Arch Orthop Trauma Surg
DOI 10.1007/s00402-017-2824-6

KNEE ARTHROPLASTY

# Does alignment of the limb and tibial width determine relative narrowing between compartments when planning mechanically aligned TKA?

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Received: 27 July 2017


**Abstract**

*Introduction* We determined (1) the range of the hip–knee–ankle (HKA) angle in the native or pre-arthritic limbs of patients with a contralateral total knee arthroplasty (TKA); and when mechanical alignment is planned (2) the relationships between the HKA angle and the tibial width, and the relative narrowing between the medial and lateral compartments and (3) the effect of tibial width on the range of narrowing.

*Methods* The HKA angle, distal lateral femoral angle (DLFA), and proximal medial tibial angle (PMTA) were measured on the native limb of 102 subjects (53 female) treated with contralateral TKA. The sine of the angle of the resection gap (PMTA minus 90° subtracted from the DLFA minus 90°) multiplied by the tibial width and by narrow (59 mm), average (75 mm), and wide (91 mm) tibias computed relative narrowing.

*Results* The HKA angle ranged from 8° varus to − 7° valgus; 20% had constitutional varus (≥ 3°) and 11% constitutional valgus (≤ − 3°). The HKA angle strongly predicted ($r^2 = 0.87$) and tibial width weakly predicted ($r^2 = 0.06$) relative narrowing. For narrow, average, and wide tibias, the maximum medial narrowing was 9, 11, 14 mm and maximum lateral narrowing was 7, 9, and 11 mm, respectively ($p < 0.0001$).

*Conclusion* When mechanical alignment is planned, there is greater relative narrowing between compartments when the pre-arthritic limb greatly deviates from a 0° HKA angle and the tibia is wide. These limbs may need soft-tissue releases until neutral postoperative limb alignment of 0° and negligible varus–valgus laxity are achieved.

*Level of evidence* IV, therapeutic study.

**Keywords** Knee arthroplasty · Mechanical alignment · Soft-tissue release

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## Introduction

One tenet of total knee arthroplasty (TKA) is that postoperative limb alignment or hip–knee–ankle (HKA) angle within 0° ± 3° promotes implant durability. The HKA angle is the angle between a line connecting the center of the femoral head to the center of the knee and a line connecting the center of the knee to the mid-width of the talus [1, 2]. Manual instruments, computer-assisted navigation, robotics, and patient-specific instrumentation that perform mechanical alignment are designed to achieve a neutral or 0° HKA angle with the intent of promoting durability and improving function [3]. However, recent studies have shown that implant survival and function with a postoperative limb alignment within 0° ± 3° are not better from those outside this range at up to 15 years after implantation [2, 4–14].

A substantial number of patients exist for whom mechanical alignment of the native or pre-arthritic limb to a 0° HKA angle is abnormal (Table 1). Native limbs with a HKA angle of ≥ 3° have constitutional varus and those with ≤ − 3° have constitutional valgus [2, 12, 15–17]. Mechanical alignment

Published online: 25 October 2017

**Table 1** Range of native hip–knee–ankle angle and proportion with constitutional varus and valgus by country, sex, and age

| Study | Country, sex, and age of subjects with native limbs (*N* = number of subjects) | Range of native hip–knee–ankle angle | Proportion with constitutional varus (≥ 3°) and valgus (≤ − 3°) (%) |
|---|---|---|---|
| Present study | United States, 49 males and 53 females, 46–89 years (*N* = 102) | 8° varus to − 7° valgus | 20 and 10 |
| Song et al. [17] | Korea, females only, 20–39 years (*N* = 118) | 7° varus to − 4° valgus | 20 and 1 |
| Shetty et al. [15] | Korea, 47 males and 47 females, 20–39 years (*N* = 94) | 11° varus to − 5° valgus | 35 and 0 |
| Shetty et al. [15] | India, 55 males and 45 females, 20–39 years (*N* = 100) | 12° varus to − 5° valgus | 34 and 5 |
| Bellemans et al. [2] | Belgium, males only 20–27 years (*N* = 125) | 8° varus to − 4° valgus | 32 and 2 |
| Bellemans et al. [2] | Belgium, females only, 20–27 years (*N* = 125) | 7° varus to − 5° valgus | 17 and 3 |
| Eckhoff et al. [12] | United States, 20 males and 70 females, unknown age (*N* = 90) | 12° varus to − 16° valgus | 25 and 12 |

of a pre-arthritic limb with a HKA angle different from 0° creates a joint line congruency angle different from 0° (i.e., angle between a line tangent to the distal femur and a line tangent to the proximal tibia) that indicates relative narrowing between medial and lateral compartments (Figs. 1, 2) [2, 12, 16, 18]. A HKA angle different from 0° would likely require some degree of soft-tissue release on the narrow side to equal the gap on the wide side until a neutral postoperative limb alignment of 0° is achieved and the negligible varus–valgus laxity of the native knee in extension is restored [2, 12, 19–22]. When treating pre-arthritic limbs with the same HKA angle, the extent of soft-tissue release would likely be greater for wider than narrower tibias.

The proportion of patients with a mechanically aligned TKA treated with a soft-tissue release widely varies. One study reported that 56% of patients required one or two releases and 10% required three or more releases [23], whereas another only 2% [24]. Physical examination

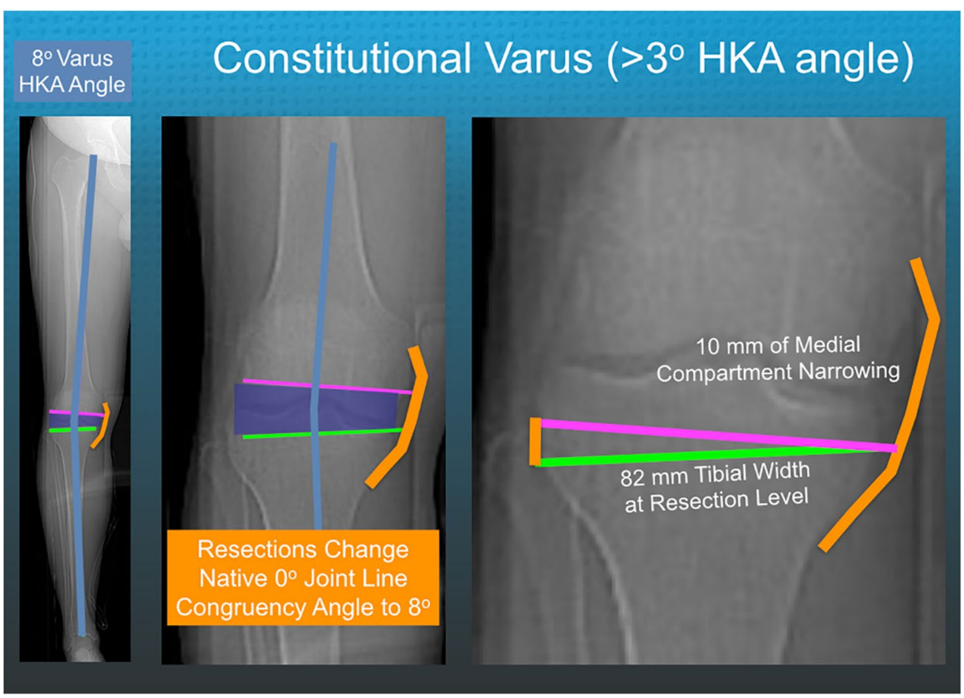


**Fig. 1** Composite views of a scanogram of the native or pre-arthritic right limb (left) and knee (center and right) of a patient with constitutional varus and a hip–knee–ankle (HKA) angle of 8° showing the planned distal femoral resection (pink line) 90° perpendicular to the mechanical axis of the femur (upper blue line) and the planned proximal tibial resection (green line) 90° perpendicular to the mechanical axis of the tibia (lower blue line). The resections changed the native 0° joint line congruency angle to 8°. Ten millimeters of relative narrowing in the medial compartment (short vertical orange line) was computed for a tibial width of 82 mm. Release of the medial soft tissues (orange curvilinear line) is needed until a postoperative HKA angle and a joint line congruency angle of 0° are achieved and the negligible varus–valgus laxity of the native knee in extension is restored

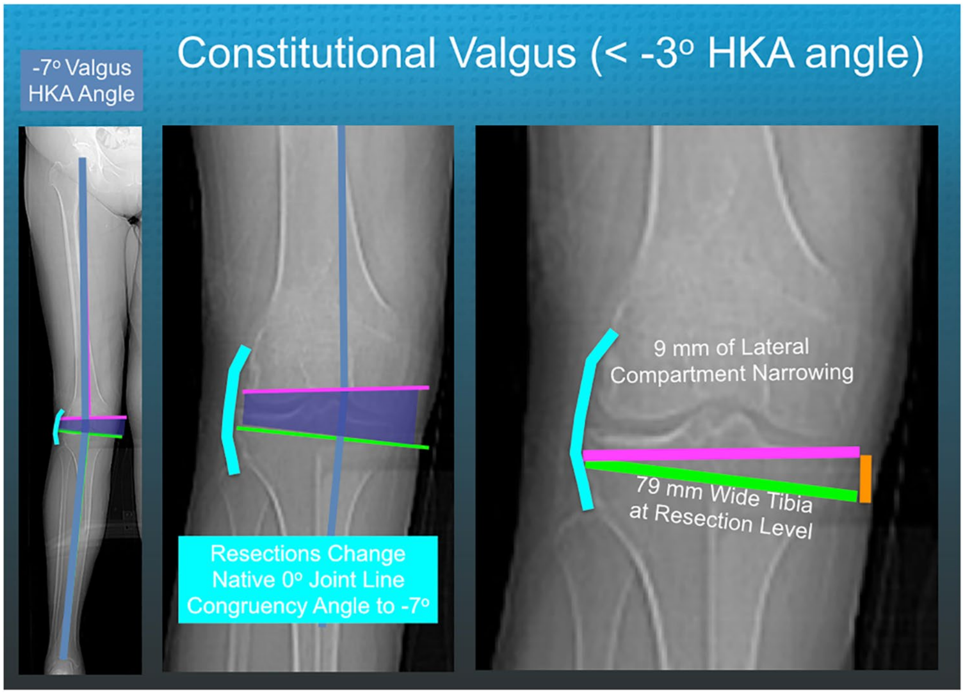


**Fig. 2** Composite views of a scanogram of the native or pre-arthritic right limb (left) and knee (center and right) of a patient with constitutional valgus and a hip–knee–ankle (HKA) angle of − 7° showing the planned distal femoral resection (pink line) 90° perpendicular to the mechanical axis of the femur (upper blue line) and the planned proximal tibial resection (green line) 90° perpendicular to the mechanical axis of the tibia (lower blue line). The resections changed the native 0° joint line congruency angle to − 7°. Nine millimeters of relative narrowing in the lateral compartment (short vertical orange line) was computed for a tibial width of 69 mm. Release of the medial soft tissues (cyano curvilinear line) is needed until a postoperative HKA angle and a joint line congruency angle of 0° are achieved and the negligible varus–valgus laxity of the native knee in extension is restored

easily detects relative narrowing of ≥ 2 mm, which is often adjusted by changing the varus–valgus position of the components, exchanging the thickness of the tibial insert, and/or releasing soft tissues to fine-tune stability [11, 13, 21, 22, 25]. Knowing the variability of the pre-arthritic HKA angle, the relationships between the HKA angle and tibial width and relative narrowing, and the proportion of patients with ≥ 2 mm of relative narrowing might provide insight into the need for soft-tissue release when performing mechanical alignment.

Accordingly, this study asked: (1) What is the range of the HKA angle and the proportion of constitutional varus and valgus in native or pre-arthritic limbs of patients treated with a contralateral TKA? (2) How strongly does the HKA angle of the native limb and the width of the tibia predict the relative narrowing between compartments when planning mechanical alignment? and 3) For narrow (59 mm), average (75 mm), and wide (91 mm) tibias, what is the range and proportion of pre-arthritic knees with ≥ 2 mm of relative narrowing when planning mechanical alignment?

## Methods and materials

With approval of our institutional review board (IRB 918840-1), we retrospectively identified all patients in our registry that fulfilled the Centers for Medicare and Medicaid Services guidelines for medical necessity and were treated with primary TKA between August 2014 and March 2016. On the day of discharge, each patient had computer tomographic (CT) scans consisting of an anteroposterior, rotationally controlled, non-weight-bearing, long-leg scanogram of both limbs and axial images of both knees [26–28]. Two authors (AJN and AKS) selected all subjects in which the anteroposterior scanogram showed a native or pre-arthritic limb with the patella centered between the most medial and lateral edges of the condyles of the distal femur. Subjects were included when the native knee had a 0° joint line congruency angle on the CT scanogram and on the coronal reconstruction of the axial images (Fig. 3). A 0° joint line congruency angle is the angle of the joint space in the normal knee, which indicates a symmetric joint space with no asymmetric narrowing [16, 29].

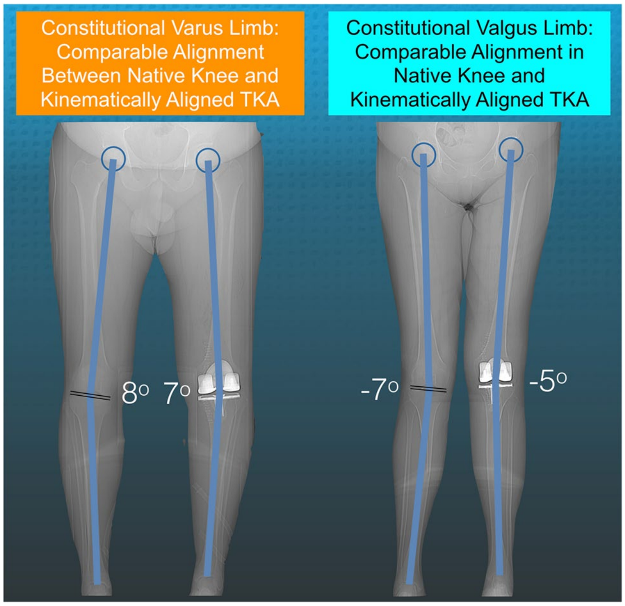


**Fig. 3** Two scanograms show comparable alignment between the native limb and contralateral limb after performing a kinematically aligned TKA without soft-tissue release in limbs with the most severe varus (left image) and valgus (right image) constitutional alignment. The 0° joint line congruency angle (parallel black lines) in the subject with constitutional varus and constitutional valgus is the angle of the joint space in the weight-bearing normal knee, which indicates symmetric medial and lateral joint space and no asymmetric narrowing. Including native knees with a 0° joint line congruency angle minimized bias in the computed values of relative narrowing even in the presence of small osteophytes and subchondral sclerosis

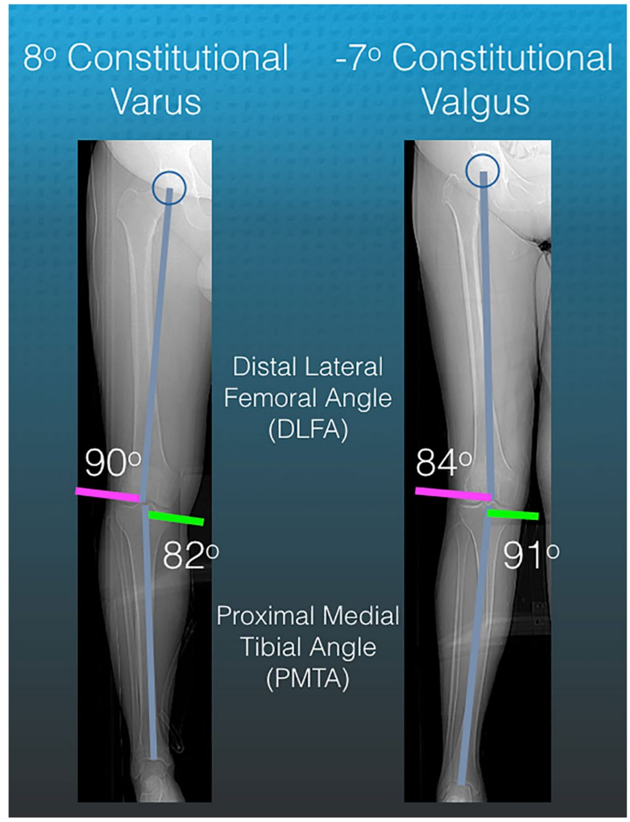


**Fig. 4** Composite views of a scanogram of the native right limb with 8° constitutional varus (left) and − 7° constitutional valgus (right). The distal lateral femoral angle (DLFA) is formed by the intersection of the line tangent to the distal femoral joint line (magenta line) and the mechanical axis of the femur (proximal blue line). The proximal medial tibial angle (PMTA) is formed by the intersection of the line tangent to the proximal medial tibial joint line (green line) with the mechanical axis of the tibia (distal blue line)

Two authors (AJN and AKS) identified the following landmarks described by Bellemans and measured the alignments using an open source medical image viewer (Horos, http://www.horosproject.org) (Fig. 4) [2]. The center of the femoral head was the center of a circle best-fit to the femoral head. The center of the knee was the center of the width of the distal femur at the distal joint line. The center of the ankle was the center of the width of the talus at the ankle joint. The mechanical femoral axis was the line from the center of the femoral head to the center of the knee. The mechanical tibial axis was the line from the center of the knee to the center of the ankle. The mechanical alignment of the limb was the HKA angle between the mechanical axes of the femur and tibia (an angle more varus than neutral was positive and more valgus than neutral was negative). The distal lateral femoral angle (DLFA) was the lateral angle between the distal femoral joint line and the mechanical axis of the femur (varus > 90° and valgus < 90°) [30]. The proximal medial tibial angle (PMTA) was the medial angle between the proximal tibial joint line and the mechanical axis of the tibia (varus < 90° and valgus > 90°) [31]. The width of the tibia was measured at the level of the tibial resection.

Mechanical alignment was planned on the native limb by simulating resections of the distal femur and proximal tibia perpendicular to their respective mechanical axes. The angle of the resection gap equaled the PMTA minus 90°, which was subtracted from the DLFA minus 90° (+ medial narrowing/− lateral narrowing) (Figs. 1, 2). The sine of the angle of the resection gap multiplied by the tibial width and by the narrow (59 mm), average (75 mm), and wide (91 mm) tibias, which were selected from the offerings of a commercially available tibial component (Vanguard, Zimmer Biomet, Warsaw, IN, USA).

To quantify reproducibility, three observers (AJN, AKS, SMH) independently measured the HKA angle, DLFA, and PMTA on ten randomly selected CT scanograms. The intraclass correlation coefficient (ICC) was computed for each measurement with use of a two-factor analysis of variance (ANOVA) with random effects. The first factor was the observer with three levels (observers 1, 2, and 3) and the second factor was the patient with 10 levels. An absolute analysis was used. An ICC value of > 0.9 indicated excellent agreement, 0.75–0.90 indicated good agreement, and 0.5–0.75 indicated moderate agreement (JMP, 12.1, http://www.jmp.com).

The HKA angle ≥ 3° was categorized as constitutional varus and an angle ≤ − 3° was categorized as constitutional valgus. Continuous variables (i.e. angles) were reported as mean ± standard deviation (SD) and proportions were reported as fractions (percentages). Step-wise regression determined the strength of the relationships between the hip–knee–ankle angle and the tibial width, and the relative narrowing between the medial and lateral compartments. Levene's test determined whether the variances of the relative narrowing between compartments differed between narrow (59 mm), average (75 mm), and wide (91 mm) tibias (JMP, 12.1, http://www.jmp.com). Significance was $p < 0.05$.

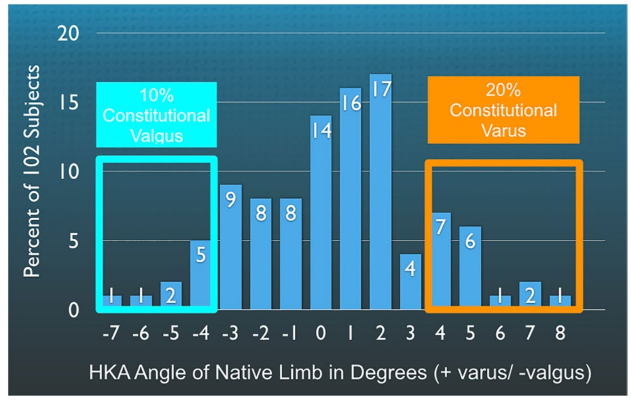


**Fig. 5** Column graph shows the distribution of the hip–knee–ankle (HKA) angle of the native or pre-arthritic limb of the 102 subjects treated with a contralateral TKA. The proportion of native limbs with constitutional valgus was 10% and the proportion with constitutional varus was 20%. The HKA angle ranged from − 7° valgus to 8° varus

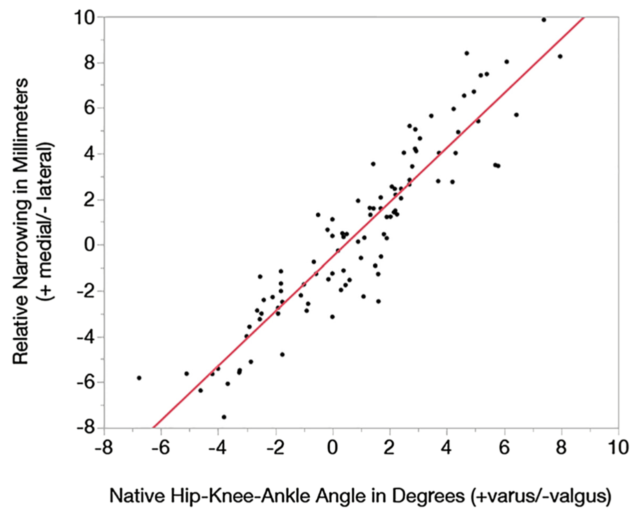


**Fig. 6** Simple linear regression shows a strong linear relationship ($r^2 = 0.87$) between the HKA angle of the native limb and the millimeters of medial (+) or lateral (−) relative narrowing between compartments after planning mechanical alignment of the limb

## Results

One hundred and two patients had a native or pre-arthritic limb and a contralateral TKA. The average age was 68 ± 8 years (range 46–89), 53 were females, and the body-mass index averaged 29 ± 5 kg/m$^2$. The Kellgren Lawrence classification of the knees treated with TKA was IV in 36%, III in 57%, and II 11% as determined from review of preoperative standing full-extension and 45° flexion knee radiographs.

The ICC was 0.95 for HKA angle, 0.95 for DLFA, and 0.79 for PMTA, which indicates good-to-excellent agreement between the radiographic measurements made by three observers. The HKA angle ranged from 8° varus to − 7° valgus. The proportion of native limbs categorized as constitutional varus, constitutional valgus, or within 0 ± 3° was 20% ($N = 20$; 14 male), 11% ($N = 10$; 2 male) and 71% ($N = 72$; 33 male), respectively (Fig. 5). The HKA angle strongly predicted ($r^2 = 0.87$) and tibial width weakly predicted ($r^2 = 0.06$) relative narrowing when planning mechanical alignment (Fig. 6). There were different ranges of relative narrowing between the medial and lateral compartments for narrow (59 mm), average (75 mm), and wide (91 mm) tibias. For narrow, average, and wide tibias, the maximum medial narrowing was 9, 11, 14 mm and maximum lateral narrowing was 7, 9, and 11 mm, respectively ($p < 0.0001$) (Fig. 7). The percentage of knees with a ≥ 2 mm medial narrowing relative to the lateral compartment was 31% for 59 mm (narrow), 36% for 75 mm (average), and 40% for 91 mm (wide) tibial widths. The percentage of knees with a ≥ 2 mm lateral narrowing relative to the medial compartment was 24% for 59 mm (narrow), 30% for 75 mm (average), and 33% for 91 mm (wide) tibial widths.

## Discussion

Categorizing the native or pre-arthritic limb as constitutional varus or valgus has gained interest because performing mechanically aligned TKA on these limbs causes relative narrowing between the medial and lateral compartments that would be abnormal and would likely require a soft-tissue release until a postoperative HKA angle and a joint line congruency angle of 0° are achieved and the negligible varus–valgus laxity of the native knee in extension is restored [12, 16, 18–22, 25]. The most important findings of the present study were that (1) the HKA angle ranged from 8° varus to − 7° valgus, (2) the HKA angle more strongly

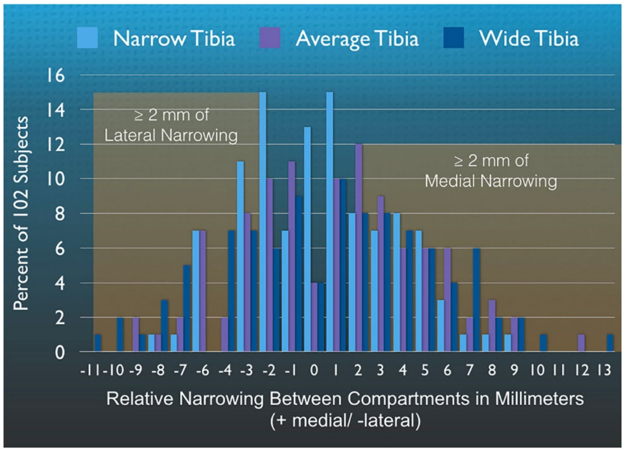


**Fig. 7** Frequency distributions shows the ranges of relative narrowing between medial and lateral compartments for narrow (59 mm), average (75 mm), and wide (91 mm) tibias. Relative narrowing ranged from 9 to 7 mm for narrow tibias, 11–9 mm for average tibias, and 14–11 mm lateral for wide tibias ($p < 0.0001$)

predicted relative narrowing between the medial and lateral compartments than tibial width, and (3) the proportion of knees with a ≥ 2 mm narrowing was up to 44% in the medial compartment and 33% in the lateral compartment when planning mechanical alignment on the native knee.

Two limitations might affect the generalizability of the findings. First, the inclusion of native knees with undetected osteoarthritis resulting in asymmetric narrowing between the medial and lateral joint spaces might have caused bias in the computed values of relative narrowing. This bias was minimized by including only native knees with a 0° joint line congruency angle and a symmetric medial and lateral joint space, which is the angle and symmetry of the joint space in the weight-bearing native knee [16, 29] (Fig. 3). Second, variability in the rotational position of the native limb might have caused measurement inaccuracies by the observers. These errors were minimized by selecting only those native limbs that showed the patella centered on the distal femur on the anteroposterior scanogram.

The range of the HKA angle of the native limb and proportion categorized as constitutional varus or valgus in the present study adds to the growing body of evidence that a substantial number of native limbs do not have a neutral HKA angle prior to the onset of osteoarthritis (Table 1) [12, 15, 17, 25]. The 8° varus to − 7° valgus range of the HKA angle is comparable to the 7°–12° range of maximum varus and the − 4° to − 16° range of maximum valgus reported for subjects in Korea, India, and Belgium. Similarly, the 20% with constitutional varus and 10% with constitutional valgus are comparable to the 17–35% with constitutional varus and the 0–12% with constitutional valgus reported for subjects from Korea, India, and Belgium. Hence, patients from different countries often have a pre-arthritic HKA angle outside 0° ± 3°, and constitutional varus is more frequent than constitutional valgus.

The present study provides a biomechanical explanation for the variability in the proportion of patients that require soft-tissue release, the number of releases, and the extent of the release when mechanical alignment is used to achieve a postoperative limb alignment of 0°. The HKA angle strongly predicted and the tibial width weakly predicted the relative narrowing and the proportion of knees with a ≥ 2 mm narrowing. Over-tight soft tissues on the narrow side and excessive varus–valgus laxity on the wide side might be perceived by patients as pain, stiffness, instability, and/or limited flexion after TKA [19, 21, 22]. Limbs with larger pre-arthritic HKA angles and knees with wider tibias might require greater medial or lateral soft tissue release on the narrow side to achieve a neutral postoperative limb alignment of 0°, a 0° joint line congruency angle, and to restore the negligible varus–valgus laxity of the native knee in extension [2, 12, 19–22]. Difficulty in achieving a balanced extension gap with negligible varus–valgus laxity even with meticulous attention to technique was reported by Insall [32].

## Conclusion

When mechanical alignment is planned, there is greater relative narrowing between compartments when the pre-arthritic limb greatly deviates from a 0° HKA angle and the tibia is wide. These limbs may need a soft-tissue release until a neutral postoperative limb alignment of 0° is achieved, and a 0° joint line congruency angle and the negligible varus–valgus laxity of the native knee in extension are restored.

### Compliance with ethical standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Funding** The authors have not received grant support or research funding and do not have any proprietary interests in the materials described in the article.

**Ethical approval** An institutional review board approved this study (IRB 918840-1).

**Informed consent** For this type of study formal consent is not required.

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