

Effect of foot rotation on the mechanical axis and correlation between knee and whole leg radiographs

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Abstract

Purpose The purposes of this study were (1) to evaluate the foot rotational effects on local and whole leg alignment and (2) to confirm the correlation between local and whole leg alignment. The hypotheses of this study were that (1) the alignment would become varus if the rotation of the foot changes from internal to external rotation, and (2) there would be some correlation between local and whole leg radiographs, and local knee radiographs could then be used indirectly for the assessment of whole leg alignment in patients with bilateral medial compartment knee osteoarthritis.

Methods A total of 80 lower limbs with genu varum of patients who complained of medial knee pain were examined. The standing anterior–posterior view of whole leg radiographs was taken in the four foot positions, and a custom-made foot plate was used for the attainment of accurate radiographs: feet straight ahead with foot contact at the medial side (R: routine), feet straight ahead at shoulder width (N: neutral), 30° external rotated (ER) and 15° internal rotated (IR) position. In order to obtain a local radiograph of the knee, we took only whole leg radiographs and selected the area of interest on the whole leg radiograph. We evaluated the total width of the tibia plateau (Total), the length of the weight-bearing line, the ratio of weight-bearing line/Total and femorotibial angle (FTA).

Results The absolute value of weight-bearing line was shifted laterally in the 30° ER position and shifted medially in the 15° IR position compared to the neutral position (1.8 mm lateral and 0.2 mm medial in the WLR; 3.5 mm lateral and 3 mm medial in the local radiograph). Significant statistical differences were observed in the local knee weight-bearing line; however, no significant statistical differences were observed in the weight-bearing line of the whole leg radiograph (*n.s.*). Results of the % (weight-bearing line/Total) were similar to those of weight-bearing line. The FTA of the local radiograph showed statistical differences, and it showed more valgus in the 30° ER position. In the correlation analysis between whole leg radiograph and local knee radiograph, moderate correlation (correlation coefficient = 0.67) was observed; however, significant statistical differences were observed in the comparison of weight-bearing line and % weight-bearing line/Total ($p < 0.01$ and < 0.01 , respectively) between local knee and whole leg radiograph.

Conclusions Foot position of ER could show less varus alignment and the reverse could occur in the IR position, compared to the neutral foot position. The severity of varus alignment could be underestimated in the local radiograph, compared with that of whole leg radiograph.

Level of evidence Cohort study (diagnosis), Level II.

Keywords Knee · Alignment · Whole leg radiograph · Local knee radiograph · Foot rotation

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Introduction

Varus, valgus or neutral alignment is defined on the basis of the hip–knee–ankle angle, which requires visualization of all three joints [7, 12]. The whole leg radiograph (WLR)

is usually checked at the weight-bearing conditions, and the positioning is an important factor when measuring whole leg alignment because the accuracy of the WLR is affected by flexion or rotation of the leg [3, 4, 8, 11]. In general, patella facing forward position is relatively well controlled because this is an essential method while taking the lower extremity radiographs. However, there is little description of foot position of WLR, and this could be a factor affecting the measurement of the whole leg alignment.

However, acquisition of WLR is not common in many clinical settings, and the physician usually obtains only knee radiographs that do not include the hip and ankle joints [6]. Therefore, indirect use of the local radiograph instead of the WLR could be an important issue. In the previous reports, knee radiographs were not sufficient for accurate determination of the impact of alignment; however, another report demonstrated a clear relationship of knee radiograph with the compartmental pattern and severity of knee osteoarthritis [5, 6, 12].

The purposes of this study were (1) to evaluate the foot rotational effects on local and whole leg alignment and (2) to confirm the correlation between local and whole leg alignment. The hypotheses of this study were that (1) the alignment would become varus if the rotation of the foot changes from internal to external rotation, and (2) there would be some correlation between local and WLR, and local knee radiographs could then be used indirectly for the assessment of whole leg alignment in patients with bilateral medial compartment knee osteoarthritis.

Materials and methods

From April 2011 to August 2012, a total of 80 lower limbs were examined from bilateral, standing anterior–posterior (AP) view of WLRs obtained from 40 individuals (27 female and 13 male patients; mean age 65.2 and 61.4 years, respectively) and with genu varum who complained of medial knee pain. Institutional review board approval was obtained, and all patients provided informed consent for participation. The AP view of WLRs was taken in the following foot positions, and a custom-made foot plate was used for the attainment of accurate radiographs: feet straight ahead with foot contact at the medial side, feet straight ahead at shoulder width, 30° external rotated (ER) and 15° internal rotated (IR) position (Fig. 1). Each position was named as routine, neutral, 30° ER and 15° IR, respectively.

In order to obtain a local radiograph of the knee, we took only WLR and selected the area of interest on the WLR. The PACS (Picture Archiving Communication System, INFINTT Co, Seoul, Korea) was used in performance of radiograph measurements. The centre line function that enables drawing the line automatically between two centres was used to evaluate the crossing point at the knee joint (Fig. 2). The centre line was drawn between the femoral head and ankle joint in the WLR of four positions (Fig. 3).

Total width of the tibia plateau (Total), the length of the weight-bearing line (WBL), the ratio of WBL/Total and the femorotibial angle (FTA) were evaluated. The Total was

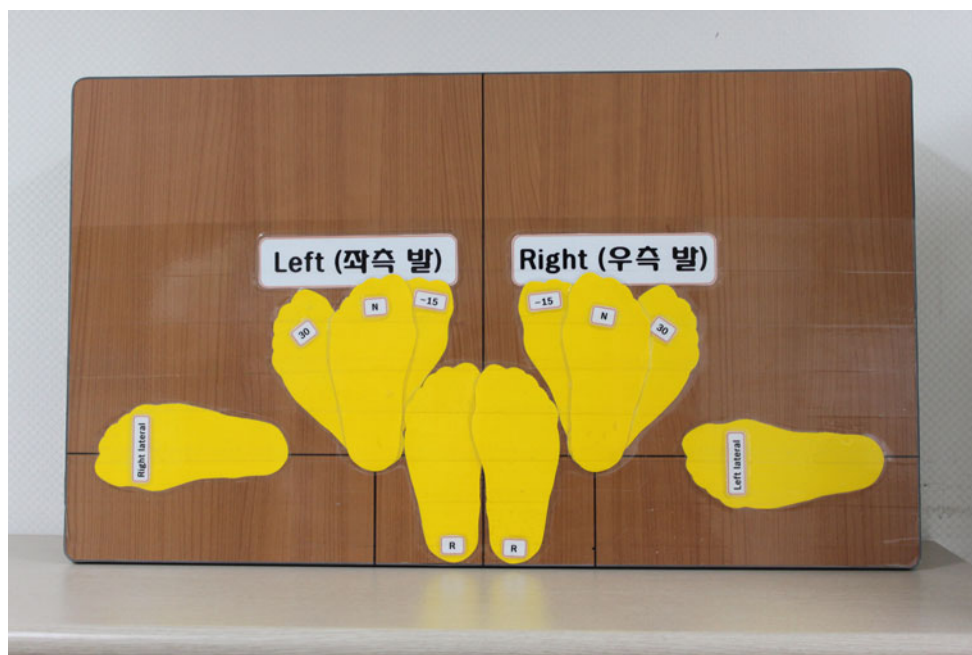


Fig. 1 A custom-made foot plate was used for taking WLR: feet straight ahead with foot contact at the medial side (R: routine), feet straight ahead at shoulder width (N: neutral), 30° ER and 15° IR position

measured by the distance between the medial and lateral edge of the tibia plateau in both whole leg and local radiograph. The WBL was measured by the distance from the medial edge of the tibia plateau to the crossing point between the centre line and tibia plateau in the whole leg radiographs. The local WBL was measured by the distance from the medial edge of the tibia plateau to the crossing point between the bisecting line (connecting the line between the femoral and tibial bisecting point at 10 cm distance from the joint level) and tibia plateau in the local radiographs (Fig. 4a). The ratio of WBL/Total was calculated using a measured Total and WBL in both whole leg and local radiographs. The FTA was determined using a method similar to that described by Kraus et al. [7]. The femoral shaft was bisected at a point 10 cm proximal to the centre of the intercondylar notch, and the two points (from the bisecting point to the centre of the intercondylar notch) were connected. Similarly, the tibial shaft was bisected 10 cm distal to the centre of the intercondylar eminence, and the two points (from the bisecting point to the centre of

the intercondylar eminence) were connected. The angle between the two lines was measured in local radiographs (Fig. 4b).

Statistical analysis

The SPSS version 18.0 statistical package (SPSS Corp, Chicago, USA) was used. A p value <0.05 was considered significant. The reliability of the measurements was assessed by examining the intra-rater and inter-rater reliability using the intra-class correlation coefficient (ICC). Two physical assistants working in the orthopaedic department performed measurements twice with two-week intervals. For the evaluation of foot rotational effects on local and whole leg alignment, statistical significances were tested by one-way ANOVA test, and multiple comparisons were performed using a Bonferroni test. For the evaluation of the correlation between local and whole leg alignment, one-way ANOVA test and Pearson's correlation analysis were performed.



Fig. 2 Centre line function was used, and the line is drawn automatically if the transverse line is at the mid portion of femoral head and upper surface of talus

Results

ICCs for the measurement of WBL in four different positions were excellent, and the intra- and inter-rater agreement ranged from 0.92 to 0.98. Values for each of the four testing positions were listed in Table 1. No statistical differences were observed in comparison with Total and local Total according to the four testing positions. The absolute value of WBL was shifted laterally in the 30° ER position and shifted medially in the 15° IR position compared to the neutral position (1.8 mm lateral and 0.2 mm medial in the WLR; 3.5 mm lateral and 3 mm medial in the local radiograph). Significant statistical differences were observed in the local WBL; however, no significant statistical differences were observed in the WBL of WLR (*n.s.*) (Table 2). The % (local WBL/local Total) showed significant statistical differences; however, no statistical differences were observed in the % (WBL/Total) of WLR (*n.s.*) (Table 3). The % (local WBL/local Total) was larger in the 30° ER position and smaller in the 15° IR position. The FTA of the local radiograph showed statistical differences, and it showed more valgus in the 30° ER position, compared with the routine, neutral and 15° IR positions (Table 4).

In the correction analysis between WLR and local radiograph, moderate correlation was observed, with a correlation coefficient of 0.67. For comparison of Total between local and WLR, no statistical differences were observed in all four positions (*n.s.*). However, significant statistical differences were observed in the comparison of WBL and % WBL/Total ($p < 0.01$ and <0.01 , respectively) between local and WLR.

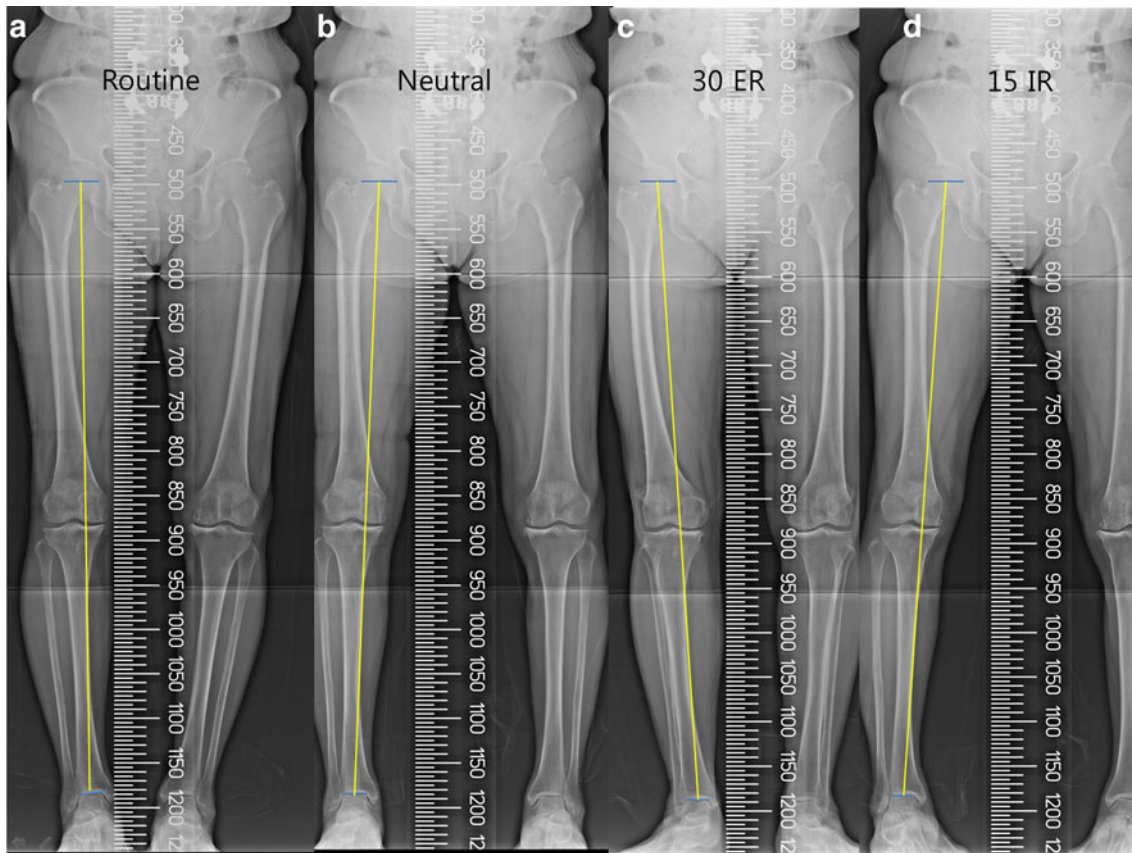


Fig. 3 Mechanical axis deviation *line* in the routine (a), neutral (b), 30° ER (c) and 15° IR (d) position. At the 30° ER position, neck shaft angle is decreased and lateral bowing of distal femur becomes prominent

Fig. 4 For measurements of mechanical axis deviation of the local radiograph, the femoral shaft was bisected at a point 10 cm proximal to the *centre* of intercondylar notch, and the tibial shaft was bisected 10 cm distal to the *centre* of the intercondylar eminence and two points were connected (a). FTA was evaluated by measuring the angle between *two lines* (b)



Table 1 Values for each of the 4 testing positions

Mean (SD)	Routine	Neutral	30 ER	15 IR
Total (mm)	74.2 (5)	74 (5.3)	72.8 (4.9)	73.3 (5.3)
WBL (mm)	23.5 (9.8)	23 (10.4)	23 (10.4)	22.8 (10.5)
% (WBL/Total)	32 (13)	31 (14)	34 (16)	31 (14)
L Total (mm)	74.1 (5.3)	74.2 (5.4)	73.2 (4.8)	73.2 (5.4)
*L WBL (mm)	36.9 (5.4)	37.5 (5.2)	41 (6.5)	34.5 (5.9)
*L % (WBL/Total)	50 (6)	50 (5)	56 (8)	47 (7)
*FTA (degrees)	2.6 (4.6)	2.5 (4.3)	5 (5.2)	1.1 (5)

Values indicate a mean (standard deviation)

WBL weight-bearing line, FTA femorotibial angle, L local, ER external rotation, IR internal rotation

(–) varus, (+) valgus

* Statistically significant

Table 2 Comparison of local weight-bearing line

<i>p</i> value	Routine	Neutral	30 ER	15 IR
Routine			<0.01	0.01
Neutral			<0.01	<0.01
30 ER	<0.01	<0.01		<0.01
15 IR	0.01	<0.01	<0.01	

Values indicate a *p* value

Table 3 Comparison of local % (weight-bearing line/Total)

<i>p</i> value	Routine	Neutral	30 ER	15 IR
Routine			<0.01	0.01
Neutral			<0.01	<0.01
30 ER	<0.01	<0.01		<0.01
15 IR	0.01	<0.01	<0.01	

Values indicate a *p* value

Table 4 Comparison of FTA

<i>p</i> value	Routine	Neutral	30 ER	15 IR
Routine			<0.01	
Neutral			<0.01	
30 ER	<0.01	<0.01		<0.01
15 IR			<0.01	

Values indicate a *p* value

Discussion

The principal findings of this study were that (1) the absolute value of WBL was shifted laterally in the 30° ER position and shifted medially in the 15° IR position, with

statistical significance in the local radiograph and without statistical significance in the WLR, (2) results of the % (WBL/Total) were similar to those of WBL, (3) the FTA of the local radiograph showed more valgus in the 30° ER position, and (4) moderate correlation was observed between WLR and local radiograph; however, the WBL and % WBL/Total of WLR showed more varus than the local radiograph. The WLR is regarded as an important tool for the assessment of lower limb alignment. The alignment could be changed by the status of weight bearing; therefore, it is recommended that the WLR be checked at the real weight-bearing position [13]. The reliability of WLR was assessed by Marx et al. [9], who reported correlation coefficient of 0.93–0.99. Rauh et al. [10] reported significant inter- and intra-rater reliability in determining lower extremity alignment; however, an average deviation of approximately 1° between measured and actual alignment was suggested.

Pitfalls in determination of knee alignment using a WLR were introduced by Brouwer et al. [1, 2], who reported that isolated flexion or rotation has little effect and that simultaneous flexion of the knee and rotation of the leg cause large changes in projected angles. Results of our study correspond well with those of a study of Brouwer et al. Our patients had varus alignment, but negligible flexion contracture, because most patients had medial mono-compartmental arthritis. Foot position has little effect on the WLR; however, it has some effects on the local radiograph. Hunt et al. [4] compared three positions (15° of internal foot rotation, no foot rotation and 15° of external foot rotation). They reported that 15° of external foot rotation resulted in approximately 3.5° more measured varus alignment, compared with 15° of internal rotation. Results of our study differed from those of the study reported by Hunt et al. [4]. Our patients showed little effect on the WLR, but some effects on the local radiograph were observed. However, the tendency was opposite to that reported by Hunt et al. [4], and 30° ER position showed more valgus than 15° IR position. In our evaluation, if the foot rotated externally, above the 10 cm point of the knee joint that we bisected was moved to lateral with the knee joint maintaining constant position because the anterolateral bowing of femur was magnified (Fig. 3). In addition, the femoral head showed relative lateral translation because neck shaft angle was increased by ER (Fig. 3).

In a report by Khan et al. [6], the relationship between local knee alignment was determined from short standing knee radiographs and the compartmental pattern and severity of knee osteoarthritis. They reported a clear relationship, and physicians can assess the contribution of knee alignment to the observed patterns and severity of osteoarthritis in an individual patient. Acquisition of WLR is not common in the clinical setting, and the physician usually

obtains only local knee radiographs. However, in our study, the WBL and % WBL/Total of WLR showed more varus than local radiograph, although moderate correlation was observed between WLR and local radiograph. This result could imply that the severity of varus alignment in the local radiograph would be less than that of real alignment by WLR.

Some limitations must be considered in our study. First, mild varus alignment in medial mono-compartmental arthritis was only considered in this study. Therefore, knowledge of the severe varus knee is not known, compared with mono-compartmental arthritis or valgus alignment because the deformity of the distal femur or the proximal tibia could be severe or reverse. However, this study was oriented from the correction accuracy during the open-wedge high tibial osteotomy. Second, 30° ER and 15° IR positions were only chosen. Therefore, exact determination of the changes of alignment that would be shown in between the angles could not be made. These angles were chosen because most patients showed 30° ER position without any comments about the foot position and 15° IR was a maximal IR angle if we comment the patient to stand with the foot straight forward position. Third, the effect of ligamentous laxity of the knee joint is also questionable, and there is certain mobility in the ankle joint. However, in this study, we only want to know the effect of foot rotation on the mechanical axis itself and, we do not know the origin of the effect (ankle, knee or hip joint).

Results of the present study indicate that surgeons performing a mechanical realignment of the lower extremity should standardize the patient position with a neutral position during the WLR acquisition. In addition, the degree of correction should be checked using a WLR because it could be underestimated in the local knee radiograph.

Conclusion

Foot position of ER could show less varus alignment and the reverse could occur in the IR position, compared to the neutral foot position. The severity of varus alignment could

be underestimated in the local radiograph, compared with that of WLR.

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