Correlation of Knee and Hindfoot Deformities in Advanced Knee OA: Compensatory Hindfoot Alignment and Where It Occurs

Adam A. Norton BA, John J. Callaghan MD, Annunziato Amendola MD,
Phinit Phisitkul MD, Siwadol Wongsak MD, Steve S. Liu MD,
Catherine Fruehling-Wall BA

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Abstract

Background Many patients undergoing TKA have both knee and ankle pathology, and it seems likely that some compensatory changes occur at each joint in response to deformity at the other. However, it is not fully understood how the foot and ankle compensate for a given varus or valgus deformity of the knee.

Questions/purposes (1) What is the compensatory hindfoot alignment in patients with end-stage osteoarthritis who

undergo total knee arthroplasty (TKA)? (2) Where in the hindfoot does the compensation occur?

Methods Between January 1, 2005, and December 31, 2009, one surgeon (JJC) obtained full-length radiographs on all patients undergoing primary TKA (N = 518) as part of routine practice; patients were analyzed for the current study and after meeting inclusion criteria, a total of 401 knees in 324 patients were reviewed for this analysis. Preoperative standing long-leg AP radiographs and Saltzman hindfoot views were analyzed for the following measurements: mechanical axis angle, Saltzman hindfoot alignment and angle, anatomic lateral distal tibial angle, and the ankle line convergence angle. Statistical analysis included two-tailed Pearson correlations and linear regression models. Intraobserver and interobserver intra-class coefficients for the measurements considered were evaluated and all were excellent (in excess of 0.8).

Results As the mechanical axis angle becomes either more varus or valgus, the hindfoot will subsequently orient in more valgus or varus position, respectively. For every degree increase in the valgus mechanical axis angle, the hindfoot shifts into varus by -0.43° (95% confidence interval [CI], -0.76° to -0.1° ; $r = -0.302$, $p = 0.0012$). For every degree increase in the varus mechanical axis angle, the hindfoot shifts into valgus by -0.49° (95% CI, -0.67° to -0.31° ; $r = -0.347$, $p < 0.0001$). In addition, the subtalar joint had a strong positive correlation ($r = 0.848$, $r^2 = 0.72$, $p < 0.0001$) with the Saltzman hindfoot angle, whereas the anatomic lateral distal tibial

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This work was performed at the University of Iowa Hospitals and Clinics, Iowa City, IA, USA.

A. A. Norton, J. J. Callaghan (✉), A. Amendola, P. Phisitkul,
S. Wongsak, S. S. Liu, C. Fruehling-Wall
University of Iowa Hospitals and Clinics, 200 Hawkins Drive,
UIHC, 01029 JPP, Iowa City, IA 52242, USA
e-mail: john-callaghan@uiowa.edu

J. J. Callaghan, P. Phisitkul
VA Medical Center, Iowa City,
IA, USA

angle ($r = 0.450$, $r^2 = 0.20$, $p < 0.0001$) and the ankle line convergence angle ($r = 0.319$, $r^2 = 0.10$, $p < 0.0001$) had a moderate positive correlation. The coefficient of determination (r^2) shows that 72% of the variance in the overall hindfoot angle can be explained by changes in the subtalar joint orientation.

Conclusions These findings have implications for treating patients with both knee and foot/ankle problems. For example, a patient with varus arthritis of the knee should be examined for fixed hindfoot valgus deformity. The concern is that patients undergoing TKA, who also present with a stiff subtalar joint, may have exacerbated, post-TKA foot/ankle pain or disability or malalignment of the lower extremity mechanical axis as a result of the inability of the subtalar joint to reorient itself after knee realignment. A prospective study is underway to confirm this speculation.

Level of Evidence Level III, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Deformities of the hip, knee, and/or ankle all play a role in determining overall lower extremity alignment. As alignment shifts either toward varus or valgus at the knee, the hindfoot may compensate to restore neutral hip-knee-ankle coronal plane alignment. It is not fully understood how the foot and ankle compensate for a given varus or valgus deformity of the knee [1–4, 7, 12, 13, 17]. It has been stated that if there is varus deformity in the knee, the subtalar joint compensates by going into eversion and valgus position [9, 10]. However, with the valgus knee, the foot should compensate into varus [1, 3, 7, 13] but there are no present data to support this and perhaps the subtalar joint aggravates the valgus orientation by going into more valgus [2, 17]. In addition, there are three locations where compensation potentially could occur including the distal tibia, the ankle, and the subtalar joint.

Knowing the normal compensatory relationships among the knee, ankle, and hindfoot in response to deformity, and having more precise information about where they occur, would help guide alignment in TKA. However, normative data on the relationship between knee and hindfoot alignment in patients undergoing TKA are, to our knowledge, not available.

We therefore sought to investigate and elucidate the relationship between knee deformity and hindfoot alignment. The main objectives of this study were to determine: (1) What is the compensatory hindfoot alignment in patients with end-stage osteoarthritis requiring TKA? (2) Where does the compensation occur in the hindfoot?

Patients and Methods

Study Design and Patient Cohort

Institutional review board approval was obtained for this study. Between January 1, 2005, and December 31, 2009, one surgeon (JJC) performed 518 primary TKAs. Of those, full-length radiographs were available before surgery on 518 knees (100%). For this analysis, we excluded 117 knees in 109 patients with a majority excluded for having a prior lower extremity surgery (Table 1). The remaining 401 TKAs (324 patients) were included and evaluated for this study.

Demographic data collected on the cohort included age, sex, and body mass index (BMI). Of the study cohort, 178 of 401 TKAs were performed in males and 223 of 401 TKAs were performed in females. The average age (range) at the time of surgery for male and female subjects was 64 years (range, 34–88 years) and 63 years (range, 33–92 years), respectively. The average BMI (range) for male and female subjects, respectively, was 33 kg/m² (range, 21–52 kg/m²) and 34 kg/m² (range, 20–64 kg/m²).

To address the second objective of where the compensation within the hindfoot is occurring, a subset of the study cohort (378 TKAs in 304 patients) was evaluated. A subset of the study cohort had to be used because 11 subjects did not have long-leg lateral radiographs and an additional 12 subjects had radiographic images of inadequate quality to obtain an accurate measurement (Table 2). For this subset, 168 of 378 TKAs were performed in men and 210 of 378 TKAs were performed in women. The average age (range) at the time of surgery for male and female subjects was 65 years (range, 39–88 years) and 62 years (range, 33–92 years), respectively. The average BMI (range) for male and female subjects, respectively, was 33 kg/m² (range, 21–52 kg/m²) and 34 kg/m² (range, 20–64 kg/m²).

Table 1. Exclusions from the cohort of 518 knees

Reason for exclusion	Number
Inadequate films (dislocated hip)	1
Nondigital films	2
Missing preoperative long-leg AP films	5
Missing preoperative hindfoot films	7
Inadequate radiographic quality	10
Dead	22
Surgery before TKA	70
Total	117

Table 2. Exclusions for analysis of where the compensation occurs in the hindfoot

Reason for exclusion	Number
Inadequate films (dislocated hip)	1
Nondigital films	2
Missing preoperative long-leg AP films	5
Missing preoperative hindfoot films	7
Missing preoperative long leg lateral films	11
Inadequate radiographic quality	22
Dead	22
Surgery before TKA	70
Total	140

Power Analysis

A sample size calculation was carried out based on the Pearson correlation, $r = -0.145$, found by Chandler and Moskal [2], which shows little correlation between knee and hindfoot alignment in the only reported literature investigating this lower extremity alignment relationship. A power analysis was done for this study using the proc power in SAS® (SAS Institute Inc, Cary, NC, USA). With an assumed $\alpha = 0.05$, a sample size of 370 is needed to achieve a power equal to 0.80. The power associated with the current study ($N = 401$) is approximately 0.830 and 0.810 for the subset study cohort ($N = 378$).

Radiographic Analysis

Standing full-leg-length AP and Saltzman hindfoot alignment view [10] radiographs were obtained for each subject preoperatively. Radiographic films for each subject were digitized and stored within Stentor (Stentor, Inc, San Francisco, CA, USA). Chart review and radiographs were evaluated to determine if subjects underwent any bony surgeries before their primary TKA.

Using image measurement software (iSite Enterprise, Eindhoven, The Netherlands), single-observer (AAN) measurements were completed to determine the mechanical axis angle [8] and the degree of hindfoot malalignment using the Saltzman measurement [10]. Because most measurements used in lower extremity alignment are angular rather than distance, the “Saltzman hindfoot angle” (Fig. 1) was also evaluated. Using image measurement software (iSite Enterprise), single-observer (AAN) measurements were completed on the subset of patients ($N = 378$) to determine the mechanical axis angle [8], the hindfoot angle (Fig. 1), the anatomic lateral distal tibial angle [8] (Fig. 2), and the ankle line convergence angle [8] (Fig. 3). We applied the technique reported by Paley [8] for measuring the anatomic lateral distal tibial angle to the hindfoot to keep all

Fig. 1 Saltzman hindfoot angle is shown. We defined a middiaphyseal point of the tibial shaft by bisecting the tibia at a distance of 15 cm proximal to the tibiotalar joint (Point A). Point B is defined as the center of the talar dome. Point C is defined as the most distal point of the calcaneus that intersects a line parallel to the reference block (ie, the floor).

Fig. 2 Anatomic lateral distal tibial angle is shown. We defined the middiaphyseal axis of the tibia by bisecting the tibia at a distance of 15 cm proximal to the tibiotalar joint (Point A) and at a distance of 10 cm proximal to the tibiotalar joint (Point B) and extended the line distally. Line C is defined as the tibial joint line axis.

measurements used to obtain the subtalar joint alignment consistently on one radiographic image. This modification was important because Stufkens et al. [15] has shown that measurements of the distal tibial angle on long-leg images ($94.6^\circ \pm 2.6^\circ$) were significantly different compared with

Fig. 3 Ankle line convergence angle is shown. The ankle JLCA is defined as the angle formed between the tibial joint line axis and the talar joint line axis. Line A is defined as the tibial joint line axis. Line B is defined as the talar joint line axis.

those taken with a mortise view of the ankle ($92.1^\circ \pm 2.2^\circ$) ($p < 0.01$) [15]. Varus and valgus knee deformities are characterized by an angle measurement of greater than zero and less than zero, respectively. Varus and valgus hindfoot deformities are distinguished by a distance measurement that is either medial or lateral to the longitudinal axis of the tibia, respectively. For this study, “significant deformity” of the knee was defined as $\geq 10^\circ$ varus or valgus of the mechanical axis. Hindfoot deformity was defined to be greater than or equal to 8 mm of malalignment [10].

Data Analysis

As a means to validate the Saltzman hindfoot angle measurement, a two-tailed Pearson correlation was used to determine the relationship between the Saltzman measurement [10] and the Saltzman hindfoot angle measurement in the entire cohort. There was a strong positive correlation between the two indicating that increases in the Saltzman distance measurement strongly correlated with increases in the Saltzman hindfoot angle measurement ($p < 0.01$). A scatterplot summarizes the results (Fig. 4).

The study data were analyzed using SPSS software (SPSS, Chicago, IL, USA). Two-tailed Pearson correlations were done to compare the pre-TKA mechanical axis angle, the Saltzman measurement, and the Saltzman hindfoot angle

Fig. 4 Correlation of Saltzman view (mm) versus hindfoot angle is demonstrated.

measurement in all subjects in a variety of categories. Two-tailed Pearson correlations were also done to compare the pre-TKA mechanical axis angle, the Saltzman hindfoot angle, the anatomic lateral distal tibial angle, the ankle line convergence angle, and the subtalar joint angle.

Interobserver and Intraobserver Reliability

In addition, as a means of validating our methodology, we performed an assessment of interobserver and intraobserver variability in terms of radiographic measurements before the completion of the study [4]. SPSS software was used to randomly select 24 (6%) subjects from the overall study cohort ($N = 401$) and 20 (5%) subjects from the subset of TKAs ($N = 378$) to be remeasured to assess interobserver and intraobserver reliability of the radiographic measurements. Interobserver (SW) and intraobserver (AAN) measurements took place 1 month after the initial measurements. An intraclass correlation coefficient with a 95% confidence interval was used to evaluate reliability. Settings assumed absolute agreement in a two-way random effects model. A coefficient of 1.0 designates a perfect correlation and > 0.8 designates excellent reliability [6]. Interobserver intraclass coefficients for the preoperative mechanical axis angle, the Saltzman measurement, the Saltzman hindfoot angle, and the ankle line convergence angle all indicated excellent reliability being above the 0.9 level; the anatomic lateral distal tibial angle indicated excellent reliability being above the 0.8 level (Table 3). Intraobserver intraclass coefficients for the preoperative mechanical axis angle, the

Saltzman measurement, the Saltzman hindfoot angle, the anatomic lateral distal tibial angle, and the ankle line convergence angle also all indicated excellent reliability being above the 0.9 level (Table 3).

Results

As the mechanical axis angle becomes either more varus or valgus, the hindfoot will subsequently orient in more valgus or varus, respectively. In valgus knees, there was a moderate negative correlation (-0.302 , $p = 0.0012$) between the mechanical axis angle and the Saltzman hindfoot angle. For every degree increase in the mechanical axis angle (valgus orientation), the hindfoot shifts into varus by -0.43° (95% confidence interval [CI], -0.76° to -0.1°). In varus knees, there was a moderate negative correlation (-0.347 , $p < 0.0001$) between the mechanical axis angle and the Saltzman hindfoot angle. For every degree increase in the mechanical axis angle (varus orientation), the hindfoot shifts into valgus by -0.49° (95% CI, -0.67° to -0.31°). This same trend held when further analysis was limited to subjects who had more severe angular deformities at the knee before TKA ($\geq 10^\circ$ of varus or valgus; Table 4). However, the trend did not hold with subanalysis limited to

subjects who had milder malalignments before TKA ($\leq 9^\circ$ of varus or valgus; Table 4).

The subtalar joint had a strong positive correlation ($r = 0.848$, $r^2 = 0.72$, $p < 0.0001$) with the Saltzman hindfoot angle (Table 5). There was a moderate positive correlation with the Saltzman hindfoot angle and the anatomic lateral distal tibial angle ($r = 0.450$, $r^2 = 0.20$, $p < 0.0001$) and with the ankle line convergence angle ($r = 0.319$, $r^2 = 0.10$, $p < 0.0001$) (Table 5). The coefficient of determination (r^2) shows that 72% of the variance in the overall hindfoot angle can be explained by changes in the subtalar joint orientation. Furthermore, approximately 20% of the variance in the overall hindfoot angle can be explained by changes in the anatomic lateral distal tibial angle, whereas approximately 10% of the variance in the overall hindfoot angle can be explained by changes in the ankle line convergence angle.

Discussion

The role that knee deformities have on foot and ankle alignment is not fully understood and requires additional evidence to predict the clinical outcome of foot and ankle alignment in patients presenting with knee deformity. The

Table 3. Intraclass correlation coefficients (95% confidence interval)

Radiographic measurement	Interobserver reliability	Intraobserver reliability
Mechanical axis angle (preoperative)	0.997* (0.992–0.999)	0.996* (0.988–0.999)
Saltzman view (preoperative)	0.937* (0.861–0.972)	0.978* (0.950–0.991)
Hindfoot angle (preoperative)	0.968* (0.912–0.987)	0.987* (0.969–0.994)
Anatomic lateral distal tibial angle (preoperative)	0.827* (0.611–0.928)	0.954* (0.883–0.982)
Ankle line convergence angle (preoperative)	0.903* (0.771–0.960)	0.977* (0.943–0.991)

* Greater than 0.8 indicates excellent reliability.

Table 4. Relationship of mechanical axis and hindfoot angle

Mechanical axis	Total	Saltzman (mm) correlation (p value)	Hindfoot angle correlation (p value)
Knee deformity [†]	401	-0.464^* (< 0.001)	-0.413^* (< 0.001)
$\geq 10^\circ$ knee deformity	185	-0.610^* (< 0.001)	-0.536^* (< 0.001)
$\leq 9^\circ$ knee deformity	216	-0.125 (0.066)	-0.093 (0.174)

* Correlation is significant at the 0.01 level; [†]all deformities.

Table 5. Correlation of the hindfoot angle with anatomic lateral distal tibial angle, ankle line convergence angle, and the subtalar joint

Variable	Total	Anatomic lateral distal tibial angle correlation	Ankle line convergence angle correlation	Subtalar joint correlation
Hindfoot angle [†]	378	0.450*	0.319*	0.848*

* Correlation is significant at the 0.01 level; [†]all deformities.

main objectives of this study were to determine: (1) What is the compensatory hindfoot alignment in patients with end-stage osteoarthritis requiring TKA? (2) Where does the compensation occur in the hindfoot? We found that a varus knee deformity was associated with a valgus hindfoot alignment, whereas a valgus knee deformity was associated with a varus hindfoot alignment. In addition, we found that the majority of that compensation occurred at the subtalar joint.

Our study had several limitations. Although radiographs were taken in orthogonal planes under standard protocols, the rotational effect of the lower extremity was not taken into account when determining the degree of malalignment. Tilting in the knee or ankle was not included in the overall malalignment measurement. Additionally, bone deformity in the hindfoot was not studied. The reasoning behind this was that the particular age group used in this study (mid-30 s to 90 s) was unlikely to have congenital deformities of the hindfoot, because any deformity would have presented earlier in life and they would not have been included in this study. Also, subtalar joint measurements were not directly measured but derived from direct measurements of the hindfoot angle, the lateral distal tibial angle, and the ankle line convergence angle. Finally, a

dynamic kinematic evaluation of the subjects would provide a higher degree of accuracy compared with the static measurement that was used in this study. No specific foot and ankle examinations were performed for the purpose of this study. Therefore, it is hard to make definitive comments on whether subtalar stiffness played into the ability of the foot to compensate for alignment changes at the knee.

In answering our first objective of determining the compensatory hindfoot alignment in patients with end-stage osteoarthritis requiring TKA, this study demonstrated that a valgus knee deformity is correlated with varus hindfoot position (Fig. 5) and a varus knee deformity is correlated with valgus hindfoot position (Fig. 6).

These findings differ from those obtained by Chandler and Moskal [2] in which they found no correlation between knee orientation and hindfoot alignment. Our study differed from Chandler and Moskal's study [2] in several ways. Chandler and Moskal completed a prospective analysis that included 86 subjects, whereas our study was a retrospective review that included 401 subjects. All digital radiographs (Picture Archiving and Communication System) and an electronic measuring system were used in our study contrasted to plain films. Another major difference

Fig. 5A–C (A) Mechanical axis alignment shows valgus knee deformity. (B) Saltzman hindfoot measurement, in the same patient as A, shows varus hindfoot compensation. (C) Saltzman hindfoot angle, in the same patient as A, shows varus hindfoot compensation.

Fig. 6A–C (A) Mechanical axis alignment shows varus knee deformity. (B) Saltzman hindfoot measurement, in the same patient as A, shows valgus hindfoot compensation. (C) Saltzman hindfoot angle, in the same patient as A, shows valgus hindfoot compensation.

Fig. 7A–D This patient has varus preoperative deformity (A, preoperative), valgus hindfoot deformity (B, preoperative), and a stiff subtalar joint. Post-TKA (C, postoperative) demonstrates persistent subtalar valgus deformity (D, postoperative), which became more clinically apparent and symptomatic.

between the studies involved the measurement techniques used. Chandler and Moskal measured the femorotibial (anatomic) axis angle and the calcaneotibial angle, whereas this study measured the mechanical axis angle and the degree of hindfoot deformity using the validated Saltzman measurement [10] and the Saltzman hindfoot angle. This study showed a strong correlation between the Saltzman measurement and the Saltzman hindfoot angle that suggests they are both a strong indicator of hindfoot malalignment. However, the use of a hindfoot angle measurement is more desirable in determining the amount of malalignment for the planning of corrective treatment, has no magnification effects, and may be more clinically relevant [9].

Kraus et al. [5] showed that there was no statistical difference between the degree of malalignment using either the anatomic axis angle or the mechanical axis angle. However, Sheehy et al. [11] shows that using the mechanical axis angle to determine malalignment is superior to the anatomic axis. They showed that the measurement correlation between the two was dependent on the shaft length in the radiograph indicating the advantage of standing full leg-length radiographs. Furthermore, the mechanical axis angle can be used to assess the overall contribution that the lower extremity has on alignment.

We found that most of the compensation to angular deformity at the knee occurs in the subtalar joint. To our knowledge, the only other study of knee and ankle deformity in TKA by Chandler and Moskal [2] was not able to evaluate subtalar motion or positioning because Saltzman hindfoot radiographs were not obtained.

In addressing our first two objectives, we can provide objective data concerning the implications for treating patients with both knee and foot/ankle problems. The concern is that patients undergoing TKA, who also present with a stiff subtalar joint, may have subsequent, post-TKA foot/ankle pain or disability resulting from the inability of the subtalar joint to reorient itself after knee realignment (Fig. 7) [16]. Patients undergoing TKA who also have stiff subtalar joints, on preoperative examination, should be counseled that their hindfoot symptoms might worsen after TKA. Further prospective studies will be necessary to confirm this speculation. Additionally, prospective studies are necessary to confirm the authors' belief that patients with severe knee arthritis, who present with foot/ankle pain caused by impingement or tibial posterior tendonitis resulting from the compensatory mechanism of the subtalar joint [14, 18] secondary to knee deformity, should consider undergoing TKA before foot surgery.

We found a correlation between knee and hindfoot deformities in patients with advanced knee arthritis. This correlation is stronger in patients with larger knee deformities. Patients with a varus knee tend to have a valgus hindfoot and

vice versa. Surgeons should carefully examine any fixed or supple hindfoot deformities in patients with knee arthritis who are considering TKA. This study also shows that in patients with hindfoot malalignment, as a result of knee deformity, there exists a strong correlation between the hindfoot angle and the subtalar joint. The majority of compensation within the hindfoot, in response to knee deformity, occurs through the subtalar joint, whereas the anatomic lateral distal tibial angle and ankle line convergence angle have a minimal role in the overall compensatory ability of the hindfoot. To help further determine the relationship between knee deformity and hindfoot alignment, additional research is needed. Several areas that need to be further investigated would be to determine the effect of ankle and knee tilting—both in the coronal and sagittal plane—on the degree of malalignment in the hindfoot and knee, respectively. Additionally, studies should be done that assess the degree of femoral and tibial bowing in the coronal and sagittal plane and their effects on lower extremity malalignment, similar to our previous study by Yehyawi et al. [19]. Further studies evaluating the clinical outcome of both the knee and ankle, after knee arthroplasty in patients with hindfoot malalignment, are also essential.

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References

1. Bouysset M, Huguency P. The rheumatoid foot: pathomechanics, clinical and radiological features. Therapeutic conditions. In: Bouysset M, Tourne Y, Tillmann K, eds. *Foot and Ankle in Rheumatoid Arthritis*. Paris, France: Springer Verlag; 2006:9–48.
2. Chandler JT, Moskal JT. Evaluation of knee and hindfoot alignment before and after total knee arthroplasty: a prospective analysis. *J Arthroplasty*. 2004;19:211–216.
3. Desai SS, Shetty GM, Song HR, Lee SH, Kim TY, Hur CY. Effect of foot deformity on conventional mechanical axis deviation and ground mechanical axis deviation during single leg stance and two leg stance in genu varum. *Knee*. 2007;14:452–457.
4. Keenan M, Peabody T, Gronley J, Perry J. Valgus deformities of the feet and characteristics of gait in patients who have rheumatoid arthritis. *J Bone Joint Surg Am*. 1991;73:237–247.
5. Kraus VB, Vail TP, Worrell T, McDaniel G. *A Comparative Assessment of Alignment Angle of the Knee by Radiographic and Physical Examination Methods*. Hoboken, NJ, USA: Wiley Subscription Services, Inc, a Wiley Company; 2005.
6. Lee KM, Chung CY, Park MS, Lee SH, Cho JH, Choi IH. Reliability and validity of radiographic measurements in hindfoot varus and valgus. *J Bone Joint Surg Am*. 2010;92:2319–2327.
7. Mullaji A, Shetty G. Persistent hindfoot valgus causes lateral deviation of weightbearing axis after total knee arthroplasty. *Clin Orthop Relat Res*. 2011;469:1154–1160.
8. Paley D. *Principles of Deformity Correction*. Berlin, Germany: Springer; 2002:1–18.
9. Reilingh ML, Beimers L, Tuijthof GJM, Stufkens SAS, Maas M, Dijk CN. Measuring hindfoot alignment radiographically: the long axial view is more reliable than the hindfoot alignment view. *Skeletal Radiol*. 2010;39:1103–1108.

10. Saltzman CL, el-Khoury GY. The hindfoot alignment view. *Foot Ankle Int.* 1995;16:572–576.
11. Sheehy L, Felson D, Zhang Y, Niu J, Lam Y, Segal N, Lynch J, Cooke TD. Does measurement of the anatomic axis consistently predict hip-knee-ankle angle (HKA) for knee alignment studies in osteoarthritis? Analysis of long limb radiographs from the multicenter osteoarthritis (MOST) study. *Osteoarthritis Cartilage.* 2011;19:58–64.
12. Sobel M, Stern SH, Manoli A II, Bohne WHO. The association of posterior tibialis tendon insufficiency with valgus osteoarthritis of the knee. *Am J Knee Surg.* 1992;5:59–64.
13. Souter WA. Surgical strategy in surgery of the lower limb in rheumatoid arthritis. In: Bouysset M, Tourne Y, Tillmann K, eds. *Foot and Ankle in Rheumatoid Arthritis*. Paris, France: Springer Verlag; 2006:229–236.
14. Stanish WD, Curwin S. *Tendinitis: Its Etiology and Treatment*. Lexington, MA, USA: DC Heath & Co; 1984.
15. Stufkens SA, Barg A, Bolliger L, Stucinskas J, Knupp M, Hintermann B. Measurement of the medial distal tibial angle. *Foot Ankle Int.* 2011;32:288–293.
16. Tiberio D. Pathomechanics of structural foot deformities. *Phys Ther.* 1988;68:1840.
17. Tillman K. *The Rheumatoid Foot: Diagnosis, Pathomechanics, and Treatment*. New York, NY, USA: Thieme Medical Publishers, Inc; 1979:48.
18. Winter DA. *Biomechanics of Human Movement*. New York, NY, USA: John Wiley & Sons Inc; 1979.
19. Yehyawli TM, Callaghan JJ, Pedersen DR, O'Rourke MR, Liu SS. Variances in sagittal femoral shaft bowing in patients undergoing TKA. *Clin Orthop Relat Res.* 2007;464:99–104.