의학석사 학위논문

Effect of total hip arthroplasty on ipsilateral lower limb alignment and knee joint space width: minimum 5-year follow-up

인공 고관절 전치환술 후 관상 하지 정렬 변화와 무릎 관절 공간에 미치는 영향: 최소 5년 추시

2023년 2월

서울대학교 대학원

의학과 정형외과 전공

최 윤 성

Effect of total hip arthroplasty on ipsilateral lower limb alignment and knee joint space width: minimum 5-year follow-up

지도교수 장 종 범

이 논문을 의학석사 학위논문으로 제출함
2022년 10월

서울대학교 대학원
의학과 정형외과 전공
최 윤 성

최윤성의 의학석사 학위논문을 인준함
2023년 1월

위 원 장 ______ 강승백 ______ (인)

부위원장 ______ 장종범 ______ (인)

위 원 ______ 최자영 ______ (인)

Abstract

Effect of total hip arthroplasty on ipsilateral lower limb alignment and knee joint space width: minimum 5-year follow-up

Yun Seong Choi
College of medicine, Orthopaedic Surgery Major
The Graduate School
Seoul National University

Background: This study aimed to 1) assess the effect of total hip arthroplasty (THA) on coronal limb alignment, namely, the hip-knee-ankle angle (HKA), 2) identify factors that determine changes in the HKA, and 3) determine whether alignment changes influence the knee joint space width.

Methods: We retrospectively evaluated 266 limbs of patients who underwent THA. Three types of prostheses with neck shaft angles (NSAs) of 132°, 135°, and 138° were used. Several radiographic parameters were measured in the preoperative and final radiographs (at least 5 years after THA). A paired t-test was used to confirm the effect of THA on HKA change. Multiple regression analysis was performed to identify radiographic parameters related to HKA changes following THA and changes in knee joint space width. Subgroup analyses were performed to reveal the effect of NSA change on the HKA change, and the proportion of total knee arthroplasty (TKA) usage and changes in radiographic parameters between maintained joint space and narrowed joint space groups were compared.

Results: The preoperative mean HKA was 1.4° varus and increased to 2.7° varus after THA. This change was related to changes in the NSA, lateral distal femoral angle, and femoral bowing angle. In particular, in the group with a decrease in NSA of > 5°, the preoperative mean HKA was largely changed from 1.4° varus to 4.6° varus after THA. The prostheses with NSA of 132° and 135° also led to greater varus HKA changes than those with an NSA of 138°. Narrowing of the medial knee joint space was related to changes in the varus direction of the HKA, decrease in NSA, increase in femoral offset.

Conclusion: A large reduction in NSA can lead to considerable varus limb alignment after THA, which can have adverse effects on the medial compartment of the ipsilateral knee.

Keyword : Hip−Knee−Ankle angle; Total hip arthroplasty; Neck shaft angle; Knee osteoarthritis

Student Number : 2021−26519

CONTENTS

List of Tables

List of Figures

Introduction

Total joint arthroplasty, including total hip arthroplasty (THA) and total knee arthroplasty (TKA), is a popular surgical option for elderly patients with advanced joint disease (1–11). Unlike TKA, THA is not an operation that is commonly known to control the lower limb alignment. However, we can reasonably expect that lower limb alignment is influenced by changes in the hip joint profile after THA, eventually affecting the condition of knee joints.

Some studies have evaluated the effects of THA on knee joint (12–16). Olliver et al. and Van Drongelen et al. reported that the hip-knee-ankle angle (HKA) changes in the varus direction after THA (15, 16). In particular, Van Drongelen et al. showed that this change could cause progression of medial knee OA (16). In contrast, Umeda et al. reported that the ipsilateral knee joint changed in the valgus direction after THA and this change was associated with a decreased femoral offset. Furthermore, they reported that the OA progression was more prominent in the contralateral knee than in the knee ipsilateral to the THA (12). Similarly, Shakoor et al. reported that the progression of knee osteoarthritis after THA was higher in the contralateral knee joint than in the ipsilateral knee joint (14). Therefore, it remains unclear whether THA can affect coronal alignment in the ipsilateral limb and whether this alignment change can influence the condition of the ipsilateral knee joint, notably OA progression.

This study aimed to 1) assess the effect of THA on coronal limb alignment, namely, the HKA, 2) identify factors related to changes in the HKA, and 3) determine whether alignment changes influence the knee joint space width. We hypothesized that the ipsilateral coronal limb alignment, i.e., the HKA, would change after THA, and this change in the HKA would be affected by the change in the hip joint profile. In addition, such alignment changes would adversely affect the corresponding ipsilateral knee joint space, that is, the medial knee joint space in the case of more varus change, at the follow-up of more than 5 years.

Material and methods

Subjects

We retrospectively reviewed the records of 1572 patients who underwent primary THA in a single institution between January 2008 and December 2014. The inclusion criteria were as follows: 1) osteonecrosis of the femoral head (ONFH) or OA, 2) ipsilateral knee of Kellgren–Lawrence (KL) grade (17) I, II or III when undergoing THA, 3) follow–up period of at least 5 years, 4) underwent cementless THA, and 5) underwent optimal full lower limb anteroposterior (AP) radiography and a standing hip AP radiograph before and at least 5 years after THA. After implementing the inclusion criteria, 254 patients (120 men and 134 women) with 266 limbs (OA = 133, ONFH = 133) were enrolled (Figure 1). Twelve patients with bilateral THA underwent separate procedures with separate radiographs and a follow–up of at least 5 years for each limb. The average age at the time of THA was 52 ± 14 years (range, 17-88 years), and the mean follow–up period was 6.9 years (range, 5–12 years, standard deviation [SD] = 1.9). The mean body mass index (BMI) was 24.4 ± 3.9 kg/m2 (range, 10.7-37.7). Post hoc power analysis was performed using the HKA as the primary outcome (preoperative HKA, mean = 1.4, SD = 3.9; postoperative HKA, mean = 2.7, SD = 4.3), and the statistical power was over 80% (G*Power 3.1.0).

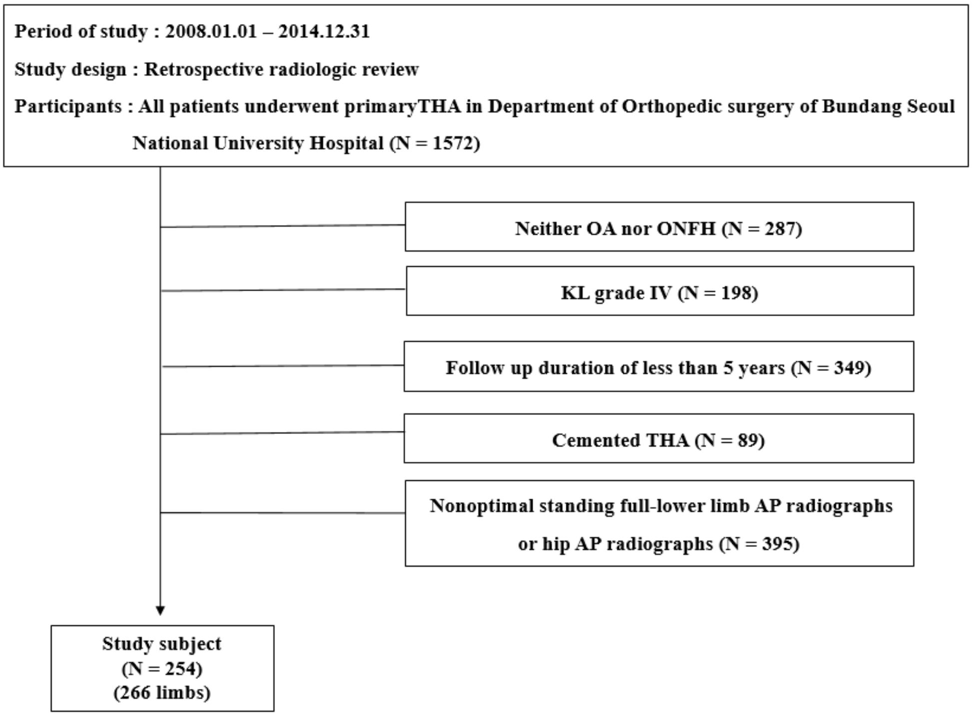

Figure 1. Flow chart of patient enrollment in this study

THA, total hip arthroplasty; N, number; AP, anteroposterior; OA, osteoarthritis; ONFH, osteonecrosis of the femoral head; KL, Kellgren–Lawrence

Operative Technique

All THAs were performed by three surgeons (YKL, YCH, and KHK) using the posterolateral approach (18). Acetabular and femoral components were inserted in a press-fit manner. Three combinations of cementless implants (Bencox M Stem, Mirabo Cup [Corentec] : 94 cases; Corail Stem, plasma cup [Depuy] : 97 cases; and Taperloc Stem, ABT cup [Zimmer Biomet] : 75 cases) were used. Delta ceramic bearings were used in all hips.

We used the combined anteversion technique to determine the location and orientation of the inserted implants (19). First, the femoral side was prepared. The cancellous bone in the femoral canal was removed with a box chisel, and a single starter reamer was inserted into the distal femoral canal to a level appropriate for the templated stem size. The femoral canal was prepared using stem-specific broaches. We used the smallest broach first and then progressively increased the broach size until the broach tightly engaged the medial and lateral cortex of the proximal femur. Next, we measured stem version of the final broach. The target anteversion of the metal shell was calculated using the following formula: cup anteversion = 37.3° - (0.7 × stem anteversion) (20). The target abduction of the metal shell was 43° (21). The acetabular cup was positioned at the target site using the method described by Ha et al. (21). Follow-up visits were scheduled for 6 weeks, 6 months, 1 year, and every year thereafter. At each annual visit, standing full lower limb AP radiographs and standing hip AP radiographs were obtained.

Radiographic examination

Radiographic evaluations were performed using standing full lower limb AP radiographs and standing hip AP radiographs, which were obtained using a UT 2000 X-ray machine (Philips Research, Eindhoven, The Netherlands) set to 90 kV and 50 mAs. Standing full lower limb AP radiographs were acquired by vertically entering the horizontal center beam to the patellar height and vertical beam to the midline. The X-ray beam was centered at the midpoint between the upper part of the symphysis and the line connecting the anterior superior iliac spines on standing hip AP radiographs. Both standing full-lower limb AP and Standing hip AP radiographs were acquired with the patella facing forward. All radiographic images were digitally acquired using a picture archiving and communication system (PACS). Assessments were performed on a 24-inch (61-cm) LCD monitor (T245:Samsung, Seoul) in portrait mode using the PACS software.

Radiographic measurement

Preoperative radiographs were used as baseline for comparison. In the preoperative and final follow-up (minimum 5 years postoperatively) radiographs, several radiographic parameters were measured : HKA, femur length (FL), femoral bowing angle (FBA)(22, 23), lateral distal femoral angle (LDFA), medial and lateral joint space width on standing full lower limb AP radiographs, hip center position (vertical center of rotation [V-COR], horizontal center of rotation [H-COR])(24) , limb length discrepancy (LLD), Femoral offset (FO), neck shaft angle (NSA), and neck length (NL) on standing anteroposterior hip radiographs (Figure 2). HKA was defined as the angle between the mechanical axes of the tibia and femur. A positive value was assigned to the knees in varus alignment. The FL was defined as the distance from the uppermost margin of the head to the lowermost margin of the medial condyle. FBA was defined as the angle between the line connecting the points bisecting the femur at 0 and 5 cm below the lowest portion of the lesser trochanter and the line connecting the points bisecting the femur at 5 cm and 10 cm above the lowest portion of the lateral femoral condyle. Positive numbers were used if the femoral shaft displayed lateral bowing. LDFA was defined as the lateral angle between the femoral mechanical axis and the tangent of the distal femur. The medial and lateral joint space widths were measured as the minimum distance in each part of the knee joint. We measured two hip center positions: the V−COR and H−COR. The V−COR was defined as the vertical distance from the center of the femoral head to the inter−teardrop line. The H−COR was defined as the horizontal distance from the V−COR line to the radiographic teardrop. LLD was defined as the difference in the perpendicular distance between the line passing through the lower edge of the teardrop point to the corresponding tip of the lesser trochanter. FO was defined as the vertical distance from the center of rotation of the femoral head to a line bisecting the long axis of the femur. The NSA was defined as the angle between the longitudinal axis of the native or prosthetic neck and the anatomical axis of the femoral shaft. Postoperative NSA was also the measured NSA in the radiographs, not the implant angle. NL was defined as the distance from the cross point of the shaft axis and the central axis of the femoral neck to the head center. All radiographic parameters were measured by manual methods, and the minimum detectable changes by the software were 0.1° in angle and 0.1 mm in length. The intra- and inter-observer reliabilities of all radiographic measurements were evaluated using intraclass correlation coefficients (ICCs). Two orthopedic surgeons (YSC and TWK) independently measured the radiographic parameters. Radiologic parameters were re-measured twice at 3-week intervals by each examiner. The ICCs of the intra-and inter-observer reliabilities were >0.9 (range: 0.910 - 0.982), indicating that the measurements were highly reliable (Table 1)

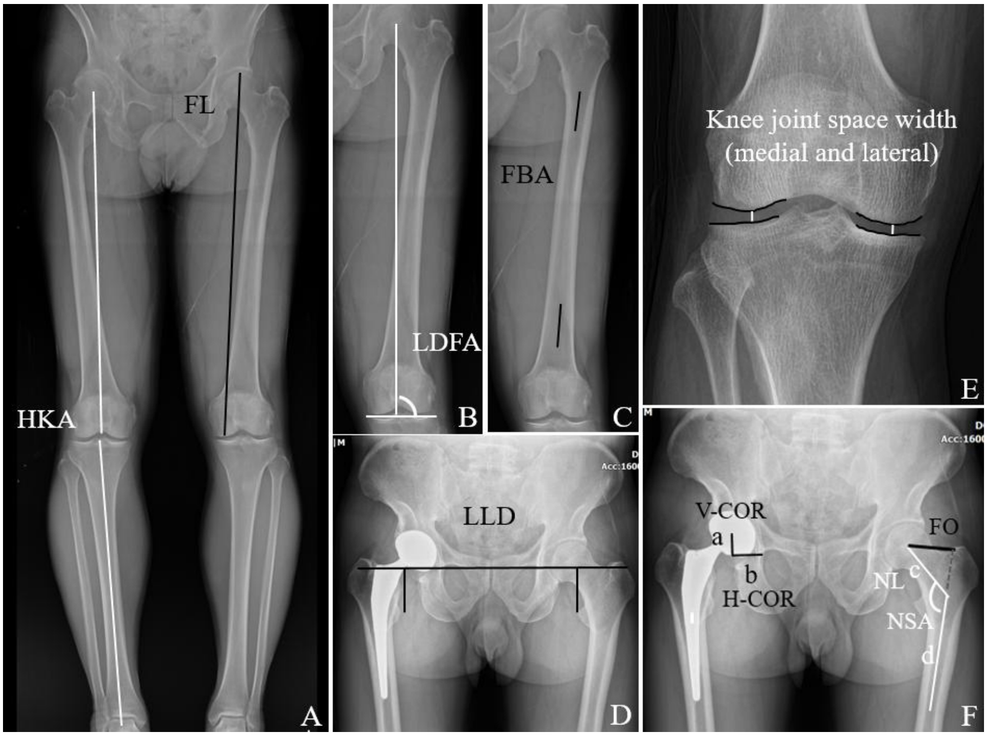

Figure 2. Radiographic measurements

A. Hip−knee−ankle angle (HKA), Femur length

B. Lateral distal femoral angle (LDFA)

C. Femoral bowing angle (FBA)

D. Limb−length discrepancy (LLD)

E. Medial and lateral joint space widths

F. Vertical center of rotation (V−COR) : black line a, Horizontal center of rotation (H−COR) : black line b, Femoral offset (FO), Neck shaft angle (NSA) : Angle formed by white line c and white line d, Neck length (NL) : white line c

Table 1. Intraobserver & interobserver reliability of radiographic measurements.

	Intraobserver reliability	Interobservar reliability	*P* value
HKA (°)	0.930 (0.923 – 0.946)	0.910 (0.898 – 0.922)	$p < 0.001$
Femur length (cm)	0.963 (0.946 – 0.971)	0.932 (0.925 – 0.943)	$p < 0.001$
FBA (°)	0.944 (0.903 – 0.966)	0.922 (0.918 – 0.936)	$p < 0.001$
LDFA (°)	0.963 (0.956 – 0.976)	0.935 (0.929 – 0.949)	$p < 0.001$
V–COR (mm)	0.943 (0.927 – 0.951)	0.927 (0.918 – 0.937)	$p < 0.001$
H–COR (mm)	0.982 (0.977 – 0.990)	0.930 (0.921 – 0.939)	$p < 0.001$
LLD (mm)	0.924 (0.883 – 0.946)	0.918 (0.911 – 0.923)	$p < 0.001$
Femoral offset (mm)	0.954 (0.913 – 0.976)	0.924 (0.918 – 0.930)	$p < 0.001$
NSA (°)	0.972 (0.967 – 0.979)	0.931 (0.925 – 0.936)	$p < 0.001$
Neck length (mm)	0.966 (0.957 – 0.969)	0.927 (0.918 – 0.936)	$p < 0.001$
Joint space width (medial) (mm)	0.954 (0.913 – 0.976)	0.917 (0.908 – 0.923)	$p < 0.001$
Joint space width (lateral) (mm)	0.973 (0.967 – 0.976)	0.921 (0.911 – 0.933)	$p < 0.001$

HKA, hip–knee–ankle angle; FBA, femoral bowing angle; LDFA, lateral distal femoral angle; V–COR, vertical center of rotation; H–COR, horizontal center of rotation; LLD, limb–length discrepancy; NSA, neck shaft angle

Clinical evaluation

We evaluated whether patients underwent ipsilateral TKA after THA by reviewing medical records and radiographs.

Statistical analysis

A paired t−test was used to confirm the effect of THA on HKA change (⊿). Changes in other radiological parameters were also analyzed (⊿ : postoperative parameters − preoperative parameters).

An analysis of the relationship between demographic variables (gender, age, BMI, diagnosis [OA, ONFH]) and ⊿HKA was performed. An analysis of the relationship between gender and ⊿HKA was were analyzed using the Student' s t−test, and an analysis of the relationship between age, BMI and ⊿HKA was analyzed using the Pearson's correlation analysis, and paired t−test was performed to confirmed the preoperative and postoperative HKA of the OA and ONFH patients. Multiple regression analysis was used to determine the ⊿radiographic parameters that were significantly related to the ⊿HKA. Subgroup analysis was performed to to evaluate the effects of ⊿NSA on ⊿HKA. The subjects were divided according to ⊿NSA: 1) ⊿NSA $< -5°$, 2) $-5° <$ ⊿NSA $< 5°$, and 3) ⊿NSA $> 5°$. No significant differences were noted in the preoperative HKA and KL grades between the groups (Table 2). Paired t−test and simple regression analysis were performed to confirm ⊿HKA and the relationship between ⊿NSA and ⊿HKA in each group, respectively. Next, subjects were divided according to the three stems with different NSAs: 1) Bencox M Stem (NSA: 132°), 2) Corail Stem (NSA:

135°), and 3) Taperloc Stem (NSA: 138°), and the ⊿HKA of these subgroups was compared according to neck length: short, medium, and long necks. The differences in these subgroups were analyzed using a one-way ANOVA test and post hoc analysis.

Finally, to determine whether alignment changes influence the knee joint's condition, a multiple regression analysis was performed to identify factors related to the ⊿knee joint space width, and subgroup analysis was also performed. The subjects were divided according to the ⊿knee joint space: 1) ⊿knee joint space > −1 mm (maintained joint space group) and 2) ⊿knee joint space < −1 mm (narrowed joint space group) (25). The demographic variables of these groups were compared (Table 3). The ⊿radiologic parameters and proportion of ipsilateral TKA were compared according to these subgroups. ⊿Radiologic parameters were compared using Student's t-test, and the proportion of TKA were compared using the chi-square test. Statistical analysis was performed using SPSS (version 26.0; IBM), and significance was set at $P < 0.05$.

Table 2. Preoperative HKA and KL grade according to ⊿NSA

Preoperatively	⊿NSA< −5˚ (N=79)	− 5˚ <⊿NSA<5˚ (N=107)	⊿NSA>5˚ (N=80)	*P* value
HKA (˚)	1.4±4.5	1.2±3.5	1.9±3.8	0.476*
KL I (N, %)	39 (49.3%)	48 (44.9%)	36 (45%)	
KL II (N, %)	30 (38%)	43 (40.2%)	27 (33.8%)	0.264†
KL III (N, %)	10 (12.7%)	16 (14.9%)	17 (21.2%)	

HKA are presented as means ± standard deviation.
KL are presented as number with the percent in parentheses

N, number; NSA, neck shaft angle; HKA, hip−knee−ankle angle; KL, Kellgren−Lawrence
⊿NSA : postoperative NSA – preoperative NSA

*Derived using the one way ANOVA test
†Derived using the linear by linear association.

Table 3. Patient demographics between maintained joint space group vs narrowed joint space group

Demographic variable	Maintained joint space (N = 210)	Narrowed joint space (N = 56)	*P* value
Age (years)	52.1 ± 13.9	54.8 ± 15.6	0.241*
Gender (W/M)	114/96	30/26	0.924†
BMI (kg/m2)	24.3 ± 3.8	24.8 ± 4.1	0.412*
Preoperative KL grade (I//II/III)	96/81/33	27/19/10	0.803†

Continuous variables are expressed as means ± standard deviation.
Categorical variables are presented as number

N, number; W, women; M, men; BMI, body mass index; KL, Kellgren−Lawrence

*Derived using the Student’s t test
†Derived using the Chi−square test

Results

The HKA changed 1.3° in the varus direction (P < 0.001) (Table 4).

Table 4. Changes in radiographic parameters

Radiographic parameter	Preoperatively	At last follow up	*P* value
HKA (°)	1.4±3.9 (−14.1~14.1)	2.7±4.3 (−14.9 ~ 18)	<0.001
Femur length (cm)	45.9±3.2(35.8~53.0)	47.1±3.4(37.9~56.7)	<0.001
FBA (°)	0.7±2.5 (−6.5 ~ 10.5)	−0.4±2.4 (−5.8 ~ 11.3)	<0.001
LDFA (°)	86.4±2.3 (80.6 ~ 95.3)	86.9±2.2 (80.6 ~ 95.0)	<0.001
V−COR (mm)	22.9±7.0 (6.1 ~ 49.2)	23.5±6.1 (7.0 ~ 47.0)	0.079
H−COR (mm)	38.8±6.4 (7.4 ~ 60.7)	29.7±3.5(20.8~43.3)	<0.001
LLD (mm)	−0.8 ± 1.0(−4~2)	0.2±0.8(−3.1~2.5)	<0.001
Femoral offset (mm)	37.3±7.9 (8.5 ~ 54.1)	43.4±6.1(24.0~59.1)	<0.001
NSA (°)	134.1±8.8 (95 ~ 170)	134.2±5.1 (120.8 ~ 149.8)	0.915
Neck length (mm)	52.2±7.7(20.2~67.1)	60.8±6.1(44.4~76.4)	<0.001
Joint space width (medial) (mm)	4.4±1.2 (0 ~ 7.4)	4.0±1.5 (0 ~ 7.6)	0.001
Joint space width (lateral) (mm)	5.0±1.1 (0.7 ~ 7.9)	4.9±1.3 (0 ~ 8.1)	0.001

Data are presented as means ± standard deviations (minimum ~ maximum)
HKA, hip−knee−ankle angle; FBA, femoral bowing angle; LDFA, lateral distal femoral angle; V−COR, vertical center of rotation; H−COR, horizontal center of rotation; LLD, limb−length discrepancy; NSA, neck shaft angle

There was no significant relationship between demographic variables and ΔHKA (Table 5). HKA changed in the varus direction in both OA and ONFH patients (Table 6). ΔHKA was related to ΔNSA (coefficient: -0.45, $P < 0.001$), ΔLDFA (coefficient: 0.27, $P < 0.001$), and ΔFBA (coefficient: 0.19, $P < 0.001$). The lower limb changed in the varus direction when the NSA decreased or LDFA or FBA increased compared with the preoperative value after THA. In the ΔNSA < -5° group, the preoperative mean HKA was 1.4° varus (SD = 4.5°), which changed to 4.6° varus (SD = 4.6°) after THA ($P < 0.001$) (Figure 3). A significant correlation was noted between ΔNSA and ΔHKA in this group (coefficient = −0.68, $P < 0.001$) but not in the other two groups. Thus, the smaller the NSA after THA, the greater the change in the varus direction in this group. In the short neck group, both the Bencox M Stem (132°) and Corail Stem (135°) changed the HKA in the varus direction more than the Taperlock Stem (138°) ($P = 0.009$ and $P < 0.001$, respectively). However, no significant difference was noted in ΔHKA between Bencox M Stem (132°) and Corail Stem (135°) ($P = 0.292$). The same pattern was observed in the medium-neck group; however, in the long neck group, no significant difference was noted in ΔHKA ($P = 0.298$) between the three stems (Figure 4).

Table 5. Relationship between demographic variable and ⊿HKA after THA

	Gender		*P* value
	Women (n = 144)	Men (n = 122)	
⊿HKA (°)	1.2 ± 2.8	1.3 ± 2.7	0.914*

	Age	
⊿HKA (r)	−0.081	0.186†

	BMI	
⊿HKA (r)	−0.096	0.118†

HKA (°) are presented as means ± standard deviation.

THA, total hip arthroplasty; N, number; HKA, hip−knee−ankle angle; BMI, body mass index; r, correlation coefficient

⊿HKA : postoperative HKA − preoperative HKA

*Derived using the Student' s t test
†Derived using the Pearson's correlation analysis

Table 6. Comparison of HKA between OA and ONFH

	ONFH		P value	OA		*P* value
	Preoperatively	At last follow up		Preoperatively	At last follow up	
HKA (°)	1.3 ± 3.7	2.2 ± 4.1	<0.001	1.5 ± 4.2	3.2 ± 4.0	<0.001

Data are presented as means ± standard deviations
ONFH, osteonecrosis of the femoral head; OA, osteoarthritis; HKA, hip−knee−ankle angle

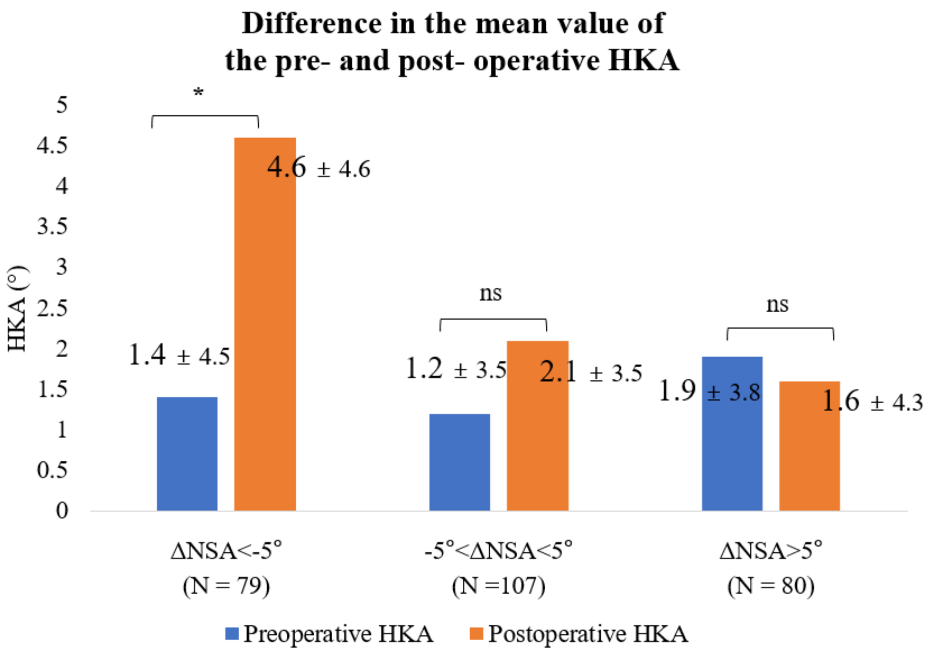

Figure 3. Difference in the mean value of the pre- and post-operative HKA in the three subgroups based on the change in NSA induced by THA

HKA is presented as means ± standard deviations

* Statistically significant ($P < 0.001$)

HKA, hip-knee-ankle; NSA, neck shaft angle; THA, total hip arthroplasty; ΔNSA, postoperative NSA – preoperative NSA; ns, not significant

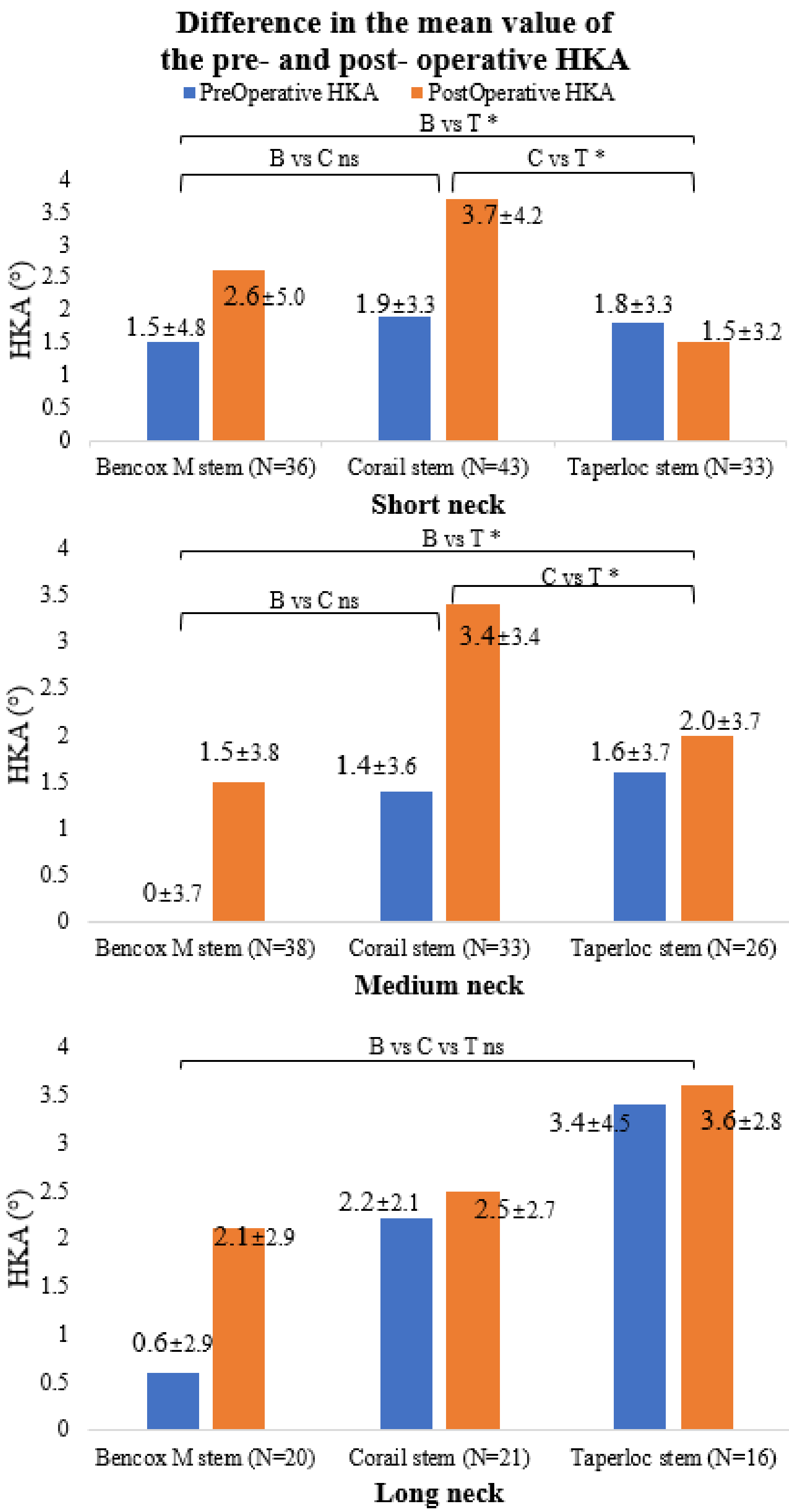
Difference in the mean value of
the pre- and post- operative HKA
PreOperative HKA
PostOperative HKA
B vs T *
B vs C ns
C vs T *
HKA (°)
4
3.5
3
2.5
2
1.5
1
0.5
0
1.5±4.8
2.6±5.0
1.9±3.3
3.7±4.2
1.8±3.3
1.5±3.2
Bencox M stem (N=36)
Corail stem (N=43)
Taperloc stem (N=33)
Short neck
B vs T *
B vs C ns
C vs T *
0±3.7
1.5±3.8
1.4±3.6
3.4±3.4
1.6±3.7
2.0±3.7
Bencox M stem (N=38)
Corail stem (N=33)
Taperloc stem (N=26)
Medium neck
B vs C vs T ns
0.6±2.9
2.1±2.9
2.2±2.1
2.5±2.7
3.4±4.5
3.6±2.8
Bencox M stem (N=20)
Corail stem (N=21)
Taperloc stem (N=16)
Long neck

Figure 4. Difference in the mean value of the pre- and post-operative HKA in the three prosthesis groups based on the neck length

HKA is presented as means ± standard deviations
* Statistically significant

Short neck : ANOVA test (p=0.002), post hoc analysis (B vs T, p=0.009 ; C vs T, p=0.0001 ; B vs C, p=0.292
Medium neck : ANOVA test (p=0.004), post hoc analysis (B vs T, p=0.016 ; C vs T, p=0.006 ; B vs C, p=0.882)
Long neck : ANOVA test (p=0.298)

HKA, hip-knee-ankle angle; THA, total hip arthroplasty; N, number; ns, not significant; B, Bencox M stem; C, corail stem; T, Taperloc stem

As the change in the varus direction of the lower limb increased after THA, the medial knee joint space width narrowed. ΔMedial knee joint space width was related to ΔHKA (coefficient: −0.418, $P < 0.001$). The narrowed joint space group showed a greater varus ΔHKA (1.0° vs. 2.1°), a greater chance of undergoing TKA (3/210 [0.014%] vs. 6/56 [10.7%]; odds ratio = 8.3, $P < 0.001$) compared with the maintained joint space group. Additionally, ΔNSA of the maintained joint space group and narrowed joint space group was 0.8° and −2.7°, respectively, and ΔFO was 5.5 and 8.5 mm, respectively (Table 7).

Table 7. Comparison of ⊿radiologic parameters of the non-arthritic change group and arthritic change group

⊿Radiologic parameter	Non-arthritic change (N=210)	Arthritic change (N=56)	*P* value
⊿HKA (°)	1.0±2.3	2.1±3.3	0.005*
⊿NSA (°)	0.8±9.4	−2.7±9.4	0.014*
⊿Postoperative LLD (mm)	1.0±0.9	0.8±1.2	0.220
⊿Femur length (cm)	1.3±1.7	0.9±2.4	0.236
⊿Neck length (mm)	8.2±7.6	9.7±8.5	0.221
⊿Femoral offset (mm)	5.5±8.4	8.5±8.7	0.018*
⊿FBA (°)	−1.1±1.9	−0.9±2.2	0.524
⊿H-COR (mm)	8.8±6.9	10.4±6.9	0.129
⊿V-COR (mm)	0.8±6.1	0.3±5.8	0.577
⊿LDFA (°)	0.4±1.8	1±2.1	0.068
⊿Joint space width (medial) (mm)	−0.1±0.5	−1.5±1.2	<0.001*
⊿Joint space width (lateral) (mm)	0±0.4	−0.7±1.1	<0.001*

Data are presented as means ± standard deviations
HKA,hip-knee-ankle angle; NSA, neck shaft angle; LLD, limb-length discrepancy; FBA, femoral bowing angle; H-COR, horizontal center of rotation; V-COR, vertical center of rotation; LDFA, lateral distal femoral angle

⊿Radiographic parameter :
postoperative radiographic parameter – preoperative radiographic parameter

*Statistically significant ($P < 0.05$)

Discussion

This study showed that the HKA of the ipsilateral limb changed in the varus direction at least 5 years after THA. In particular, a significant relationship was noted between the large decrease in the NSA and the change in the varus direction. Narrowing of the medial knee joint space was related to an increase in the varus direction. Thus, we assumed that significant varus change in coronal limb alignment would mainly occur immediately after THA, if there is a large reduction in NSA. Our results suggest that significant varus change could lead to progression of medial knee joint space narrowing (Figure 5).

Figure 5. Exemplar Change in HKA and medial knee joint space width after THA

THA, total hip arthroplasty; NSA, neck shaft angle; HKA, hip-knee-ankle angle

Changes in HKA and FO are known to be related to varus changes in lower limb alignment after THA. Olliver et al. and Van Drongelen et al. reported that the ipsilateral HKA changed in the varus direction by approximately 1.5° and 1° after THA, respectively (15, 16), and that FO increased after THA, which could change the lower limbs to varus alignment. In the present study, the mean HKA and FO increased by 1.3° and 6.1mm, respectively after THA. We also found that the mean H-COR decreased by 9.1mm after THA, indicating medialization of the hip center. This is in line with a recent study by Akasaki et al. in which the authors suggest that varus change (0.8°) after THA is related to medial shifting of the hip center (26). Furthermore, we found that the change in HKA was related to various radiological parameters, such as ΔNSA, ΔLDFA, and ΔFBA. Although whether each parameter has a causative relationship with varus change is unclear, the increase in HKA seems to be multifactorial rather than related to a single strong radiologic parameter. One possible logical explanation is that simultaneous increase in FO and medialization of the hip center could result in an increase in HKA by medial shifting of the hip center without altering the knee and ankle centers. In this setting, the HKA could be additionally increased if the femur changed to varus alignment (smaller NSA, larger LDFA, and FBA).

Interestingly, the HKA changed much more in the varus direction in certain groups where the NSA became significantly smaller after THA (Figure 3). Umeda et al. reported that the ipsilateral knee joint changed in the valgus instead of in the varus direction after THA(12). This may be because prostheses with a high NSA were used, and the FO decreased in their study. The relationship between ΔNSA and ΔHKA may be explained by the FO, which is usually restored or increased to improve the efficiency of the gluteus medius and reduce polyethylene wear during THA(27−29). According to the ΔNSA subgroup analysis, ΔFO in $\Delta NSA < -5°$, $-5° < \Delta NSA < 5°$, and $\Delta NSA > 5°$ were 12.8, 5.7, and 0.1 mm, respectively. If the NSA increases after THA, the potential to restore FO is limited. Therefore, in the $\Delta NSA > 5°$ group, the change in the varus direction was not as apparent as in the other groups. Consequently, to prevent an increase in HKA, an excessive decrease in NSA throughout THA should be avoided. While other radiological parameters are difficult to manipulate during THA, NSA could be adjusted using different femoral stems, neck lengths, and lateralized stems. Among the three femoral stems used in this study, the Taperloc stem demonstrated the least change in HKA compared with Bencox stem and Corail stem (Figure 4).

In this study, we found that THA could be associated with the medial knee joint space narrowing. Shakoor et al. reported that the peak load and adduction moment of the medial compartment of the knee were already high in end−stage hip OA; thus, the adapted knee state did not recover even after THA (14). However, our study was not limited to end−stage hip OA but was conducted on hip OA and ONFH at various stages. Olliver et al. showed that HKA changes in the varus direction after THA, as in our study; however, this did not affect the knee joint (15). Concurrently, Van Drongelen et al. reported that HKA changes in the varus direction after THA and that this increases the knee adduction moment; thus, medial knee OA can progress(16). Our study also confirmed medial knee joint space narrowing after THA, similar to Van Drongelen's study, and further confirmed that medial knee joint space narrowing was associated with ΔHKA, ΔNSA, and ΔFO. In this study, the narrowed joint space group showed more varus changes and a higher chance of experiencing ipsilateral TKA. This may be associated with the greater decrease in NSA and increase in FO compared with the maintained joint space group. However, it cannot be said that our study elucidated these relationship, and it is clinically meaningful that the possibility that such a relationship may exist has been shown. These findings should preclude surgeons from making the decrease in NSA too large in patients with preexisting varus limb alignment or medial knee OA.

This study has limitations. First, the age range of the study subjects is wide. As age would potentially affect changes of limb alignment and knee joint conditions, such chronological effect on physiological changes of the limb and knee joint during > 5 years follow-up may be different between young and old subjects. However, age would not be related to degrees of alignment and knee joint condition changes in this study cohort(Table 3) (Table 5), probably because of relatively small proportion of very young and/or very old subjects. Second, we were unable to assess the differences between manufacturers, surgeons, or prosthesis sizes. Lateralized femoral stems were not used in this study. Lateralized stems are currently widely used especially in THA of dysplastic hips where medialization of the hip center is frequently required. Further studies assessing the standard and lateralized stems by the same manufacturers are warranted. Third, exclusion criteria eliminate 83% of the target THA population. However, as most of them were excluded due to unavailable optimal radiographs rather than intrinsic characteristics of the subjects, it is not expected that this will affect the generalizability of the results of this study. Fourth, the prognosis of patients with KL grade IV knee arthritis could not be confirmed. Since TKA subjects are generally KL grade IV, it would have been more clinically meaningful if we could actually confirm the prognosis of these patients after THA. Fifth, although not evaluated in our study, since the geometry of the proximal femur changes after THA, this should be considered in preoperative measurements for distal femur cutting during TKA.

In conclusion, coronal limb alignment tended to change in the varus direction after THA, but the average HKA change was small (1.3°). Nevertheless, a large reduction in NSA can be associated with considerable varus limb alignment change after THA, which can have adverse effects on the medial compartment of the ipsilateral knee. This study does not suggest the current best practice in the field of THA should be changed. Nevertheless, information in this study would be useful for estimation of limb alignment change after THA by a surgeon and counseling and further planning for a subset of patient who are expected to experience aggravation of varus malalignment and deterioration of established medial knee OA.

Reference

1. Chang RW, Pellisier JM, Hazen GB. A cost-effectiveness analysis of total hip arthroplasty for osteoarthritis of the hip. Jama. 1996;275(11):858-65.

2. Graves SC, Dropkin BM, Keeney BJ, Lurie JD, Tomek IM. Does Surgical Approach Affect Patient-reported Function After Primary THA? Clin Orthop Relat Res. 2016;474(4):971-81.

3. Rosenlund S, Broeng L, Jensen C, Holsgaard-Larsen A, Overgaard S. The effect of posterior and lateral approach on patient-reported outcome measures and physical function in patients with osteoarthritis, undergoing total hip replacement: a randomised controlled trial protocol. BMC Musculoskelet Disord. 2014;15:354.

4. Losina E, Walensky RP, Kessler CL, Emrani PS, Reichmann WM, Wright EA, et al. Cost-effectiveness of total knee arthroplasty in the United States: patient risk and hospital volume. Arch Intern Med. 2009;169(12):1113-21; discussion 21-2.

5. O'Connor MI. Implant survival, knee function, and pain relief after TKA: are there differences between men and women? Clin Orthop Relat Res. 2011;469(7):1846-51.

6. Lee WY, Hwang DS, Noh CK. Descriptive Epidemiology of Patients Undergoing Total Hip Arthroplasty in Korea with Focus on Incidence of Femoroacetabular Impingement: Single Center Study. J Korean Med Sci. 2017;32(4):581-6.

7. Kim HS, Park JW, Moon SY, Lee YK, Ha YC, Koo KH. Current and Future Burden of Periprosthetic Joint Infection from National Claim Database. J Korean Med Sci. 2020;35(49):e410.

8. Seo JG, Moon YW, Cho BC, Kim SC, Ko YH, Jang SP, et al.

Is Total Knee Arthroplasty a Viable Treatment Option in Octogenarians with Advanced Osteoarthritis? Knee Surg Relat Res. 2015;27(4):221-7.
9. Lee NK, Won SJ, Lee JY, Kang SB, Yoo SY, Chang CB. Presence of Night Pain, Neuropathic Pain, or Depressive Disorder Does Not Adversely Affect Outcomes After Total Knee Arthroplasty: A Prospective Cohort Study. J Korean Med Sci. 2022;37(43):e309.
10. Lee SM, Seong SC, Lee S, Choi WC, Lee MC. Outcomes of the different types of total knee arthroplasty with the identical femoral geometry. Knee Surg Relat Res. 2012;24(4):214-20.
11. Yoon PW, Yoo JJ, Kim Y, Yoo S, Lee S, Kim HJ. The Epidemiology and National Trends of Bearing Surface Usage in Primary Total Hip Arthroplasty in Korea. Clin Orthop Surg. 2016;8(1):29-37.
12. Umeda N, Miki H, Nishii T, Yoshikawa H, Sugano N. Progression of osteoarthritis of the knee after unilateral total hip arthroplasty: minimum 10-year follow-up study. Arch Orthop Trauma Surg. 2009;129(2):149-54.
13. Jungmann PM, Nevitt MC, Baum T, Liebl H, Nardo L, Liu F, et al. Relationship of unilateral total hip arthroplasty (THA) to contralateral and ipsilateral knee joint degeneration - a longitudinal 3T MRI study from the Osteoarthritis Initiative (OAI). Osteoarthritis Cartilage. 2015;23(7):1144-53.
14. Shakoor N, Hurwitz DE, Block JA, Shott S, Case JP. Asymmetric knee loading in advanced unilateral hip osteoarthritis. Arthritis Rheum. 2003;48(6):1556-61.
15. Ollivier M, Parratte S, Lecoz L, Flecher X, Argenson JN.

Relation between lower extremity alignment and proximal femur anatomy. Parameters during total hip arthroplasty. Orthop Traumatol Surg Res. 2013;99(5):493-500.
16. van Drongelen S, Kaldowski H, Tarhan T, Assi A, Meurer A, Stief F. Are changes in radiological leg alignment and femoral parameters after total hip replacement responsible for joint loading during gait? BMC Musculoskelet Disord. 2019;20(1):526.
17. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957;16(4):494-502.
18. Von Langenbeck B. Ueber die Schussverletzungen des Huftgelenks. Archi Klin Chir. 1874;16:263-339.
19. Dorr LD, Malik A, Dastane M, Wan Z. Combined anteversion technique for total hip arthroplasty. Clin Orthop Relat Res. 2009;467(1):119-27.
20. Widmer KH, Zurfluh B. Compliant positioning of total hip components for optimal range of motion. J Orthop Res. 2004;22(4):815-21.
21. Ha YC, Yoo JJ, Lee YK, Kim JY, Koo KH. Acetabular component positioning using anatomic landmarks of the acetabulum. Clin Orthop Relat Res. 2012;470(12):3515-23.
22. Chang CB, Choi JY, Koh IJ, Seo ES, Seong SC, Kim TK. What should be considered in using standard knee radiographs to estimate mechanical alignment of the knee? Osteoarthritis Cartilage. 2010;18(4):530-8.
23. Lasam MP, Lee KJ, Chang CB, Kang YG, Kim TK. Femoral lateral bowing and varus condylar orientation are prevalent and affect axial alignment of TKA in Koreans. Clin Orthop Relat Res. 2013;471(5):1472-83.

24. Flecher X, Ollivier M, Argenson JN. Lower limb length and offset in total hip arthroplasty. Orthop Traumatol Surg Res. 2016;102(1 Suppl):S9-20.
25. Runhaar J, Deroisy R, van Middelkoop M, Barretta F, Barbetta B, Oei EH, et al. The role of diet and exercise and of glucosamine sulfate in the prevention of knee osteoarthritis: Further results from the PRevention of knee Osteoarthritis in Overweight Females (PROOF) study. Semin Arthritis Rheum. 2016;45(4 Suppl):S42-8.
26. Akasaki Y, Kitade K, Motomura G, Hamai S, Ikemura S, Fujii M, et al. Morphological changes affecting ipsilateral and contralateral leg alignment after total hip arthroplasty. J Orthop. 2021;23:73-7.
27. McGrory BJ, Morrey BF, Cahalan TD, An K, Cabanela ME. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. The Journal of bone and joint surgery British volume. 1995;77(6):865-9.
28. Sakalkale DP, Sharkey PF, Eng K, Hozack WJ, Rothman RH. Effect of femoral component offset on polyethylene wear in total hip arthroplasty. Clinical Orthopaedics and Related Research®. 2001;388:125-34.
29. Vaishya R, Vaish A, Ansari AH. Challenges in Total Hip Replacement after McMurray's Osteotomy: A Report of 3 Cases and Review of Literature. Clin Orthop Surg. 2020;12(4):442-7.

국문초록

목적 : 본 연구는 1)인공 고관절 전치환술 이후 동측 하지의 관상 정렬(고관절-무릎-발목 각도)의 변화를 평가하고, 2) 고관절-무릎-발목 각도의 변화를 결정하는 요인을 확인하고, 3) 이러한 정렬의 변화가 무릎 관절의 공간에 미치는 영향에 대해서 알아보고자 하였다.

대상과 방법 : 본 연구는 인공 고관절 전치환술을 시행 받은 266 하지를 후향적으로 평가 하였다. 수술에는 132°, 135° 및 138° 의 다른 경간각을 가진 세 가지 유형의 보철물이 사용되었다. 수술 전 및 수술 후 최소 5년 후의 방사선 사진에서 여러 방사선학적 매개변수가 측정되었다. 인공 고관절 전치환술이 고관절-무릎-발목 각도 변화에 미치는 영향을 확인하기 위해 대응표본 T-검정을 시행 하였다. 또한, 고관절-무릎-발목 각도 변화와 관련된 방사선학적 매개변수를 식별하기 위해 다중회귀분석을 시행 하였으며, 고관절-무릎-발목 각도 변화에 대한 경간각 변화의 영향을 확인하기 위해 하위군 분석을 시행 하였다. 또한, 무릎 관절 공간 폭의 변화와 관련된 방사선학적 매개변수를 찾기 위해 다중회귀분석을 수행하였고, 무릎 관절공간이 유지된 그룹과 협소 해진 그룹 사이에서 인공슬관절전치환술의 비율과 방사선학적 매개변수 변화를 비교하였다.

결과 : 수술 전 평균 고관절-무릎-발목 각도는 1.4도 였으며 수술 후 내반 2.7도로 증가 하였다. 이 변화는 경간각, 외측 원위 대퇴 각도 및 대퇴골 휨각의 변화와 관련이 있었다. 특히 수술 후 경간각이 5도이상 감소한 환자들의 고관절-무릎-발목 각도는 수술 전 평균 내반 1.4도에서 수술 후 내반 4.6도로 유의하게 변화 되었다. 또한 경간각 132° 및 135° 의 보철물을 사용했을 경우 138° 의 보철물을 사용했을 때보다 고관절-무릎-발목 각도가 더 내반 방향으로 변화 하였다. 또한 무릎의 내측 공간의 감소는 고관절-무릎-발목 각도의 내반 방향 변화, 경간각의 감소, 대퇴골 오프셋의 증가와 관련이 있었다.

결론 : 인공 고관절 전치환술을 할 때 경간각이 수술 후 현저하게 감소된다면 동측 하지의 정렬이 상당히 내반 방향으로 변할 수 있으며 이는

동측 무릎의 내측 관절 공간의 협소화를 일으킬 수 있다.

주요어 : 고관절-무릎-발목 각도, 인공 고관절 전치환술, 경간각, 무릎 관절염

학번 : 2021-26519