Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 35 (2024) 39–42

Contents lists available at ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology

journal homepage: www.ap-smart.com

original article

Traditional suture tape versus multiple high-strength sutures for augmentation of anterior cruciate ligament primary repair: A time-zero biomechanical study

Thun Itthipanichpong [a], Puchong Kulrat [a], Danaithep Limskul [a], Thanathep Tanpowpong [a], Chanyaphan Virulsri [b], Pairat Tangpornprasert [b], Somsak Kuptniratsaikul [a], Napatpong Thamrongskulsiri [c,*]

[a] Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University and King Chulalongkorn Memorial Hospital, The Thai Red Cross Society, Bangkok, Thailand

[b] Center of Excellence for Prosthetic and Orthopedic Implant, Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

[c] Department of Anatomy, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand

ARTICLE INFO

Keywords:
Anterior cruciate ligament repair
High-strength suture
Internal brace
Suture tape
Synthetic augmentation

ABSTRACT

Background/objective: During the initial stages of rehabilitation after anterior cruciate ligament (ACL) surgery, a pivotal role is played in ensuring effective recuperation and averting complications. An often-employed strategy to tackle ACL laxity during this period involves the incorporation of synthetic materials for reinforcement. The objective of this study is to compare the effectiveness of conventional suture tape and multiple high-strength sutures as augmentation techniques for ACL repair.

Methods: Ten preserved cadaveric knees embalmed using the Thiel method were segregated into two groups, each containing five knees. In one group, traditional suture tape was employed for augmentation, while the other group utilized multiple high-strength sutures. Each knee underwent a cyclic load of 1000 sine wave cycles, succeeded by an axial distraction load until failure ensued. The resultant displacement and ultimate load at failure were assessed to contrast the efficacy of the two augmentation techniques.

Results: The group utilizing multiple high-strength sutures exhibited a significantly higher load to failure at time-zero (1690.7 N) compared to the suture tape group (987.6 N) ($P = .003$). Furthermore, the multiple high-strength sutures group demonstrated significantly reduced displacement after 1000 cyclic loads (6.6 mm) in comparison to the suture tape group (16.3 mm) ($P < .001$).

Conclusions: Multiple high-strength sutures show better biomechanical properties for the augmentation of ACL repair at time-zero. Both suture tape and multiple high-strength sutures had ultimate load-to-failure values higher than the natural ACL loads. Therefore, these substances might serve as augmentation options to prevent the ACL's gradual elongation, a critical concern particularly in the initial stages of rehabilitation.

1. Introduction

When the anterior cruciate ligament (ACL) is not functioning adequately, it can cause symptomatic instability, secondary meniscal pathologies, and chondral injuries.[1] ACL reconstruction is the primary surgical treatment for ACL insufficiency. Nonetheless, only about 63–65% of patients are able to return to their pre-injury sport level, and graft failure occurs in 10–15% of patients within ten years.[2–4] ACL reconstruction has the disadvantages of loss of proprioceptive function, inability to restore the native kinetics of the knee, inability to prevent osteoarthritis, donor-site morbidity, and unsatisfactory outcomes of revision surgery.[5,6]

* Corresponding author. Department of Anatomy, Faculty of Medicine, Chulalongkorn University, 1873 Rama IV Rd, Khwaeng Pathum Wan, Khet Pathum Wan, Bangkok, 10330, Thailand.

E-mail addresses: thun.i@chula.ac.th (T. Itthipanichpong), puchong.kul@chulahospital.org (P. Kulrat), danaithep.l@chula.ac.th (D. Limskul), ttanpowpong@gmail.com (T. Tanpowpong), chanyaphan.v@eng.chula.ac.th (C. Virulsri), pairat.t@chula.ac.th (P. Tangpornprasert), somk50@hotmail.com (S. Kuptniratsaikul), napatpong.tha@gmail.com (N. Thamrongskulsiri).

https://doi.org/10.1016/j.asmart.2023.11.007
Received 3 September 2023; Received in revised form 20 October 2023; Accepted 27 November 2023

Historically, ACL primary repair has shown disappointing outcomes because of surgical techniques, suture materials, and rehabilitation. In 2014, Heitmann et al. proposed the ligament bracing concept and demonstrated significantly higher stability in ACL repair with synthetic suture augmentation compared to repair or reconstruction without suture augmentation in a biomechanical study on the porcine knee.[7] Multiple recent studies showed the satisfactory outcome of arthroscopic ACL primary repair with an internal brace in the short-to mid-term follow-up.[8,9] Heusdens et al. reported satisfactory 2-year follow-up results of patients who were treated with the arthroscopic ACL primary repair with an internal brace.[8] The findings indicated that there were significant improvements in all aspects of the Knee Injury and Osteoarthritis Outcome Score (KOOS) when compared to the scores before the operation. The most notable improvements were observed three months after the surgery, with the KOOS score for sports and recreation showing the most substantial enhancement at this point and the greatest overall improvement after one year. Additionally, both the Visual Analogue Pain Scale and the physical scores from the Veterans RAND 12 Item Health Survey showed significant improvement. However, the Marx activity scale exhibited a significant decrease when compared to preoperative scores. Notably, two out of the 42 patients (4.8%) reported experiencing a recurrence of their ACL injury.[8] Jonkergouw et al. also reported satisfactory outcomes after 3.2 years of patient follow-up.[9] Results showed a 10.7% failure rate, with four reoperations for issues such as meniscus tears and suture anchor irritation. The majority of patients achieved good objective and subjective outcomes, with no significant differences in subjective scores between those who received internal bracing and those who didn't.[9] As a result, there is renewed interest in ACL primary repair with synthetic suture augmentation or internal brace.

In the context of arthroscopic primary repair, the technique of suture augmentation utilizing suture tape was presented by Heusdens et al. and Van der List et al.[10,11] Kuptniratsaikul et al. presented the technique using multiple high-strength sutures.[12] They hypothesize that using multiple No. 2 sutures may provide greater strength than a single suture tape. They attempt to place as many as six No. 2 sutures into the cortical button's hole. Their findings indicate that a maximum of six sutures can be inserted into the hole.[12] Both techniques can be augmented with ACL primary repair. As of now, no research has been conducted to compare the biomechanical properties of traditional suture tape and multiple high-strength sutures for augmenting an ACL repair.

The aim of this research is to assess the biomechanical characteristics of conventional suture tape and multiple high-strength sutures when employed for augmenting ACL repair during the initial stage of postoperative rehabilitation. The researchers hypothesize that there will be no significant disparity in the time-zero ultimate load-to-failure and the displacement following cyclic load between the two materials.

2. Materials and methods

2.1. Inclusions

This research has been approved by the institutional review board of the authors' affiliated institutions. Ten paired Thiel's embalmed[13,14] cadaveric knees were extracted from five embalmed cadavers. Specimens with altered knee anatomy due to any pathology were ruled out. All ten paired Thiel's embalmed cadaveric knees for this study were obtained from five male cadavers, with an average weight of 74.4 kg (SD, 11.7 kg) and an average age of 70.8 years (SD, 8.1 years). The specimens were equally divided into five left knee and five right knee specimens from the five cadavers. The authors' affiliated institution soft cadaver surgical training center's registry provided cadaver demographic data such as age, weight, and gender.

2.2. Study Procedures

Ten Thiel's embalmed cadaveric knees were prepared.[13,14] The femur and tibia were cut 15 cm from the joint line. The specimens were dissected. The collateral and posterior cruciate ligaments were left attached to the native origin and insertion. The ACL was peeled off from its femoral attachment, and the ACL stump was left free. The specimens were randomly allocated and divided into two groups, with each group consisting of five knees. The first group utilized suture tape (referred to as the "Tape group"), while the second group employed multiple high-strength sutures (referred to as the "Multi group"). Each knee was augmented with the respective materials. The sutures or tape augmentation were applied to the allocated cadaveric knees. We left the ACL free because we wanted to examine the biomechanical properties of the augmentation. This can eliminate a confounding factor if the ACL is still attached.

2.3. Surgical technique

In the Tape group, five knees were augmented by one HiFi tape (Conmed, Utica, NY).[11] The HiFi tape was inserted through the XO button's (Conmed, Utica, NY) holes. A 5.0-mm guide-reamer was used to create the femoral tunnel at the lateral femoral condyle. The ACL tibial guide (Conmed, Utica, NY) was used to create a tibial tunnel from the medial tibial cortex to the ACL tibial footprint, followed by a 5.0-mm tunnel. The XO button (Conmed, Utica, NY), loaded with one HiFi tape (Conmed, Utica, NY), was then shuttled through the tibial and femoral tunnel and flipped over the lateral femoral cortex. The HiFi tape (Conmed, Utica, NY) underwent individual tensioning using maximum manual force to simulate a situation clinically relevant to a fully extended knee. It was then secured with a surgical knot and five half-hitches to another XO button (Conmed, Utica, NY) positioned on the inner surface of the tibia (Fig. 1a).

In the Multi group, five knees were augmented by five #2 HiFi sutures (Conmed, Utica, NY). The method closely resembled the previously mentioned approach,[12] with the distinction being the utilization of five #2 HiFi sutures (Conmed, Utica, NY), which were passed through the holes of the XO button and fastened to another XO button (Conmed, Utica, NY) located on the tibial aspect (Fig. 1b).

2.4. Model for testing

The specimens were mounted onto the Instron E10000 machine in full extension with the tibia attached to the stationary portion and the femur connected to a servohydrolic testing system (see Fig. 2). The Instron E10000 applied cyclic loading to each knee in a position-controlled mode, with a sine wave cyclic load of 0–250 N and a frequency of 1 Hz for 1000 cycles. The displacement of the knee was

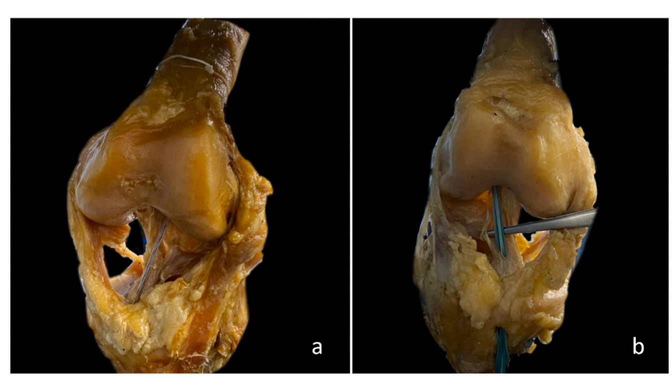

Fig. 1. (a) Cadaveric anterior cruciate ligament augmentation with conventional suture tape (b) Cadaveric anterior cruciate ligament augmentation with multiple high-strength sutures.

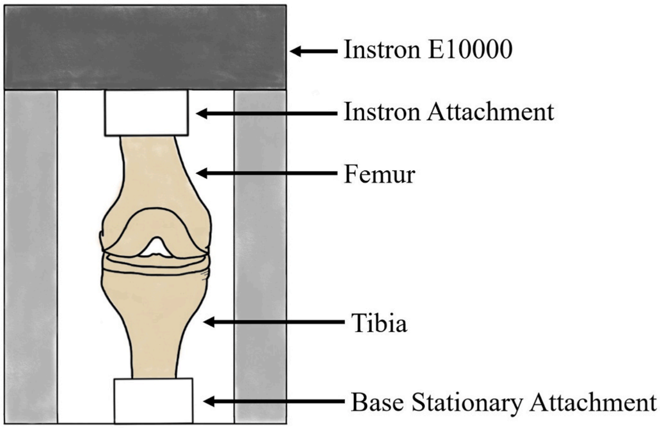

Fig. 2. Schematic illustration of test setup of cadaveric knee after suture augmentation with the tibia attached to the base stationary portion and the femur attached to a servohydrolic testing system in full extension (Instron E10000, Canton, MA).

measured following cyclic loading. Finally, an axial distraction load was applied by the Instron E10000 to each group at a rate of 50 mm/min until failure. The ultimate load-to-failure between the pull-to-failure in both groups was measured.

2.5. Outcome Measurement

The primary objective of this investigation is to comparatively analyze the point of failure under extreme load in ACL repair with synthetic reinforcement. Additionally, the secondary objective of this investigation is to evaluate the extent of displacement after applying cyclic loads.

2.6. Statistical analysis

Statistical analysis was performed using SPSS version 22.0 (IBM, USA) for Windows. The student's t-test was used to compare the load-to-failure (N) and displacement (mm) values between the two groups. The 95% confidence interval was also calculated for both groups. The significance level was set at $P \leq .05$.

To evaluate this possibility, a post-hoc power analysis was done. With ten samples and a significance level of 5% (alpha of 0.05), a post hoc power analysis of the ultimate load-to-failure has a power of 98.9%.

3. Results

3.1. Displacement after cyclic loading

The results for time-zero displacement after cyclic loading are presented in Fig. 3. The mean displacement for the suture tape group was 16.3 ± 2.0 mm, while the mean displacement for the multiple high-strength sutures group was 6.6 ± 1.9 mm. A significant difference in gap formation was observed between the two groups using a student's t-test (P < .001, 95% confidence interval, 6.4 to 12.1).

3.2. Ultimate load-to-failure and mode of failure

Fig. 4 displays the time-zero ultimate load-to-failure results, which showed that the ultimate load-to-failure of the suture tape group (987.6 ± 114.4 N) was lower than the multiple high-strength sutures group (1690.7 ± 350.7 N). This difference was significant according to the student's t-test analysis (P = .003, 95% confidence interval, −1083.5 to −322.7). All 10 specimens had suture slippage through the femoral tunnel as the mode of failure.

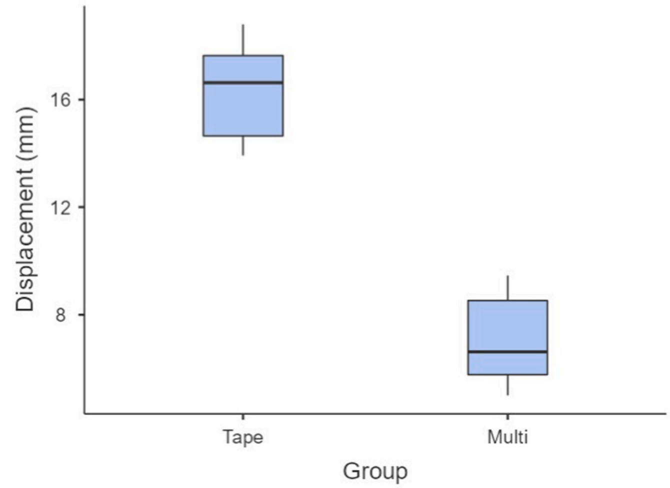

Fig. 3. Boxplot demonstrating the distribution of the displacement after cyclic loading values in Tape group, and Multi group.

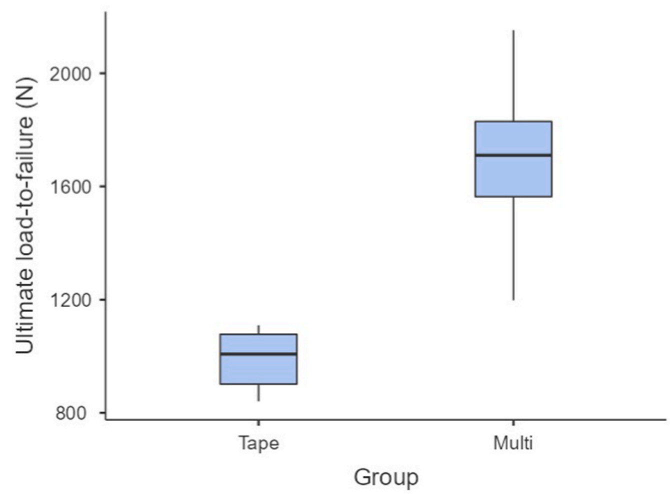

Fig. 4. Boxplot demonstrating the distribution of the ultimate load-to-failure values in Tape group, and Multi group.

4. Discussion

The principal outcome of this investigation reveals noteworthy improvements in the time-zero ultimate load-to-failure (1690.7 N vs 987.6 N, P = .003) and a significant reduction in displacement after subjecting the specimens to 1000 cyclic loads (6.6 mm vs 16.3 mm, P < .001) in the multiple high-strength sutures group compared to the suture tape group.

The literature has become more interested in ACL primary repair in the last decade.[5,6,8,9,15,16] Several surgeons who use repair techniques have recently pushed for performing ACL primary repair with sufficient tissue quality and length.[16] The ACL primary repair with synthetic augmentation may optimize biomechanical properties and surgical outcomes.[8,9,17]

This study suggests that the use of multiple high-strength sutures for augmenting ACL primary repair at time-zero results in superior biomechanical properties compared to other methods. The suture tape had the ultimate load-to-failure value of 987.6 ± 114.4 N. The suture tape displacement following cyclic loading was 16.3 ± 2.0 mm. The ultimate load-to-failure and displacement of the multiple high-strength sutures were 1690.7 ± 350.7 N and 6.6 ± 1.9 mm, respectively. The study examined ACL loads during daily activities and found that normal level walking generated 169 N of force, whereas descending stairs generated

445 N of force due to the knee extensor mechanism being activated.[18] In the case where a torn ACL is reattached to the footprint, certain activities under normal circumstances may pose a risk to the repaired ACL. Consequently, both suture tape and multiple high-strength sutures utilized for augmenting primary ACL repair demonstrate ultimate load-to-failure values that surpass those experienced during regular daily activities. The suture augmentation functions like a safety belt, becoming active only during excessive loads due to intentionally maintaining a looser tension compared to the ACL repair construct. Thus, these augmentation methods present as potential adjuncts for safeguarding the integrity of the primary ACL repair, particularly during the initial stages of the healing process.

5. Limitations

This study has several limitations. First, Thiel's embalmed cadavers were used instead of fresh frozen cadavers in this study, which have the same elasticity, color, and flexibility as in vivo ligaments. However, Thiel embalming has been shown in studies to be effective for preserving ligaments for research purposes.[13,14] Second, the average age of our cadavers was 70.7 $\pm$ 14.5 years, which does not properly represent the younger population for whom ACL primary repair are commonly performed, and the quality of the bones and ligaments may deteriorate with age. Third, the loads were pulled vertically along the longitudinal axis, resembling the worst-case scenario rather than anterior translation or pivot-shifting. The results of our study suggest that the biomechanical properties of the multiple sutures in our research are representative of the scenario when the load is pulled vertically. Finally, this study had a small sample size.

6. Conclusions

The results of this study offer substantiated proof endorsing the enhanced biomechanical attributes of multiple high-strength sutures in contrast to traditional suture tape when employed for reinforcing primary ACL repair initially. Notably, both materials demonstrated ultimate load-to-failure values exceeding those of the native ACL loads. Consequently, the authors propose the integration of these augmentation materials as a strategy to counteract ACL elongation, particularly during the initial rehabilitation phase.

Institutional review board statement

This study was approved by the Ethics Committee of the Faculty of Medicine, Chulalongkorn University (IRB No.711/63). The requirement for individual consent was waived by the committee.

Informed consent statement

This article does not contain any studies involving human subjects.

Data sharing statement

No additional data are available.

Authors contributions

TI carried out the investigation, participated in the data curation and edited the manuscript. PK, DL, and TT performed statistical analysis. PT and CV carried out the mechanical testing. SK participated in the data curation and coordination and helped to draft the manuscript. NT participated in the design of the study, performed statistical analysis, reviewed, wrote, and edited the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no relevant financial or non-financial interests related to this work.

Acknowledgements

We thank the Chula soft cadaver surgical training center for providing Thiel's embalmed cadaveric knees for this study and the Chulalongkorn University Faculty of Engineering's Biomechanical Laboratory for biomechanical testing.

References

1. Louboutin H, Debarge R, Richou J, et al. Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. *Knee*. 2009;16(4):239–244.
2. George MS, Dunn WR, Spindler KP. Current concepts review: revision anterior cruciate ligament reconstruction. *Am J Sports Med*. 2006;34(12):2026–2037.
3. Samitier G, Marcano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. *Arch Bone Jt Surg*. 2015;3(4):220–240.
4. Sandon A, Engström B, Forssblad M. High risk of further anterior cruciate ligament injury in a 10-year follow-up study of anterior cruciate ligament-reconstructed soccer players in the Swedish national knee ligament registry. *Arthroscopy*. 2020;36 (1):189–195.
5. Achtnich A, Herbst E, Forkel P, et al. Acute proximal anterior cruciate ligament tears: outcomes after arthroscopic suture anchor repair versus anatomic single-bundle reconstruction. *Arthroscopy 2016*. 2016;32(12):2562–2569.
6. DiFelice GS, Villegas C, Taylor S. Anterior cruciate ligament preservation: early results of a novel arthroscopic technique for suture anchor primary anterior cruciate ligament repair. *Arthroscopy*. 2015;31(11):2162–2171.
7. Heitmann M, Dratzidis A, Jagodzinski M, et al. Ligament bracing-augmented cruciate ligament sutures: biomechanical studies of a new treatment concept. *Unfallchirurg*. 2014;117(7):650–657.
8. Heusdens CHW, Hopper GP, Dossche L, Roelant E, Mackay GM. Anterior cruciate ligament repair with Independent Suture Tape Reinforcement: a case series with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):60–67.
9. Jonkergouw A, van der List JP, DiFelice GS. Arthroscopic primary repair of proximal anterior cruciate ligament tears: outcomes of the first 56 consecutive patients and the role of additional internal bracing. *Knee Surg Sports Traumatol Arthrosc*. 2019;27 (1):21–28.
10. Heusdens CHW, Hopper GP, Dossche L, Mackay GM. Anterior cruciate ligament repair using independent suture tape reinforcement. *Arthrosc Tech*. 2018;7(7): e747–e753.
11. van der List JP, DiFelice GS. Arthroscopic primary anterior cruciate ligament repair with suture augmentation. *Arthrosc Tech*. 2017;6(5):e1529–e1534.
12. Kuptniratsaikul S, Itthipanichpong T, Kuptniratsaikul V. Arthroscopic synthetic augmentation in acute partial injury of the anterior cruciate ligament. *Arthrosc Tech*. 2018;7(11):e1123–e1127.
13. Benkhadra M, Bouchot A, Gérard J, et al. Flexibility of Thiel's embalmed cadavers: the explanation is probably in the muscles. *Surg Radiol Anat*. 2011;33(4):365–368.
14. Liao X, Kemp S, Corner G, Eisma R, Huang Z. Elastic properties of Thiel-embalmed human ankle tendon and ligament. *Clin Anat*. 2015;28(7):917–924.
15. Gee MSM, Peterson CDR, Zhou ML, Bottoni CR. Anterior cruciate ligament repair: historical perspective, indications, techniques, and outcomes. *J Am Acad Orthop Surg*. 2020;28(23):963–971.
16. Vermeijden HD, van der List JP, DiFelice GS. Acute and delayed anterior cruciate ligament repair results in similar short to mid-term outcomes. *Knee*. 2021;29: 142–149.
17. Massey P, Parker D, McClary K, Robinson J, Barton RS, Solitro GF. Biomechanical comparison of anterior cruciate ligament repair with internal brace augmentation versus anterior cruciate ligament repair without augmentation. *Clin Biomech*. 2020; 77, 105065.
18. Dargel J, Gotter M, Mader K, Pennig D, Koebke J, Schmidt-Wiethoff R. Biomechanics of the anterior cruciate ligament and implications for surgical reconstruction. *Strategies Trauma Limb Reconstr*. 2007;2(1):1–12.