The evaluation of the distance between the popliteus tendon and the lateral collateral ligament footprint and the implant in Total Knee Arthroplasty using a 3-dimensional template.

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Abstract

Background When surgeons perform TKA, popliteus tendon (PT) and lateral collateral ligament (LCL) iatrogenic injuries are a risk because the femoral attachments are relatively close to the bone resection area. The purpose of this study was to evaluate the distance between the PT or LCL footprint and the TKA implant using a 3D template system and to evaluate any significant differences according to the implant model. **Methods** Eighteen non-paired formalin fixed cadaveric lower limbs were used. All the surrounding soft tissue except the PT, ligaments and meniscus were removed from the knee. Careful dissection of the PT and LCL was performed, and the femoral footprints were detected. Each footprint periphery was marked with a K-wire. CT scanning was then performed. The data was analyzed with a 3D template system. This simulation models for TKA were the Journey II BCS and the Persona PS. The area of each footprint, and the length between the most distal and posterior point of the lateral femoral condyle and the edge of each footprint were measured. Matching the implant model to the CT image, the shortest length between each footprint and the osteotomy area were calculated. **Results** The area of the PT and LCL footprints was $38.7 \pm 17.7 \text{ mm}^2$ and $58.0 \pm 24.6 \text{ mm}^2$. The length between the most distal and posterior point of the lateral femoral condyle and the edge of the PT footprint was $10.3 \pm 2.4 \text{ mm}$ and $14.2 \pm 2.8 \text{ mm}$. The length between these same points and the edge of the LCL footprint was $16.3 \pm 2.3 \text{ mm}$ and $15.5 \pm 3.3 \text{ mm}$. Under TKA simulation, for the Journey II BCS and the Persona PS, the shortest length between the PT footprint and the osteotomy area was $4.3 \pm 2.5 \text{ mm}$ and $3.2 \pm 2.9 \text{ mm}$, and the shortest length between the LCL footprint and the osteotomy area was $7.2 \pm 2.3 \text{ mm}$ and $5.6 \pm 2.1 \text{ mm}$. The PT attachment was damaged by the bone resection of the Journey II BCS and the Persona PS TKA in 3 and 9 knee. **Conclusion** The PT and LCL femoral attachments existed close to the femoral bone resection area of the TKA. Careful attention is needed to avoid damage to the PT and LCL during surgical procedures.

Background

It has been known that the popliteus tendon (PT) or lateral collateral ligament (LCL) stabilizes the postero-lateral aspects of the knees [1,2,5,8,11]. Anatomically, The PT attaches to the antero-distal area of the lateral femoral epicondyle on the femoral side and it widely attaches to the posterior of tibia plateau on the tibia side. The mid-substance of the PT runs popliteus hiatus when the knee is flexed, and functionally, the PT has considered as a primary restraint to external knee rotation [1,2,5,11,14,17]. The LCL also attaches antero-distal area of femoral epicondyle close to the PT footprint on the femoral side, and distally, it attaches to the fibula head. LCL has described as the primary restraint to a varus knee loading [17,20].

For the surgical treatment of osteoarthritic changes in the knee joint, total knee arthroplasty (TKA) is well known for its excellent clinical results and long-term survival rates [3,10,13,15,18]. When the surgeons perform TKA, iatrogenic injury of the PT or LCL is worried because those femoral footprints are relatively close to the bone resection lesion. Several reports have been evaluated the PT or LCL injury in the surgical procedure of TKA. Simone et al showed that iatrogenic PT injury during total knee arthroplasty results in decreased knee function two to three years [1,5,8,11,16,19,20]. Tantavisut et al. reported that complete PT

resection in PS TKA led to increase gaps both flexion and extension [19]. Ghosh et al. reported that isolated PT injury doesn't lead to abnormal laxity in PS TKA [8]. Unnanuntana et al showed that LCL injuries in TKA surgery could be the cause of the knee varus instability [20]. Although, the PT or LCL iatrogenic injury was concerned in the TKA procedures, not many studies have been approached the distance between those femoral footprint and bone resection in the surgery [17].

The purpose of this study was to evaluate the distance between PT or LCL footprint and TKA implant using the three-dimensional (3D) template system. Revealing this issue would be useful to prevent the iatrogenic PT or LCL injury within the TKA surgery. The hypothesis was that the PT or LCL footprint would be highly interfered by the TKA bone resection and implants.

Methods

Cadaveric specimens were donated to the department of functional morphology in the university. Donors and their bereaved family gave their informed consent within the donation of anatomical gift statement when donors were alive. The study protocol of this study was approved by the ethics committee of the Nihon university school of medicine in accordance with the Declaration of Helsinki.

Eighteen (18) non-paired formalin fixed cadaveric lower limbs were used (9 males and 9 females). The mean age at the time of death was 80.3 (range 54-90). Whole length lower limbs including femoral head and ankle were resected from the pelvis. All the surrounded soft tissue except the PT and knee ligaments were removed from the limb. Careful dissection of the PT and LCL was performed, and those femoral footprints were detected. Each footprint was periphery marked with a 1.5 mm K-wire (Figure1. Resection and the footprint of PT or LCL dissection. Whole lower limb was resected from the pelvis, and PT or LCL footprint dissection was performed. The footprints were periphery marked with K-wire, and then the CT scan of the whole limb was taken.). Computed tomography (CT) scanning of the whole lower limb was then performed (Aquilion One™. Toshiba Medical System, Tokyo, Japan). The CT data was analyzed with 3D template system (Zedknee software: LEXI co., Ltd. Tokyo, Japan) [6,12]. The area of each footprint, and the length between most distal or posterior point of femur and the edge of each footprint were measured (National institute of health). The accuracy of the area measurement was less than 0.1mm².

In the 3D template system, simulated models of TKA were Journey II BCS (Smith and Nephew Co., Ltd.) and Persona PS (Zimmer-Biomet Co., Ltd.). In many types of TKA designs, the reason why Journey II BCS and Persona PS were selected for evaluation in this study was that the amount of bone resection is approximately minimal in Journey II BCS TKA and approximately maximum in Persona PS TKA. Simulation bone cut is that distal femoral bone cut thickness was 7.0mm with Journey II BCS and 9.0mm with Persona PS, respectively. The posterior bone cut was 7.4mm with Journey II BCS and 10.0mm with Persona PS, respectively[9,10]. Valgus angle to the femoral shaft was 6° and external rotation angle was 3° from the posterior femoral condyle axis.

When the implant model was matched to the CT image of the femur, firstly the overlap between each footprint and implant is evaluated (Figure 2. Red area is LCL footprint. Yellow area is PT footprint. Blue area is a TKA implant. PT footprint is overlapped with a TKA implant.). In the limbs which did not show the overlap between the footprint and implant, the shortest length between most distal or posterior point of implant and the edge of each footprint were measured. The area of each footprint was also measured in all limbs.

Statistical analysis

Data are presented as mean $\pm$ standard deviations. Man-Whitney's U test was performed to compare the footprint edge-implant distance between Journey II BCS and Persona PS. It was assumed that there was statistical significance when $P < 0.05$. All statistical data were calculated with SPSS 19.0 (SPSS Inc., Chicago, IL).

Results

PT and LCL footprint could be detected in all knees. The area of PT and LCL footprint were, $38.7 \pm 17.7 \text{ mm}^2$ (range 21.3-79.8) and $58 \pm 24.6 \text{ mm}^2$ (range 26.6-117.4) respectively. The length between most distal or posterior point of femur and the edge of the PT footprint were $10.3 \pm 2.4 \text{ mm}$ (range 5.7-12.8), and $14.2 \pm 2.8 \text{ mm}$ (range 7.2-17.8), respectively. The length between most distal or posterior point of femur and the edge of the LCL footprint were $16.3 \pm 2.3 \text{ mm}$ (range 11.0-19.4), and $15.5 \pm 3.3 \text{ mm}$ (range 10.5-21.0), respectively.

When simulated the TKA, PT footprint was overlapped with the implant of Journey II BCS TKA in 3 knees, and also with the Persona PS TKA in 9 knees.

In not overlapped knees, the shortest length between PT footprint and implant of Journey II BCS or Persona PS was, $4.3 \pm 2.5 \text{ mm}$ (range 0-6.9), or $3.2 \pm 2.9 \text{ mm}$ (range 1.4-4.4), respectively. The shortest length between LCL footprint and bone resection lesion of Journey II BCS and Persona PS were, $7.2 \pm 2.3 \text{ mm}$ (range 3.2-11.7), and $5.6 \pm 2.1 \text{ mm}$ (range 3.3-10.6), respectively (Table 1). No significant difference of footprint edge-implant distance was observed between Journey II BCS and Persona PS TKAs.

Discussion

The most important finding of this study was that the PT and LCL femoral footprint existed close to the femoral bone resection lesion of the TKA. When simulate the TKA using 3D template, approximately 17% of knees with BCS-TKA, and 50% knees with PS-TKA showed overlap between PT femoral footprint and the implant. In these knees, potential risk of the iatrogenic PT footprint injury is concerned. To prevent the postero-lateral instability in the TKA, careful attention is needed not to injure the PT and LCL in the surgical procedures.

Historically, several studies have been reported about femoral PT or LCL footprint anatomy [11,14,16,17]. Takeda et al. reported that the average area of PT and LCL footprint were $55.8 \pm 25.0 \text{ mm}^2$ and $52.5 \pm 24.2 \text{ mm}^2$ with 3D-CT evaluation [17]. LaPrade et al. reported that the average area of PT and LCL footprint were 0.59 cm^2 (range $0.53\text{-}0.62 \text{ cm}^2$) and 0.48 cm^2 (range $0.43\text{-}0.52 \text{ cm}^2$) with computer-controlled video motion analysis captures systems [11]. Takahashi et al. reported that the average area of PT footprint was $51.4 \pm 12.0 \text{ mm}^2$ (range $30.8\text{-}70.2 \text{ mm}^2$) [16]. In this study, the length between most distal or posterior point of femur and the edge of the PT footprint were $10.3 \pm 2.4 \text{ mm}$, and $14.2 \pm 2.8 \text{ mm}$, respectively. Takahashi et al. reported that average distance from the PT to the distal articular surface and the posterior articular surface was 10.2 mm (range $6.5 \text{ to } 16.2 \text{ mm}$), 15.1 mm (range $11.7 \text{ to } 19.0 \text{ mm}$) respectively [16]. Tantavisut et al. reported that the mean distance between the most distal femoral attachment of the PT and the most distal lateral condyle was 8.9 mm (range $6.4\text{-}10.5 \text{ mm}$), and the distance from the most posterior femoral attachment of the PT to the posterior lateral femoral condyle was 11.5 mm (range $9.5\text{-}14.0 \text{ mm}$) [19]. Compared with previous anatomical studies, the measured area and placement of PT or LCL femoral footprint in this study was similar. Although, the excellent anatomical evaluation has been reported about PT or LCL morphology, to the best of our knowledge, not many studies approached its correlation with the TKA implants [16]. In case of Persona PS, distal and posterior bone cut thickness was 9 mm and 10.0 mm [9]. In case of Journey BCS, distal and posterior bone cut thickness was 7.4 mm and 9 mm [10,18]. Considering the femoral PT footprint placement, the standard thickness of bone resection on TKA has potential risk of iatrogenic femoral PT footprint injury. On the other hands, considering that the femoral LCL footprint exists more proximal and anterior than the PT footprint, standard bone cut of TKA is potentially unlikely to injure the LCL footprint. In this study, PT footprint was overlapped with the bone resection of Journey II BCS TKA in 3 knees, and also by the Persona PS's bone resection in 9 knees. Contrary, no knees showed the overlap with LCL footprint and TKA bone resection. Takahashi et al. evaluated the distance between TKA femoral component and PT footprint using 21 cadaveric knees [16]. They used lateral femoral photograph and two dimensionally evaluate its relationship. They concluded that during primary TKA, the femoral insertion of the PT could be inevitably excised regardless of technical problems. Aki et al. reported that the accidental partial and complete excision of the femoral footprint of the PT during TKA was observed in 34.2 and 17.8% of the 275 knees, respectively [1]. In this study, the relationship of the femoral TKA implant and PT or LCL footprint was evaluated 3 dimensionally. The PT footprint would be excised when bone was resected in routine procedures, and it should be avoided during TKA surgery.

There was no report that bone resection line and LCL footprint was overlapped. The results of this study showed that the length between most distal or posterior point of femur and the edge of the LCL footprint were $16.3 \pm 2.3 \text{ mm}$, and $15.5 \pm 3.3 \text{ mm}$, respectively. Considering that the distal and posterior bone resection in the TKA is normally less than 10 mm , the risk of LCL injury may be low, however, potential risk of LCL footprint injury would be existed in the knees severe valgus knees or knees with dysplasia of the lateral femoral condyle.

This study has several limitations. 1) small sample size and the only Japanese specimens were investigated. 2) the height of the specimens was not evaluated, there might exist some correlation between the height and the risk for cutting the PT or LCL. 3) this study performed with CT based 3D template system, and therefore, cartilaginous tissue was not evaluated. Clinically, the bone cut thickness might be less than CT simulation. These limitations should be approached in the future plans.

Conclusion

In conclusion, the PT and LCL femoral footprint existed close to the femoral bone resection lesion of the TKA. A standard bone resection was possible to excise the femoral PT footprint. To prevent the postero-lateral instability in the TKA, careful attention is needed not to injure the PT and LCL in the surgical procedures.

Abbreviations

Popliteus tendon: PT, Lateral collateral ligament: LCL, Total knee arthroplasty: TKA, Three dimensional: 3D, Computed tomography: CT

Declarations

Ethics approval and consent to participate

This study has been approved by the ethics committee of Nihon University School of Medicine. The IRB number was 20-14.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Not applicable

Authors' contribution

TI analyzed and interpreted the 3D-CT data. KR was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Not applicable

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Table

Table1

n=18	PT	LCL
Area of femoral footprint	38.8±17.7mm ² (21.3~79.8)	58±24.6mm ² (26.6~117.4)
Distance between the edge of the footprint and the most distal/posterior point of femur	10.3±2.4mm(5.7~12.8) /14.2±2.8mm(7.2~17.8)	16.3±2.3mm(11.0~19.4) /15.5±3.3mm(10.5~21.0)
The footprint overlapped with the implant in the Journey II BCS-TKA/Persona CR-TKA	3/9knees	0/0knee
Shortest length between the edge of the footprint and the bone resection lesion		
Journey II BCS	4.3±2.5mm(0~6.9)	7.2±2.3mm (3.2-11.7)
Persona CR	3.2±2.9mm(1.4~4.4)	5.6±2.1mm (3.3-10.6)

The measured PT or LCL footprint area. The distance between the footprint and articular surface or TKA implant. The number of footprints overlapped with the implant. Shortest lengths between the edge of the footprint and the bone resection lesion.

Figures

Figure 1

Resection and the footprint of PT or LCL dissection. Whole lower limb was resected from the pelvis, and PT or LCL footprint dissection was performed. The footprints were periphery marked with K-wire, and then the CT scan of the whole limb was taken.

Figure 2

Red area is LCL footprint. Yellow area is PT footprint. Blue area is a TKA implant. PT foot print is overlapped with a TKA implant.