Original Research

Higher contact pressure of the lateral tibiofemoral joint in lateral extra-articular tenodesis with tensioned graft in external rotation than in neutral rotation: A biomechanical study

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ARTICLE INFO

Keywords:
Lateral extra-articular tenodesis
Lateral extra-articular augmentation
Biomechanical study
Tension
External rotation
Neutral rotation

ABSTRACT

Objective: To determine the mean contact pressure, peak contact pressure, and mean contact area of the lateral tibiofemoral joint in lateral extra-articular tenodesis (LET) with tension on the graft in tibial neutral and external rotation.

Methods: A total of eight Thiel-embalmed cadaveric knees were prepared and divided into two groups (4 knees in each group): the LET-NR group (lateral extra-articular tenodesis tension in neutral rotation) and (2) the LET-ER group (lateral extra-articular tenodesis tension in external rotation). Each knee was prepared according to the corresponding technique. A hydraulic testing system (E10000, Instron) simulates an axial load of 735 N for 10 s in each group.

Results: The LET-ER group exhibited a statistically significant higher peak contact pressure compared to the LET-NR group. The peak contact pressure values in the LET-NR and LET-ER groups were 702.3 ± 233.9 kPa and 1235.5 ± 171.4 kPa, respectively (p = 0.010, 95% CI, 888.0 to 178.5). The mean contact pressure values in the LET-NR and LET-ER groups were 344.9 ± 69.0 kPa and 355.3 ± 34.9 kPa, respectively (p = 0.796, 95% CI, 105.1–84.2). The mean contact area values in the LET-NR and LET-ER groups were 36.8 ± 3.1 mm² and 33.3 ± 6.4 mm², respectively (p = 0.360, 95% CI, 5.2–12.2).

Conclusions: The peak contact pressure of the lateral tibiofemoral joint is greater in LET when the graft is tensioned in external rotation than in neutral rotation. However, no statistically significant difference in the mean contact pressure or the mean contact area was observed between the two groups.

Level of evidence: III.

What are the new findings?

- This study shows higher peak contact pressure of the lateral tibiofemoral joint in lateral extra-articular tenodesis tensioned in external rotation than in neutral rotation.
- As the result, lateral extra-articular tenodesis tension in neutral rotation might be employed for anterior cruciate ligament reconstruction augmentation to prevent over-constrain of the lateral tibiofemoral joint.

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https://doi.org/10.1016/j.jisako.2024.04.009
Received 28 February 2024; Received in revised form 29 March 2024; Accepted 12 April 2024
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Please cite this article as: Ithipanichpong T et al., Higher contact pressure of the lateral tibiofemoral joint in lateral extra-articular tenodesis with tensioned graft in external rotation than in neutral rotation: A biomechanical study, Journal of ISAKOS, https://doi.org/10.1016/j.jisako.2024.04.009
INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is a surgical procedure for treating ACL injury to restore anterior translation laxity and pivot shift. However, residual rotational instability after ACL reconstruction exists in some cases [1]. The two most common additional lateral augmentations are lateral extra-articular tenodesis (LET) and anterolateral ligament (ALL) reconstruction [2]. Lateral augmentations are performed to increase rotational stability in patients with high-risk graft failure, such as high-grade pivot shift, revision ACL reconstruction, and participation in high-risk sports [3,4]. Getgood et al. reported that a modified Lemaire LET lowers the likelihood of recurrent ACL rupture or residual rotatory laxity following hamstring autograft ACL reconstruction [5]. Similarly, Sonnery-Cottet et al. showed that ALL reconstruction decreases the graft failure rate and increases the likelihood of returning to the preinjury sport level [6].

Early methods of LET by Lamaire (1967) [7] and MacIntosh (1976) [8] were performed by tensioning grafts in the tibial external rotation to control internal tibial rotation and pivot shift phenomenon. However, this can result in overconstraint of the lateral tibiofemoral joint, which may result in lateral tibiofemoral joint osteoarthritis. A systematic review of biomechanical studies showed that LET overconstrained the knee in ACL-deficient knees and reduced internal tibial rotation compared to the native state [9]. Furthermore, Xu et al. reported that ACL reconstruction combined with LET causes the lateral knee to be overconstrained compared with ACL reconstruction combined with ALL reconstruction [10]. Therefore, the overconstraint of the lateral knee may cause degenerative changes in lateral compartment osteoarthritis. In a randomized controlled trial of bone-patellar tendon-bone ACL reconstruction with and without the LET (a modified Lemaire LET) procedure, Castoldi et al. found that the LET group had a higher rate of lateral tibiofemoral osteoarthritis [4].

Posttraumatic osteoarthritis is a problem for all patients who underwent ACL reconstruction, with an occurrence rate of 0%–13% following an isolated ACL injury and 21%–48% following an ACL injury associated with meniscal injury [11,12]. Osteoarthritis changes in the lateral tibiofemoral joint of the knee due to overtightening of the LET graft are of concern in LET cases [4,13,14]. The tensioned graft in tibial external rotation has raised concerns about the overconstraint of the lateral tibiofemoral joint. Thus, the tensioned graft in neutral rotation should reduce the overconstraint of the lateral tibiofemoral joint. Neri et al. conducted a preliminary biomechanical investigation involving four cadaveric knees, revealing that both the Lemaire and modified MacIntosh techniques for lateral extra-articular tenodesis led to a notable elevation in overall lateral tibiofemoral contact pressure during internal knee rotation [15]. Thus, this study aimed to expand upon this research by increasing the sample size and comparing the mean contact pressure, peak contact pressure, and mean contact area of the lateral compartment in the LET with tension on the graft in tibial neutral and external rotation. It was hypothesized that the mean contact pressure, peak contact pressure, and mean contact area in the lateral compartment would be greater after tensioned LET graft in external rotation than in neutral rotation.

METHODS

Inclusion

Thiel-embalmed cadavers [16,17] were used to obtain eight paired cadaveric knees. Specimens with altered knee anatomy due to pathology, cartilage lesion, osteoarthritic change (grade ≥2), ACL pathology, posterior cruciate ligament pathology, meniscus tear, or poor bone quality were excluded. Cadaver demographic data such as age, weight, height, and gender were provided by the Chula Soft Cadaver Surgical Training Center. This study was approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University (IRB No. 0869/64).

A total of eight specimens were obtained from four cadavers. The average age of the cadavers was 68.00 ± 17.40 years, with a body weight of 65.00 ± 10.80 kg and a height of 171.25 ± 12.50 cm. Of the four cadavers, three were males, and one was female (Table 1).

Surgical technique

A total of eight Thiel-embalmed paired cadaveric knees were prepared [16,17]. The femur and tibia were cut fifteen centimeters from the joint line. The specimens were dissected. The specimens were randomly assigned to two groups: the LET-NR group (lateral extra-articular tenodesis tension in neutral rotation) and the LET-ER group (lateral extra-articular tenodesis tension in external rotation). The iliotibial band (IT band) was stripped to make a modified Lemaire LET with a width of 10 mm and a length of 10 cm (Fig. 1a). The graft was sewn in a whipstitch fashion using #2 HiFi suture (CONMED, Utica, NY). The graft was passed underneath the lateral collateral ligament and then attached to the lateral femur just posterior and proximal to the lateral femoral epicondyle. A hole in the lateral femoral cortex was made using a 2.4 mm drill, and a 7.0 mm bone socket was created using a 7.0 mm reamer.

In the LET-NR group, the suture limbs from the stripped IT band were shuttled through the bone socket in the lateral femoral cortex. The knees were then flexed to 30° and rotated in a neutral tibial rotation. Finally, the knees were held in a neutral position to account for varus and valgus stress before a tension of 15 N was applied to the graft, and the graft was fixed to the femur using a 7.0 mm bioabsorbable interference screw (Fig. 1b). Graft tensioning was performed in a standardized way using a dynamometer (Baseline 12–0341 MMT, Fabrication Enterprises, NY). The defect in the IT band is sewn with vicryl suture in a figure-of-eight fashion. After performing a lateral parapatellar arthroscopy, a pressure sensor (K-Scan Joint Analysis System, Tekscan, MA) was inserted on the lateral tibial plateau under the lateral meniscus (Fig. 2a).

In the LET-ER group, LET was performed by the modified Lemaire procedure in the same manner, but when tension and fixation of the graft were applied, the knees were positioned at 30° of flexion, neutral to varus and valgus stress and external tibial rotation. A 5 mm lateralization of the tibial tubercle from the center of the patellar bone indicated the tibial external rotation. A lateral parapatellar arthroscopy was performed, and a pressure sensor was placed in the same manner.

Model for testing

Biomechanical testing was performed on specimens using a mechanical testing machine (E10000, Instron, Canton, MA) with the tibia attached to the stationary base portion and the femur attached to a hydraulic testing system (E10000, Instron, Canton, MA). The hydraulic testing system (E10000, Instron, Canton, MA) simulates an axial load of 735 N (equivalent to a 75 kg person standing vertically) and a 5 mm lateralization of the tibial tubercle from the center of the patellar bone indicated the tibial external rotation. A lateral parapatellar arthroscopy was performed, and a pressure sensor was placed in the same manner.

Table 1

<table>
<thead>
<tr>
<th>Cadaver number</th>
<th>Age (years)</th>
<th>Body weight (kg)</th>
<th>Height (cm)</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77</td>
<td>65</td>
<td>170</td>
<td>Male</td>
</tr>
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<td>2</td>
<td>85</td>
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<td>Male</td>
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<tr>
<td>4</td>
<td>65</td>
<td>50</td>
<td>155</td>
<td>Female</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>68.00 ± 17.40</td>
<td>65.00 ± 10.80</td>
<td>171.25 ± 12.50</td>
<td></td>
</tr>
</tbody>
</table>

kg = kilogram; cm = centimeter; SD = standard deviation.
Statistical analysis was performed using Jamovi 2.3.5 (Sydney, Australia) for Windows. The mean contact pressure (kPa), peak contact pressure (kPa), and mean contact area (mm²) values were compared between the two groups using Student’s t-test. 95% confidence intervals (CI) were calculated for both groups. $p \leq 0.05$ indicated a significance level.

This study may not have enough power. A post hoc power analysis was performed to assess this possibility. A post hoc power calculation of the peak contact pressure achieved a power of 95.7% with eight samples and a significance level of 5% (alpha of 0.05).
The normality test and effect size calculations were also performed. The Shapiro–Wilks test for normality was computed due to the small sample size in our study, which comprised fewer than 50 participants. Subsequently, p-values of 0.310, 0.541, and 0.987 were obtained for the peak contact pressure, mean contact pressure, and mean contact area, respectively. As these p-values exceed the conventional significance level of 0.05, the null hypothesis indicating normality in the data distribution is not rejected. Consequently, the data were presented using descriptive statistics such as the mean and standard deviation. The effect sizes were calculated using Cohen’s d. It was found that the Cohen’s d effect size was 0.701, indicating a large effect size.

RESULTS

The LET-ER group exhibited a statistically significant higher peak contact pressure compared to the LET-NR group. The peak contact pressure values in the LET-NR and LET-ER groups were 702.3 ± 233.9 kPa (range, 407–906) and 1255.5 ± 171.4 kPa (range, 1012–1406), respectively (p = 0.010, 95% CI, −888.0 to −178.5) (Fig. 3). The mean contact pressure values in the LET-NR and LET-ER groups were 344.9 ± 69.0 kPa (range, 246–403) and 355.3 ± 34.9 kPa (range, 326–405), respectively (p = 0.796, 95% CI, −105.1–64.2) (Fig. 4). The mean contact area values in the LET-NR and LET-ER groups were 36.8 ± 3.1 mm² (range, 33.2–40.8) and 33.3 ± 6.4 mm² (range, 26.0–41.2), respectively (p = 0.360, 95% CI, −5.2–12.2) (Fig. 5).

DISCUSSION

The study findings showed that the peak contact pressure of the lateral tibiofemoral joint is greater in LET when the graft is tensioned in external rotation than in neutral rotation. However, no statistically significant difference in the mean contact pressure or the mean contact area was observed between the two groups. As a result, LET graft tension in neutral rotation may be used for ACL reconstruction augmentation to prevent lateral tibiofemoral joint overconstraint and lateral tibiofemoral osteoarthritis in the future [3].

LET and ALL reconstruction are lateral extra-articular augmentations. LET focuses on stabilizing knee rotational instability by supporting the anterolateral structure of the knee with the LET typically entails securing a portion of the IT band to the femur just above the knee joint [18]. With the renewed interest in ALL, novel techniques have been developed to reconstruct ALL [19,20]. The goals of ALL reconstruction are similar to those of LET, but they focus on creating a native ligament that is more anatomically correct, like the native ALL. ALL reconstruction entails fixing a free tendon graft in the anatomic location of the ALL between the tibia and the femur. However, the existence of ALL is disputed despite anatomical and histological evidence to the contrary. The ALL is crucial to anterolateral rotational instability, regardless of whether this structure is a ligament or a thickening of the capsular layer [21,22]. Previous studies reported that LET effectively reduces rotational instability and graft failure [4,18,23–25]. Herbst et al. documented in their biomechanical investigation that the pairing of ACL reconstruction with the LET procedure is effective in diminishing anterior translation and internal rotation of the tibia. Nonetheless, when the anterolateral capsule remained intact, the combination of ACL reconstruction and LET resulted in excessive constraint of internal tibial rotation and the lateral compartment [26]. Ahsan et al. also noted in their biomechanical analysis that the LET technique increased the restriction on tibial internal rotation, with this rotational movement being positively associated with the inherent laxity observed in the LET tissue [27]. Consequently, LET can overconstrain the lateral tibiofemoral compartment and increase the chance of postoperative osteoarthritis and stiffness [28–30]. There is a concern that LET, a non-anatomic reconstruction technique, may overconstrain the knee more than ALL reconstruction, which is anatomic reconstruction [4,9,14,31,32]. Previous research found that excessive knee constraints can contribute to abnormal knee kinematics [33–35].
The rate of osteoarthritis after ACL reconstruction combined with LET is still debatable. Perrin et al. showed no increased rate of osteoarthritis development in a case series of 148 patients who underwent bone-patellar tendon-bone ACL reconstruction combined with LET (modified Lemaire LET) [14]. Additionally, Zaffagnini et al. showed no increased rate of osteoarthritis development in a case series of patients who had over-the-top ACL reconstruction combined with LET using the remnant part of a hamstring graft [36]. However, a randomized controlled trial, with a mean follow-up of 19 years, by Castoldi et al. comparing bone-patellar tendon-bone ACL reconstruction with and without LET (modified Lemaire LET) demonstrated that LET reduced the rate of graft failure. The LET group had a higher rate of osteoarthritis in the lateral tibiofemoral joint than the control group, even though patient-reported results were similar in both groups [4].

Original LET procedures by Lamaire [7] and MacIntosh [8] tensioned grafts in tibial external rotation to control internal tibial rotation and pivot shift. However, this could cause the lateral tibiofemoral joint to be excessively constrained, leading to osteoarthritis in the lateral tibiofemoral joint. Some surgeons performed the LET procedure with a tensioned graft in neutral rotation with concern about overconstraining of the knee. To the best of our knowledge, no biomechanical and clinical investigations have been conducted to compare the stability of the LET knee with tension in neutral and external rotation. This biomechanical study expresses concerns about the lateral tibiofemoral joint of the knee being overstrained and the resultant increased risk of lateral tibiofemoral joint osteoarthritis with the addition of LET. The authors consider that this investigation demonstrates the need to stabilize the lateral tenodesis with the knee in neutral rotation rather than the externally rotated position that was previously described.

The present study’s findings suggest that peak contact pressure in the lateral tibiofemoral joint is higher during LET when the graft is tensioned in external rotation compared to neutral rotation. However, there is no statistically significant difference in mean contact pressure or contact area. This disparity in results may stem from the differing assessments of peak and mean contact pressure. Mean contact pressure evaluates pressure across the entire lateral tibiofemoral compartment, while peak contact pressure may highlight isolated points with notably high-pressure values. Thus, the study implies that LET tension in external rotation positions could elevate peak contact pressure in specific areas, while mean contact pressure affects the entire area at time zero. To draw definitive conclusions regarding the long-term effects on osteoarthritis, further clinical research is warranted.

However, several limitations should be considered when interpreting the results. First, the average age of the cadavers was 68.00 ± 17.40 years. We were concerned about the poor quality of the bones of the cadavers. Therefore, it was evaluated throughout the biomechanical testing. Second, the loads were compressed vertically along the longitudinal axis of the knee in a fully extended position. This does not represent knee motions used when walking or in daily activities. Third, male cadavers were more than female cadavers. Fourth, Thiel-embalmed cadavers were used in this study, and fresh frozen cadavers were not used. However, Thiel-embalming method efficiently preserves joints and ligaments for research. Fifth, the number of specimens is low. Moreover, further clinical research is needed to determine the long-term outcomes.

CONCLUSIONS

The peak contact pressure of the lateral tibiofemoral joint is higher in LET when the graft is tensioned in external rotation than in neutral rotation. LET graft tension in neutral rotation might be employed for ACL reconstruction augmentation to prevent overconstraining of the lateral tibiofemoral joint.

Funding

None.

Ethical approval

Chulalongkorn University Faculty of Medicine’s Institutional Review Board (IRB No. 0869/64).

Informed consent

None.

Authors’ contribution

TI carried out the investigation, participated in the data curation and edited the manuscript. 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 known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Acknowledgment

The authors express their gratitude to those who contributed their bodies in order to conduct this research. As a result, the donors and their families are deserving of our thanks. The authors are grateful to the Chula soft cadaver surgical training center for providing Thiel’s embalmed cadaveric knees for this study, the Chulalongkorn University Faculty of Engineering’s Biomechanical Laboratory for biomechanical testing, as well as Enago (www.enago.com) and English editing service, Research Affairs, Faculty of Medicine, Chulalongkorn University for English-language editing.

Finally, the authors would like to thank the following people for helping us finalize the project.
1. Chavithorn Onkurchana
2. Chitapoom Choentrakool
3. Napol Tangboontithiwong
4. Somjet Jenvorapoj

References


arthro.2016.04.028.


