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의학석사 학위논문

Evaluation of Compartment Changes After Opening Wedge High Tibial Osteotomy Using Knee SPECT/CT

개방형 경골 근위부 절골술 후 구획 변화에 대한
무릎 SPECT/CT 평가

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Evaluation of Compartment Changes After Opening Wedge High Tibial Osteotomy Using Knee SPECT/CT

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Abstract

Introduction

Opening wedge high tibial osteotomy (OWHTO) is one of the surgical treatment options for young, physically active, and non-obese patients who have varus deformity with medial unicompartmental osteoarthritis (OA). Despite its potential benefits, extant literature has documented certain complications attributed to heightened contact pressure in the lateral compartment and the patellofemoral (PF) joint subsequent to OWHTO. Consequently, a plausible hypothesis suggests that the progression of OA may be triggered following OWHTO due to an increase in loading on the lateral compartment after the surgery. However, at present, there is a lack of consensus regarding the development of OA in the PF joint following OWHTO.

Methods

Thirty-four consecutive patients (consisting of 35 knees) who underwent OWHTO for medial OA of the knee joint were included in this retrospective study. The surgical outcomes were assessed using knee clinical scores and radiographic evaluations. Additionally, biomechanical changes were evaluated preoperatively and postoperatively using knee SPECT/CT. The changes in BTU within each compartment following the surgery was analyzed based on the mean values of BTU and the proportion of patients exhibiting clinically significant BTU changes.

Clinically significant BTU changes after surgery were defined as alterations exceeding 20% when compared to preoperative values.

To determine the factors associated with increased BTU in the PF joint subsequent to OWHO, patients were divided into two distinct subgroups as the increased BTU and the non-increased BTU groups. To explore the potential relationships, a multivariate regression analysis was performed, considering a set of independent variables, including age, sex, body mass index (BMI), mechanical femoro-tibial angle (MFTA), mechanical medial proximal tibial angle (MPTA), weight-bearing line ratio (WBLR), Blackburn-Peel index (BPI), posterior tibial slope angle (PTSA), tibial tuberosity to trochlear groove (TT-TG) distance, and congruence angle (CA).

Result

Regarding the overall BTU changes, a significant reduction in mean BTU was observed in the medial compartment following the surgery ($p=0.005$). However, there were no notable changes in the mean BTU values observed in the lateral and PF joints. Specifically, within the medial compartment, BTU decreased in 20 cases (57%), remained unchanged in 5 cases, and increased in 10 cases. In the lateral compartment, BTU decreased in 12 cases, remained unchanged in 13 cases, and increased in 10 cases (28%). In the PF joint, BTU decreased in 16 cases, remained unchanged in 7 cases, and increased in 12 cases (34%). Post-surgery alignment changes were not significantly correlated with BTU changes in each compartment after surgery. However, in the subgroup analysis, which involved comparing patients with and without increased BTU in the PF joint, a significant relationship

was observed between an increase in PTSA and the increase in BTU in the PF joint following OWHTO.

Conclusion

Overall, the examination of mean BTU using SPECT/CT did not reveal significant biomechanical changes in the lateral and PF joints in the short-term period following OWHTO. However, it was observed that BTU increased in 12 (34%) cases in the PF joint. Moreover, a potential correlation was noted between the, increased PTSA after surgery and the increased BTU in the PF joint after surgery. A longitudinal follow-up study is essential to substantiate whether the increased BTU in the PF joint among patients exhibiting an increased PTSA has an adverse impact on adversely affect the clinical outcome s following OWHTO.

Keywords: High tibial osteotomy; Single Photon Emission Computed Tomography; Patellofemoral joint; posterior tibial slope angle

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Introduction

The main principle of osteotomy is to redistribute the load from the affected and arthritic region of the joint to the relatively healthy and intact cartilage area. This therapeutic approach aims to alleviate knee pain, decelerate the progression of osteoarthritis (OA), and postpone the need for total knee arthroplasty. Opening wedge high tibial osteotomy (OWHTO) is a surgical alternative for treating symptomatic medial compartment OA in the knee with varus deformity, in the absence of concomitant-lateral compartment or patellofemoral (PF) OA (1). However, previous studies have highlighted that elevated contact pressure in the lateral compartment and PF joint can accelerate degenerative changes. This is attributed to alterations in the trajectory of the PF joint and unexpected shifts in patellar height following OWHTO. Moreover, it has been observed that the progression of PF cartilage degeneration primarily occurs in the trochlear groove and lateral facet (2).

Bone scintigraphy utilizing ^{99m}Tc -phosphonate is a highly valuable method for bone imaging, specifically employed to demonstrate osteoblastic activities within the bones (3,4,5). The advent of hybrid imaging modality that combines single photon emission computed tomography (SPECT) with computed tomography (CT) has significantly improved diagnostic accuracy by providing both precise anatomical localization alongside functional information. In this regard, SPECT/CT has demonstrated notable sensitivity in quantifying mechanical overload within specific compartments of the knee joint affected by OA. By facilitating the localization and measurement of increased bone tracer uptake

(BTU), SPECT/CT enables three-dimensional assessment of the extent of osteoarthritic changes and mechanical stress. This approach using SPECT/CT has unveiled a significant correlation between the intensity of BTU and the severity of OA (6,7), as previously reported in the literature.

The SPECT/CT findings demonstrated a robust correlation with conventional structural imaging methods such as plain radiography and magnetic resonance imaging (MRI). Moreover, a notable relationship was established between the SPECT/CT findings and the extent and size of chondral lesions observed on MRI. In addition, a significant correlation was observed between SPECT/CT and the macroscopic cartilage status evaluated during surgery, utilizing the International Cartilage Repair Society classification system (8).

Recently, SPECT/CT has garnered increasing attention as a valuable tool for visualizing the distribution of mechanical loads, making it a promising imaging modality for assessing the progress of patients with PF joint OA (9,10,11). Consequently, we conducted semi-quantitative measurements of BTU, assuming that it could serve as an indicator of mechanical changes resulting from the medial unloading effect following OWHTO.

The purposes of this study were as follows: 1) to investigate the effects of OWHTO on compartmental alterations using knee single photon emission computed tomography with computed tomography (SPECT/CT), 2) to assess the association between bone tracer uptake (BTU) in the medial and lateral compartments and the mechanical alignment of the knee, 3) to examine the potential correlation between increased BTU in the PF joint and the clinical

outcomes of OWHTO, 4) to identify factors that might be associated with the presence of increased BTU in the PF joint following OWHTO.

Methods

1. Subjects

A total of 58 patients (61 knees) who underwent OWHTO from June 2016 to June 2021 were eligible for this retrospective study. Among these individuals, 26 patients (26 knees) were excluded for the following reasons; 1) the presence of conditions other than arthritis (fracture, rheumatoid arthritis, history of infection), and 2) the presence of screws located too close to the tibial articular surface. In cases where screws were positioned in close proximity to the tibial articular surface, accurate evaluation of BTU was not feasible due to the interference caused by metallic components. Finally, the study comprised 34 patients (35 knees), of which 29 belonged to female patients and 6 knees to male patients. The average age of the patients was 58.1 years (range, 51-70 years), and the average body mass index (BMI) was 27.6 kg/m² (range, 19.8-31.3). For all cases, preoperative SPECT/CT imaging was conducted before the OWTHO (average: 2 months; range: 1 to 6 months), and postoperative SPECT/CT imaging was performed before the removal of the plate and screws utilized during the OWTHO (average: 17 months; range: 12 to 24 months).

2. Surgical technique

A 6 cm longitudinal skin incision was made over the pes anserinus insertion at the anteromedial aspect of the tibia. The pes anserinus, gracilis tendon, semitendinous muscle tendon and superficial layer of the medial collateral ligament are carefully elevated to expose the medial aspect of the proximal tibia. To ensure the safety of the neurovascular structures underlying the knee joint, it was protected by gentle retraction using a blunt retractor. During the osteotomy procedure, two Kirschner wires were inserted into the tibia. The distance between 2 Kirschner needles is 2 cm. Horizontal plane osteotomy: close to 2 Kirschner wires for osteotomy, reserved distance from the lateral cortex about 5 mm as a hinge point. Coronal plane osteotomy: it has an angle of about 110° to the horizontal osteotomy surface, the tibia tubercle is at least 10 mm wide. Using an image intensifier, the osteotomy line was progressively opened towards the axis on the lateral cortex by gradually inserting a set of three chisels. The posteromedial gap distance was assessed to verify the expected opening width while stabilizing the gap temporarily with a bone spreader. Then used the TOMOFIX Osteotomy system (Depuy Synthes, Switzerland) fixed the medial osteotomy site.

3. Clinical and radiographic assessments

The radiographic evaluation involves the evaluation of various projections, including full limb standing radiograph, as well as knee anteroposterior, lateral, and skyline projections. Pre- and post- OWHTO measurements encompass the mechanical femoro-tibial angle (MFTA), the medial proximal tibial angle (MPTA) and the weight-bearing line ratio (WBLR).

The MFTA represents the angle between the femur and the mechanical axis of the tibia, and its significance lies in the fact that poor coronal alignment of the lower limbs can contribute to the early progression of OA. Specifically, medial compartment OA is associated with varus alignment of the lower limb mechanical axis, leading to increased medial joint load and dynamic changes in the muscle strength surrounding the joint. This, in turn, accelerates the degeneration of the medial compartment cartilage of the knee joint. Consequently, cartilage degeneration, increased stress in the medial compartment, and dynamic changes in muscle strength surrounding the joint perpetuate poor alignment and angulation of the lower limbs, resulting in a vicious cycle that drives the continuous progression of OA. On the other hand, the MPTA is defined as the medial angle between the line parallel to the proximal condyle of the tibia and the mechanical axis of the tibia. It serves as an important indicator for evaluating the effect of OWHTO

Previous studies have defined the angle of OWHTO correction on imaging as the difference between postoperative and preoperative values. The ideal postoperative WBLR is conventionally considered to be at the Fujisawa point (62.5%). Thus, some researchers have utilized the term "lower limb WBL error" to refer to the difference between the postoperative WBLR and the Fujisawa point.

The WBLR calculation involves drawing a line from the center of the femoral head to the midpoint of the proximal articular surface of the talus. The WBLR is then determined by dividing the width of the tibial plateau by the horizontal distance from the weight-bearing line (WBL) to the medial edge of the tibial plateau. In addition, we measured the PF congruence angle (CA) (Figure 1) as an indicator of subluxation. The congruence angle is influenced by the position of the patella, particularly the lateral patellar shift, which is one of the most common cause of patellofemoral pain.

To assess patellar position, imaging parameters such as the distance from tibial tubercle to trochlear groove (TT-TG) were evaluated. The TT-TG distance, measured on CT images (Figure 2), is the distance between the most anterior end of the tibial tubercle and the deepest point of the trochlear groove. The trochlear line, defined as perpendicular to the posterior condylar line, passes through the deepest point of the trochlear groove.

Currently, there remains a lack of consensus regarding the changes in patellar height (PH) following OWHTO. The variations in evaluating PH among different studies could be a contributing factor to the observed variability in PH alterations post-OWHTO. Four common methods are utilized for PH measurement, namely the Blackburn-Peel index (BPI), Caton-Deschamps (CD), Insall-Salvati (IS) and modified Insall-Salvati (MIS) indices. The exact identification of the tibial tubercle may pose challenges due to, which can affect the accuracy of both the IS index and the MIS index. Additionally, the association of the BPI and CD index with the tibial plateau, may not always be clearly distinguishable, especially in the knee OA. Prior research indicated that BPI and IS demonstrated the highest

interobserver agreement before the operation, while CD and BPI exhibited the highest Intraclass correlation coefficient (ICC) after the operation.

The BPI was measured using a lateral radiograph with 30° flexion of the knee joint and a horizontal line is drawn at the level of the tibial plateau. Perpendicular to this line (i.e., vertically), two measurements are made: A, along the patellar articular surface, and B, the distance between the horizontal line and the inferior aspect of the patellar articular surface. The BPI is then obtained by calculating B/A , which serves as a measure of patellar height.

The posterior tibial slope angle (PTSA) is defined as the angle between the line perpendicular to the middle shaft of the tibia and the line depicting the backward inclination of the tibial plateau. The PTSA plays a critical role in determining the sagittal position of the knee and is often used to evaluate knee surgeries. Due to its influence on the position of the sagittal force line of the lower extremity, the PTSA significantly impacts the stability of the knee joint, making it an indispensable factor in the success of both left and right knee joint surgeries. Various imaging techniques, including CT, MRI, and X-ray, are commonly used to measure this angle. However, there is a lack of consistency in the measurement methods across different studies. Using CT and MRI measure PTSA provides the advantage of better distinguishing, between the medial and lateral tibial plateau. However, a limitation of these imaging methods is that they only allow visualization of the proximal tibia, precluding the determination of the anatomical axis of the tibia during routine scanning. On the other hand, when radiographs are employed for PTSA measurement, it becomes challenging to differentiate between the medial and lateral tibial plateau. To address this, it is essential to obtain

appropriately aligned medial and lateral plateau views on the lateral radiographs. In most research studies, the medial tibial plateau is utilized for PTSA measurement.

In this study, clinical outcomes before and after OWHTO were compared using the Anterior Knee Pain (AKP) and International Knee Documentation Committee (IKDC) scores.

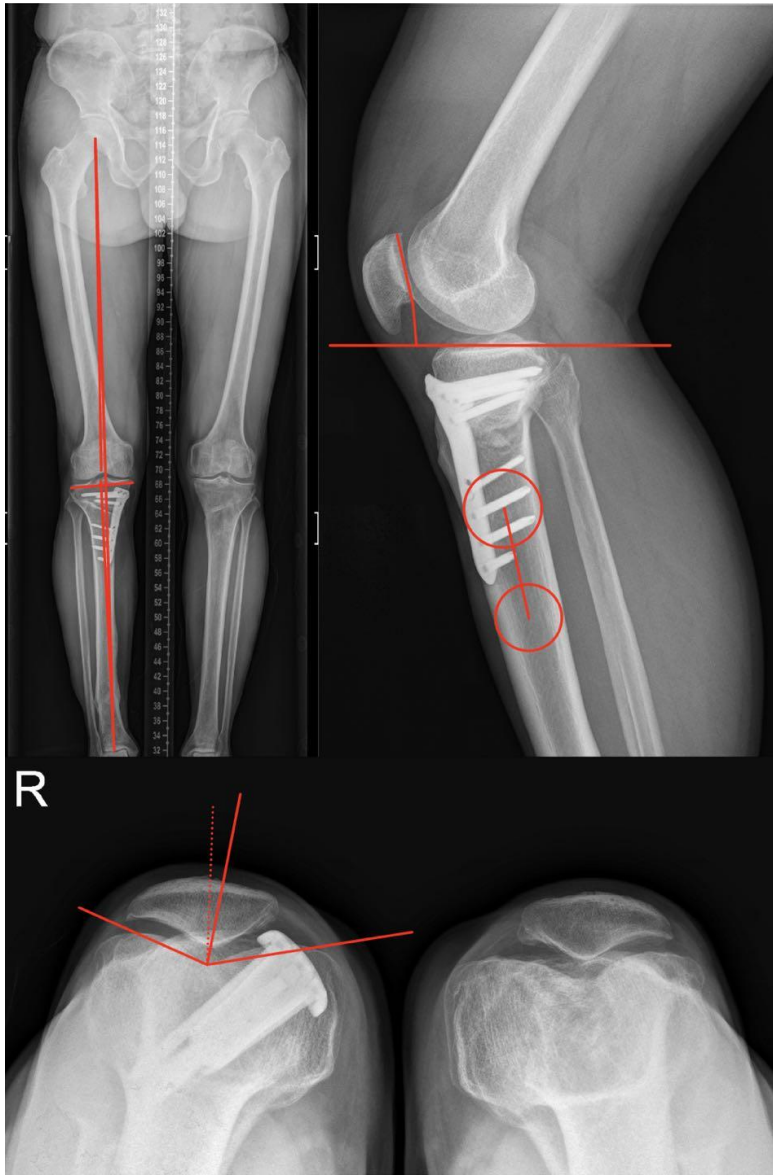


Figure 1. The radiographic evaluations for knee osteoarthritis.

The mechanical femoro-tibial angle (MFTA), the mechanical medial proximal tibial angle (mMPTA), weight bearing line (WBL), the Blackburn-Peel index (BPI), the posterior tibial slope angle (PSTA), and the congruence angle (CA) were measured in the various projections of radiographs.

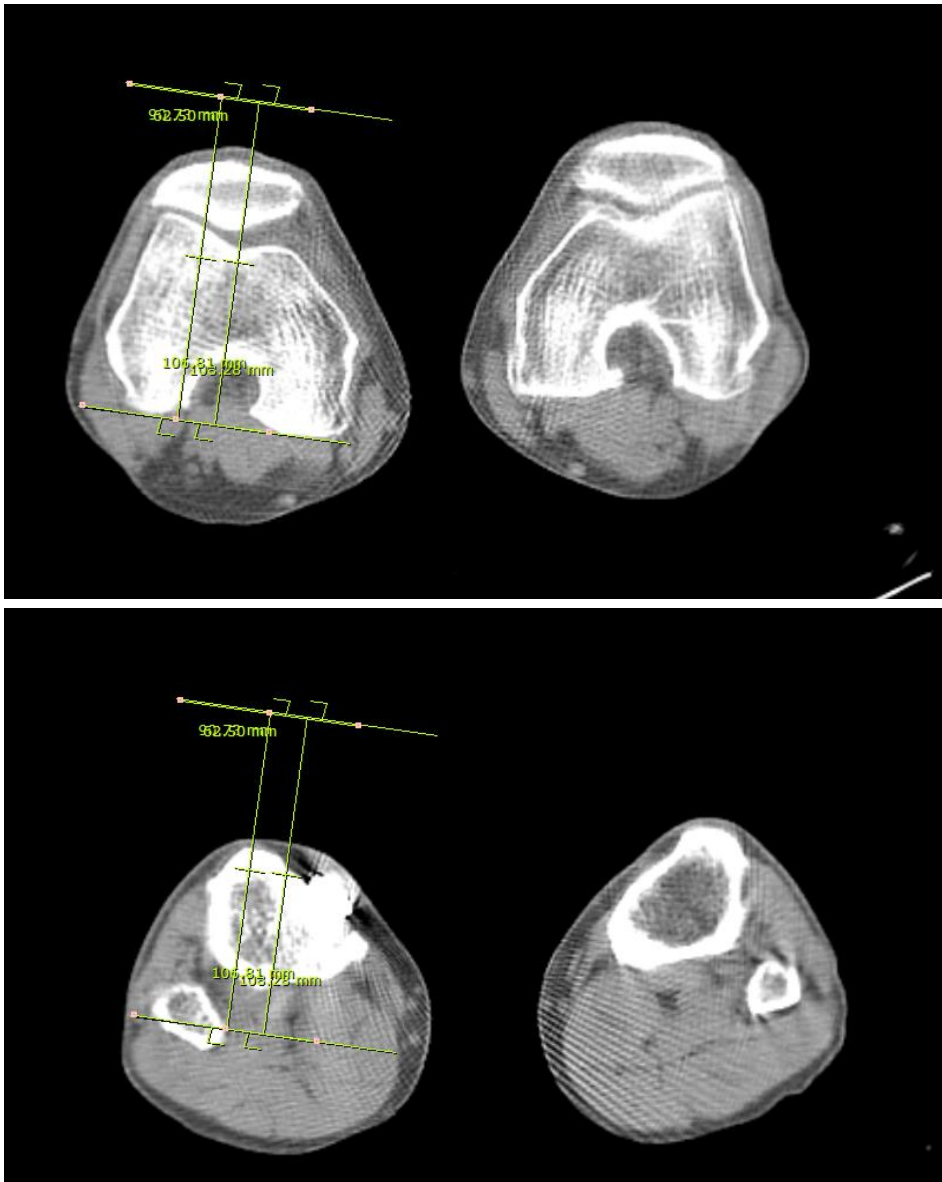


Figure2. The assessment of patellar position.

The distance from tibial tubercle to trochlear groove (TT-TG) was measured on CT axial images.

4. SPECT/CT acquisition and analysis

A total of 34 patients (35 knees) performed both pre- and postoperative SPECT/CT to assess changes in BTU. After receiving an intravenous injection of ^{99m}Tc -hydroxymethylenediphosphonate (1,110 MBq), knee SPECT/CT scans were performed using a dedicated SPECT/CT scanner (Hawkeye 4 system, GE Healthcare, Milwaukee, WI, USA) three hours later. The CT images were acquired with 5.0 mm slices and 512×512 matrices, employing a standard filter (140 kV, 2.5 mA). Meanwhile, the SPECT images were obtained using a $1.5 \times$ zoom, 128×128 matrices, employing a step-and-shoot scan mode. Subsequently, the SPECT/CT images were reconstructed and transferred to the vendor-provided software program (Xeleris Workstation, GE Healthcare, Milwaukee, WI, USA) for interpretation. The interpreted SPECT/CT images in the axial, coronal, and sagittal planes were evaluated.

For the quantification of BTU in the knee joint, three separate region-of-interest (ROI) were placed; for medial and lateral compartment in the coronal plane and for PF joint in the transverse plane (Figures 3 and 4). In cases where patients had metallic screws or plates inserted, precautions were taken to avoid metallic artifacts by ensuring that the screws were positioned at least 10 mm away from the medial tibial plateau. The medial length of each plateau was defined after removing the intercondylar eminence, establishing a width of 10 mm of the tibia and 10 mm of the femur, along with 5 mm of joint space. Additionally, a depth of 25 mm was defined to form a rectangle, thus establishing the medial and lateral ROIs.

The ROI for the PF joint was defined by considering the width as the length of the lateral femoral trochlea and the depth as the thickness of the patella, forming a

rectangular ROI. The average BTU value of the three regions within the ROI was recorded. In order to establish a consistent reference point, the femoral shaft located 10 cm above the knee's articular surface was selected. The average BTU value was then divided by the uptake of the reference point, resulting in a ratio that facilitated a semi-quantitative analysis of the osteoblastic activity. To compare BTU before and after surgery, changes in BTU greater than 20% were defined as either increased or decreased.

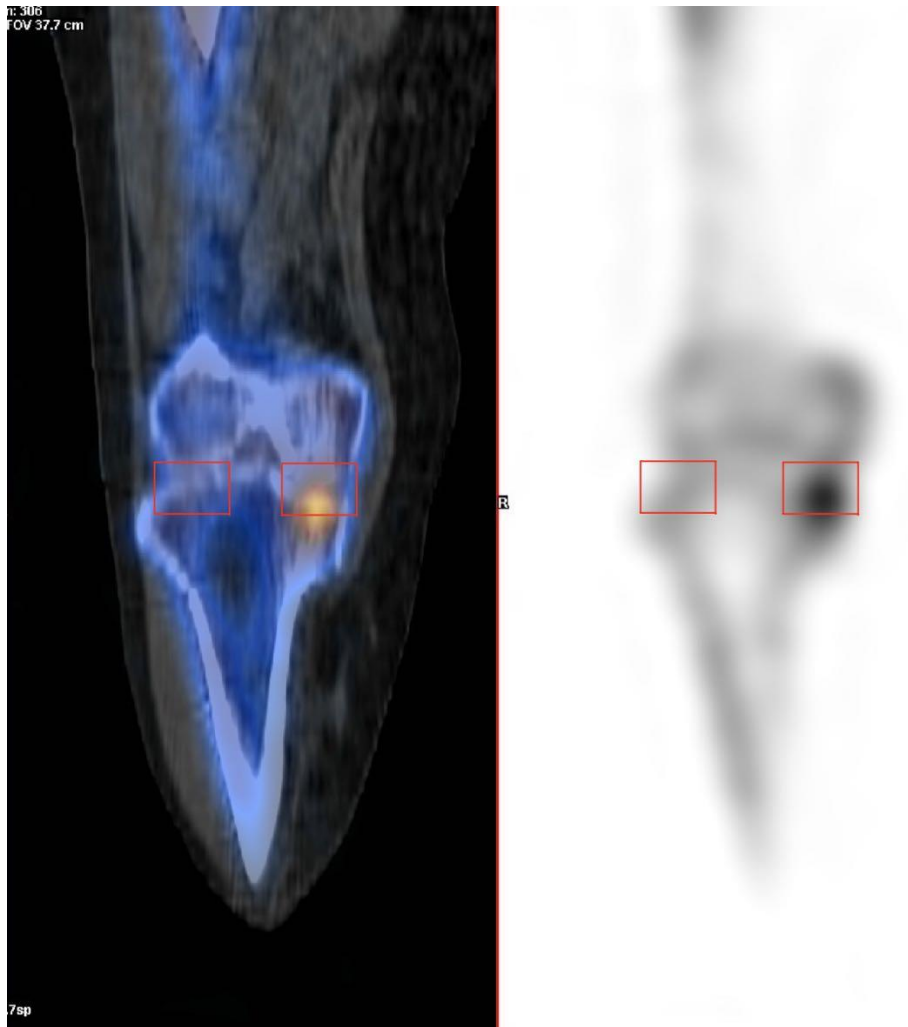


Figure 3. Region of interest (ROI) placement for the medial and lateral compartment.

Rectangular-shaped ROIs were positioned on the SPECT/CT coronal plane to evaluate bone tracer uptake within each medial and lateral compartment. These ROIs were carefully placed to adequately encompass the articular surface of both the tibia and femur within each compartment

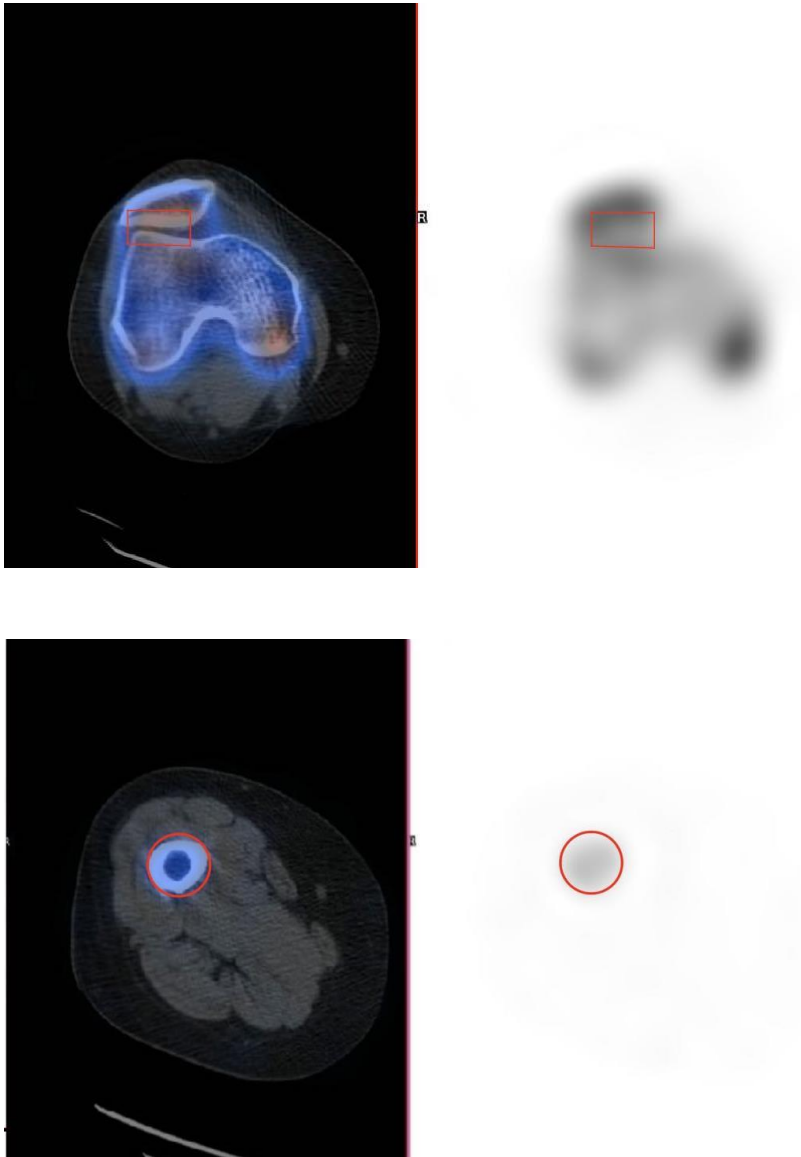


Figure 4. Region of interest (ROI) placement for the patellofemoral (PF) joint and the reference point.

A rectangular-shaped ROI was selected on the SPECT/CT coronal plane to assess the PF joint, the width of which was defined as the length of the lateral femoral trochlea and the depth as the thickness of the patella. A round ROI was placed on the femoral shaft, situated 10 cm above the knee's articular surface, to establish a consistent reference point.

5. Statistical analysis

SPSS version 27.0 (SPSS Corp, Chicago, IL, USA) was used for statistical analyses. P values <0.05 were considered significant. The Shapiro–Wilk test was used to evaluate the normality of distribution. The Wilcoxon signed-rank test was used to compare differences in the preoperative and postoperative values. For the investigation of factors related to the increased BTU in the PF joint after OWHTO, patients were divided into two subgroups: the increased uptake and the non-increased groups. There were 23 knees without increased BTU in the PF joint whereas 12 knees exhibited increased BTU in the PF joint.

To compare demographic data and preoperative and postoperative outcomes between the increased uptake group and non-increased uptake group, continuous variables were analyzed either the student's t-test or Mann–Whitney U test. To explore factors related to the PF joint BTU increased, multivariate regression analysis was performed, incorporating independent variables such as sex, BMI, MFTA, MPTA, WBLR, BPI, PSTA, TT-TG distance and CA. Inter- and intra-observer reliability for SPECT/CT measurements and radiographic measurements were evaluated by two independent observers. The intraclass correlation coefficients (ICC) for both inter- and intra-observer reliability were quantified by intraclass correlation coefficients (ICC) were all >0.85 , indicating high consistency and agreement.

Result

The mean BTU changes varied across compartments following OWHTO. A higher frequency of BTU decrease was observed in the medial compartment compared to other compartments, and the amount of BTU decrease was significant only in the medial compartment. Among the subjects, in the medial compartment, the BTU decreased in 20 cases (57%), remained unchanged in 5 cases (14%), and increased in 10 cases (28%). In the lateral compartment, the BTU decreased in 12 cases (34%), remained unchanged in 13 cases (37%), and increased in 10 cases (28%). In the PF joint, the BTU decreased in 16 cases (46%), remained unchanged in 7 cases (20%), and increased in 12 cases (34%) (Table 1). Significant changes were observed in the mean BTU of the medial compartment, showing a significant decrease after the operation ($p=0.005$).

Both clinical outcomes and radiological assessment were improved following OWHTO. The IKDC score and AKP score exhibited significant improvement after the operation, with the IKDC score showing an increase and the AKP score showing a decrease. Radiological assessment demonstrated successful correction of the mechanical alignment, as indicated by the mean preoperative MFTA of 7.5° varus being corrected to 1.7° valgus postoperatively, and the mean preoperative MPTA of 85.9° being corrected to 94.1° postoperatively. Detailed values and changes in the mean BTU of each compartment and radiological assessments are provided in Table 2.

For the purpose of subgroup analysis, the patients were categorized into three groups based on their MFTA measurements: the varus group, the 0° – 3° valgus

group, and the $>3^{\circ}$ valgus group. This categorization aimed to assess the relationship between BTU in the medial and lateral compartments and the mechanical alignment of the knee. However, no significant association was found between the alignment changes after surgery and BTU in each compartment (Table 3).

Additionally, a subgroup analysis was conducted by classifying the patients into two groups: the increased BTU group (consisting of 12 knees) and the non-increased BTU group (consisting of 23 knees), based on a 20% change in the mean BTU of the PF joint after the operation. Upon comparison of the two groups, it was found that the increased BTU group showed a greater change in the PTSA. The PTSA exhibited a significant increase from 8.8° to 10.5° postoperatively. Additionally, the average TT–TG distance significantly decreased from 10.7 mm to 9.3 mm after the operation. The average BPI also showed a significant decrease from 0.83 to 0.69. However, there was no significant change with CA. Table 4 provides a comprehensive summary of the comparison of clinical outcomes between the two groups. Furthermore, multivariate regression analysis revealed that PTSA ($\beta=0.17$, $p=0.039$) exhibited a significant association with the change in the mean BTU in the PF joint following OWHTO. Table 5 presents the results of the multivariate regression analysis, identifying predictive factors influencing progressive changes in the PF joint following OWHTO.

Table 1 Mean BTU Changes in Each Compartment

	Mean BTU decreased	Mean BTU no change	Mean BTU increased
Medial	20 (57%)	5 (14%)	10 (28%)
Lateral	12 (34%)	13 (37%)	10 (28%)
PF joint	16 (46%)	7 (20%)	12 (34%)

BTU=bone tracer uptake, PF=patellofemoral

Table 2 Changes in Radiological Assessments, Clinical Outcomes, and SPECT/CT

Findings Following OWHTO

Values		Preoperative (Mean \pm SD)	Postoperative (Mean \pm SD)	<i>p</i> -value
MFTA (°)		7.52 \pm 2.70	-1.73 \pm 2.49	< 0.001
MPTA (°)		85.97 \pm 2.67	94.06 \pm 2.60	< 0.001
WBLR		22.43 \pm 15.70	56.91 \pm 10.71	< 0.001
PTSA (°)		8.76 \pm 2.39	10.52 \pm 2.82	< 0.001
BPI		0.83 \pm 0.14	0.69 \pm 0.14	< 0.001
CA (°)		4.61 \pm 9.72	3.38 \pm 8.49	0.330
TT-TG		10.67 \pm 2.79	9.26 \pm 3.38	0.009
BTU	Med.	4.61 \pm 2.46	3.38 \pm 1.50	0.005
	Lat.	2.34 \pm 1.94	2.01 \pm 0.58	0.417
	PF.	2.50 \pm 0.94	2.32 \pm 0.93	0.338
IKDC score		34.94 \pm 7.34	45.84 \pm 6.40	0.001
AKP score		50.7 \pm 16.14	72.67 \pm 14.35	0.001

OWHTO=open wedge high tibial osteotomy, MFTA=mechanical femorotibial angle,

MPTA=mechanical medial proximal tibial angle, WBLR=weight bearing line ratio, BPI=Blackburne–

Peel Index, PSTA =posterior tibial slope angle, CA=congruence angle, TT-TG=tibial tuberosity to

trochlear groove distance, BTU=bone tracer uptake, Med.=medial, Lat.=lateral, PF=patellofemoral,

IKDC=International Knee Documentation Committee, AKP=anterior knee pain

Table 3. Comparisons of Mean BTU Values Among Groups Based on MFTA
Measurements Following OWHTO

Groups		Varus (n=6)	0°–3° valgus (n=21)	>3° valgus (n= 8)	p-value
Med.	Pre	4.33 ± 2.49	4.61 ± 2.56	4.81 ± 2.50	0.811
	Post	3.14 ± 1.55	3.31 ± 1.32	3.80 ± 1.98	0.791
	Delta	-1.20 ± 1.49	-1.28 ± 2.81	-1.04 ± 3.18	0.880
Lat.	Pre	1.90 ± 0.41	2.52 ± 2.48	2.22 ± 0.61	0.693
	Post	1.73 ± 0.46	2.1 ± 0.66	1.97 ± 0.41	0.331
	Delta	-0.16 ± 0.46	-0.42 ± 2.4	-0.25 ± 0.51	0.550
PF.	Pre	2.67 ± 1.28	2.4 ± 0.88	2.64 ± 0.91	0.769
	Post	1.73 ± 0.46	2.45 ± 1.03	2.34 ± 0.85	0.709
	Delta	-0.80 ± 1.22	0.40 ± 1.39	-0.30 ± 1.45	0.541

Bone tracer uptake (BTU) values are presented as mean values and standard deviations (mean ± SD).

MFTA=mechanical femorotibial angle, OWHTO=open wedge high tibial osteotomy,

Pre=preoperative, Post=postoperative, Delta = changes between pre- and post-operative values,

Med.=medial, Lat.=lateral, PF=patellofemoral

Table 4-1 Comparisons Between Groups Based on Mean BTU Changes of the PF joint
Following OWHTO

Groups		Non-increased BTU (n=23)	Increased BTU (n=12)	<i>p</i> -value
MFTA	Pre	7.44 ± 2.83	7.37 ± 2.31	0.837
	Post	-1.71 ± 3.10	-1.48 ± 2.37	0.631
	Delta	-9.16 ± 4.32	-8.85 ± 2.25	0.802
MPTA	Pre	85.3 ± 2.81	87.7 ± 2.01	0.015
	Post	93.97 ± 2.27	95.23 ± 2.27	0.133
	Delta	8.06 ± 4.14	7.56 ± 2.41	0.537
WBLR	Pre	20.89 ± 13.04	26.62 ± 16.12	0.371
	Post	55.61 ± 12.42	56.49 ± 10.81	0.837
	Delta	34.73 ± 17.64	29.81 ± 20.12	0.507
PTSA	Pre	9.36 ± 2.67	7.98 ± 2.26	0.397
	Post	10.08 ± 3.22	10.84 ± 2.56	0.423
	Delta	0.73 ± 2.93	2.87 ± 1.79	0.029
BPI	Pre	0.81 ± 0.15	0.87 ± 0.12	0.324
	Post	0.71 ± 0.16	0.72 ± 0.10	0.909
	Delta	-0.1 ± 0.15	-0.16 ± 1.56	0.082

Values are presented as mean values and standard deviations (mean ± SD).

BTU= bone tracer uptake, PF=patellofemoral, OWHTO=open wedge high tibial osteotomy,

MFTA=mechanical femorotibial angle, MPTA=mechanical medial proximal tibial angle,

WBLR=weight bearing line ratio, BPI=Blackburne–Peel Index, Pre=preoperative,

Post=postoperative, Delta = changes between pre- and post-operative values

Table 4-2 Comparisons Between Groups Based on Mean BTU Changes of the PF joint
Following OWHTO

Groups		Non-increased BTU (n=23)	Increased BTU (n=12)	<i>p</i> -value
CA	Pre	4.94 ± 10.41	3.18 ± 9.92	0.537
	Post	3.30 ± 9.51	3.85 ± 9.09	0.945
	Delta	-1.64 ± 11.29	0.67 ± 12.03	0.698
TT-TG	Pre	12.04 ± 2.37	9.73 ± 2.51	0.017
	Post	10.45 ± 2.93	8.25 ± 3.91	0.189
	Delta	-1.59 ± 2.88	-1.47 ± 2.66	0.945
BTU (Med.)	Pre	4.81 ± 2.68	2.81 ± 2.59	0.767
	Post	2.80 ± 1.06	4.11 ± 1.83	0.053
	Delta	-2.01 ± 2.84	-0.70 ± 2.60	0.397
BTU (Lat.)	Pre	2.91 ± 2.74	1.78 ± 0.56	0.029
	Post	1.91 ± 0.60	2.25 ± 0.61	0.110
	Delta	-1.00 ± 2.56	0.47 ± 0.63	<0.001
IKDC score	Pre	33.50 ± 5.02	33.20 ± 5.54	0.383
	Post	47.72 ± 7.02	44.4 ± 5.23	0.768
AKP score	Pre	50.42 ± 16.77	40.6 ± 7.80	0.198
	Post	76.20 ± 14.68	72.60 ± 14.24	0.594

Values are presented as mean values and standard deviations (mean ± SD).

BTU= bone tracer uptake, PF=patellofemoral, OWHTO=open wedge high tibial osteotomy,

CA=congruence angle, TT-TG=tibial tuberosity to trochlear groove distance, Med.=medial,

Lat.=lateral, IKDC=International Knee Documentation Committee, AKP=anterior knee pain,

Pre=preoperative, Post=postoperative, Delta = changes between pre- and post-operative values

Table 5 Multivariate Regression Analysis of Predictive Factors Affecting Progressive Change in the PF Joint after OWHTO

	β	P-value
MFTA_ change	0.26	0.867
MPTA_ change	-0.66	0.675
WBLR_ change	0.79	0.606
BP_ change	0.06	0.972
CA_ change	1.39	0.551
TT-TG_ change	-0.19	0.608
PTSA_ change	0.17	0.039
BMI_ change	0.96	0.536
Age	-0.02	0.991
Gender	0.46	0.766

OWHTO=open wedge high tibial osteotomy, PF=patellofemoral, MFTA=mechanical femorotibial angle, MPTA=mechanical medial proximal tibial angle, WBLR=weight bearing line ratio, BPI=Blackburne–Peel Index, PSTA =posterior tibial slope angle, TT-TG=tibial tuberosity to trochlear groove distance, CA=congruence angle, BMI=body mass index

Discussion

In the present study, I observed a statistically significant decrease in BTU exclusively in the medial compartment after OWHTO. As expected, there were concurrent improvements in clinical outcomes and radiographic assessments. However, there was no statistically significant correlation between postoperative alignment adjustments and BTU in the entire compartment. Interestingly, a subgroup analysis based on increased BTU in the PF joints revealed a pronounced change in PTSA in the increased BTU group. Subsequent multivariate regression analysis revealed a significant association between PTSA and mean BTU change within the PF joint after OWHTO.

I have discovered a paradoxical alteration in BTU between the medial and lateral compartments following the OWHTO procedure. A significant reduction in the mean BTU, indicative of diminished *in vivo* mechanical stress on each compartment, was observed in the medial compartment after OWHTO. This finding indicates a clinical improvement of the medial knee joint, which is consistent with our anticipated clinical outcomes from OWHTO. However, in contrast to the medial compartment, the mean BTU in the lateral compartment showed no significant change after OWHTO. This outcome contradicts our initial concern that OWHTO might have an adverse impact on the lateral compartment and PF joint. Previous studies have demonstrated a correlation between mechanical varus/valgus alignment and increased BTU in either the medial or lateral compartment (7,12). Furthermore, alterations in both varus and valgus alignment also elevate the risk of osteoarthritis progression in the biomechanically stressed compartment within an 18-month timeframe (13). This inconsistency could

potentially be attributed to the method employed for measuring BTU. Our methodology involved placing ROIs to evaluate uptake across the entire medial, lateral, or patellar area, followed by a comparison of the mean BTU within the overall region. However, this approach might not capture the peak uptake value, as it calculates the average rather than the maximum value within the region. After undergoing the OWHTO procedure, various alterations occur, including adjustments in tibial anterversion and patellar trajectory due to the increased posterior inclination of the tibia. These modifications could potentially lead to a shift in the precise anatomical point of joint contact after the operation. Nonetheless, despite these alterations, the average value of the region may remain relatively unaffected.

I investigated the effect of PTSA on PF joint alterations after OWHTO. It is crucial to emphasize that changes in PTSA were closely monitored throughout our study, given the established correlation between significant PTSA changes and multiple parameters concerning the PF joint. It is worth mentioning that a dearth of short-term studies exists, exploring the influence of PTSA on the PF joint . Previous studies have demonstrated that OWHTO leads to elevated patellofemoral contact pressure, potentially resulting in damage to the PF joint (14). Furthermore, biomechanical studies have indicated a substantial rise in PF contact pressure after the operation (15). The augmented pressure on the PF joint has been associated with postoperative pain and its potential contribution to the development and progression of PF osteoarthritis (16). A meta-analysis examining alterations in PTSA after OWHTO has documented a postoperative increase in PTSA (17). The importance of PTSA in influencing knee biomechanics has received escalating

attention in recent years, as changes in PTSA affect knee kinematics and stability (18). A reduction in PTSA could compromise knee joint stability, potentially leading to knee overextension and increased stress on the posterior cruciate ligament. Conversely, an increase in PTSA also increases stress on the ACL (19,20). It's clear that PTSA is generally increased after OWHTO, and factors such as hinge position, wedge insertion angle, and correction angle may contribute to alterations in PTSA. Therefore, surgeons should pay special attention to PTSA during the procedure (21,22,23).

This study is subject to several inherent limitations that warrant acknowledgment. Firstly, it is essential to note that our study design adopted a retrospective design, which inherently carries certain inherent constraints in terms of data collection and potential biases. Secondly, the size of each group was comparatively small, which may impose limitations on the generalizability of this findings to broader populations. Thirdly, the preponderance of female subjects in this study sample could potentially introduce gender-related confounders that may influence the extrapolation of this study results to a more diverse demographic. Fourthly, the precision of defining ROIs for BTU assessment may be prone to inaccuracies, potentially impacting the robustness of our conclusions. Furthermore, it is important to acknowledge that the present study did not incorporate a comparative analysis with respect to cartilage assessment. This absence of direct comparison with cartilage assessment introduces a notable limitation in contextualizing the broader implications of this study results.

Conclusion

Overall, there was no meaningful biomechanical changes in the short-term period in the lateral and PF joints after OWHTO when evaluating the mean BTU using SPECT/CT. However, in the PF joint, the BTU increased in 12 (34%) cases. In addition, increased PTSA after surgery probably related to the increased uptake in the PF joint after surgery. Longer-term follow-up study should be needed to confirm whether the increased uptake in the PF joint observed in patients with increased PTSA adversely affect the clinical outcome after OWHTO.

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개방형 경골 근위부 절골술후 구획 변화에 대한 SPECT/CT 평가

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배경: 개방형 경골 근위부 절골술은 무릎 관절염 및 내반 변형이 동반된
젊고 활동적이며, 비만이 아닌 환자에게 적합한 치료법이다. 그러나 일부
연구에서는 무릎 외측구획과 슬개대퇴 관절(PF)의 접촉 압력이 증가할 수
있다는 단점을 보고했다. 수술 후 무릎 관절의 외측 구획에 대한 부하
증가로 인해 OWHTO 이후 시간이 지남에 따라 OA 변화가 진행될 수

있다고 가정하는 것이 합리적입니다. 그러나 현재 개방형 경골 근위부 절골술 후 슬개대퇴 관절에서 관절염의 진행에 대한 합의가 없다.

대상 및 방법: 개방형 경골 근위부 절골술을 시행하는 34 명의 환자

35 개 무릎을 SPECT/를 사용하여 수술 전후의 변화를 평가하였다. 수술 전 및 수술 후 슬개대퇴관절 BTU (bone tracer uptake)를 하였다.

슬개대퇴관절의 BTU 변화와 관련된 인자를 분석하기 위하여 BTU 증가된 환자와 증가되지 않은 환자의 두 군으로 나누어 비교하고 다변량 분석을 시행하였다. 다변량 분석을 위하여 연령, 성별, BMI 신체질량 지수, 역학적 대퇴-경골각, 내측 근위 경골 각도, 역학적 내측 근위 경골 각도, 체중 부하 선, Blackburn-Peel ratio, 경골 후방경사각, 경골 결절-활차 홈 거리 및 congruence angle 을 분석하였다.

결과: 무릎 내측 구획의 BTU 는 수술 후에 유의하게 감소하였으나

($p=0.005$) 외측($p=0.417$)과 슬개대퇴관절 ($p=0.318$)은 SPECT/CT 상의 평균 BTU 에 유의한 변화가 없었다. 무릎 내측 구획의 BTU 는 20 레 (57%)에서

감소했고, 5 레에서는 변화가 없었으며, 10 레에서는 증가하였다. 외측 구획의 BTU 는 12 레에서 감소했고, 13 레에서 변화가 없었으며, 10 레(28%)에서 증가하였다. 슬개대퇴관절 관절 BTU 는 감소한 경우가 16 레, 변화가 없는 경우가 7 레, 증가한 경우가 12 레(34%)이었다. 근위 경골 절골술 후 슬개대퇴관절의 평균 BTU 증가와 관련된 요소는 경골 후방경사각의 증가였다.

결론: 경골 근위부 절골술 후 SPECT/CT 를 사용하여 평균 BTU 를 평가할 때 외측 구획 및 슬개대퇴관절에서 단기간 유의한 생체역학적 변화가 없었다. 그러나 슬개대퇴관절에서 12 레 (34%)에서 평균 BTU 가 증가하였다. 수술 후 경골 후방경사각의 증가는 수술 후 슬개대퇴관절의 평균 BTU 증가와 관련 있을 수 있다. 경골 근위부 절골술 후 경골 후방경사각이 증가된 환자 중 슬개대퇴관절 평균 BTU 의 증가가 임상결과에 나쁜 영향을 미치는지 확인하기 위하여 장기간의 추적연구가 필요하다.

주요어 : (경찰 근무부 절골술, 단일광자방출단층촬영술, 슬개대퇴관절,

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