의학석사 학위논문

Is there a Relationship between Distal Femoral Hypoplasia and Coronal and Rotational Alignments in Osteoarthritis Knees?

슬관절 골관절염에서 원위 대퇴골 저형성과 관상면 및 회전정렬 간 관계가 있는가?

2018년 2월

서울대학교 대학원

의학과 정형외과학 전공

정 현 장

Abstract

Introduction:

The knee joint has coupled motion of femur and tibia. A change in the anatomy of one part of the articulating structure will have an effect on the counterpart. There were several previous studies regarding correlation between coronal and axial alignment in osteoarthritis with varus knee alignments, however, in authors knowledge, there has been no study regarding analysis of the correlation of lateral femoral hypoplasia with degree of coronal and rotational alignment in osteoarthritis with valgus knee alignment.

Therefore, authors analyzed the correlation of hypoplasia of distal femur with coronal and rotational alignments of the femoral condyle to evaluate the relationship between coronal alignment and rotational profile of the lower limb in Korean patients with knee osteoarthritis.

Materials and Methods:

From November 2011 to May 2015, 422 knees from 211 patients (20 male, 191 female) who were examined with a standing anteroposterior radiograph and computed tomography for total knee replacement arthroplasty were selected for the study. Tibiofemoral angle (mTFA) was measured using the standing anteroposterior radiograph, subsquently divided into three groups based on the 3 degrees of valgus and/or varus; more than 3 degrees of valgus (n = 31), 3 degrees of valgus to 3 degrees of varus (n = 78), and more than 3 degrees of varus (n = 313). Mean age was 70.2 ± 6.69 years and showed no differences according to sex (*p* = 0.875) and mTFA (*p* = 0.647). Condylar twisting angle (CTA) was defined as the angle formed by clinical transepicondylar axis of distal femur (TEA) and posterior condylar axis (PCA). Femoral anteversion (FeAV) was measured based on TEA (tFeAV) and PCA (pFeAV), respectively. CTA, FeAV, and tibial torsion were measured using computed tomography. Subsequently, correlations between the indicators were analyzed.

Results:

Mean value of mTFA, CTA, pFeAV, and tibial torsion was significantly different by groups divided according to mTFA (all $p < 0.001$), however, tFeAV was not significantly different ($p = 0.290$). There were positive correlation between mTFA and other rotational profile except tFeAV; correlation coefficient of mTFA vs. CTA 0.253, $p < 0.001$; vs. tFeAV 0.060, $p = 0.218$; vs. pFeAV 0.145, $p = 0.003$; and vs. tibial torsion 0.374, $p < 0.001$.

Conclusions:

In this study, condylar twisting angle was significantly greater in valgus group, indicating lateral condyle has hypoplastic change relative to medial condyle. Also, pFeAV was significantly different, however tFeAV was not, which indicating the difference according to hypoplasia of lateral femoral condyle. Therefore, conventional femoral cutting guide based on the posterior condyle without considering the difference between pFeAV and tFeAV may induce the malrotation of femoral component in valgus knee patients. mTFA showed positive correlation with other rotational profile which suggests the increased CTA and tibial torsion in valgus group, therefore axes formed by hip, knee, and ankle joints were intimately correlated. Therefore, these rotational profiled should be preoperatively evaluated and the degree of hypoplasia of lateral femoral condyle and external torsion of tibia should be considered to obtain satisfactory rotational alignment in TKA of valgus knee patient.

Keywords : Femoral hypoplasia, Knee joint, Osteoarthritis, Coronal alignment, Rotational alignment, Axial computed tomography

Student Number : 2016-21940

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Study Background

Knee joint deformity with flexion contracture is a common finding in patients with osteoarthritis of knee. It is well known that recovering normal mechanical axis of deformed lower extremity and positioning the insert in an accurate position significantly affects durability of the insert, range of motion, and pain[1]. Therefore, surgeons should predict the amount of bone resection and correction degree preoperatively to restore the coronal alignment by measuring anatomical and mechanical axis of the lower extremity using a standing full-limb anteroposterior (AP) radiograph[2]. And sagittal lower extremity alignment and posterior slope of the proximal tibia are also should be considered to correct flexion contracture and genu recurvatum.

Axial rotational alignment is also important in total knee arthroplasty (TKA) just as coronal and sagittal alignments are. Precisely adjusting rotational alignment of the femoral component is essential to accomplish satisfactory patello-femoral and tibio-femoral kinematics and flexion gap balance. If the rotational alignment of distal femoral component or tibial plate is inappropriate, patients may complain of anterior knee pain, patellar dislocation or other problems related to patello-femoral joint instability. Also, it may cause discrepancy of medial and lateral flexion gaps, which in turn brings about joint instability, decreased range of motion, early implant wear, and premature loosening even without any particular problems such as infection and/or component failure[3-6].

Therefore, many surgeons have tried to obtain optimal coronal and axial alignments, as a result, gap technique and measured resection technique are generally applied for this. Gap technique uses medial and lateral ligament tensions on cut surfaces of distal femur and proximal tibia, and measured resection technique uses anatomical landmarks such as transepicondylar axis (TEA), Whiteside's line, and posterior condylar axis of distal femur (PCA).

The knee joint has coupled motion of femur and tibia. A change in the anatomy of one part of the articulating structure will have an effect on the counterpart. In osteoarthritis of knee with varus knee deformity, femoral anteversion(7) and tibial torsion(8) were relatively decreased than that of normal knee alignment. Osteoarthritis with valgus knee alignment is relatively uncommon than varus knee alignment, and incidence of osteoarthritis with valgus alignment was reported in 10-15 % of the patients who undergoes TKA(9). Valgus deformity is sustained by bone remodeling consists of lateral cartilage erosion, lateral condylar hypoplasia, and metaphyseal femur and tibial plateau remodeling(10). Matsuda et al. have been compared the anatomy of distal femoral condyle according to knee alignment. In their study, hypoplasia of medial femoral condyle was not observed in varus knee group, whereas hypoplasia of lateral femoral condyle was presented in valgus knee group(11, 12). Akagi et al. also reported similar results. In their study, condylar twisting angle was almost constant at averaged 6 degrees in neutral & varus knees, however, it was increased gradually along the mechanical tibiofemoral angle in valgus knees(13). Therefore, in patients with valgus knee deformity, the angle between TEA and PCA are often measured greater than patients with the normal knee alignment during surgical procedure, due to cartilage erosion and hypoplasia of lateral femoral condyle(13).

And, if the surgeons routinely rotate the distal femur cutting guide by externally 3 degrees, femoral component will be fixed internally rotated position, leading to poor clinical outcomes. Therefore, analyzing a correlation of coronal alignment of the lower limb with distal femoral hypoplasia and the consequent anatomical changes in the tibia, especially for the tibial torsion, would be very important for determining the proper location of the implants of TKA.

1.2. Purpose of Research

Recently, distal femur cutting guide can be adjusted in various angles relative to the PCA. Thus, determining appropriate external rotation in accordance with personal anatomical variations would be important for satisfactory clinical results of TKA. And also, extraarticular references become more important when using an extramedullary guide to make tibial cutting and decide rotation of the tibial component of TKA. Although Tamari et al. have been reported correlation between tibiofemoral angle and torsion of hip and/or knee in healthy population[(14)], in authors knowledge, there has been no study until now, regarding analysis of the correlation of lateral femoral hypoplasia with degree of coronal and rotational alignment of whole lower extremities in osteoarthritis with valgus knee alignment. Therefore, authors analyzed the correlation of hypoplasia of distal femur with coronal and rotational alignments of the femoral condyle to evaluate the relationship between coronal alignment and rotational profile of the lower limb in Korean patients with knee osteoarthritis.

Chapter 2. Body

2.1. Materials and Methods

The present study was approved by institutional review board of the senior author's affiliation. Patients who underwent total knee arthroplasty due to osteoarthritis of knee in senior author's affiliation between November 2011 and May 2015 were enrolled, and we retrospectively analyzed the records of 231 patients (462 legs), examined with a standing full-limb AP radiograph and axial computed tomography (CT). Patients' demographics and past medical history were evaluated through medical records including the physician's admission and progress notes, and operative records. Twenty patients (40 legs) who had previous surgical history due to deformity and/or fracture of lower extremity, and current weakness and/or functional deficit due to neuromuscular disease were excluded. Finally, 211 patients (422 legs) were included for this study, consisting 20 male and 191 female patients. Mean age was 70.2 ± 6.69 years, and there were no differences by sex (male 70.5 ± 7.58 vs. female 70.2 ± 6.61; $p = 0.875$). Mean height was 153.4 ± 6.72 cm, and there were differences according to sex (male 165.5 ± 4.85 vs. female 152.1 ± 5.52; $p < 0.001$). Mean weight was 61.9 ± 8.88 kg, and male (69.7 ± 9.09) was heavier than female (61.1 ± 8.47; $p < 0.001$), However, demographics were not different according to mTFA (all $p > 0.05$, Table 1).

Table 1. Demographics of patients who examined a standing full-limb anteroposterior radiograph and axial computed tomography for total knee arthroplasty between November 2011 and May 2015.

	Valgus group	Neutral group	Varus group	*P*-value
	> valgus 3°	valgus 3°-varus 3°	> varus 3°	
Age, years	70.9 ± 6.70	70.0 ± 6.77	70.2 ± 6.70	0.647
Sex, male:female	3:28	9:69	28:285	0.773
Height, cm	154.2 ± 7.69	155.1 ± 7.45	153.0 ± 6.23	0.063
Weight, kg	62.5 ± 9.53	63.1 ± 8.92	61.6 ± 8.80	0.387

Data given as mean ± standard deviation, unless otherwise specified.

Valgus, neutral, and varus group were divided according to mechanical tibiofemoral angle.

Radiologic assessments

A true AP view was obtained for the standing full-limb AP radiograph which was obtained on a 14 x 51 inch grid cassette at a source-to-image distance of 240 cm using a UT 2000 X-ray machine (Philips Research, Eindhoven, The Netherlands) set to 90 kV and 50 mA/s. To adjust the rotational position of the AP radiograph, foot rotation was held constant with a reference foot template on the platform of our radiographic system. In addition, the appropriate knee position, which was defined by widened stance to vertically align the ankle to the femoral heads, patella facing forward, and 1/2 to 1/3 of the width of the fibular head being overlapped to the tibial condyle (patellar facing forward) was confirmed using a preview monitor before final acquisition of the full-limb AP radiograph.

Axial computed tomography (Infinia™ Hawkeye® 4 device, GE Healthcare, Milwaukee, WI, USA) was used to obtain radiological information of femoral and tibial torsion. Lower extremities of patients were immobilized with supporting sponge in a state of internal rotation 5 degrees in a supine position to obtain CT scan(15, 16). Simultaneous axial images of hip, knee, and ankle joints were acquired without moving the patients(16). Multi-slice CT images (140 keV, 70–100 mA) of the whole lower extremity with multi-planar reconstruction (slice thickness 2.95 mm; pitch 1.9 mm; reconstruction interval 2.95 mm) were also constructed.

All radiographs were digitally acquired using a picture archiving and communication system (PACS, Infiniti, Seoul, Republic of Korea), and assessments were performed on a 25-inch LCD monitor (U2515H; Dell, Ultra sharp) in portrait mode. To improve intra- and interobserver reliabilities of radiographic assessment, two orthopedic surgeons performed all radiographic assessments twice, with a 2-weeks interval between the evaluation cycles. The mean values were used for statistical data analysis.

Mechanical tibiofemoral angles (mTFA) of both legs (Figure 1) was measured by intersecting the femoral and tibial anatomic axes in standing full-limb AP radiograph. Other rotational profiles parameters were measured using axial image of CT scan. Condylar twisting angle (CTA) was defined as the angle between clinical transepicondylar axis (TEA) and posterior condylar axis (PCA); TEA was defined as line connecting the vertices of the lateral and medial epicondylar prominence of distal femur, and PCA as connecting line between the posterior margins of the lateral and medial femoral condyles. Hypoplasia of the lateral femoral condyle was evaluated with condylar twisting angle (Figure 2).

Femoral anteversion was measured using PCA (pFeAV)[16, 17] and TEA (tFeAV)[18] on the bases of the line intersecting femur neck, respectively (Figure 3). In similar manner, tibial torsion was measured by the angle formed by the axis connecting posterior cortices of proximal tibial condyles[16] and the axis connecting the largest prominences of lateral and medial malleolus[17] (Figure 4).

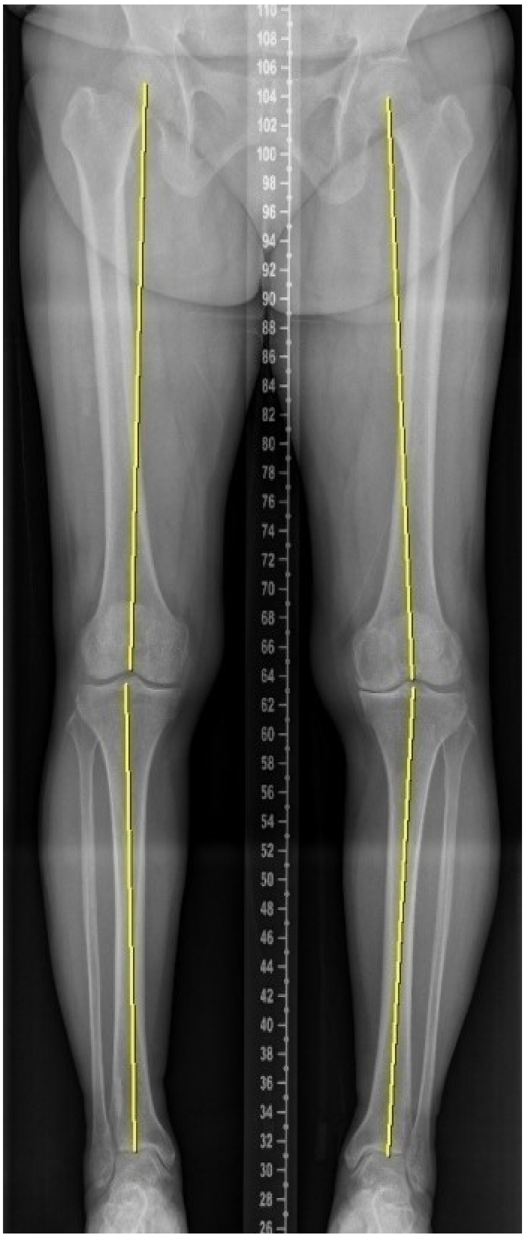

Figure 1. Mechanical tibiofemoral angle was measured by intersecting the femoral and tibial anatomic axes in weight bearing lower extremity AP x-ray.

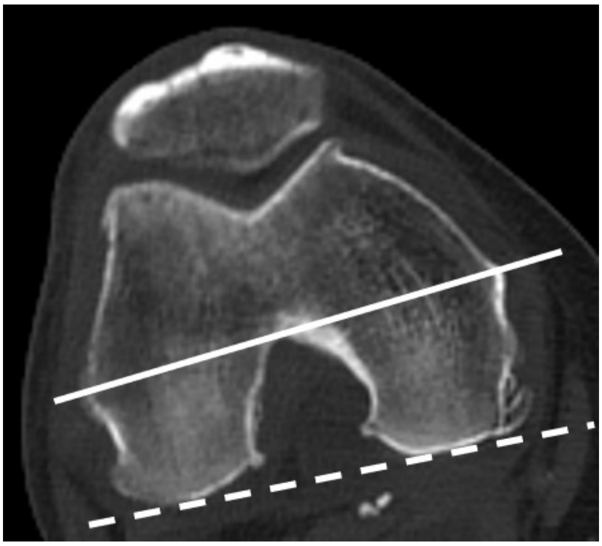

Figure 2. Computed tomographic scan of the axial view of the distal femur. Clinical transepicondylar axis (TEA) was defined as line connecting the vertices of the lateral and medial epicondylar prominence of distal femur (white straight line). Posterior condylar axis (PCA) was defined as line connecting the posterior margin of the lateral and medial femoral condyle (white dashed line). Condylar twisting angle (CTA) was defined as the angle between clinical transepicondylar axis and posterior condylar axis. Degree of the distal femur hypoplasia was measured by condylar twisting angle.

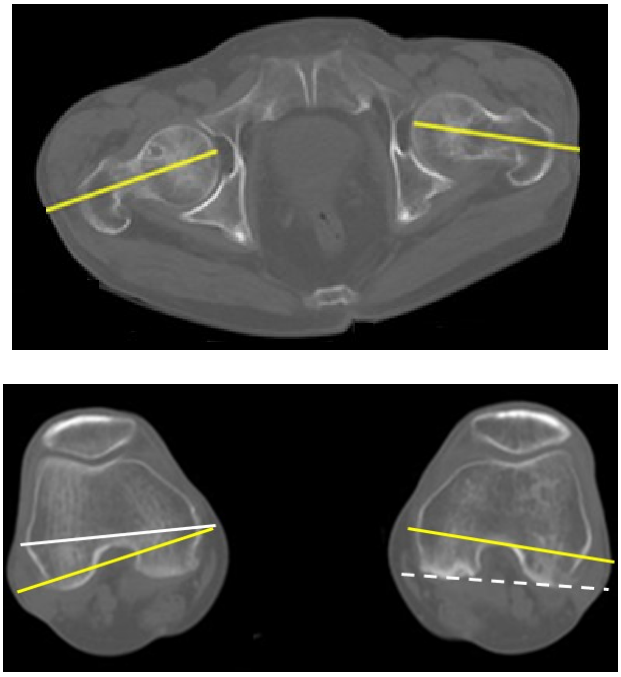

Figure 3. Femoral anteversion was measured by the angle between a yellow straight line that is intersecting femur neck and a straight white line indicating clinical transepicondylar axis (tFeAV), and a dashed white line which connecting the posterior aspects of the femoral condyles (pFeAV).

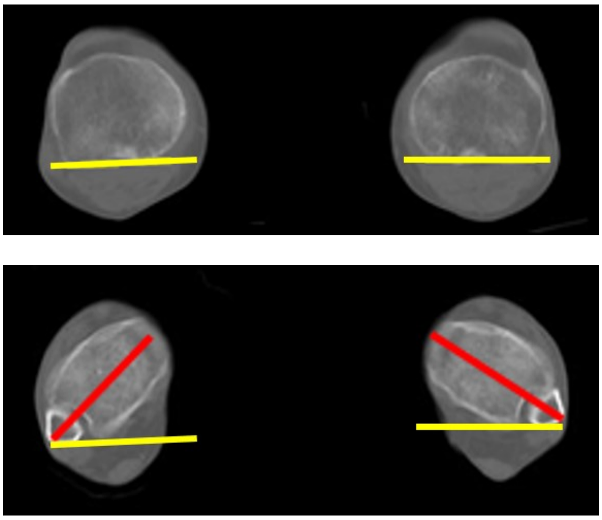

Figure 4. Tibia torsion was measured by the angle between a yellow straight line that is connecting the posterior aspects of the proximal tibia condyles and a red straight line that is connecting the most prominence of lateral and medial malleolus.

Patients were divided into three groups according to the mechanical tibiofemoral angle; more than 3 degrees of valgus (valgus group, n = 31), between 3 degrees of valgus to 3 degrees of varus (neutral group, n = 78), and more than 3 degrees of varus (varus group, n = 313). In each group, average values of mechanical tibiofemoral angle, condylar twisting angle, femoral anteversion, and tibial torsion were compared and correlation between the indices were analyzed.

Statistical analysis

All statistical analyses were conducted using PASW statistics software package, version 18.0 (SPSS Inc., Chicago, IL, USA). Kolmogorov-Smirnov normality test was conducted for continuous variables to evaluate the distribution of data composition. The demographics of the patients were summarized through descriptive statistics. Chi-square test or Fisher's exact test was conducted for nominal variables. One-way analysis of variance (ANOVA) or Kruskal-Walis test was conducted to compare multiple groups, and post-hoc analysis was conducted using the Bonferroni method. Correlation analysis was conducted using Pearson correlation analysis or Spearman correlation analysis. Linear regression analysis was conducted to reveal causal-relationship between CTA and other rotational profile. Cronbach's alpha test was conducted to evaluate the reliability of measurement. All statistical tests were performed on both sides with a significance level of 0.05.

2.2. Results

Authors measured the rotation profile twice, therefore intraclass correlation coefficient (ICC) was conducted to evaluate the reliability of measurement. The ICC of each variable was 0.8 or more (mTFA 0.968, CTA 0.963, pFeAV 0.933, tFeAV 0.948, tibial torsion 0.835; all $p < 0.001$), which indicates good reliability. Therefore, mean value of each variables were used to analysis.

Mechanical tibiofemoral angle was described positive number when it was valgus. The mean mTFA was +9.4° ± 6.1° in valgus group, -0.4° ± 1.6° in neutral group, and -8.7° ± 4.8° in varus group, respectively. CTA was 10.2° ± 1.9° in valgus group, 7.4° ± 2.5° in neutral group, and 6.6° ± 4.8° in varus group. pFeAV was 16.7° ± 5.8° in valgus group, 12.1° ± 6.0° in neutral group, and 10.9° ± 7.0° in varus group. tFeAV was 6.5° ± 5.6° in valgus group, 4.7° ± 5.6° in neutral group, and 4.3° ± 7.0° in varus group. Tibial torsion was 32.6° ± 6.2° in valgus group, 26.3° ± 6.9° in neutral group, and 22.6° ± 7.2° in varus group. These radiologic parameters except tFeAV ($p = 0.290$) were significantly different, according to group divided by mTFA (all $p < 0.001$), and also showing significantly different in post-hoc analysis (Figure 5), except pFeAV between neutral and varus group ($p = 0.327$) and tFeAV.

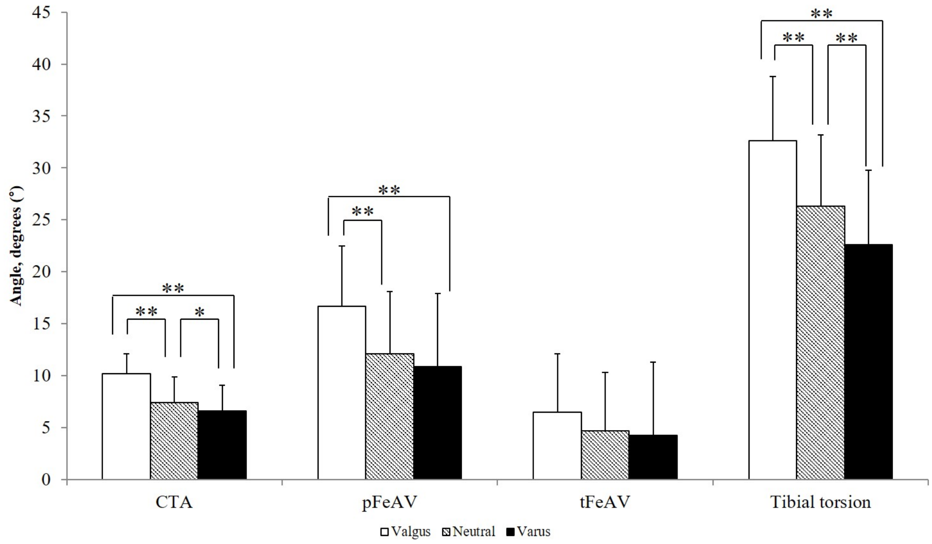

Figure 5. Comparison of radiologic parameters according to mechanical tibiofemoral angle. Valgus, neutral, and varus group were divided according to mechanical tibiofemoral angle.

Abbreviations: CTA, condylar twisting angle; pFeAV, femoral anteversion based on posterior condylar angle, tFeAV, femoral anteversion based on transepicondylar axis

**P*-value < 0.05, ***P*-value < 0.001

Correlation analysis between mTFA and other radiologic rotational profile parameters was conducted. Correlation coefficient between mTFA and CTA was 0.253 ($p < 0.001$), vs. pFeAV 0.145 ($p = 0.003$), vs. tFeAV 0.060 ($p = 0.218$), and vs. tibial torsion 0.374 ($p < 0.001$). These results indicating that CTA, pFeAV, and tibial torsion was increased with mTFA (Table 2).

Table 2. Correlation coefficient between mechanical tibiofemoral angle and other radiologic rotational profile parameters

	Correlation coefficient, r	*P*-value
Condylar twisting angle, (°)	0.253	< 0.001*
Femoral anteversion, (°)	0.145†	0.003*
	0.060‡	0.218
Tibial torsion, (°)	0.374	< 0.001*

*statistically significant ($p < 0.05$), †femoral anteversion based on posterior condylar axis (pFeAV), ‡femoral anteversion based on transepicondylar axis (tFeAV)

Correlation analysis between CTA and other radiologic rotational profile parameters was also conducted to reveal the relationship between lateral femoral condylar hypoplasia and other rotational alignment. Correlation coefficient between CTA and pFeAV was 0.242 ($p < 0.001$), vs. tFeAV 0.077 ($p = 0.113$), and vs. tibial torsion 0.219 ($p < 0.001$) (Table 3).

Table 3. Correlation coefficient between condylar twisting angle and other radiologic rotational profile parameters

	Correlation coefficient, r	*P*-value
Mechanical tibiofemoral angle, (°)	0.253	< 0.001*
Femoral anteversion, (°)	0.242†	< 0.001*
	0.077‡	0.113
Tibial torsion, (°)	0.219	< 0.001*

*statistically significant ($p < 0.05$), †femoral anteversion based on posterior condylar axis (pFeAV), ‡femoral anteversion based on transepicondylar axis (tFeAV)

Linear regression analysis between CTA and other radiologic rotational profile parameters which presented significant correlation was conducted. pFeAV and tibial torsion showed positive causality with CTA, which indicating that femoral anteversion and tibial torsion was increased with CTA (Table 4).

Table 4. Linear regression analysis between condylar twisting angle and other radiologic rotational profile parameters

	Regression coefficient, ß	*P*-value
Mechanical tibiofemoral angle, (°)	0.322	< 0.001*
Femoral anteversion†, (°)	0.265	< 0.001*
Tibial torsion, (°)	0.256	< 0.001*

*statistically significant ($p < 0.05$), †femoral anteversion based on posterior condylar axis (pFeAV)

2.3. Discussions

There have been several previous anatomical studies deal with neutral or varus aligned knees, regarding mechanical tibiofemoral angle. However, relatively few studies have dealt with surface of distal femur in valgus knees, probably due to relative rareness of valgus knees. And, in authors' knowledge, this is the first study regarding correlation of hypoplasia of distal femur and coronal and rotational alignments of the femoral condyle in Korean patients with osteoarthritis of knee. We found that mTFA was correlated with other radiologic rotational profile, and if the mTFA presented more valgus angle, the other radiological parameters became larger.

For successful TKA, obtaining optimal rotational alignment of the components is one of the essential factors. According to previous studies, femoral component must be parallel to transepicondylar axis and vertical to the AP axis(19). Therefore, accurate measurement of rotational profile is important to obtain good functional results. Typically, femoral anteversion was measured based on the PCA. Despite being routinely used up to now, there is a disadvantage in that measurement errors may occur due to degenerative changes and/or deformation in femoral anteversion based on the PCA (pFeAV), however, TEA is relatively less affected by degenerative changes(20). Therefore, authors measured the femoral anteversion using both PCA and TEA, respectively.

Asano et al. reported that surgical transepicondylar axis (sTEA) is the best landmark to align the femoral components in the functional axis of knee(19). Nevertheless, as sulcus of medial epicondyle is often absent(13, 21), identifying accurate locations of sTEA is still challenging not only during surgical procedure, but also in CT scans[21, 22]. However, clinical transepicondylar axis is relatively readily identifiable in CT scans[13, 21]. Therefore, authors measure the clinical transepicondylar axis and condylar twisting angle, instead of surgical transepicondylar axis and posterior condylar angle[21, 23, 24].

Furthermore, AP axis is also difficult to determine, as arthritic knees often develop trochlear wear and/or intercondylar osteophyte. Therefore, considerable number of bone cutting guide systems are designed to externally rotate the femoral component 3-5 degrees or more over posterior condyles, due to ease of identifying posterior condyle. However, current study showed that mTFA was increased pFeAV, but not with tFeAV. These results indicated that hypoplasia of lateral femoral condyle was prominent in valgus knee group, and routinely use of conventional femoral cutting guide based on the posterior condyle, without considering the difference between pFeAV and tFeAV, may induce the malrotation of femoral component, especially in valgus knee patients group.

In general, varus knee with osteoarthritis does not show hypoplasia or severe posterior attrition of medial femoral condyle, whereas valgus knee is known that it can be associated with hypoplasia of lateral femoral condyle[11, 12, 25]. In TKA, condylar twisting angle which formed by posterior condylar axis and clinical transepicondylar axis is related to the rotation of the femoral component, which is one of the important factors affecting the clinical outcomes of TKA[26].

There were several studies reporting differences of condylar twisting angle according to mechanical tibiofemoral angle (Table 5). Griffin et al. reported that intraoperatively measured condylar twisting angle was 5.4 degrees on valgus knees and 3.3 degrees on normal and varus knees[24]. And Matsuda et al. reported that posterior condylar axis which measured using MRI is 11.5 degrees internally rotated to transepicondylar axis in valgus knees, and about 6 degrees in normal and varus knees(12). In valgus knees, the AP length of the anterior part of the lateral condyle (a portion of lateral condyle anterior to TEA on axial plane of distal femur) was not significantly different, however, the posterior part of lateral condyle (a portion of lateral condyle posterior to TEA on axial plane of distal femur) was significantly smaller than in normal and varus knees. Also, the radius of posterior arc of lateral femoral condyle is clearly larger than normal knees(12). These findings suggest that posterior cortex of lateral condyle is distorted in valgus knees.

Table 5. Comparison of condylar twisting angle between current study and previous ones.

	Valgus alignment	Neutral alignment	Varus alignment
Current study, (°)	10.2 ± 1.9	7.4 ± 2.5	6.6 ± 4.8
Griffin et al., (°)(24)	5.4 ± 2.3	3.3 ± 2.3	3.3 ± 1.9
Matsuda et al., (°)(12)	11.5 ± 2.1	6.4 ± 1.8	6.1 ± 1.8

Data given as mean ± standard deviation.

Valgus, neutral, and varus group were divided according to mechanical tibiofemoral angle.

Thus, it can be summarized that more severe valgus knee is related to greater degree of hypoplasia, resulting in more distortion of the lateral femoral condyle. In cases of valgus knee, 3 degrees of external rotation relative to the posterior condyle would result in 8.5 degrees malrotation on TEA of the femoral component, which would result in patellofemoral joint complications(12). Therefore, in case of patient with valgus knee alignment, surgeons would be better to measure the condylar twisting angle on preoperatively using MRI or CT scan, and consider the degree of hypoplasia of lateral femoral condyle to determine the degree of external rotation of the distal femur cutting guide. In practice, additional to palpating the epicondyles, preoperatively measured rotational angle can be applied to determine the degree of external rotation of the cutting guide relative to the posterior condylar axis, which is easily palpable and therefore a relatively reliable rotational landmark(12).

The metaphyseal remodeling of lateral femoral condyle after bone loss is known to contribute the formation of valgus alignment of knee(9), and Nakabayashi et al. reported that the hardness of lateral femoral condyle is weaker than that of the medial femoral condyle(27). Therefore, authors speculate that if the mechanical axis passes from the center of knee joint to the laterally due to valgus deformity, the excessive load on the lateral femoral condyle will cause microfractures due to weaker bone quality of it and ultimately induce the hypoplasia of lateral femoral condyle as an adjustment process. Subsequently, due to the coupled movement of the femur and tibia, hypoplastic lateral femoral condyle induces external torsion of the tibia. These anatomical changes in coronal and rotational plane leads to biomechanical adaptation, relative out-toeing gait, to maintain 3-dimensional balance of the lower extremity.

Standard reference of tibial baseplate positioning during TKA is still debate. However, malrotation of the tibial component causes inhomogeneous stress distribution, leading to early loosening of the component(28). Especially, internal rotation of the tibial component is related to a high risk of instability due to unbalanced patellofemoral joint kinematics. Thus, optimal positioning of the tibial baseplate is crucial for successful TKA[9, 28, 29]. Numerous methods and landmarks have been proposed to achieve the optimal rotational alignment of the tibial baseplate. Generally, medial third of anterior tibial tubercle[30] or medial border of patellar tendon[31] is thought to be a suitable reference landmark for tibial rotational alignment to reduce postoperative patellofemoral pain. However, these anatomical landmarks were relatively unreliable particularly in patients with patellofemoral dysplasia[31]. Therefore, several methods were suggested to overcome the anatomical variance.

The ROM technique which did not use anatomical landmarks was suggested[32]. After cyclic movements through a full range of flexion and extension of knee, tibial components found its own best position in relation to femoral components. However, this technique is highly dependent on the alignment of femoral component and soft tissue balancing, and have a risk of internally rotated tibial components[31, 33].

Akagi et al. suggested a virtual line connecting the center of tibial insertion of posterior cruciate ligament and medial edge of patellar tendon attachment (Akagi's line) as a reliable AP axis of the tibia[34], which provides a more relatively exact rotational alignment. Page et al. suggested a tibial tuberosity axis connecting the most anterior points on the lateral and medial tibial condyle. placing the tibial baseplaste at anterior tibial marginal line is the method that has lowest variability[35]. Extraarticular references such as transmalleolar axis and the second metatarsal bone were also suggested[32, 34]. However, the rotational mismatch between the proximal and distal ends of tibia have been reported, and it may leads to malrotation of tibial component[36]. Therefore, considering the results of current study, more valgus knee is related to more severe hypoplasia of the lateral femoral condyle with more tibial external torsion, rotation of the tibial components should be more precisely determined.

Limitations

In authors' knowledge, this is the first study regarding analysis of the correlation between the degree of lateral femoral hypoplasia and degree of valgus coronal alignment. However, there are several limitations. First, there may be a bias due to its own nature of retrospective study itself. However, to overcome this limitation, authors enrolled the all patients of entire study period according to pre-planned inclusion and exclusion criteria. Second, demographics of patients were not matched between the groups. However, age, sex ratio and weight were not significantly different according to mTFA, and though the height of neutral and varus group was statistically different, the mean difference was just 2.3 cm. And also female patients enrolled predominantly. However, Akagi et al. reported that there was no significant difference in the geometry of knee joints according to sex(34). Thus, female predominance in our study might not have affected the results significantly. Second, the exact geometry of the femoral condyles with valgus deformity and osteoarthritic change could not be assessed precisely. CT depicts bone structures, not reflecting the true articular surface formed by cartilaginous structures, and also osteophytes may have caused measurement errors when determining the reference line on axial CT. However, to decrease the measurement errors, two orthopedic surgeon measured twice it independently. Finally, authors measured the tibiofemoral angle without taking into consideration bowing deformities of the femur and tibia. However, authors conducted this study to elucidate the relationship of hypoplasia of distal femoral condyle with coronal and rotational alignment of knee, and results was seemed consistent with the purpose of this study.

Chapter 3. Conclusion

In this study, condylar twisting angle was significantly greater in valgus group, indicating lateral condyle has hypoplastic change relative to medial condyle. Also, pFeAV was significantly different, however tFeAV was not, which indicating the difference according to hypoplasia of lateral femoral condyle. Therefore, conventional femoral cutting guide based on the posterior condyle without considering the difference between pFeAV and tFeAV may induce the malrotation of femoral component in valgus knee patients. mTFA showed positive correlation with other rotational profile which suggests the increased CTA and tibial torsion in valgus group, therefore axes formed by hip, knee, and ankle joints were intimately correlated. Therefore, these rotational profiled should be preoperatively evaluated and the degree of hypoplasia of lateral femoral condyle and external torsion of tibia should be considered to obtain satisfactory rotational alignment in TKA of valgus knee patient.

Bibliography

1. Victor J. Rotational alignment of the distal femur: a literature review. Orthop Traumatol Surg Res. 2009;95(5):365-72.

2. Victor J, Van Doninck D, Labey L, Innocenti B, Parizel PM, Bellemans J. How precise can bony landmarks be determined on a CT scan of the knee? Knee. 2009;16(5):358-65.

3. Abadie P, Galaud B, Michaut M, Fallet L, Boisrenoult P, Beaufils P. Distal femur rotational alignment and patellar subluxation: a CT scan in vivo assessment. Orthop Traumatol Surg Res. 2009;95(4):267-71.

4. Barrack RL, Schrader T, Bertot AJ, Wolfe MW, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop Relat Res. 2001(392):46-55.

5. Newbern DG, Faris PM, Ritter MA, Keating EM, Meding JB, Berend ME. A clinical comparison of patellar tracking using the transepicondylar axis and the posterior condylar axis. J Arthroplasty. 2006;21(8):1141-6.

6. Walde TA, Bussert J, Sehmisch S, Balcarek P, Sturmer KM, Walde HJ, et al. Optimized functional femoral rotation in navigated total knee arthroplasty considering ligament tension. Knee. 2010;17(6):381-6.

7. Puthumanapully PK, Harris SJ, Leong A, Cobb JP, Amis AA, Jeffers J. A morphometric study of normal and varus knees. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA. 2014;22(12):2891-9.

8. Inagaki T, Tsukagoshi N, Ichihara C, Ohishi N, Udaka S, Ghisla S, et al. In vitro synthesis of pig kidney general acyl CoA dehydrogenase. Biochem Biophys

Res Commun. 1986;137(3):1049-54.

9. Ranawat AS, Ranawat CS, Elkus M, Rasquinha VJ, Rossi R, Babhulkar S. Total knee arthroplasty for severe valgus deformity. J Bone Joint Surg Am. 2005;87 Suppl 1(Pt 2):271-84.

10. Rossi R, Rosso F, Cottino U, Dettoni F, Bonasia DE, Bruzzone M. Total knee arthroplasty in the valgus knee. Int Orthop. 2014;38(2):273-83.

11. Murray PB, Rand JA. Symptomatic Valgus Knee: The Surgical Options. J Am Acad Orthop Surg. 1993;1(1):1-9.

12. Matsuda S, Miura H, Nagamine R, Mawatari T, Tokunaga M, Nabeyama R, et al. Anatomical analysis of the femoral condyle in normal and osteoarthritic knees. J Orthop Res. 2004;22(1):104-9.

13. Akagi MMD, Yamashita EMD, Nakagawa TMD, Asano TMD, Nakamura TMD. Relationship Between Frontal Knee Alignment and Reference Axes in the Distal Femur. Clinical Orthopaedics & Related Research July. 2001;388:147-56.

14. Tamari K, Tinley P, Aoyagi K. Gender and age-related differences in axial alignment of the lower limb among healthy Japanese volunteers: comparative and correlation study. J Jpn Phys Ther Assoc. 2003;6(1):25-34.

15. Kim HY, Cha YH, Chun YS, Shin HS. Correlation of the torsion values measured by rotational profile, kinematics, and CT study in CP patients. Gait Posture. 2017;57(Supplement C):241-5.

16. Buck FM, Guggenberger R, Koch PP, Pfirrmann CW. Femoral and tibial torsion measurements with 3D models based on low-dose biplanar radiographs in comparison with standard CT measurements. AJR Am J Roentgenol. 2012;199(5):W607-12.

17. Jakob RP, Haertel M, Stussi E. Tibial torsion calculated by computerised

tomography and compared to other methods of measurement. J Bone Joint Surg Br. 1980;62-B(2):238-42.

18. Subburaj K, Ravi B, Agarwal M. Computer-aided methods for assessing lower limb deformities in orthopaedic surgery planning. Comput Med Imaging Graph. 2010;34(4):277-88.

19. Asano T, Akagi M, Nakamura T. The functional flexion-extension axis of the knee corresponds to the surgical epicondylar axis: in vivo analysis using a biplanar image-matching technique. J Arthroplasty. 2005;20(8):1060-7.

20. Kim KK, Roh JY, Kim SB, Lee WS, Won YY, Chae DS. Femoral Neck Anteversion Measured Using a 3D CT Scan Perpendicular to the Mechanical Axis of the Femur. J Korean Hip Soc. 2011;23(1):47-53.

21. Yoshino N, Takai S, Ohtsuki Y, Hirasawa Y. Computed tomography measurement of the surgical and clinical transepicondylar axis of the distal femur in osteoarthritic knees. The Journal of Arthroplasty. 2001;16(4):493-7.

22. Sharma D, Shukla A, Kumar K. Role of preoperative calculation of condylar twist angle (CTA) by CT scan in optimizing femoral component rotation during TKA. Musculoskelet Surg. 2017;101(3):207-12.

23. Berger RAMD, Rubash HEMD, Seel MJMD, Thompson WH, Crossett LSMD. Determining the Rotational Alignment of the Femoral Component in Total Knee Arthroplasty Using the Epicondylar Axis. Clinical Orthopaedics & Related Research January. 1993;286:40-7.

24. Griffin FM, Insall JN, Scuderi GR. The posterior condylar angle in osteoarthritic knees. J Arthroplasty. 1998;13(7):812-5.

25. Matsuda S, Matsuda H, Miyagi T, Sasaki K, Iwamoto Y, Miura H. Femoral condyle geometry in the normal and varus knee. Clin Orthop Relat Res.

1998(349):183-8.

26. Laskin RS. Flexion space configuration in total knee arthroplasty. J Arthroplasty. 1995;10(5):657-60.

27. Nakabayashi Y, Wevers HW, Cooke TD, Griffin M. Bone strength and histomorphometry of the distal femur. J Arthroplasty. 1994;9(3):307-15.

28. Berger RA, Crossett LS, Jacobs JJ, Rubash HE. Malrotation causing patellofemoral complications after total knee arthroplasty. Clin Orthop Relat Res. 1998(356):144-53.

29. Huddleston JI, Scott RD, Wimberley DW. Determination of neutral tibial rotational alignment in rotating platform TKA. Clin Orthop Relat Res. 2005;440:101-6.

30. Uehara K, Kadoya Y, Kobayashi A, Ohashi H, Yamano Y. Bone anatomy and rotational alignment in total knee arthroplasty. Clin Orthop Relat Res. 2002(402):196-201.

31. Ikeuchi M, Yamanaka N, Okanoue Y, Ueta E, Tani T. Determining the rotational alignment of the tibial component at total knee replacement: a comparison of two techniques. J Bone Joint Surg Br. 2007;89(1):45-9.

32. Eckhoff DG, Metzger RG, Vandewalle MV. Malrotation associated with implant alignment technique in total knee arthroplasty. Clin Orthop Relat Res. 1995(321):28-31.

33. Hanada H, Whiteside LA, Steiger J, Dyer P, Naito M. Bone landmarks are more reliable than tensioned gaps in TKA component alignment. Clin Orthop Relat Res. 2007;462:137-42.

34. Akagi M, Mori S, Nishimura S, Nishimura A, Asano T, Hamanishi C. Variability of extraarticular tibial rotation references for total knee arthroplasty. Clin

Orthop Relat Res. 2005(436):172-6.

35. Page SR, Deakin AH, Payne AP, Picard F. Reliability of frames of reference used for tibial component rotation in total knee arthroplasty. Comput Aided Surg. 2011;16(2):86-92.

36. Mizu-uchi H, Matsuda S, Miura H, Higaki H, Okazaki K, Iwamoto Y. The effect of ankle rotation on cutting of the tibia in total knee arthroplasty. J Bone Joint Surg Am. 2006;88(12):2632-6.

국 문 초 록

배경:

슬관절은 대퇴골 및 경골간 움직임이 맞물려 있다. 이에 한 관절 구조물의 해부학적 변화는 맞물린 다른 구조물에 영향을 미칠 수 있다. 이전 슬관절 내반 정렬을 동반한 골관절염에서 관상면 및 회전 정렬간의 상관 관계에 대해서 다룬 몇가지 연구들이 있었으나, 슬관절 외반 정렬을 동반한 골관절염에서 관상면 및 회전 정렬의 정도에 따른 대퇴골 외과 저형성에 대해 분석을 시행한 연구는 없었다.

이에 저자들은 한국의 슬관절 골관절염 환자에서 하지의 관상면 및 회전 정렬 지표간 관계를 평가하기 위해 원위 대퇴골 저형성과 대퇴골 과의 관상면 및 회전 정렬간 상관 관계를 분석하였다.

방법:

2011년 11월부터 2015년 5월까지 슬관절 인공관절 전치환술을 받기 위해 기립 전후면 슬관절 방사선 사진 및 컴퓨터 단층 촬영을 시행한 211명 (남성 20, 여성 191)의 슬관절 422례를 대상으로 하였다.

대퇴경골각을 기립 전후면 슬관절 방사선 사진에서 측정하였으며, 외반 및 내반 3도를 기준으로 3군으로 분류하였다; 외반 3도 이상 (31 례), 외반 3도 미만 및 내반 3도 미만 (78 례), 내반 3도 이상 (313 례).

평균 연령은 70.2 ± 6.69세 였으며, 성별 및 대퇴경골각에 따른 차이는 관찰되지 않았다 (p = 0.875, 0.647). 원위 대퇴골 경과축 및

후과축에 의해 형성되는 각도를 과 회전각으로 정의하였고, 대퇴골 전염각은 경과축 및 후과축에 따라 각기 측정하였다. 과 회전각, 대퇴골 전염각 및 경골 염전각은 컴퓨터 단층 촬영을 통해 측정하였다. 이후 각 지표간의 상관관계를 분석하였다.

결과:

평균 대퇴경골각, 과 회전각, 후과축 기준 대퇴골 전염각, 경골 염전각은 대퇴경골각을 기준으로 나눈 3군간 유의한 차이가 관찰되었으나 (all $p < 0.001$), 경과축을 기준으로 한 대퇴골 전염각은 유의한 차이가 관찰되지 않았다 ($p = 0.290$). 경과축 기준 대퇴골 전염각을 제외한 다른 회전 지표는 대퇴경골각과 양의 상관 관계가 관찰되었다 (각 지표간 상관 계수; 대퇴경골각 vs. 과 회전각 0.253, $p < 0.001$; vs. 경과축 기준 대퇴골 전염각 0.060, $p = 0.218$; vs. 후과축 기준 대퇴골 전염각 0.145, $p = 0.003$; vs. 경골염전각 0.374, $p < 0.001$).

결론:

본 연구에서 과 회전각은 슬관절 외반군에서 유의하게 증가되어 있었으며, 이는 대퇴골 외과가 내과에 비해 상대적으로 저형성이 되어있음을 의미한다. 대퇴골 전염각은 후과축을 기준으로 측정하였을 때 각 군간 유의한 차이를 보였으나, 경과축을 기준으로 측정하였을 때는 유의한 차이가 관찰되지 않아 대퇴골 외과의 저형성에 따른 차이를 보이는 것으로 간주할 수 있다. 이에 슬관절 외반군에서 후과축 및 경과축을 기준으로 하는 대퇴골 전염각의 차이를 고려하지 않고 대퇴골의 후과를 기준으로 하는 기존의 femoral cutting guide를 사용할

경우 대퇴골 삽입물의 회전 정렬이 부적합 할 수 있음을 고려해야 한다. 또한 대퇴경골각은 다른 회전 지표와 양의 상관관계를 보여, 과 회전각 및 경골 염전각이 슬관절 외반군에서 증가되며 이에 고관절, 슬관절, 족관절간 관계가 중요함을 알 수 있다. 따라서 슬관절 인공관절 전치환술 후 만족스러운 회전 정렬을 얻기위해서는 이러한 회전 지표들이 수술전 반드시 평가되어야 하며, 슬관절 외반군 환자의 인공관절 전치환술의 경우 대퇴골 외과 저형성의 정도와 경골 외회전의 정도가 반드시 고려되어야 함을 알 수 있다.

주요단어: 대퇴골 저형성, 슬관절, 골관절염, 관상면상 정렬, 회전 정렬, 컴퓨터 단층 촬영

학번: 2016-21940