Mechanical Analyses of Quadriceps Tendon Graft with Five Different Fixation Techniques on the Femoral Side: an Experimental Study on Sheep Knees

Mechanická analýza štěpu šlachy kvadricepsu fixovaného pěti různými technikami na femorální straně: experimentální studie na ovčích kolenech

M. ÇETİN[1], M. S. SÖYLEMEZ[2], B. Y. ÖZTÜRK[2], İ. MUTLU[3], Ö. KARAKUŞ[4]

[1] Fatih Sultan Mehmet Training and Research Hospital, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[2] Umraniye Training and Research Hospital, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[3] Kocaeli University, Faculty of Technology, Department of Biomedical Engineering, Istanbul, Turkey
[4] Balikesir State Hospital, Department of Orthopaedics and Traumatology, Balikesir, Turkey

ABSTRACT

PURPOSE OF THE STUDY

We aimed to evaluate the biomechanical properties of quadriceps tendon graft with a bone plug ending (QTBP) and a quadriceps graft with a tendinous ending(QTT) fixed on the femoral side with different fixation devices.

MATERIAL AND METHODS

Twenty-five paired 2-year-old calf QTs and 25 paired 2-year-old sheep femurs were used for this study. 90x8 mm central part of the quadriceps tendons with or without a bone plug was harvested. 8×25 mm tunnel was placed in lateral condyles. The QTT was fixed with four different fixation devices, including the adjustable suspensory system (QTT-ASS, group 1), biodegradable interference screws (QTT-BIS, group 2), titanium interference screws (QTT-TIS, group 3), and an adjustable suspensory system + biodegradable interference screws (QTT-(ASS+BIS), group 4); QTBP was fixed with titanium interference screws (QTBP-TIS, group 5). All groups were tested in a servohydraulic materials testing machine. Stiffness(N/mm), slippage of the tendon(mm), and the ultimate tensile load-bearing ability(N) of the groups were tested. The Kruskal–Wallis H test was used with the Monte Carlo simulation technique to compare the nonparametric variables of stiffness, slippage, and ultimate tensile load. Dunn's test was used for the post hoc analyses.

RESULTS

Group 3 had the stiffest fixation (median 45.09 N/mm). The amount of slippage was highest in group 1(median 6.41mm). Group 1 was the most resistant group against a tensile load during the load-to-failure test(464 N). Fixing the QTT with the ASS and BIS in group 4 increased both stiffness and ultimate tensile load strength. There was no significant difference between the QTBP and QTT fixed with titanium screws. Fixing QTT with titanium screws was significantly superior to fixation with BIS($p < 0.05$).

CONCLUSIONS

This study demonstrates that QTBP fixation with TIS have no advantage over QTT fixation with TIS on the femoral side. Although the QTT group fixed with ASS was the most resistant group against tensile forces during load-to-failure test, amount of slippage was highest for this group as well. Thus, if an ASS is to be used, a strong tension force must be applied prior to tibial side fixation to prevent further slippage of the graft in the tunnel.

Key words: anterior cruciate ligament, quadriceps tendon graft, femoral side, fixation, biomechanical properties.

INTRODUCTION

Different graft types, fixation techniques, and devices are used to obtain a stable knee after anterior cruciate ligament (ACL) reconstruction surgery. The main objective is to achieve quick recovery, cause less morbidity, and prevent further laxity of the knee due to failure of fixation or re-rupture of the ligament. The use of allografts has decreased for various reasons (8, 16). Anterior knee pain, patellar tendon rupture, and fat pad herniation to the donor area are common problems after BPTB graft harvesting, whereas ACL agonist muscle weakness and disruption of the protective ACL proprioceptive arc are reported donor-site morbidities after hamstring graft harvesting (29). However, the quadriceps tendon (QT) offers excellent biomechanical strength, a large cross-sectional area, appropriate length, less donor-site morbidity, and a bone plug that can be harvested from the patella (17, 28). Thus, the QTBP and QTT have been proposed as alternatives to reconstruct the ligament during ACL revision surgery or in knees with multi-ligament injury and/or deficiency (4, 9, 13, 20, 23, 26).

The weakest point of the reconstructed ligament at postoperative early stage is not the graft itself but the fixation interference point at the tunnel (4). Therefore, it is very important to use the best fixation technique and device to obtain a stiff and durable fixation. A robust and reliable fixation will allow early rehabilitation, early return to work or sports, and prevent early failure (1, 5). However, the following questions need to be clarified. Which device is biomechanically superior to fix the quadriceps tendon on the femoral side? Is QTBP superior to QTT in terms of allowing a stiffer fixation? (17) Previous studies have reported stiffer fixation of QTT on the femoral side with biodegradable interference screws (BIS) compared to EndoButtons (4, 10). However, the use of EndoButtons has decreased after the introduction of the adjustable suspensory system (ASS), as this system compresses the graft to the lateral cortex, which prevents further slippage and knee laxity. Although the successful use of ASS in fixation of hamstring grafts on the femoral side has been reported, limited data and studies are supporting their use for fixation of the QTT on the femoral side (21). In addition, no study has compared the biomechanical aspects of QTBP and QTT fixed either with TIS and compared them with the ASS device (7). We hypothesised that using an ASS device for fixation off QTT may perform as good as QTBP fixed with TIS or a QTT fixed with BIS and intended to investigate whether there is a biomechanical difference between the QTBP and QTT fixation techniques in terms of stiffness, the amount of slippage, and ultimate tensile load-bearing ability of the ASS, BIS, and TIS.

MATERIAL AND METHODS

This research has been approved by the institutional review board of the authors affiliated institutions. Twenty-five paired 2-year-old calf QTs and 25 paired 2-year-old sheep femurs were used for this study. The combination of sheep femurs with calf QTs was chosen because some biomechanical studies have reported their similarity to adult bone-ligament constructs (11, 15). Five groups, each including 10 samples, were created. All materials were obtained from a butcher after routine morning slaughter sessions. No animal was sacrificed specifically for this study. The sheep femurs were cleaned of all muscle, and calf tendons were freed from the muscles and non-ligamentous material and stored at 4° C during transfer to the laboratory and all materials were used within 12 h of sacrifice of the animal (11, 12). All material was kept in moistened dressings until the experiment and a physiological saline solution spray was used to keep the tendons moist until the experiment.

All grafts and tunnels were prepared in the same manner. A 90 mm long full-thickness central part of the quadriceps tendons with or without a bone plug from the calf knees was harvested and trimmed to pass through an 8 mm sizing tube. A 8×25 mm tunnel was placed in lateral condyles. The lateral cortex of the lateral condyles for groups 1 and 4 were prepared using an additional 4.5 mm cannulated drill to widen the lateral cortex for passage of the titanium button.

Group 1. QTT-ASS (Artrolift™, Artrotek, Ankara, Turkey). This is an adjustable suspensory cortical fixation system consisting of a braided continuous loop and a titanium button. The prepared QT was split into two tails leaving the 1.5 cm patellar end intact. ASS was passed through two tails of the tendon and incorporated on the intact end. The split tails were re-sutured with Cracow sutures keeping the two braided sides of the loop inside of the sutures. This technique added extra strength to the patellar end of the QT, tubularized the tendon, and centralized the loop on both sides of the QT that was placed in the tunnel (18). Then the ASS was introduced with a carrier rope, titanium button was seated on the lateral cortex, and the QT was passed and compressed against the lateral cortex by tensioning the ropes at the entrance of the tunnel. (Fig. 1).

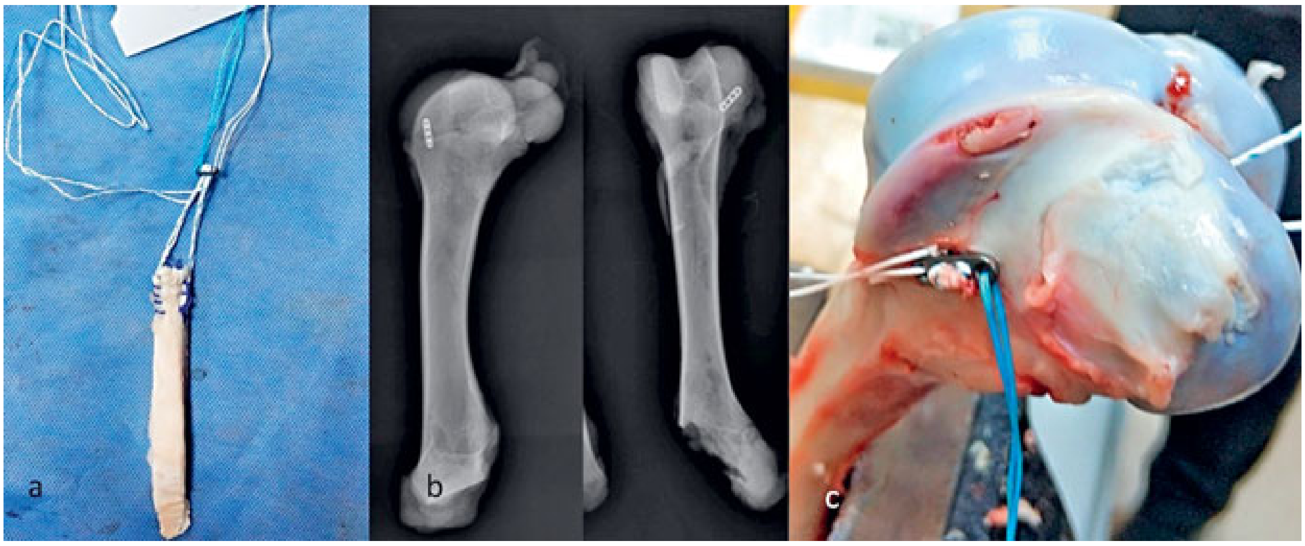

Fig. 1. a – QTT graft prepared with the ASS device; b – AP and lateral X-rays showing the placement of the ASS and tunnel position; c – titanium button passed from the tunnel and seated on the lateral cortex before loading the tendon into the tunnel.

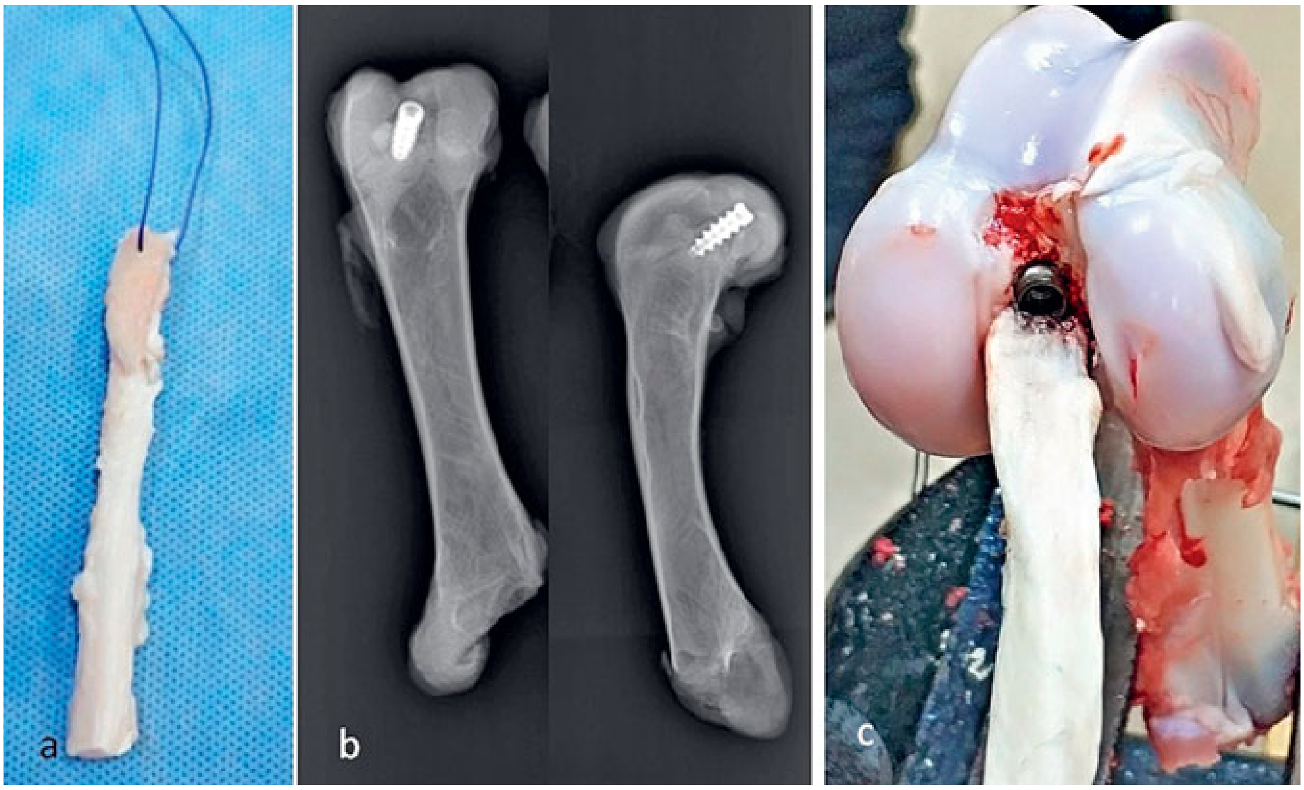

Fig. 2. a – QTBP graft prepared for the experiment; b – AP and lateral X-rays showing the QTBP fixed with TIS in the tunnel; c – sample number 2 from group 5.

Group 2. QTT-BIS (LockAktiv™, Noraker, Lyon, France). This was an 8.0×23 mm round-headed cannulated bioactive glass interference screw with a non-tapered design. The patellar end of the prepared QT was sutured with a locking whipstitch. QT was passed through the tunnel and fixed with BIS placed anterior to the graft.

Group 3. QTT-TIS (Artroline™, Artrotek, Ankara, Turkey). This was an 8.0 × 25 mm round-headed cannulated titanium interference screw with a non-tapered design. QT was prepared as in group 2 and was fixed with the TIS placed anterior to the graft.

Group 4. QTT-(ASS+BIS). The QT and femur were prepared and the tendon was fixed to the femur with an

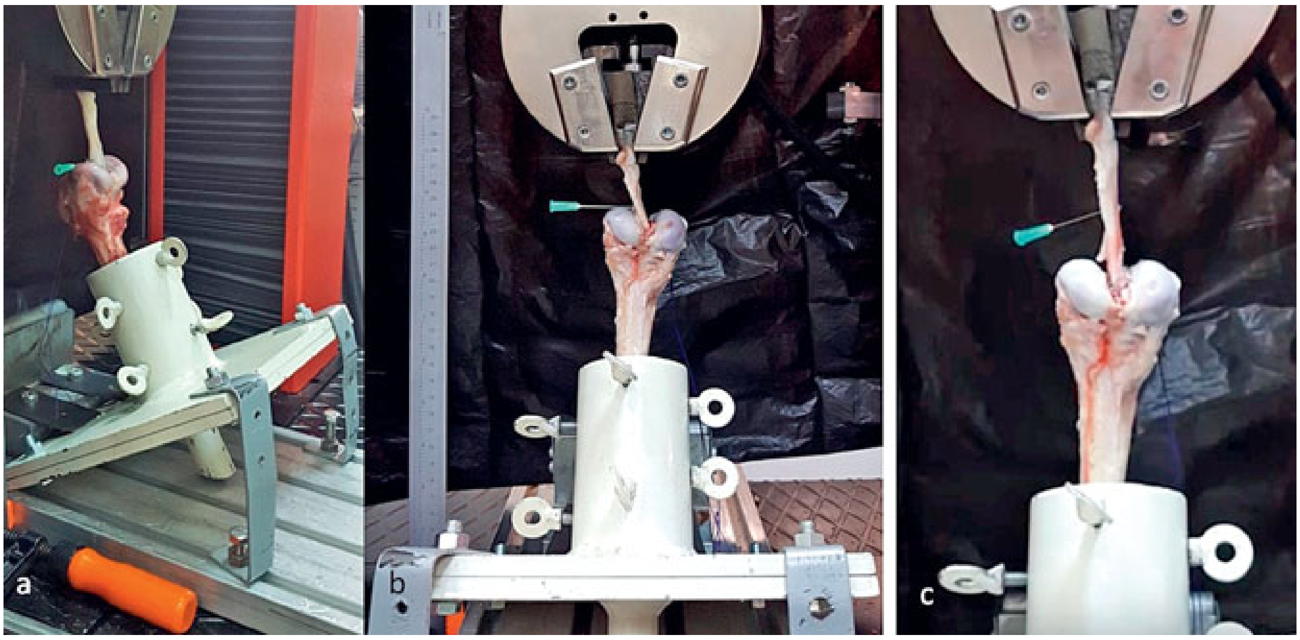

Fig. 3. Experiment set-up: a – alignment of the graft was adjusted in the same axis as the tensile load; b – a sample before the tensile load-to-failure test in group 2 pretensioned at 10 N (sample number 5); c – the graft failed within the BIS–tendon–bone interface. Note: The needle is placed to show graft movement.

ASS as in group 1. Then, additional fixation with BIS as in group 2 was carried out while QTT was tensioned as strong as possible.

Group 5. QTBP-TIS. The central part of the calf QT was harvested with a bone plug and prepared as usual. The length of the bone plugs were 1.5 cm for all samples. A single 1.0 mm hole was drilled into the bone and a non-absorbable suture was passed through the drill hole (Fig. 2). The graft was passed through the tunnel and was fixed with TIS placed anterior to the graft.

Sheep bones were attached to a custom-made jig to prevent movement of the bone. The grafts were attached to the mobile cell of the machine with a tendon holder on the upper side. The alignment of the graft was adjusted parallel to the loading vector to eliminate the effect of the tunnel position on the failure. All groups were tested in a servohydraulic materials testing machine (Test Control Systems, TCS Universal) (Fig. 3). After applying a 10 N preload, a cyclic force from 10 to 110 N was applied for 20 cycles at a 1 Hz frequency to replicate cycling performed in the operating room before the tibial portion of the graft is fixed. The amount of slippage was calculated as the difference measured in millimeters between length at 10 N after 20 cycles and starting length at 10 N using the TCS Universal software (Figure 4). To determine the ultimate tensile load-bearing ability (N), a single load-to-failure cycle was performed at a strain rate of 20 mm/min as the last step (7, 24). Than, Stiffness (N/mm) was calculated using the the TCS Universal software. A significant deviation in linearity of the load-deformation curve during the load-to-failure test indicated failure within the device–tendon–bone interface or graft–tunnel separation.

The SPSS 25.0 (IBM Corp., Armonk, NY, USA) program was used to analyze the data. The Kruskal–Wallis H test was used with the Monte Carlo simulation technique to compare the nonparametric variables of stiffness (N/mm), slippage (mm), and ultimate tensile load (N). Dunn's test was used for the post hoc analyses. Variables were examined at a 95% confidence level, and a p-value < 0.05 was considered significant.

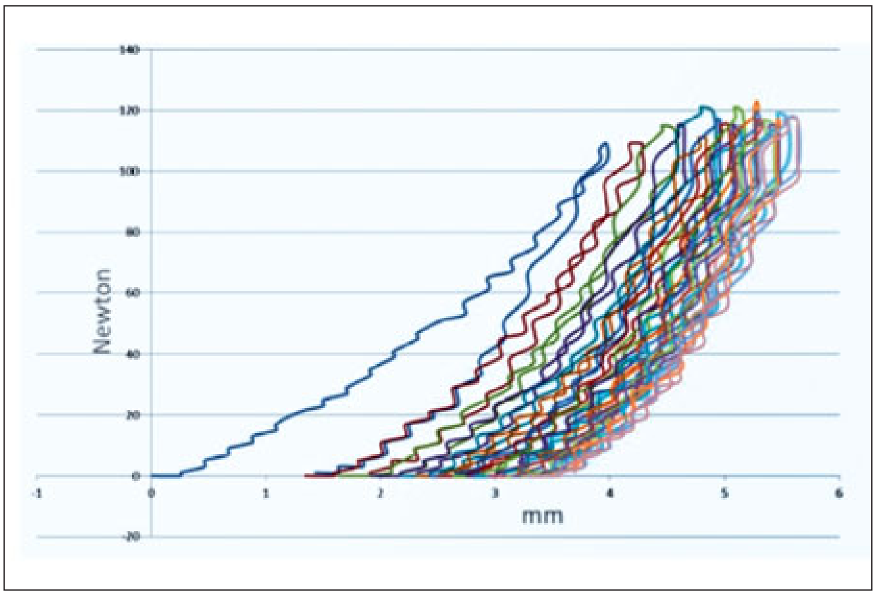

Fig. 4. A graphic obtained from the software showing the amount of slippage during 20 cycles from 10 N to 110 N at a 1 Hz frequency (from group 3, sample 5).

RESULTS

Intrasubstance rupture of the graft was not seen in any of the samples. Failure of fixation was not detected in any of the samples during the first 20 cycles. None of the samples were discarded from the mobile cell or jig during the experiments. The median stiffness value, amount of slippage, and the ultimate tensile load at the load-to-failure test for every group are shown in Table 1.

Group 1. The mode of failure was detachment of the QTT from the loop in nine samples and pull-out of the titanium button in one sample (sample number 5). None of the loops ruptured in any of the samples.

Group 2. The mode of failure was QTT slippage within the screw–tendon–bone interface for nine samples and BIS pull-out in one sample (sample number 4, Fig. 3c).

Group 3. The mode of failure was QTT slippage within the screw–tendon–bone interface in eight samples and TIS pull-out in two samples (sample numbers 4 and 8).

Group 4. The mode of failure was detachment of the QTT from the loop after slippage within the screw–tendon–bone interface in eight samples and pull-out of the titanium button and BIS in two samples (sample numbers 4 and 9). None of the loops ruptured in any of the samples. A small deviation in the linearity of the load-deformation curve smaller than 0.5 mm was detected during the load-to-failure test for this group. Then the linearity of the load-deformation curve continued to increase until failure.

Group 5. The mode of failure was QTBP slippage within the TIS–tendon–bone interface in nine samples and the QT peeled from the bone plug in one sample (sample number 6).

No significant difference in stiffness was observed between the groups (p = 0.0951). QTT-TIS had the stiffest fixation, while the QTT-ASS had the least stiff fixation (Table 1 and 2). A significant difference in slippage was detected between the groups. The amount of slippage was highest in the QTT-ASS and QTT-BIS groups and lowest in the QTT-TIS group (p < 0.001, Fig. 4). A significant difference in ultimate tensile load was detected during the load-to-failure test between the groups. The QTT-ASS group was the most resistant group against tensile load, and QTT-BIS was the weakest ($p < 0.001$). Post hoc analyses revealed no significant difference between the QTBP and QTT fixed with titanium screws for any of the factors tested. However, fixing the QTT with titanium screws was significantly superior to fixing with biodegradable screws for all of the factors tested (Table 2). Fixing QTT with both the ASS and BIS in group 4 increased stiffness and ultimate tensile load strength and also decreased the amount of slippage.

DISCUSSION

We hypothesised that using an ASS device for fixation off QTT (group 1) may perform as good as QTBP fixed with TIS (group 5) or a QTT fixed with BIS (group 2). This study shows that; although stiffness and slippage was comparable between group 1 and 2; statistically (group 1) was better than group 2 by the means of ultimate tensile load bearing ability. However, statistically group 1 had no superiority over group 5 in any terms.

Obtaining a proper and sufficient autograft can be challenging during ACL revision surgery from the knees with multi-ligament injuries, as harvesting BPTB and hamstring grafts from these extremities may increase morbidity (19, 29). Thus, the use of the quadriceps autograft is increasing in popularity for both primary and revision ACL surgeries (3, 8). Several clinical and biomechanical studies comparing different grafts with quadriceps grafts have focused on the biomechanical aspects of QT itself rather than fixation with different techniques and devices (4, 21). Thus, there is no consensus on the best fixation method or implant for fixing a quadriceps graft on the femoral side. Different studies have used different techniques for fixation and there is a lack of discussion and evaluation on this issue in the literature (3, 22).

Although QTBP fixed with TIS was presumed to be a good fixation technique, there were no significant differences in terms of stiffness, slippage, or resistance against a tensile load compared to QTT fixed with TIS acccording to our results. In contrast to a previous study, QTT fixed with BIS was inferior to QTT fixed with TIS but had comparable stiffness and slippage with QTBP fixed with TIS (7). Using a central QTT eliminates the risk for a patellar fracture due to bone block harvest, leading to a reduction in operative time and easier postoperative rehabilitation with reduced anterior knee pain compared to a BPTB graft (25). This finding applies to QTBP grafts as well. Thus, as shown by our in vitro results, harvesting a QTBP as a graft may be an unnecessary procedure that increase morbidity with no biomechanical superiority over QTT (27). Geib et al. (14) included 221 patients and performed ACL reconstruction using QTBP, QTT, and BPTB fixed on the femoral side with BIS. These authors reported comparable results among all groups but more donor-site morbidity with QTBP and BTBP. The manufacturers recommends using a similar interference screw or a +1 mm to the tunnel size for femoral fixation of the QTT. We used the same

Table 1. Stiffness, amount of slippage and ultimate tensile load bearing ability of all of the groups

Groups	Stiffness (N/mm)	Slippage (mm)	Ultimate tensile load (N)
	Median (Min/Max)	Median (Min/Max)	Median (Min/Max)
I	17.16(9.3 / 30.1)	6.41 (3.65 / 11.71)	464 (224 / 535)
II	24.82(13 / 28.5)	5.99 (3.85 / 8.45)	160 (109 / 371)
III	45.09(20 / 53.6)	3.01 (2.05 / 5.5)	350 (191 / 410)
IV	26.75(8.8 / 36.1)	4.83 (3.04 / 12.5)	350 (301 / 530)
V	23.88(15.2 / 30.3)	3.94 (3.62 / 7.19)	389.5 (244 / 669)
p	0.0951	<0.001	<0.001

Table 2. Pairwise multiple comparison results (Post Hoc Tests) between the groups regarding; stffiness, amount of slippage and ultimate tensile loads at failure

Groups	Stiffness	Slippage	Ultimate tensile load
	P	P	P
I–II	0.579	0.531	<0.001
I–III	0.030	<0.001	0.042
I–IV	0.500	0.141	0.151
I-V	0.112	0.011	0.634
II–III	0.029	0.001	0.028
II–IV	0.613	0.398	0.005
II–V	0.089	0.057	<0.001
III–IV	0.096	0.010	0.550
III–V	0.373	0.124	0.119
IV–V	0.539	0.291	0.338
Kruskal-Wallis test, post hoc test: Dunn's test			

screws with the tunnel and this may have led to lower ultimate tensile loads compared to previous studies (11) but a +1 screw can create a strong initial compression in vivo, but could lead to eventual tunnel enlargement, creating difficulties for revision surgery (6, 11). It can be speculate that the BIS used in this study may have different biomechanical properties, which may have altered the results. Ettinger et al. (10) clearly demonstrated that different BIS designs of the same size do not have a significant impact on biomechanical results.

Although QTT fixed with the ASS was the most resistant to tensile load-to-failure, it was the worst in terms of stiffness and the amount of slippage. By contrast, QTT fixed with BIS was very good in terms of stiffness but was weakest in resistance against tensile load-to-failure. Karkosch et al. (21) compared the biomechanical properties of BIS and second-generation ASS for fixing a QTT on the tibial side. Similar to our results, they found no significant difference in elongation between the groups. However, they reported a significant increase in the ultimate failure load with the ASS and a significant decrease in stiffness compared to screw fixation. Thus, we constituted group 4 using both devices to see if using both devices would provide stable fixation. Group 4 performed very well, comparable to groups 3 and 5. We detected a deformation < 0.5 mm in linearity of the load-deformation curves during the load-to-failure tests of this group. Then the load-deformation curves proceeded with a linear increase until failure. This phenomenon occurred between 120 and 200 N for all samples, indicating that this construct may decrease the risk for laxity during early rehabilitation of the knee due to the superior stiffness of the BIS. In addition, it prevented the failure of fixation due to overloading of the knee before ligamentization of the tendon due to the superior biomechanical properties of the ASS in resisting tensile loads. However, using an additional device for fixation would not be cost-effective or safe, as this kind of a fixation could complicate future revision surgeries.

Previous studies that have evaluated the properties of the ASS and screws with hamstring and other grafts have reported high ultimate tensile loads during the load-to-failure test with ASS and better stiffness with screws similar to our results (2, 4, 21). The ASS is usually used for quadriluped hamstring tendons with all inside techniques to fix the tendon to the tibia and femur or only to the femur. In this scenario, the presumed failures include pull-out of the button and loop rupture or intrasubstance rupture of the tendon itself. The intact graft is seated on the loop, so extra reinforcement between the tendon and the ASS with stitches is not needed. However, this is not possible when an ASS is used with QTTs and as a result this additional tendon–suture interface creates additional slippage (elongation) compared to a screw–tendon interface (21). If the tensile load surpasses the tensile load-bearing ability limits of the construct, detachment of the tendon and loop is a more probable scenario of failure as seen in our study (4).

It may not be possible to obtain similar test results or compare our results with those of previous studies because of different set-ups and test protocols. We experienced a greater number of pull-outs for both the BIS and TIS in our series than reported previously (5, 15, 21) for two major reasons: The QTs used were obtained from calf knees, which have a dense structure. This may have triggered more pull-out of the screws, as this creates stronger compression at the tendon–screw interface. In addition, a strain rate of 20 mm/min was used in our study in line with a previous study (7). However, strain rates < 50 mm/min result in more pull-outs (10). Karkosch et al. (21) reported 75% mid-substance rupture with a second-generation ASS and 37% mid- substance rupture with BIS on the tibial side and a cadaveric QTT in cadaveric tibias. However, Brand et al. (4) also used cadaveric bones and QT but did not report any mid-substance ruptures with screws or with EndoButtons. We did not encounter any mid-substance rupture. Our set-up with calf tendons on sheep femurs was established to evaluate fixation properties rather than modes of failure. Fresh QT of the calf had a dense structure that resisted tensile loads and surpassed the ultimate tensile load abilities of the fixations.

As this was an in vitro study, many limitations need to be addressed. First, the materials used were not human cadaveric materials and may have not represented the properties of real human tissues. Sheep femurs were chosen because of the similar bone quality to human tissue. However a bone mineral density evaluation was not carried out and this may have resulted in lower and variable ultimate failure load results due to lower bone mineral densities. Lastly, we could not apply 1000 cycles of 110 N cyclic forces at a frequency of 1 Hz, as the servohydraulic testing machine was not suitable for performing more hysteresis experiments.

CONCLUSIONS

This is the first study to compare the biomechanical properties of different fixation techniques and devices for QT fixation on the femoral side. Our results revealed that; QTBP fixed with the TIS had no advantages over QTT fixed with TIS on the femoral side. Also we conclude that, if an ASS is used, a strong tension force must be applied prior to tibial side fixation to prevent further slippage of the graft in the tunnel which can result in failed reconstruction.

References

1. Aga C, Rasmussen MT, Smith SD, Jansson KS, LaPrade RF, Engebretsen L, Wijdicks CA. Biomechanical comparison of interference screws and combination screw and sheath devices for soft tissue anterior cruciate ligament reconstruction on the tibial side. Am J Sports Med. 2013;41:841–848.
2. Ahmad SS, Hirschmann MT, Voumard B, Kohl S, Zysset P, Mukabeta T, Evangelopoulos DS, Ateschrang. Adjustable loop ACL suspension devices demonstrate less reliability in terms of reproducibility and irreversible displacement. Knee Surg Sports Traumatol Arthrosc. 2018;26:1392–1398.
3. Belk JW, Kraeutler MJ, Marshall HA, Goodrich JA, McCarty EC. Quadriceps tendon autograft for primary anterior cruciate ligament reconstruction: a systematic review of comparative studies with minimum 2-year follow-up. Arthroscopy. 2018;34:1699–1707.
4. Brand J Jr, Hamilton D, Selby J, Pienkowski D, Caborn DN, Johnson DL. Biomechanical comparison of quadriceps tendon fixation with patellar tendon bone plug interference fixation in cruciate ligament reconstruction. Arthroscopy. 2000;16:805–812.
5. Brand J Jr, Weiler A, Caborn DN, Brown CH Jr, Johnson DL. Graft fixation in cruciate ligament reconstruction. Am J Sports Med. 2000;28:761–774.
6. Buelow JU, Siebold R, Ellermann A. A prospective evaluation of tunnel enlargement in anterior cruciate ligament reconstruction with hamstrings: extracortical versus anatomical fixation. Knee Surg Sports Traumatol Arthrosc. 2002;10:80–85.
7. Caborn DN, Coen M, Neef R, Hamilton D, Nyland J, Johnson DL. Quadrupled semitendinosus-gracilis autograft fixation in the femoral tunnel: a comparison between a metal and a bioabsorbable interference screw. Arthroscopy. 1998;14:241–245.
8. Cavaignac E, Coulin B, Tscholl P, Nik Mohd Fatmy N, Duthon V, Menetrey J. Is quadriceps tendon autograft a better choice than hamstring autograft for anterior cruciate ligament reconstruction? A comparative study with a mean follow-up of 3.6 years. Am J Sports Med. 2017;45:1326–1332.
9. Chen CH, Chuang TY, Wang KC, Chen WJ, Shih CH. Arthroscopic anterior cruciate ligament reconstruction with quadriceps tendon autograft: clinical outcome in 4–7 years. Knee Surg Sports Traumatol Arthrosc. 2006;14:1077–1085.

10. Ettinger M, Werner-Lebeda T, Calliess T, Omar M, Becher C, Ezechieli M, Klintschar M, Petri M. Femoral interference screw fixation of hamstring and quadriceps tendons for ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2017;25:1241–1248.
11. Fabbriciani C, Mulas PD, Ziranu F, Deriu L, Zarelli D, Milano G. Mechanical analysis of fixation methods for anterior cruciate ligament reconstruction with hamstring tendon graft. An experimental study in sheep knees. Knee. 2005;12:135–138.
12. Fedorová P, Srnec R, Pěnčík J, Dvořák M, Krbec M, Nečas A. [Intra-articular reinforcement of a partially torn anterior cruciate ligament (ACL) using newly developed UHMWPE biomaterial in combination with Hexalon ACL/PCL screws: ex-vivo mechanical testing of an animal knee model]. Acta Chir Orthop Traumatol Cech. 2015;82:222–228.
13. Fulkerson JP, Langeland R. An alternative cruciate reconstruction graft: the central quadriceps tendon. Arthroscopy. 1995;11:252–254.
14. Geib TM, Shelton WR, Phelps RA, Clark L. Anterior cruciate ligament reconstruction using quadriceps tendon autograft: intermediate-term outcome. Arthroscopy. 2009;25:1408–1414.
15. Gwynne-Jones DP, Draffin J, Vane AG, Craig RA, McMahon SF. Failure strengths of concentric and eccentric implants for hamstring graft fixation. ANZ J Surg. 2008;78:177–181.
16. Hapa O, Barber FA. ACL fixation devices. Sports Med Arthrosc Rev. 2009;17:217–223.
17. Harris NL, Smith DA, Lamoreaux L, Purnell M. Central quadriceps tendon for anterior cruciate ligament reconstruction. Part I: Morphometric and biomechanical evaluation. Am J Sports Med. 1997;25:23–28.
18. http://www.smith-nephew.com/education/resources/video/2017/may/preparing-quad-tendon-with-ultrabutton/. [accessed 13 May 2021].
19. Hurley ET, Calvo-Gurry M, Withers D, Farrington SK, Moran R, Moran CJ. Quadriceps tendon autograft in anterior cruciate ligament reconstruction: a systematic review. Arthroscopy. 2018;34:1690–1698.
20. Joseph M, Fulkerson J, Nissen C, Sheehan TJ. Short-term recovery after anterior cruciate ligament reconstruction: a prospective comparison of three autografts. Orthopedics. 2006;29:243–248.
21. Karkosch RF, Ettinger M, Bachmaier S, Wijdicks CA, Smith T. Adjustable-length loop cortical button versus interference screw fixation in quadriceps tendon anterior cruciate ligament reconstruction – a biomechanical in vitro study. Clin Biomech (Bristol, Avon). 2018; 60:60–65.
22. Kim D, Asai S, Moon CW, Hwang SC, Lee S, Keklikci K, Linde-Rosen M, Smolinski P, Fu FH. Biomechanical evaluation of anatomic single- and double-bundle anterior cruciate ligament reconstruction techniques using the quadriceps tendon. Knee Surg Sports Traumatol Arthrosc. 2015;23:687–695.
23. Kornblatt I, Warren RF, Wickiewicz TL. Long-term followup of anterior cruciate ligament reconstruction using the quadriceps tendon substitution for chronic anterior cruciate ligament insufficiency. Am J Sports Med. 1988;16:444–448.
24. Kwak YH, Lee S, Lee MC, Han HS. Anterior cruciate ligament reconstruction with quadriceps tendon-patellar bone allograft: matched case control study. BMC Musculoskelet Disord. 2018;19:45.
25. Lund B, Nielsen T, Faunø P, Christiansen SE, Lind M. Is quadriceps tendon a better graft choice than patellar tendon? a prospective randomized study. Arthroscopy. 2014;30:593–598.
26. Mulford JS, Hutchinson SE, Hang JR. Outcomes for primary anterior cruciate reconstruction with the quadriceps autograft: a systematic review. Knee Surg Sports Traumatol Arthrosc. 2013;21:1882–1888.
27. Schulz AP, Lange V, Gille J, Voigt C, Fröhlich S, Stuhr M, Jürgens C. Anterior cruciate ligament reconstruction using bone plug-free quadriceps tendon autograft: intermediate-term clinical outcome after 24–36 months. Open Access J Sports Med. 2013;19:243–249.
28. Stäubli HU, Schatzmann L, Brunner P, Rincón L, Nolte LP. Quadriceps tendon and patellar ligament: cryosectional anatomy and structural properties in young adults. Knee Surg Sports Traumatol Arthrosc. 1996;4:100–110.
29. Yasuda K, Ohkoshi Y, Tanabe Y, Kaneda K. Muscle weakness after anterior cruciate ligament reconstruction using patellar and quadriceps tendons. Bull Hosp Jt Dis Orthop Inst. 1991;51:175–185.

Corresponding author:
Mehmet Salih Söylemez, MD
Yaprak street, Acıbadem district, No 32, D:12
Uskudar, Istanbul, Postal code: 34660, Turkey
E-mail: slhsylmz@gmail.com