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(Citation)
Knee Surgery, Sports Traumatology, Arthroscopy,30(7):2307-2313

(Issue Date)
2022-07

(Resource Type)
journal article

(Version)
Accepted Manuscript

Direct suturing quadriceps tendon to a continuous loop with a suspensory button provides biomechanically superior fixation in ACL reconstruction

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Declarations:

- **Conflict of interest**

  The authors declare that they have no conflict of interest.

- **Funding**

  There is no funding source.

- **Ethical approval**

  No ethics approval for this study was required by the institutional review board of our institute.
- **Informed consent**

  No informed consent for this study was required.

- **Acknowledgements**

  The authors thank Masato Nakanishi for assistance in creating the figure and Toshiki Hirai for providing the bovine knees.

- **Authors' contribution**

  Kanto Nagai (Ka.N.), Yuichi Hoshino (Y.H.), Daisuke Araki (D. A.), Noriyuki Kanzaki (N.K.) Takehiko Matsushita (T.M.), and Ryosuke Kuroda (R.K.) conceived the study, and Kohei Kamada (K.K.), Ka.N., and Y.H. participated in the design of the study. K.K., Ka.N., and Kouki Nagamune (Ko. N.) performed the biomechanical testing. K.K. and Ka. N. conducted the pertinent statistical tests and analyses. All authors participated in the interpretation of the data. K.K., Ka.N., Yuta Nakanishi (Y.N.) wrote the manuscript, and all authors performed critical revision of the manuscript for intellectual content. All authors have read and approved the final manuscript.

- **Number of words:**

  Abstract

  349 words

  Manuscript (excluding abstract and references)

  2530 words

Abstract

Purpose: To compare the biomechanical strength of different fixation configurations using suspensory buttons in a soft-tissue quadriceps tendon (QT) grafts in anterior cruciate ligament (ACL) reconstruction.

Methods: 40 bovine QTs, 6-cm long and 10-mm wide, were allocated into four groups with different suture configurations using suspensory buttons (n=10 in each group): Group A, a baseball suture with a knot tied to the continuous loop with a suspensory button; Group B, same configuration as in Group A but with the knot tied at the opposite end of the baseball suture; Group C, a continuous loop with a suspensory button stitched directly to the QT with simple sutures; and Group D, a baseball suture tied directly to a suspensory button. Biomechanical testing was performed by preloading followed by cyclic loading for 500 cycles between 10 and 100 N. The length of elongation (mm) and maximum load to failure (N) were recorded, and compared among the four groups.

Results: Group C showed significantly smaller elongation (4.1 mm [95%CI: 3.1–5.2]) than Group A (8.2 mm [95%CI: 7.0–9.4]), Group B (10.5 mm [95%CI: 7.7–13.3]), and Group D (8.5 mm [95%CI: 7.0–9.9]) (A-C; P = 0.004, B-C; P = 0.0001, C-D; P = 0.0018). The maximum load to failure in Group C (386 N [95%CI: 306–466]) was significantly higher than that in Group A (196 N [95%CI: 141–251]), Group B (226 N [95%CI: 164–289]), and Group D (212 N [95%CI: 171–253]) (A-C; P = 0.0001, B-C; P = 0.0009, C-D; P = 0.0002). No significant differences were observed between Group A, B, and D in terms of elongation and maximum load to failure.

Conclusion: The soft-tissue QT graft fixation configuration stitched directly to a continuous loop with suspensory button using simple sutures exhibits small elongation and high maximum load to failure among the four configurations. Regarding clinical relevance, direct suturing of the soft-tissue QT to a continuous loop with a suspensory button may be advantageous for femoral fixation in ACL reconstruction from a biomechanical perspective, and warrant future development of a novel fixation device using this principle.

Keywords: anterior cruciate ligament, quadriceps tendon, graft fixation, soft-tissue, biomechanical study

Introduction

Although hamstring tendon (HT) or bone patellar tendon bone (BPTB) are the most commonly used in anterior cruciate ligament (ACL) reconstruction, the quadriceps tendon (QT) graft has recently gained great interest as an autograft for ACL reconstruction[8, 24]. Several studies have reported that the QT has more advantages than BPTB, such as versatility and decreased morbidity at the harvest site [8, 14, 34]. In addition, clinical outcomes of ACL reconstruction using the QT, including postoperative stability and flexor muscle strength recovery, are equal to or better than those of the conventional HT and BPTB in primary or revision ACL surgery[3, 10, 13, 21, 25, 27]. Some cadaveric studies demonstrated greater biomechanical properties of QT graft than of HT or BPTB grafts with respect to thickness and stiffness[29, 30]. Furthermore, the QT exhibits stronger microstructural and mechanical properties than the HT and BPTB[4].

A unique characteristic of QT grafts is their versatility: they can be harvested with or without a patellar bone block, and with full thickness or partial thickness. Primary ACL reconstruction using QT autografts appears to have successful outcomes with a low rate of graft failure, irrespective of tendon thickness[17] and the use of a bone block[5]. However, a systematic review demonstrated that soft-tissue QT grafts showed smaller postoperative rotatory instability and fewer complication profiles than the QT with a bone block[5]. Especially in skeletally immature patients, soft-tissue QT grafts are preferable for physeal-respecting reconstruction[19, 31, 32].

The graft preparation strategy is crucial for ACL reconstruction with a soft-tissue QT. Femoral fixation of soft-tissue QT grafts is usually secured using a suspensory button[6]. Some authors have reported that a suspensory button with a suture loop was used for one-stranded QT soft-tissue graft fixation on the femoral side[12, 36], while others have reported techniques for soft-tissue QT fixation using an adjustable loop device[16, 28, 33, 35]. Therefore, surgeons seem to use various fixation techniques in the clinical setting. A recent biomechanical study investigated the effects of different stitching methods and suture diameters on graft fixation of soft-tissue QT grafts[23]. However, the biomechanical strength of fixation configurations using a suspensory button has not been investigated, and thus remains uncertain.

Therefore, the purpose of the present study was to compare the biomechanical strength of different fixation configurations using a suspensory button in soft-tissue QT graft in ACL reconstruction. The hypotheses were that (1) a continuous loop with suspensory button stitched directly to the QT with simple sutures would have smaller elongation and higher maximum load to failure than the other configurations, and (2) a baseball suture tied directly to a suspensory button would have larger elongation and a lower maximum load to failure than the other configurations. The novelty of the present study is that it compares the biomechanical strength of the fixation configurations using a suspensory button, so it could reflect clinical situation more closely than previous reports, and the findings of the present study will provide surgeons novel knowledge about femoral fixation of soft-tissue QT grafts in ACL reconstruction.

Materials and methods

Forty fresh-frozen bovine knees were used in the present study. The use of bovine knees, which were originally processed for food consumption, did not require approval from an institutional review board. The frozen bovine knees were thawed at room temperature for 24 hours, and tested immediately after thawing. Forty QTs, 10-mm wide and 60-mm long, were harvested as partial-thickness grafts without a patellar bone block. Soft-tissue QTs were allocated into four groups (n = 10 in each group) with different suture configurations using a suspensory button (ENDOBUTTON CL, Smith & Nephew Inc., Boston, MA, USA) according to previous reports[35, 36]; Group A, a baseball suture with a knot tied to the continuous loop with a suspensory button (ENDOBUTTON CL 20 mm); Group B, the same configuration as in Group A but with the knot tied at the opposite end of the baseball suture (ENDOBUTTON CL 20 mm); Group C, a continuous loop with a suspensory button (ENDOBUTTON CL 35 mm) stitched directly to the QT with eight simple sutures, and 15mm of 30mm loop was stitched to the QT; and Group D, a baseball suture tied directly to a suspensory button (**Figure 1**). All baseball sutures and simple sutures were created with #2 ULTRABRAID (Smith & Nephew) and by a single experienced surgeon. The number of baseball sutures was standardized among the groups (four times on each side). All knots were secured by tying them five times[15].

Biomechanical Testing

The sutured QT was set in a originally developed tensile testing machine with an aluminum frame and a custom clamp[26]. The distal 1 cm of the tendon was secured with a clamp, and the button was mounted on an aluminum frame that mimicked the bone cortex (**Figure 2**). A gauze was tied around the site of the tendon where it was clamped to prevent slippage of the tendon from the clamp [1]. The tensile testing machine consisted of an electric actuator (PWA II Cylinder; Oriental Motor, Tokyo, Japan), which moved the cylinder and pulled the QT while the load cell (LCTA-A-1KN; Kyowa Electronic Instruments, Tokyo, Japan) measured the tensile force. The load cell signal was transferred to a personal computer via a load cell amplifier (TUSB-S01LC2Z; Turtle Industry, Linden, NJ, USA). The resolution of the electric actuator was 0.01 mm, and the load cell was set at 1.0×10^{-6} N. A metric ruler with 1-mm increments was positioned parallel to the clamp to serve as a calibration scale for image processing, as described later. Preloading was performed at 50 N for five loading cycles and then statically held at 50 N for 1 minute. Next, each specimen was cyclically loaded for 500 cycles between 10 and 100 N at a frequency of 1 Hz. The protocol was determined based on that in previous reports[2, 7, 23].

Subsequently, a digital photograph (OM-D E-M10; Olympus Corporation, Tokyo, Japan) was taken with the QT under a 20-N load at each step of the process; before preloading, after preloading, and after cyclic loading. The length of the graft complex (mm) was defined as the distance between the suspensory button and the edge of the clamp (**Figure 2**), and measured at each step using image processing software (ImageJ, United States National Institutes of Health, Bethesda, MD, USA). Specifically, the digital photographs were uploaded using ImageJ, which can be used as an electronic ruler, as previously described[26]. Using this software, 50 mm was measured as pixels on the metric ruler to serve as the standard scale for calibration. The resolution using ImageJ was 0.04 mm/pixel. Graft elongation (mm) was defined as the difference in the graft length after preloading and 500 cyclic loading: the length of the graft after preloading (mm) – the length of the graft after cyclic loading (mm). Two examiners with 20 specimens calculated the inter-examiner reproducibility of the elongation measurements by calculating the inter-rater intraclass correlation coefficient (ICC). The inter-rater ICC was 0.95 (95% confidence interval [CI]: 0.88–0.98), indicating good to excellent reliability[18]. Finally, load-to-failure testing was conducted at 5 mm/min. The maximum load to failure (N) and the failure mode of each specimen were recorded.

Statistical Analysis

Statistical analysis was performed using Graphpad Prism 9 (GraphPad Software, San Diego, CA, USA). One-way analysis of variance (ANOVA) was used to explore differences in graft elongation and maximum load to failure between the four groups, and the Tukey test was used to perform post-hoc multiple comparison analysis. Data are reported as the mean (95% CI). Statistical significance was set at $P < 0.05$.

The sample size was determined by power analysis based on data from the pilot study using G*Power 3.1, as described in previous reports[2, 23]. A prior sample size calculation revealed that an elongation difference of 3 mm would be detectable in four groups with a sample size of 36 (9 in each group) by using one-way ANOVA (effect size = 0.6, with an α of 0.05 and a power of 0.8).

Results

Graft Elongation

Group C showed significantly smaller elongation (4.1 mm [95%CI: 3.1–5.2]) than Group A (8.2 mm [95%CI: 7.0–9.4]), Group B (10.5 mm [95%CI: 7.7–13.3]), and Group D (8.5 mm [95%CI: 7.0–9.9]) (A-C; P = 0.004, B-C; P = 0.0001, and C-D; P = 0.0018, **Figure 3**). No significant differences were observed between Group A, B, and D.

Maximum Load to Failure

The maximum load to failure in Group C (386 N [95%CI: 306–466]) was significantly higher than that in Group A (196 N [95%CI: 141–251]), Group B (226 N [95%CI: 164–289]), and Group D (212 N [95%CI: 171–253]) (A-C; P = 0.0001, B-C; P = 0.0009, C-D; P = 0.0002, **Figure 4**). No significant differences were observed between Group A, B, and D.

Failure Mode

Analysis of the mode of failure showed differences between the groups, as summarized in **Table 1**. The characteristic failure mode of Group A and B was suture pull-out (7 of 10 and 7 of 10 specimens, respectively). In Group C, the typical mode of failure was graft shredding at the stitch (8 of 10 specimens). In Group D, suture breakage was observed in 7 of 10 specimens. Tendon slippage from the clamp was observed in 5 of 40 specimens (1 in Group A, 2 in Group B, 2 in Group C). Tendons in which slippage from the clamp occurred were not included in the analysis of the maximum load to failure.

Discussion

The most important finding of the present study was that soft-tissue QT graft fixation configuration in Group C (a continuous loop with a suspensory button stitched directly to the QT with simple sutures) showed smaller elongation and a higher maximum load to failure than that in the other groups, which supported the first study hypothesis. The current study provides biomechanical testing comparison results of four different fixation configurations for soft-tissue QT using a suspensory button. The present findings suggest that the direct stitch to the suspensory button device may be better for femoral fixation using a suspensory button in soft-tissue QT grafts to minimize elongation of the complex of the graft and suspensory button.

Recently, QT grafts have been more frequently used in ACL reconstruction than ever before[8, 24]; however, surgeons seem to use various fixation techniques in clinical settings and there is no standardized fixation technique[12, 16, 28, 33, 35, 36]. A recent biomechanical study showed that QT grafts have mechanical properties similar to those of six-strand HT grafts[37]. Another study investigated the effects of different stitching methods and suture diameters on graft fixation of soft-tissue QT grafts[23]. The authors reported that the double Krackow stitch with a no. 2 braided composite suture exhibits a high maximum load to failure combined with a small amount of elongation[23]. Although there is concern that the connecting part with the loop of the suspensory button might loosen and elongate due to cyclic loading, the biomechanical strength of fixation configurations using a suspensory button has not been investigated. Todor et al. reported a technique for harvesting a free bone QT graft and attaching a suspensory button for femoral fixation in ACL reconstruction[36]. In their techniques, the knots were tied through the button loop with the high-strength sutures placed initially to secure the button to the graft, which is similar to the fixation configurations in Group A and B in the current study. The present findings for Group A and B showed that the position of the tied knot was not significantly related to the amount of elongation and failure load when the configurations were the same.

The fixation configurations used in Group C in the present study was similar to the methods described by Sprowls et al.[35] with respect to securing the loop of the suspensory button directly to the QT graft. Their fixation methods secured the adjustable suspensory loop device to the superior surface of the graft with a free suture. In the past, several reports described fixation techniques to secure the suspensory devices to the graft using a FiberLoop with a tag[28, 33]. In contrast, Hughes et al. reported a unique method in which the graft was secured with a continuous loop fixation device using a rip-stop stitch[12]. However, there is currently no consensus on which fixation configurations is superior.

The present study results suggest that stitching a continuous loop with a suspensory button directly to the QT with simple sutures may be advantageous in an *in vitro* environment, although friction between the bone tunnel and the graft complex may be higher than that in other configurations at the time of graft insertion in the clinical setting. Hence, these graft configurations need to be verified in an *in vivo* clinical situation in future studies.

Interestingly, the elongation of Group D (a baseball suture tied directly to a suspensory button) was not significantly different from that of Group A and B, which is contrary to the second study hypothesis. The typical failure mode in Group A and B was a suture pull-out, whereas in Grouo D, the typical failure mode was suture breakage. The advantage of the suture method in Group D is that it is a simple and straightforward fixation configuration in the clinical setting. Moreover, one could assume that the use of a stronger thread, such as a tape-type suture[20], may increase the biomechanical strength of the fixation configuration in Group D. Thus, a baseball suture tied directly to a suspensory button would be another option for soft-tissue QT graft fixation on the femoral side.

The present study has some limitations. First, bovine QTs were used. However, bovine tendons have been commonly used for biomechanical testing of suture methods in previous studies[2, 9, 11, 22], and the results could be translated into clinical practice. Second, in the present *in vitro* study, only distraction force was applied in one direction, mainly because of the testing apparatus. However, this is a common limitation for all biomechanical tensile testing of tendons because of the difficulty in reproducing the complex combination of distraction, shear, and compression forces in the *in vivo* knee. Third, fixation methods using locking stitch, suture-loop with a tag, or adjustable loop button devices were not investigated. Finally, the present study was a biomechanical time-zero experiment, and it could not consider the biological healing of the graft *in vivo*.

Regarding clinical relevance, direct suturing the soft-tissue QT to a continuous loop with a suspensory button may secure rigid femoral fixation in ACL reconstruction from a biomechanical perspective. Thus, this suture configuration may be recommended in ACL reconstruction using the soft-tissue QT graft when a suspensory button is used for femoral fixation. Additionally, the present findings warrant future development of a novel fixation device for soft-tissue QT using this principle.

Conclusions

Soft-tissue QT graft fixation configuration stitched directly to a continuous loop with a suspensory button using simple sutures exhibited small elongation and a high maximum load to failure among the four configurations in the current time-zero biomechanical study. Concerning clinical relevance, direct suturing of the soft-tissue QT to a continuous loop with a suspensory button may be advantageous for femoral fixation in ACL reconstruction from a biomechanical perspective, and warrant future development of novel fixation device using this principle.

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7(10):2325967119879113

Figure Legends

Figure 1. Four fixation configurations of soft-tissue quadriceps tendon graft using a suspensory button

A: Schematic representations. Group A, baseball suture with knot tied to the continuous loop with suspensory button; Group B, same configuration as Group A but knot tied at opposite end of the baseball suture; Group C, a continuous loop with suspensory button stitched directly to the QT with eight simple sutures; Group D, baseball suture tied directly to a suspensory button.

B: The picture shows four types of different configurations (Group A, B, C, D)

Figure 2. Testing set up: The distal 1 cm of the tendon was secured with the clamp, and the button was mounted on the aluminum frame that mimicked a bone tunnel.

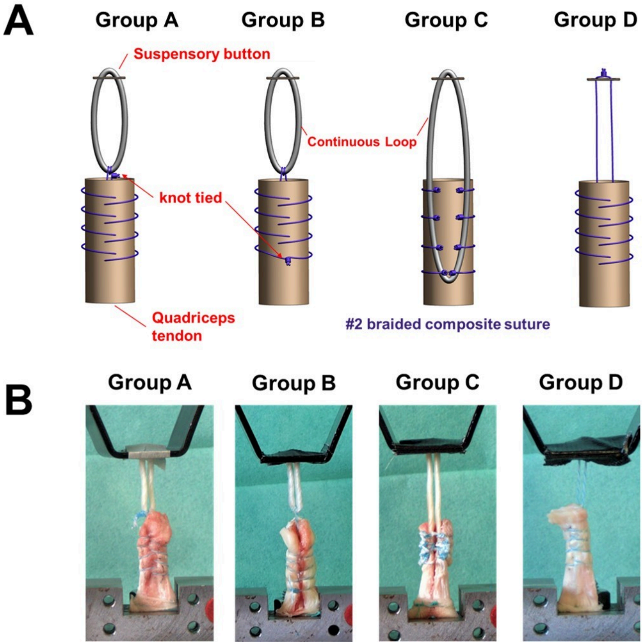
Figure 3. Results of graft elongation after 500 cyclic loading. The graft elongation in Group C was significantly smaller than that in Group A, Group B, and Group D. No significant differences were observed between Group A, B, and D.

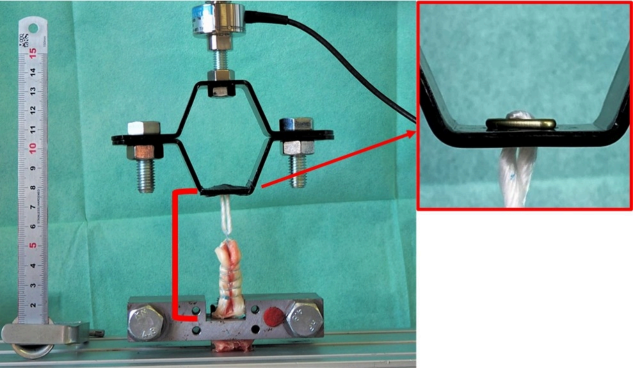
Figure 4. Results of maximum load to failure. The maximum load to failure in Group C was significantly higher than that in Group A, Group B, and Group D. No significant differences were observed between Group A, B, and D.

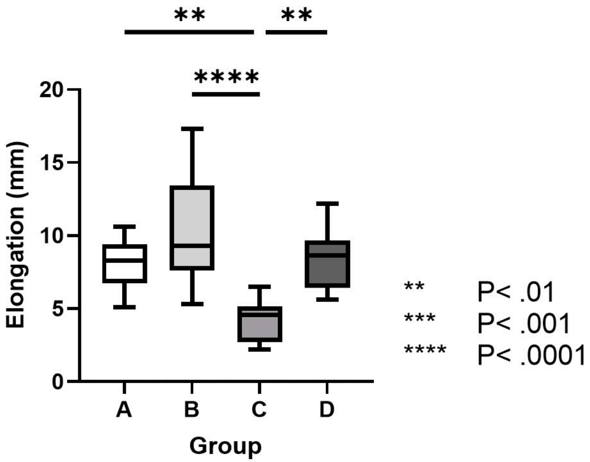
Tables

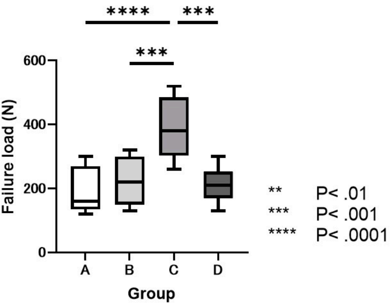
Table 1. Summary of failure mode.

Fixation Configurations	Failure Mode			
	Graft Shredding at the stitch	Suture Pull-Out	Suture Breakage	Slippage from the clamp
Group A	0	7	2 (1 in the knot)	1
Group B	0	7	1	2
Group C	8	0	0	2
Group D	0	3	7 (3 in the knot)	0


A
Group A
Group B
Group C
Group D
Suspensory button
Continuous Loop
knot tied
Quadriceps tendon
#2 braided composite suture
B
Group A
Group B
Group C
Group D




**
**
****
20
15
10
5
0
Elongation (mm)
A
B
C
D
Group
** P< .01
*** P< .001
**** P< .0001



****
***
***
600
400
200
0
Failure load (N)
A
B
C
D
Group
** P< .01
*** P< .001
**** P< .0001