Original Article
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Comparison of Lower-Limb Alignment in Patients with Advanced Knee Osteoarthritis: EOS Biplanar Stereoradiography versus Conventional Scanography

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Background: Accurate measurement of the lower limb alignment is one of the most crucial factors in advanced knee osteoarthritis patients scheduled for surgery. Recently, EOS biplanar stereoradiography with three-dimensional reconstruction was developed. The purpose of this study was to compare radiographic parameters between conventional scanography and EOS in patients with advanced knee osteoarthritis who need surgical treatment.

Methods: A total of 52 consecutive patients (104 knees) with bilateral knee osteoarthritis of advanced stage (Kellgren-Lawrence [KL] grade 3 or 4) were retrospectively reviewed. We measured the hip-knee-ankle angle (HKA) on conventional scanograms. In EOS, we measured HKA, hip-knee-shaft angle, mechanical lateral distal femoral angle, and mechanical medial proximal tibial angle. To evaluate sagittal and axial plane alignment, knee flexion angle (KFA), and knee joint rotation (KJR) were also measured.

Results: Ninety knees were KL grade 4, and 14 knees were grade 3. The average HKA was 10.14° ± 6.16° on conventional scanograms and 11.26° ± 6.21° in EOS. HKA was greater in EOS than on conventional scanograms, and the difference (1.12°; range, –1.07° to 3.22°) was statistically significant ($p < 0.001$). Significant correlations were observed on the difference in HKA and mechanical medial proximal tibial angle ($r = –0.198$, $p = 0.044$), KFA ($r = 0.193$, $p = 0.049$), and KJR ($r = 0.290$, $p = 0.003$). In multivariable linear regression analysis, the difference in HKA had significant relationship with KFA ($\beta = 0.286$, $p = 0.003$) and KJR ($\beta = 0.363$, $p < 0.001$).

Conclusions: HKA measured on conventional scanograms and in EOS differed significantly and the difference had a significant correlations with KFA, KJR, and medial proximal tibial angle. Surgeons can consider these results before orthopedic surgery in patients who have advanced knee osteoarthritis.

Keywords: *Knee osteoarthritis, Alignment, Biplanar steroradiography, Scanoram, Total knee arthroplasty*

The number of patients with advanced knee osteoarthritis (OA) increases with the aging of the society. Total knee arthroplasty (TKA) or corrective osteotomies could be a treatment option for patients with advanced OA of the knee with lower limb malalignment. As people live longer and need to stay healthy and withstand high physical demands, the longevity of surgery is becoming an issue.

Many factors affect the prognosis of knee surgery.[1-3] Accurate measurement of the coronal alignment of the lower limb is one of the most crucial factors in advanced knee OA patient evaluation and treatment in clinical practice. Many authors have reported that overcorrection or undercorrection of lower limb alignment results in poor

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prognosis and that restoration of proper alignment of the lower limbs can result in a lower revision rate and higher longevity in TKA or corrective osteotomy.[4,5] Traditionally, lower limb alignment was evaluated using conventional scanograms with radiographic parameters using a picture-acquiring communication system (PACS). But conventional scanograms can assess only coronal plane angular malalignment, while progression of OA could affect the prevalence of knee flexion contractures, which affects coronal alignment.[6] Recently, biplanar stereoradiography with three-dimensional (3D) reconstruction was developed. It is biplane X-ray imaging system and increasingly used in many countries because it makes possible to acquire simultaneous anteroposterior (AP) and lateral images of the entire body and reduce radiation exposure.

The purpose of this study was to compare radiographic parameters between conventional scanography and EOS in patients with advanced knee OA who need surgical treatment. We hypothesized that there would be a significant difference between conventional scanography and EOS with regard to radiologic parameters.

METHODS

This study was approved by the Ethics Committee of our institution (DSMC 2020-09-060) and informed consent was obtained from all patients.

From April 2019 to April 2020, patients who had advanced knee OA and were evaluated by both conventional scanography and EOS were retrospectively reviewed. Among 197 patients, those with unilateral OA, a history of previous arthroplasty, or fractures in low extremities were excluded. A total of 52 consecutive patients (104 knees) who had bilateral knee OA of an advanced stage (Kellgren-Lawrence grade 3 or 4) and were planned for TKA or corrective osteotomy were enrolled in this study (Fig. 1).

Conventional Scanography

Patients were positioned to stand with both lower extremities equally without an assistive device, with both patellae pointing anteriorly and feet directed straight, parallel to each other. Patients were asked not to flex their knees intentionally. A radiopaque ruler was taped to the table. The patient-to-tube distance was typically 101 cm. Three separate AP images centered over the hip, knee, and ankle joints were obtained, using three separate 35 × 9 × 43 cm cassettes. The film cassette was moved behind the patient between exposures while the patient remained motionless between the three exposures.[7] Radiographic images were obtained using SH3 (DK Medical, Seoul, Korea).

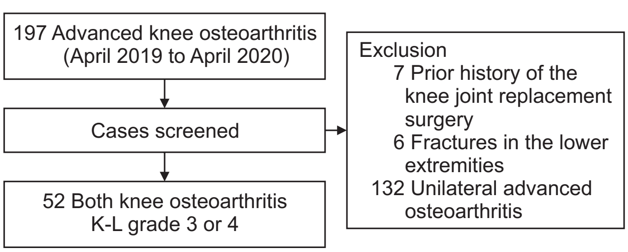

Fig. 1. Flow diagram of patient selection process. K-L: Kellgren-Lawrence.

EOS System

The EOS system (EOS Imaging, Paris, France) is a biplane X-ray imaging system composed of two X-ray sources shaped as fan beams projected through collimation slits; EOS allows the acquisition of 2 X-ray images simultaneously.[8,9] The sources are coupled to linear detectors built using the micromesh gaseous structure technology. The distance between sources and detectors is 130 cm, with the patient standing at approximately 100 cm from both sources in the same position as for conventional scanography. EOS also enables a precise 3D reconstruction of the skeletal system because images are captured in a spatially calibrated manner. EOS enables the acquisition of images whilst the patient is in an upright, weight-bearing standing position, obviating the need for digital stitching or manual joining of multiple images.

Radiologic Evaluation

The radiographic alignment was determined with refer-

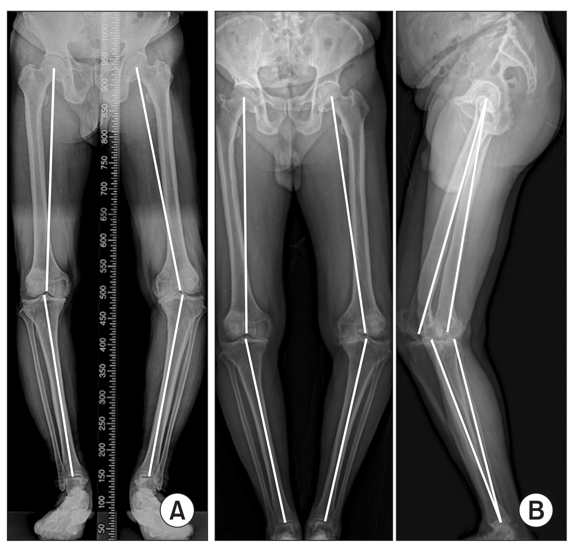

Fig. 2. Radiographic imaging of the hip-knee-ankle angle on conventional scanograms (A) and in EOS (B). (B) The reference points were set simultaneously in both the coronal and sagittal planes.

ence to standard anatomical landmarks that have been proven to be available and reliable.[10,11] We measured the hip-knee-ankle angle (HKA) on conventional scanograms. In EOS, HKA, hip-knee-shaft angle (HKS), mechanical lateral distal femoral angle (LDFA), and mechanical medial proximal tibial angle (MPTA) were measured. To evaluate sagittal and axial plane alignment, knee flexion angle (KFA) and knee joint rotation (KJR) were also measured. HKA was defined as the angle between the mechanical axes of the femur and tibia. The definition of neutral alignment was HKA within 3°, varus alignment > 3° and set to have a positive value, and valgus alignment > 3° and set to have a negative value.

On conventional scanograms, reference points were set only in the coronal plane using PACS (Infinitt Healthcare, Seoul, Korea). In EOS, reference points were set simultaneously in both coronal and sagittal planes, using an imaging reconstruction program from EOS imaging (Fig. 2). HKS was defined as the angle between the anatomical axis and the femur's mechanical axis.[12] LDFA was defined as the lateral angle between the femur's mechanical axis and the knee joint orientation line of the femur. MPTA was defined as the medial angle between the mechanical axis of the tibia and the knee joint orientation line of the tibia.[13] KFA was defined as the angle between the mechanical axes of the femur and tibia in the sagittal plane (Fig. 3). KJR was defined as the degree of deviation of the patellar center inward or outward relative to the midpoint of the line connecting both femoral epicondyles.[14] Axial alignment of the lower limb was set to have a positive value in internal rotation and a negative value in external rotation (Fig. 4).

Statistical Analysis

The IBM SPSS ver. 26.0 software (IBM Corp., Armonk, NY, USA) was used for all data analyses. Wilcoxon signed-rank test was used to analyze HKA on conventional scanograms and in EOS. Pearson's correlation coefficient (r) was used for analysis of correlations between radiographic measurements. The linear correlations were interpreted as follows: $|r| = 0.5–1.0$ as strong; $|r| = 0.3–0.5$ as moderate; and $|r| = 0.1–0.3$ as weak. In linear regression analyses, the difference in HKA was a dependent variable, and other radiologic parameters were independent variables. Statistical significance was set at $p < 0.05$ for all analyses.

Fig. 4. Knee joint rotation was defined as the degree of deviation of the patellar center inward or outward relative to the midpoint of the line connecting both femoral epicondyles (A / B × 100, %). ER: external rotation, IR: internal rotation.

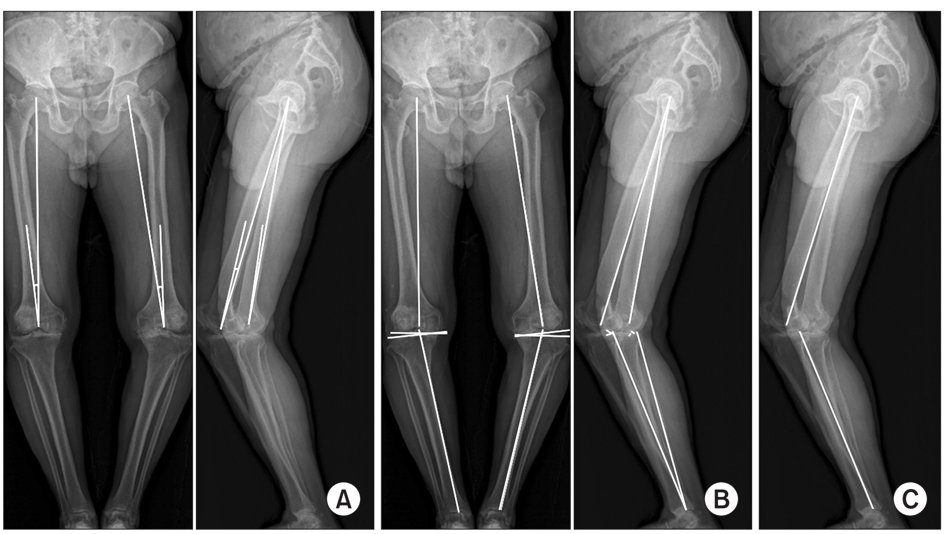

Fig. 3. Radiographic imaging of the hip-knee-shaft angle (A), mechanical lateral distal femoral angle (B), and knee flexion angle (C) in EOS.

RESULTS

The average age of the patients was 71.25 years (range, 57 to 83 years); 4 patients were male and 48 were female. Ninety knees were KL grade 4, and 14 knees were grade 3; and 95 knees had varus alignment. External rotation was found in 72 knees (Table 1).

The average HKA was 10.14° ± 6.16° on conventional scanograms and 11.26° ± 6.21° in EOS. HKA was greater in EOS than on conventional scanograms, and the difference (1.12°; range, −1.07° to 3.22°) was statistically significant ($p < 0.001$). The average HKA on conventional scanograms and HKA, HKS, LDFA, MPTA, KFA, and KJR in EOS are listed in Table 1. HKA was larger in EOS than on conventional scanograms in 63 lower limbs (60.6%), smaller in 15 (14.4%), and the same in 26 (25%).

Strong correlations of LDFA with both HKA were observed on conventional scanograms ($r = -0.564$, $p < 0.001$) and in EOS ($r = -0.522$, $p < 0.001$). Strong correlation of MPTA with HKA in EOS was observed ($r = -0.506$, $p < 0.001$) and moderate correlation was observed with HKA on conventional scanograms. ($r = -0.442$, $p < 0.001$).

Weak correlation of HKS with HKA on conventional scanograms was observed ($r = 0.206$, $p = 0.036$). Weak correlations of KFA with both HKA were observed on conventional scanograms ($r = 0.196$, $p = 0.046$) and in EOS ($r = 0.259$, $p = 0.008$). KJR showed no correlation with both HKA on conventional scanograms and in EOS, while KFA and KJR showed weak but significant correlation ($r = -0.256$, $p = 0.009$).

The correlation coefficients for the difference in HKA and radiologic parameters are listed in Table 2. The difference in HKA showed weak correlations with MPTA ($r = -0.198$, $p = 0.044$), KFA ($r = 0.193$, $p = 0.049$), and KJR ($r = 0.290$, $p = 0.003$). In simple linear regression analysis, the difference in HKA had low coefficients of determination but significant relationship between MPTA ($\beta = -0.118$, $R^2 = 0.039$), KFA ($\beta = 0.061$, $R^2 = 0.037$), and KJR ($\beta = 0.053$, $R^2 = 0.084$) (Table 3). In multivariable linear regression analysis, the difference in HKA had significant relation-

Table 1. Demographics and Mean Values of Radiologic Parameters

Parameter	Value	95% CI
Age (yr)	71.25 ± 6.70 (57–83)	69.38 to 73.12
Sex		
Male	4	
Female	48	
Kellgren-Lawrence grade (knee)		
4	90	
3	14	
Coronal alignment (knee)		
Varus	95	
Neutral	8	
Valgus	1	
Axial alignment (knee)		
External rotation	72	
Neutral rotation	2	
Internal rotation	30	
Conventional scanogram		
HKA (°)	10.14 ± 6.19	8.94 to 11.35
EOS		
HKA (°)	11.26 ± 6.21	10.05 to 12.47
HKS (°)	6.73 ± 1.57	6.43 to 7.04
LDFA (°)	90.48 ± 2.00	90.09 to 90.87
MPTA (°)	82.96 ± 3.42	82.30 to 83.63
KFA (°)	9.22 ± 9.54	7.37 to 11.08
KJR (%)	–5.36 ± 11.28	–7.56 to –3.17

Values are presented as mean ± SD (range) or mean ± SD.
SD: standard deviation, CI: confidence interval, HKA: hip-knee-ankle angle, HKS: hip-knee-shaft angle, LDFA: mechanical lateral distal femoral angle, MPTA: mechanical medial proximal tibial angle, KFA: knee flexion angle, KJR: knee joint rotation.

Table 2. Correlation Coefficients for the Difference in HKA and Radiographic Parameters

Variable	Correlation coefficient (*R*)	*p*-value
HKA in CS	–0.155	0.115
HKA in EOS	0.174	0.077
HKS in EOS	–0.105	0.289
LDFA in EOS	0.124	0.209
MPTA in EOS	–0.198	0.044*
KFA in EOS	0.193	0.049*
KJR in EOS	0.290	0.003*

HKA: hip-knee-ankle angle, CS: conventional scanogram, HKS: hip-knee-shaft angle, LDFA: mechanical lateral distal femoral angle, MPTA: mechanical medial proximal tibial angle, KFA: knee flexion angle, KJR: knee joint rotation.
*Statistical significance at $p < 0.05$.

Table 3. Simple Linear Regression Analysis Showing Variables Affecting the Difference in HKA

Variable	*p*-value	Beta	R^2
HKS	0.289	–0.137	0.011
LDFA	0.209	0.127	0.015
MPTA	0.044*	–0.118	0.039
KFA	0.049*	0.061	0.037
KJR	0.003*	0.053	0.084

HKA: hip-knee-ankle angle, HKS: hip-knee-shaft angle, LDFA: mechanical lateral distal femoral angle, MPTA: mechanical medial proximal tibial angle, KFA: knee flexion angle, KJR: knee joint rotation.
*Statistical significance at $p < 0.05$.

Table 4. Multivariable Linear Regression Analysis with the Difference in HKA as the Dependent Variable

Variable	Standardized coefficient beta	Unstandardized coefficient beta (95% CI)	*p*-value
HKS	–0.055	-	0.571
LDFA	0.093	-	0.329
MPTA	–0.197	-	0.104
KFA	0.286	0.061 (0.041–0.081)	0.003*
KJR	0.363	0.066 (0.049–0.083)	0.000*

HKA: hip-knee-ankle angle, CI: confidence interval, HKS: hip-knee-shaft angle, LDFA: mechanical lateral distal femoral angle, MPTA: mechanical medial proximal tibial angle, KFA: knee flexion angle, KJR: knee joint rotation.
*Statistical significance at $p < 0.05$.

ship with KFA (β = 0.286, $p = 0.003$) and KJR (β = 0.363, $p < 0.001$) (Table 4). With KJR as the control variable, the difference in HKA between conventional scanograms and EOS also had significant correlation with KFA in EOS ($r = 0.289$, $p = 0.03$).

DISCUSSION

The most principal finding of our study is that HKA was greater in EOS than on conventional scanograms. In addition, significant correlations were observed between the difference in HKA and KFA, KJR, and MPTA. Previous studies have reported on many factors affecting coronal alignment.[15-17] In a study by Shetty et al.,[15] the patients who had flexion deformity greater than 10° showed a greater difference of ≥ 3° in HKA between conventional scanograms and navigation-assisted measurements. Thus, they recommended that the surgeon should consider that HKA in conventional scanograms could be incorrect when flexion deformity is greater than 10°. More than one-third of knee OA patients have moderate to severe flexion contracture; therefore, it is important to notice that HKA on conventional scanograms differs from actual alignment, which is needed in surgical planning and patient evaluation.[18)]

Another factor affecting coronal alignment is axial alignment. Lee et al.[16] analyzed the relationship between foot rotation and HKA. The study, which consisted of 80 lower limbs with genu varum, compared HKA in various positions of the foot; neutral rotation, 30° external rotation, and 15° internal rotation. The study concluded that external rotation could show less varus alignment and the reverse could occur in internal rotation compared to neutral rotation. Another study, which included 87 patients, analyzed the effect of KJR and concluded that even a 3° rotational deviation can lead to a statistically significantly different value.[19]

However, there is some disagreement. Brouwer et al.,[17] who reported the combined effect of both sagittal and axial alignment on coronal alignment, concluded that flexion of the knee without rotation had little effect on angles as projected on full-length AP radiographs and rotation of the lower extremity without flexion also had little effect. However, simultaneous flexion of the knee and rotation resulted in significant changes in projected angle. A study by Jud et al.[20] analyzing a 3D surface model of lower limbs generated from computed tomography (CT) compared the difference in HKA between baseline measurement and in conditions of knee flexion and rotation. A greater difference in HKA was observed in combined condition of knee flexion and rotation, while it was less than 3° in either condition of knee flexion or rotation. Yoo et al.[5] analyzed the relationship between HKA and knee flexion and rotation. The study included 115 patients and concluded that combined knee flexion and rotation had a greater effect on HKA than flexion or rotation alone. In our study, average KFA was 9.2° and KJA was –5.36%. Considering the studies mentioned above, it was strong enough to affect coronal alignment, which is consistent with our findings that the difference in HKA showed significant correlation with KFA and KJR.

Regarding other aspects, several papers reported clinical effectiveness of the EOS.[21,22] Rosskopf et al.[23] reported that femoral and tibial torsion measurements using biplanar radiography in children were comparable to CT measurement results and reliable. Somoskeoy et al.[24] reported that vertebra vectors measured on EOS showed excellent intraobserver and interobserver reliability compared with traditional 2D measurement. Due to these advantages, EOS is widely used in daily clinics by various orthopedic surgeons including spine and pediatric departments. Nonetheless, EOS has predominantly been used to aid in the evaluation of lower limb alignment. Guenoun et al.[22] reported the reliability of EOS for lower extremity measurements. The study population included 25 patients (50 lower limbs) awaiting total hip arthroplasty, and most variables showed excellent inter- and intraobserver reproducibility. Escott et al.[9] compared the accuracy of lower limb length measurements between conventional scanograms and EOS. They standardized phantom limbs and assessed ten times each with different imaging modalities, concluding that EOS was more accurate than conventional scanograms and associated with significantly lower radiation exposure.

While many studies mentioned above reported that EOS is reliable and reproducible for assessing lower limb alignment compared to conventional scanograms, some authors focused on the difference of lower limb measurements between EOS and conventional scanograms. Wise et al.[25] conducted a study that included 10 patients with posttraumatic deformity who presented for evaluation of osteotomies. They concluded that the differences between conventional X-ray and EOS measurements were statistically significant; however, the value was 0.26°, too small to drive a treatment decision. But mean HKA on conventional scanograms was 0.78°, accounting for up to one-third in terms of proportion.

Moon et al.,[14] who also conducted a study that included 90 patients (180 lower limbs) who took both the full-length weight-bearing AP radiographs and EOS images, found significant correlation between HKA and KFA ($r = 0.368$, $p < 0.001$), whereas no correlation was observed for axial rotation. Their results were similar to those of our study. However, the difference between our study and the study mentioned above is that HKA was greater in our study (2.1° vs. 11.3° in EOS) because our study population consisted of advanced knee OA patients. This may more accurately reflect the real population of patients who were scheduled for arthroplasty or osteotomy.

Our study has several limitations. First, because it has a retrospective design and patients enrolled in this study were the only group evaluated with both conventional scanography and EOS, bias could have been introduced. Second, there was no consideration of soft-tissue balance and rotational malalignment of hip and ankle joints, which are known to affect coronal alignment. Third, patients were asked to be in the same position with the same protocol during image acquisition, but position could not be exactly the same in all patients. Nevertheless, the strength of our study is that the study population consisted of advanced OA patients who were planned for surgery, which made our conclusions more realistic in comparison with studies that addressed factors affecting coronal alignment in a general population.

HKA measured on conventional scanograms and in EOS differed significantly and the difference had significant correlations with KFA, KJR, and MPTA. Surgeons can consider these results before orthopedic surgery in patients who have advanced OA of the knee.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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