permitted to move the knee through that arc of motion immediately postoperatively. From that starting point, the range of motion could then be advanced in a graduated fashion, as is customary after extensor mechanism repair.

Our findings were similar to those of a previous biomechanical study that reported the biomechanical properties of an adjustable cortical fixation technique for patellar tendon repair.¹² Those investigators reported significantly smaller gap formation when using an adjustable cortical fixation technique compared with suture anchor repair (cycles, 1-20) and transosseous suture repair (cycles, 1-250). Furthermore, the adjustable cortical fixation technique demonstrated significantly higher load to failure compared with both control repairs.

Our results also compare favorably with previously published results for the transosseous and conventional suture anchor quadriceps tendon repair techniques. With regard to early displacement (cycles, 1-20), we observed a plastic gap with adjustable cortical fixation repair of 1.28 ± 0.40 mm up to 250 N of applied force compared with 5.1 ± 0.9 mm for conventional suture anchor repair and 6.3 ± 1.9 mm for transosseous repair with only 100 N of maximum force.⁷ Similarly, our early displacement maximum gap value of 2.26 ± 0.51 mm up to 250 N of applied force was comparable

TABLE 2
Comparison of Least-Squares Estimates From Weighted Linear Mixed-Effect Model^a

No. of Cycles	Difference Between Groups, mm	SE, mm	P Value
Plastic gap			
1	N/A	N/A	N/A
2	1.15	0.32	<.001
5	1.05	0.32	.001
10	1.11	0.36	.002
20	1.22	0.41	.004
50	1.58	0.52	.003
100	1.82	0.60	.003
200	2.73	0.77	<.001
500	3.23	0.91	<.001
Maximum gap			
1	N/A	N/A	N/A
2	1.53	0.39	<.001
5	1.64	0.44	<.001
10	1.83	0.48	<.001
20	2.01	0.54	<.001
50	2.41	0.63	<.001
100	2.56	0.71	<.001
200	3.68	0.85	<.001
500	3.85	0.95	<.001

^aAll differences were statistically significant, with $\alpha < .05$. N/A, not applicable.

with previously reported values for other repair methods up to 100 N of force: 3.2 ± 0.5 mm for titanium suture anchor repair, 3.9 ± 0.8 mm for hydroxyapatite suture anchor repair, and 12.2 ± 3.2 mm for transosseous repair.¹⁶ In terms of late displacement (cycles, ≥100), our adjustable cortical fixation technique showed plastic gap values of 2.18 ± 0.68 mm and 2.62 ± 0.98 mm at 100 and 200 cycles compared with 7.7 mm and 5 ± 4 mm for suture anchor repair and 10.7 mm and 8 ± 3 mm for transosseous repair at 130 and 250 cycles, respectively.^{6,21}

Our control repair was a modification of a previously reported knotless suture anchor and suture tape technique.^{7,15} We utilized 2 Krackow stitches in our control technique instead of the single Krackow stitch as previously described. This provided for consistency between the control technique and our experimental technique, which required 2 separate Krackow stitches to adequately secure the adjustable loop devices. Despite this modification, our cyclic displacement data with the knotless suture anchor and suture tape technique were similar to those previously reported for both early plastic gap formation (3.02 ± 1.43 mm vs 3.0 ± 0.8 mm and 3.6 ± 1.3 mm) and late plastic gap formation (5.59 ± 1.65 mm vs 4.9 ± 1.3 mm and 5.6 ± 1.7 mm).⁷ Of note, we did not test conventional transosseous repair or conventional suture anchor repair because knotless suture anchor and suture tape repair has been shown to be biomechanically superior to those established techniques.⁷

Gapping of 5 mm has been defined as a threshold of clinical failure in previous biomechanical studies of extensor mechanism repair.^{8,17} In our study, the knotless suture anchor and suture tape repair reached a 5-mm threshold

for maximum gap formation between 20 and 50 cycles and for plastic gap formation between 100 and 200 cycles. In the adjustable cortical fixation group, both maximum and plastic gap formation remained below this 5-mm threshold through 500 cycles of cyclic loading.

Aside from its biomechanical strength, quadriceps tendon repair using adjustable cortical fixation may be advantageous because it permits repeated cycling and retensioning of the repair while in the operating room. After seating the cortical fixation buttons at the inferior pole, the surgeon may cycle the knee and retension the adjustable loop devices to his or her satisfaction before ultimately tying off the lagging strands to finalize the repair. This ability to retension the repair creates the potential for stronger compression at the repair site, thereby maximizing the contact area and contact pressure between the quadriceps tendon and the superior pole of the patella. Although no previous study has investigated the effect of these factors on tendon-bone healing after extensor mechanism repair, increased contact area and contact pressure have been suggested to improve healing potential after rotator cuff repair.¹⁴ Another theoretical advantage of quadriceps tendon repair using adjustable cortical fixation is the potential to accommodate more aggressive rehabilitation protocols postoperatively. Accelerated functional rehabilitation after quadriceps tendon repair can protect against the development of knee stiffness and quadriceps atrophy, thereby expediting return to play in affected athletes.⁹

These advantages of quadriceps tendon repair using adjustable cortical fixation must be weighed against the potential disadvantages of our technique. The transosseous nature of the adjustable cortical fixation repair method necessitates a larger surgical exposure than does suture anchor fixation. It is not known whether the size of the surgical exposure is correlated with the risk of wound complications or surgical site infection in patients with extensor mechanism rupture. Compared with a conventional transosseous repair, larger-diameter (4-mm) tunnels must be drilled to accommodate the size of the cortical fixation button. However, this requirement for larger-diameter tunnels may be balanced by the fact that our technique utilizes only 2 transosseous tunnels rather than the 3 tunnels drilled in a conventional transosseous repair. Although patellar fracture and tunnel osteolysis have been reported after conventional transosseous repair,⁵ the comparative incidence of these complications between transosseous and suture anchor fixation techniques remains unknown. Another theoretical disadvantage of our technique is the potential for hardware irritation (particularly with kneeling) or patellar tendinitis due to the placement of the cortical fixation buttons at the inferior pole of the patella. However, disproportionate inferior pole irritation after conventional transosseous fixation has not been reported in the literature, as 2 previous systematic reviews found no difference in functional outcomes or overall complication rate between transosseous and suture anchor fixation techniques.^{3,20}

Several limitations to this study may be identified. The cadaveric design is inherently limited in that it does not

replicate the properties of live human tissue, and therefore the data are limited to time zero. The simulated quadriceps tendon avulsion was performed by sharply dividing the tendon from the superior patellar pole, which is not representative of the more ragged tendon morphology typically observed clinically. This study exclusively reported cyclic displacement and did not measure other biomechanical parameters, such as construct stiffness and ultimate load to failure. Our testing protocol included 500 cycles of loading. Although this is consistent with previous biomechanical studies, the number of cycles may not adequately simulate the loads experienced with an early functional rehabilitation protocol. Finally, we did not perform a comparative cost analysis of the 2 repair techniques.

CONCLUSION

A technique for quadriceps tendon repair using 2 adjustable cortical fixation devices demonstrated significantly smaller gap formation with cyclic loading compared with a modified suture anchor technique using knotless anchors and suture tape. Our results suggest that adjustable cortical fixation devices possess biomechanical properties that may make them effective for preventing tendon gap formation after quadriceps tendon repair.

ACKNOWLEDGMENT

The authors thank Lyn Camire, MA, ELS, for editorial assistance and Valerie Carbajal, BA, for assistance with cadaveric specimen preparation.

REFERENCES

1. Ahn HW, Seon JK, Song EK, Park CJ, Lim HA. Comparison of clinical and radiologic outcomes and second-look arthroscopic findings after anterior cruciate ligament reconstruction using fixed and adjustable loop cortical suspension devices. *Arthroscopy*. 2019;35(6):1736-1742.
2. Bin Abd Razak HR, Yeo EN, Yeo W, Lie TD. Short-term outcomes of arthroscopic TightRope[®] fixation are better than hook plate fixation in acute unstable acromioclavicular joint dislocations. *Eur J Orthop Surg Traumatol*. 2018;28(5):869-875.
3. Ciriello V, Gudipati S, Tosounidis T, Soucacos PN, Giannoudis PV. Clinical outcomes after repair of quadriceps tendon rupture: a systematic review. *Injury*. 2012;43(11):1931-1938.
4. De Baere T, Geulette B, Manche E, Barras L. Functional results after surgical repair of quadriceps tendon rupture. *Acta Orthop Belg*. 2002;68(2):146-149.
5. Gregory JM, Sherman SL, Mather R, Bach BR Jr. Patellar stress fracture after transosseous extensor mechanism repair: report of 3 cases. *Am J Sports Med*. 2012;40(7):1668-1672.
6. Hart ND, Wallace MK, Scovell JF, Krupp RJ, Cook C, Wyland DJ. Quadriceps tendon rupture: a biomechanical comparison of transosseous equivalent double-row suture anchor versus transosseous tunnel repair. *J Knee Surg*. 2012;25(4):335-339.
7. Kindya MC, Konicek J, Rizzi A, Komatsu DE, Paci JM. Knotless suture anchor with suture tape quadriceps tendon repair is biomechanically superior to transosseous and traditional suture anchor-based repairs in a cadaveric model. *Arthroscopy*. 2017;33(1):190-198.

8. Krushinski EM, Parks BG, Hinton RY. Gap formation in transpatellar tendon repair: pretensioning Krackow sutures versus standard repair in a cadaver model. *Am J Sports Med.* 2010;38(1):171-175.
9. Langenhan R, Baumann M, Ricart P, et al. Postoperative functional rehabilitation after repair of quadriceps tendon ruptures: a comparison of two different protocols. *Knee Surg Sports Traumatol Arthrosc.* 2012;20(11):2275-2278.
10. Larsen E, Lund PM. Ruptures of the extensor mechanism of the knee joint. Clinical results and patellofemoral articulation. *Clin Orthop Relat Res.* 1986;213:150-153.
11. Lighthart WA, Cohen DA, Levine RG, Parks BG, Boucher HR. Suture anchor versus suture through tunnel fixation for quadriceps tendon rupture: a biomechanical study. *Orthopedics.* 2008;31(5):441.
12. Ode GE, Piasecki DP, Habet NA, Peindl RD. Cortical button fixation: a better patellar tendon repair? *Am J Sports Med.* 2016;44(10):2622-2628.
13. O'Shea K, Kenny P, Donovan J, Condon F, McElwain JP. Outcomes following quadriceps tendon ruptures. *Injury.* 2002;33(3):257-260.
14. Ostrander RV III, McKinney BI. Evaluation of footprint contact area and pressure using a triple-row modification of the suture-bridge technique for rotator cuff repair. *J Shoulder Elbow Surg.* 2012; 21(10):1406-1412.
15. Paci JM, Pawlak A. Knotless tape suture fixation of quadriceps tendon rupture: a novel technique. *Am J Orthop (Belle Mead NJ).* 2018;47(1).
16. Petri M, Dratzidis A, Brand S, et al. Suture anchor repair yields better biomechanical properties than transosseous sutures in ruptured quadriceps tendons. *Knee Surg Sports Traumatol Arthrosc.* 2015; 23(4):1039-1045.
17. Ravaliin RV, Mazzocca AD, Grady-Benson JC, Nissen CW, Adams DJ. Biomechanical comparison of patellar tendon repairs in a cadaver model: an evaluation of gap formation at the repair site with cyclic loading. *Am J Sports Med.* 2002;30(4):469-473.
18. Rougraff BT, Reeck CC, Essenmacher J. Complete quadriceps tendon ruptures. *Orthopedics.* 1996;19(6):509-514.
19. Sanders D, Schneider P, Taylor M, Tieszer C, Lawendy AR; Canadian Orthopaedic Trauma Society. Improved reduction of the tibiofibular syndesmosis with TightRope compared with screw fixation: results of a randomized controlled study. *J Orthop Trauma.* 2019;33(11):531-537.
20. Serino J, Mohamadi A, Orman S, et al. Comparison of adverse events and postoperative mobilization following knee extensor mechanism rupture repair: a systematic review and network meta-analysis. *Injury.* 2017;48(12):2793-2799.
21. Sherman SL, Copeland ME, Milles JL, Flood DA, Pfeiffer FM. Biomechanical evaluation of suture anchor versus transosseous tunnel quadriceps tendon repair techniques. *Arthroscopy.* 2016;32(6): 1117-1124.
22. Vainionpaa S, Bostman O, Patiala H, Rokkanen P. Rupture of the quadriceps tendon. *Acta Orthop Scand.* 1985;56(5):433-435.
23. West JL, Keene JS, Kaplan LD. Early motion after quadriceps and patellar tendon repairs: outcomes with single-suture augmentation. *Am J Sports Med.* 2008;36(2):316-323.