The Knee 26 (2019) 1386–1394

Contents lists available at ScienceDirect

The Knee

The fibular shaft axis and medial cortex of the proximal fibula are reliable landmarks for the mechanical axis of the tibia in patients with knee osteoarthritis

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ARTICLE INFO

Article history:
Received 3 November 2018
Received in revised form 28 May 2019
Accepted 19 August 2019

Keywords:
Alignment
Fibula
Fibular axis
Landmark
Osteoarthritis
Tibial mechanical axis

ABSTRACT

Background: This study aimed to evaluate the validity of proximal fibular anatomic landmarks for measuring the coronal tibial mechanical axis in patients with knee osteoarthritis and to investigate individual factors associated with their reliability.

Methods: A total of 106 knees in 96 patients were retrospectively reviewed. The angles between the tibial mechanical axis and fibular shaft axis (TFA), medial cortex of the proximal fibular shaft (MTA), and lateral cortex of the proximal fibular shaft (LTA) were measured from full-leg standing digital anteroposterior radiographs. An angle within three degrees was considered reliable. The association between the above three angles and individual factors, such as age, sex, body mass index (BMI), and varus–valgus knee malalignment, was determined to investigate individual factors associated with their reliability.

Results: The median TFA, MTA, and LTA were 1.52°, 1.56°, and 2.62°, respectively. The reliability rates of TFA, MTA, and LTA were 73.6% (95% CI: 65.19–81.98%), 82.1% (74.77–89.38%), and 58.5% (49.11–67.87%), respectively. The reliability of TFA and MTA was not associated with individual variables. The reliability of LTA was associated with BMI. Among patients with BMI greater than 25.3 kg/m^2, LTA was considered reliable in 65.7%; this rate was significantly higher than that among patients with BMI less than 25.3 kg/m^2.

Conclusions: The fibular shaft axis and medial cortex of the proximal fibular shaft are reliable landmarks of the mechanical axis of the tibia. However, the reliability of the lateral cortex of the proximal fibular shaft is less satisfactory, especially in patients with BMI less than 25.3 kg/m^2.

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https://doi.org/10.1016/j.knee.2019.08.007
0968-0160/

1. Introduction

Knee osteoarthritis (OA) is one of the most important causes of disability in older adults in both developed and developing countries [1]. The pathogenesis of OA is complicated, and it is widely accepted that inappropriate joint biomechanical loading caused by knee malalignment is an important cause of OA [2–4]. Lower extremity alignment is correlated with OA progression, patient management and prognosis, and is crucial for improving both outcome and a patient's clinical experience [5–8]. However, single-knee plain radiography as a routine examination for outpatients with knee degeneration remains problematic when it is used to determine knee alignment, especially tibial mechanical alignment [9]. Full-leg standing digital anteroposterior (AP) radiography is commonly used for evaluating mechanical alignment of the knee [10]. Compared with plain radiography of the knee, full-leg standing digital AP radiography requires special equipment and involves increased time, radiation exposure, and economic burden [11]. Therefore, it is important to determine a reliable reference for the tibial mechanical axis on plain radiography of the knee for routine evaluation in outpatients with knee degeneration, especially in hospitals that do not have the special device required for full-leg standing digital AP radiography.

Accurate intra-operative determination of tibial mechanical alignment is important for bone cut in total knee arthroplasty (TKA), especially for the tibia-first gap technique. Unlike femoral resection, there is uncertainty as to whether an intramedullary or extra-medullary guide is better for tibial resection. Since it is still challenging to obtain full-leg radiographs intraoperatively, determining auxiliary references for the tibial mechanical axis with intraoperative fluoroscopy is meaningful for both orthopedists and patients.

The tibial anatomic axis has received extensive attention in this field [12]. However, a study found that the tibial anatomic axis could not accurately predict lower extremity alignment in patients with knee OA [13]. It is common to observe an anatomic variation in the proximal tibia in patients with knee OA, which could influence judgment of the tibial anatomic axis on plain radiography and intraoperative fluoroscopy of the knee [14]. Therefore, the anatomic landmarks of the fibula – including the fibular shaft axis, lateral cortex of the fibular shaft, and medial cortex of the fibular shaft – have been used to determine the tibial mechanical axis in clinical practice. Several previous studies have evaluated the reliability of the fibular shaft axis as a reference for the tibial mechanical axis on the basis of radiological measurements [15–18], which was first hypothesized by Laskin in 2003 [19]. However, this topic remains controversial because of varying definitions of fibular shafts and different research results. Moreover, individual factors – such as body mass index (BMI) and knee malalignment – associated with reliability of the fibular shaft axis as the landmark for the tibial mechanical axis are not well established. In addition, the validity of the lateral and medial cortices of the fibular shaft for measuring the tibial mechanical axis in knee OA is rarely reported.

Given these observations, the current study was conducted to: 1) determine the validity of the proximal fibular shaft, lateral cortex of the proximal fibular shaft, and medial cortex of the proximal fibular shaft for measuring the coronal tibial mechanical axis in patients with knee OA and 2) evaluate whether there are individual factors associated with reliability of the fibular landmark as the reference for the tibial mechanical axis. In order to determine those fibular anatomic references on knee plain radiography and intraoperative fluoroscopy, fibular anatomic references on the proximal quarter of the fibula were used in this study.

2. Materials and methods

The current study was approved by the Institutional Review Board. Informed consent was obtained from all individual participants included in the study. The study reviewed 118 knee OA patients with varus or natural knee alignment who had undergone knee arthroplasty at the current center. Exclusion criteria were: 1) inadequate radiographic examination, 2) missing radiographs, 3) previous operation of the ipsilateral lower extremity, and 4) insufficient data on individual characteristics. Twenty-two patients were excluded on the basis of the exclusion criteria; therefore, 106 knees of 96 patients were included in this study. According to Kellgren–Lawrence radiographic classification of OA, 33 knees were Grade 3 and 73 knees Grade 4 [20,21]. The mean patient age was 63.9 years. There were 25 male and 71 female patients. Data on individual characteristics, including age, sex, weight, and height, were obtained from electronic medical records. BMI was calculated as the weight (kg) / (height [m]) [2].

Full-leg standing digital AP radiographs were used to perform all radiological measurements with Materialise Mimics version 20.0 (Materialise, Leuven, Belgium). Digital radiographs of all patients were obtained pre-operatively and stored using the General Electric system (General Electric, Boston, MA, USA). Patients were required to undergo full-leg standing digital AP radiography with the patellae forward and knee fully extended, to reduce the measurement errors caused by rotation of the lower limb [22]. The hip–knee–ankle (HKA) angle and medial proximal tibial angle (MPTA) were used to determine knee alignment [23]. The HKA was defined as the angle between the mechanical axis of the femur and tibia. The angle between the mechanical axis of the tibia and the joint surface of the tibial plateau was defined as the MPTA. As presented in Figure 1, the tibiofibular angle (TFA) was defined as the angle between the coronal mechanical axis of the tibia and the fibular shaft axis. The fibular shaft axis was taken as the anatomic axis of the fibular shaft (proximal quarter). The angle between the lateral cortex of the proximal fibular shaft and the tibial mechanical axis was defined as the lateral tibiofibular angle (LTA), whereas the angle between the medial cortex of the proximal fibular shaft and the tibial mechanical axis was defined as the medial tibiofibular angle (MTA). Angles between the fibular landmark and the mechanical axis of the tibia within three degrees in the coronal plane were considered reliable [15].

The interobserver and intraobserver reliabilities were determined from intraclass correlation coefficients (ICCs) with the two-way random model. For interobserver reliability assessments, the radiological measurements were independently performed by

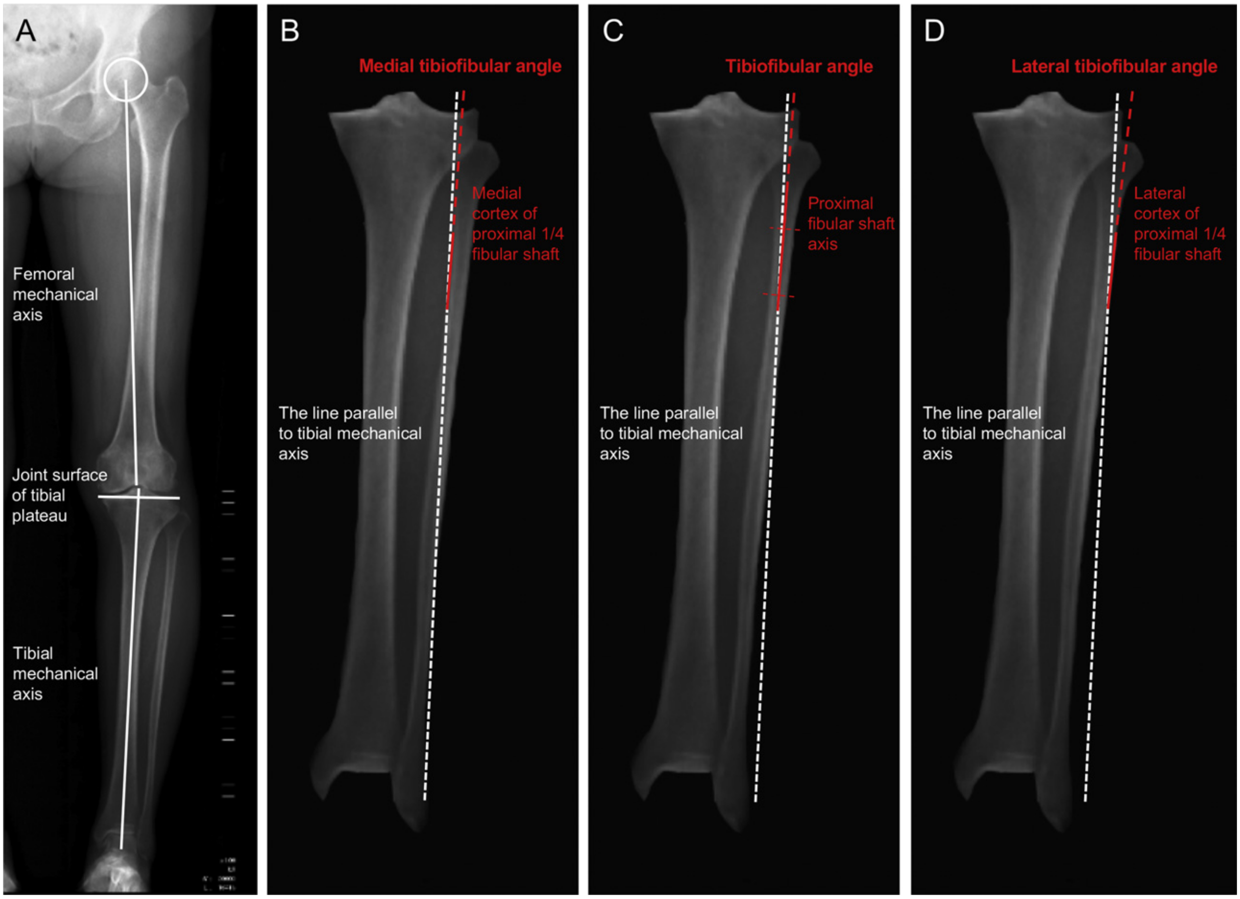

Figure 1. Radiological measurement based on full-leg standing anteroposterior radiographs. A. The hip-knee-ankle angle was defined as the angle between the femoral mechanical axis and tibial mechanical axis. The medial proximal tibial angle defined as the medial angle between the tibial mechanical axis and the joint surface of tibial surface. B. The medial tibiofibular angle was defined as the angle between the medial cortex of the proximal fibular shaft and the tibial mechanical axis. C. The tibiofibular angle was defined as the angle between the tibial mechanical axis and the proximal fibular shaft axis. D. The lateral tibiofibular angle was defined as the angle between the lateral cortex of the proximal fibular shaft and the tibial mechanical axis.

two investigators. For intraobserver reliability assessments, two measurements were performed with a two-week interval. The interobserver (ICC range: 0.84–0.91) and intraobserver (ICC range: 0.89–0.94) reliabilities of all radiological measurements were satisfactory. Given the excellent reliability of all radiological measurements (ICC > 0.8), results from one investigator were used for the analysis [24].

Data were presented as means ± standard deviations. All statistical analyses were performed using R packages (http://www.r-project.org). A two-tailed *P*-value <0.05 was considered statistically significant. The normality of independent variables was determined with Kolmogorov–Smirnov test. Individual factors and radiological measurements in the reliable groups were compared with those in the unreliable groups using the *t*-test. Multivariable regression analyses after adjusting for age, sex, and disease duration were performed to determine individual factors associated with the reliability of the fibular landmark as a reference for the tibial mechanical axis. In addition, to examine the nonlinear association between individual factors and the reliability of the fibular

Table 1
The radiological measurement of tibiofibular, lateral tibiofibular, and medial tibiofibular angles.

	Tibiofibular angle	Lateral tibiofibular angle	Medial tibiofibular angle
Mean	1.94 ± 1.40°	2.67 ± 1.55°	1.92 ± 1.56°
Median	1.52°	2.62°	1.56°
Q1–Q3	0.86–3.09°	1.36–3.67°	0.73–2.64°
Range	0.11–6.55°	0.20–8.17°	0.05–8.04°
Number of knees	106	106	106
< 1° (n, reliability rate)	32, 30.2%	17, 16.0%	36, 34.0%
<2° (n, reliability rate)	66, 66.2%	39, 36.8%	62, 58.5%
<3° (n, reliability rate)	78, 73.6%	62, 58.5%	87, 82.1%

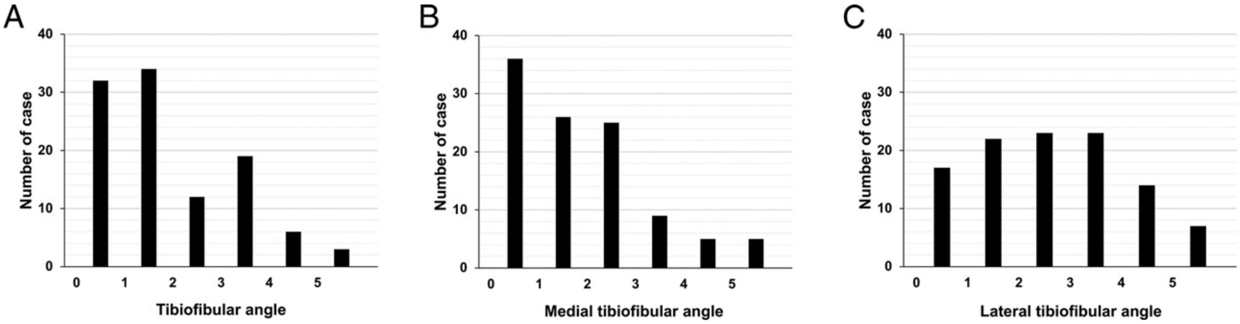

Figure 2. Distribution of tibiofibular angle (A), medial tibiofibular angle (B), and lateral tibiofibular angle (C).

landmark as the reference for the tibial mechanical axis, a two-piecewise linear regression model using a smoothing function after adjusting for age, sex, and disease duration was further applied. The threshold level was determined by trial and error, including selection of turning points along a predefined interval and then choosing the turning point that gave the maximum model likelihood. In addition, a log-likelihood ratio test comparing the one-line linear regression model with the two-piecewise linear model was conducted.

3. Results

The mean angles between the mechanical axis of the tibia and fibular landmarks were as follows: mean TFA, 1.94 ± 1.40°; mean LTA, 2.67 ± 1.55°, and mean MTA, 1.92 ± 1.56°. The TFA and MTA were statistically significantly lower than LTA (both $P < 0.001$). An angle within 3° was considered reliable. The reliability rates were: TFA, 73.6% (78 knees, 95% confidence interval (CI) 65.19–81.98%); LTA, 58.5% (62 knees, 95% CI 49.11–67.87%); MTA, 82.1% (87 knees, 95% CI 74.77–89.38%) (Table 1). As presented in Figure 2, most TFA and MTA were considered reliable. In addition, radiological measurements and individual characteristics were calculated in both the reliable and unreliable groups (Table 2). For LTA, the mean BMI in the reliable group was 27.4 ± 3.9 kg/m^2, which was significantly higher than that in the unreliable group (25.8 ± 2.9 kg/m^2, $P = 0.022$). Figure 3 shows the distribution of cases according to sex, BMI, HKA, and MPTA. The LTA of cases with BMI < 25.0 kg/m^2 were mainly distributed in the unreliable group.

The mean BMI, HKA, and MPTA were 26.7 ± 3.9 kg/m^2, 7.92 ± 4.92°, and 85.29 ± 2.89°, respectively. The BMI, HKA, and MPTA were normally distributed. After adjusting for age, sex, and disease duration, there was no linear correlation between the reliability of the fibular landmarks and BMI, HKA, or MPTA (Table 3). In addition, a nonlinear association between individual factors and the reliability of the fibular landmark as a reference for the tibial mechanical axis were further determined after adjusting for age, sex, and disease duration. A nonlinear association between BMI and LTA was observed (cut-off 25.3 kg/m^2, $P = 0.019$). Therefore, all cases were divided into two groups according to BMI (cut-off 25.3 kg/m^2). In patients with BMI > 25.3 kg/m^2, LTA was considered reliable in 65.7% of cases; this rate was significantly higher than that among patients with BMI < 25.3 kg/m^2 (44.4%, $P = 0.035$) (Table 4, Figure 4A). According to two-piecewise linear regression analyses, HKA showed a nonlinear association with MTA (cutoff 7.0°, $P = 0.011$). However, there was no significant difference in the reliability rate of MTA between patients with HKA > 7.0° and those with HKA < 7.0° (Table 4, Figure 4B).

Table 2
The characteristics of patients in reliable and unreliable groups.

	Tibiofibular angle			Medial tibiofibular angle			Lateral tibiofibular angle		
	<3°	≥3°	*P*	<3°	≥3°	*P*	<3°	≥3°	*P*
Number (n)	78	28		87	19		62	44	
Age (yrs)	68.9 ± 7.1	70.4 ± 6.7	0.334	68.8 ± 7.1	72.0 ± 5.9	0.071	68.4 ± 7.3	70.6 ± 6.4	0.111
Sex			0.485			0.241			0.246
Female (n)	56	22		19	9		62	16	
Male (n)	22	6		43	35		25	3	
Disease duration (yrs)	7.1 ± 6.1	6.9 ± 5.0	0.873	7.1 ± 6.0	6.8 ± 4.7	0.856	6.7 ± 4.3	7.6 ± 7.4	0.412
BMI (kg/m^2)	27.0 ± 3.7	26.1 ± 3.3	0.261	26.8 ± 3.6	26.6 ± 3.59	0.808	27.4 ± 3.9	25.8 ± 2.9	0.022
HKA (°)	7.9 ± 5.2	7.8 ± 4.1	0.915	8.0 ± 5.1	7.6 ± 4.4	0.723	7.6 ± 4.9	8.4 ± 5.0	0.400
MPTA (°)	85.4 ± 2.7	85.0 ± 3.5	0.597	85.3 ± 2.8	85.4 ± 3.3	0.871	85.3 ± 2.7	85.3 ± 3.2	0.878

HKA, Hip–knee–ankle angle; MPTA, medial proximal tibial angle; BMI, body mass index.

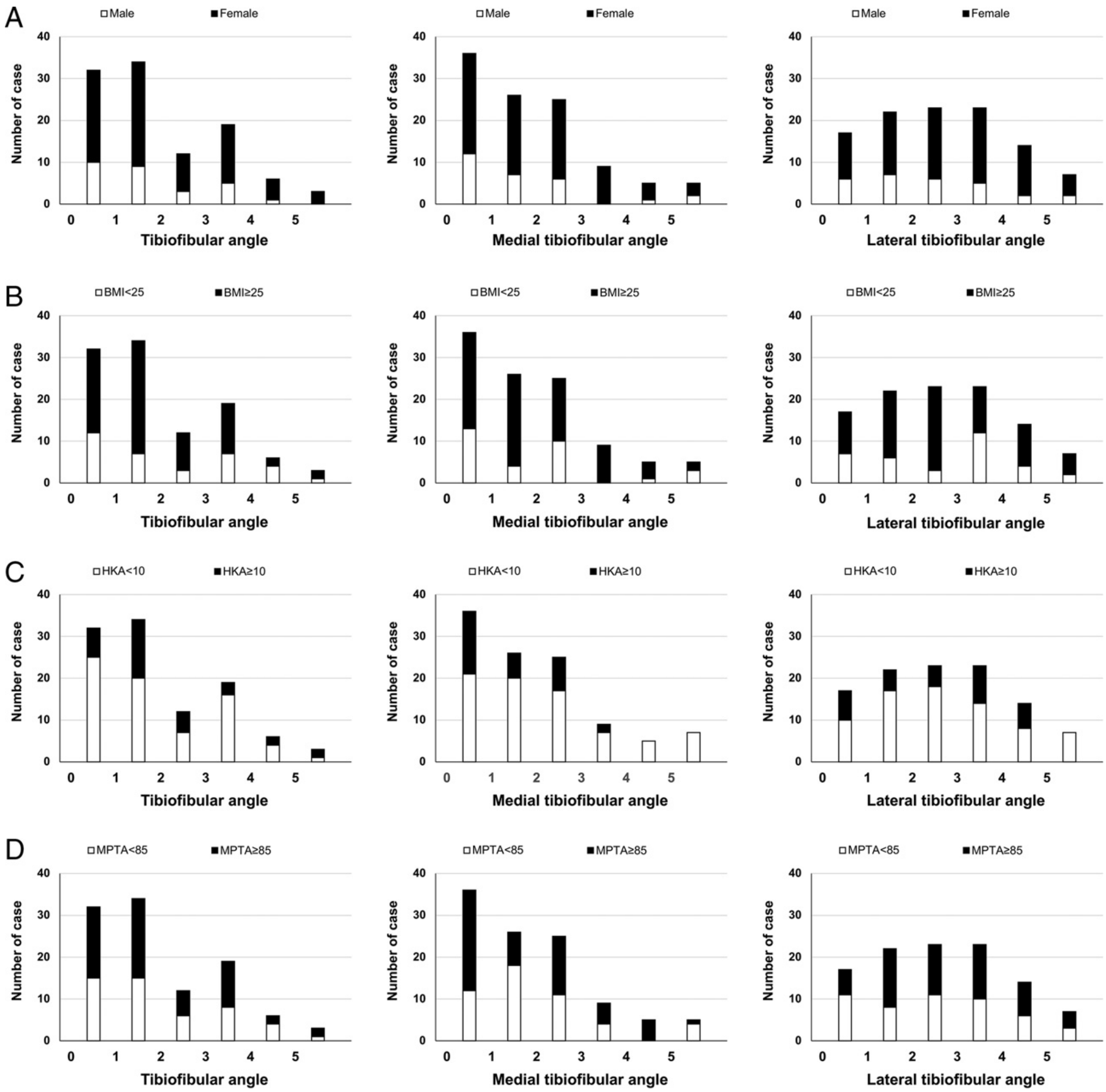

Figure 3. Distribution of patients according to: A. sex, B. body mass index (BMI), C. hip-knee-ankle angle, and D. medial proximal tibial angle. The tibial mechanical axis and the fibular shaft axis angle of patients with BMI <25.0 kg/m^2 were mainly distributed in the unreliable group (B).

4. Discussion

The current results suggest that the fibular shaft axis and medial cortex of the proximal fibular shaft are reliable landmarks for the mechanical axis of the tibia in patients with knee OA. Moreover, the validity of TFA and MTA was not associated with knee malalignment and BMI. The reliability of the lateral cortex of the proximal fibular shaft was less satisfactory, especially in patients with BMI <25.3 kg/m^2.

In patients with knee degeneration it is crucial to evaluate the lower extremity mechanical axis because of the important role of joint biomechanical loading in the development and progression of knee OA. As a routine outpatient examination, knee plain radiography is an efficient way to identify joint wear and osteophyte formation. However, using a single-knee plain radiograph is less reliable for mechanical axis evaluation, and the full-leg standing digital AP radiograph is recommended to determine knee malalignment [25,26]. Unfortunately, full-leg standing digital AP radiography is a time-consuming examination that requires a special device that is not available in community hospitals and in some areas of developing countries. Therefore, routine evaluation of the tibial mechanical axis using the proximal fibular landmark from a single-knee plain radiograph is an alternative with

Table 3
The multivariate and two-piecewise linear analysis of factors associated with the reliability of fibular landmarks as reference for the tibial mechanical axis.

Characteristic	Multivariate regression		Two-piecewise linear regression	
	β value (95% CI)	*P*	Cut-off	*P*
Tibiofibular angle				
BMI	−0.034 (−0.111 to 0.043)	0.3883	23.373	0.087
HKA	0.035 (−0.021 to 0.091)	0.2237	15.038	0.065
MPTA	−0.062 (−0.158 to 0.033)	0.2040	81.549	0.145
Medial tibiofibular angle				
BMI	−0.002 (−0.090 to 0.086)	0.9644	26.037	0.436
HKA	−0.007 (−0.071 to 0.057)	0.8278	7.006	0.011
MPTA	−0.075 (−0.183 to 0.033)	0.1769	81.549	0.345
Lateral tibiofibular angle				
BMI	−0.044 (−0.130 to 0.041)	0.3122	25.299	0.019
HKA	0.003 (−0.060 to 0.066)	0.9185	3.241	0.374
MPTA	−0.015 (−0.122 to 0.092)	0.7795	81.549	0.352

BMI, body mass index; HKA, hip–knee–ankle angle; MPTA, medial proximal tibial angle.

reduced radiation exposure. The fibular shaft axis, lateral cortex of the proximal fibular shaft, and medial cortex of the proximal fibular shaft can be determined from a plain radiograph of the knee. However, reliability of these landmarks for determining the tibial mechanical axis has not been well established.

Few studies have reported the validity of fibular landmarks for measuring the tibial mechanical axis in patients with knee OA (Table 5). All previous studies have focused on determining whether the fibular shaft axis could be the reference for proximal tibial cutting during TKA. Distal anatomic landmarks, such as the lateral malleolus and distal ends of the fibular diaphysis, were used to define the fibular shaft axis. Therefore, those fibular references could not be detected using plain radiography and intraoperative fluoroscopy of the knee. Because of the inconsistent definition of the reference and the method of measurement, contradictory results have been reported from different studies. Laskin first reported that the shaft of the fibula is parallel to the shaft of the tibia in the sagittal plane, which is a suitable landmark for the tibia-cutting block [19]. Han et al. defined the line connecting the center of the fibular neck and the lateral crest of the distal fibula as the fibular shaft axis and reported a mean angle of 2.1 ± 0.98° between the fibular shaft axis and tibial mechanical axis in the sagittal plane [16]. Tsukeoka et al. defined the line connecting the prominent parts of the fibular head with the lateral malleolus as the fibular shaft axis and reported a mean angle of 2.9 ± 0.6° between the fibular shaft axis and the tibial mechanical axis in the coronal plane [17]. Kuroda et al. defined the fibular shaft axis as the line connecting the center of the fibular head to the center of the lateral malleolus and determined the variation between the fibular shaft axis and tibial mechanical axis in both coronal and sagittal planes [18]. According to their results, the mean angle between the fibular shaft axis and the tibial mechanical axis was 0.9 ± 2.0° and the percentage of cases with a TFA within two degrees was 69.3% in the coronal plane; however, in the sagittal plane, 17.7% of the patients were reported to have a TFA within two degrees.

The current study defined the fibular shaft axis as the anatomic axis of the proximal fibula, which could be determined from a single-knee plain radiograph. According to the results, the percentage of outliers was 26.4% for the proximal fibular shaft axis, and the fibular shaft axis was considered to be a reliable pre-operative reference for the tibial mechanical axis. Notably, it was further evaluated, using multiple statistical models and a two-piecewise linear regression model, whether individual characteristics were associated with the reliability of the TFA as the reference for the tibial mechanical axis. The reliability of TFA was not influenced by individual variables such as BMI, HKA, and MPTA. These results suggest that the fibular shaft axis is a reliable landmark for the coronal tibial mechanical axis, even in patients with severe knee varus deformity and tibial varus deformity.

Table 4
The distribution of cases in different body mass index and hip-knee-ankle angle.

	BMI			HKA		
	<25.3	≥25.3	*P*	<7°	≥7°	*P*
Number (n)	36	70		44	62	
Tibiofibular angle			0.247			0.468
<3° (n)	24	54		34	44	
≥3° (n)	12	16		10	18	
Medial tibiofibular angle			0.770			0.954
<3° (n)	29	58		36	51	
≥3° (n)	7	12		8	11	
Lateral tibiofibular angle			0.035			0.192
<3° (n)	16	46		29	33	
≥3° (n)	20	24		13	29	

BMI, body mass index; HKA, hip–knee–ankle angle.

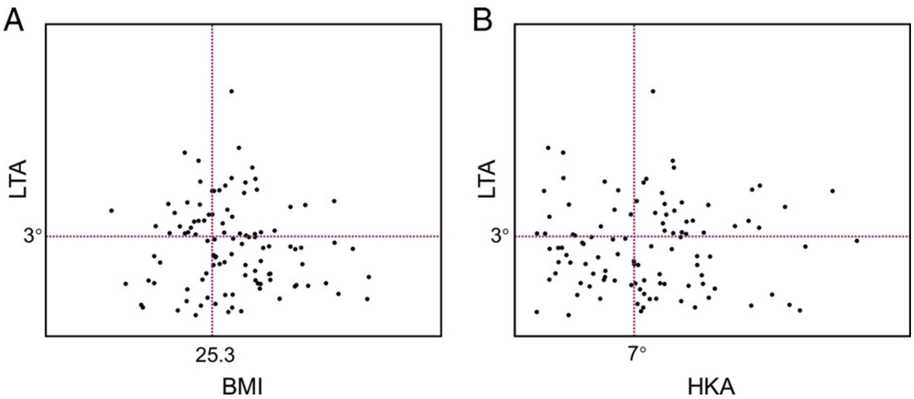

Figure 4. Distribution of lateral tibiofibular angle (LTA) according to body mass index (BMI) (A) and hip-knee-ankle (HKA) (B).

It is believed that this is the first study to determine the validity of the lateral and medial cortices of the proximal fibular shaft for measuring the coronal tibial mechanical axis in patients with knee OA. The lateral and medial cortices of the proximal fibular shaft can be detected on a single plain radiograph of the knee. The percentage of outliers was 17.9% and 41.5% for the medial and lateral cortices of the proximal fibular shaft, respectively. The medial cortex of the proximal fibula could be a reliable landmark for

Table 5
Studies reporting the variation between fibular anatomical references and tibial mechanical axis.

Study	Number of knees	Radiographic assessment	Target	Anatomic references	Definition	Mean variation	Accepted range	Reliable rate
Han et al. 2008	133	Computed tomography	Sagittal tibial mechanical axis	Fibular shaft axis	Line connecting the center of fibular neck and lateral crest of distal fibula	0.9 ± 0.67°	NA	NA
				Anterior tibial cortex	Line tangential to the anterior cortex at 7 cm below the tibial plateau and 7 cm above the tibial distal plafond	2.2 ± 0.92°	NA	NA
				Tibial anatomical axis	Line connecting the upper and lower midpoints of the tibial shaft	−2.1 ± 0.98°	NA	NA
Kuroda et al. 2014	62	Computed tomography	Sagittal tibial mechanical axis	Fibular shaft axis	Line connecting the center of the fibular head to the center of the lateral malleolus	2.6 ± 2.3°	±2°	17.7%
			Coronal tibial mechanical axis			0.9 ± 2.0°		69.3%
Tsukeoka et al. 2014	100	Computed tomography	Sagittal tibial mechanical axis	Tibial crest	Line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line	3.6 ± 1.0° of anterior inclination	0–3°	87% when used with 5° of posterior inclination
				Fibular line in sagittal plane	Line connecting the center of the fibular head and the center of the lateral malleolus	2.2 ± 0.8° of posterior inclination	0–3°	85%
			Coronal tibial mechanical axis	Tibial crest	Line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line	0.7 ± 0.9° of varus	± 3°	98%
				Fibular line in coronal plane	Tangential line connecting the most prominent parts of the fibular head and the lateral malleolus	2.9 ± 0.6° of valgus	± 2°	100% when used with 3° of varus
Erdem et al. 2015	35	Radiograph	Sagittal tibial mechanical axis	Fibular shaft axis	Line connecting the midpoints of the outer cortical diameter of the proximal and distal ends of the fibular diaphysis	2.1 ± 0.83° (Pre-operative)	NA	NA
Current study	106	Full-leg standing radiographs	Coronal tibial mechanical axis	Fibular shaft axis	Anatomic axis of the proximal fibular shaft	1.94 ± 1.40°	± 3°	73.6%
				Medial fibular cortex	Medial cortex of the proximal fibular shaft	1.92 ± 1.56°		58.5%
				Lateral fibular cortex	Lateral cortex of the proximal fibular shaft	2.67 ± 1.55°		82.1%

the tibial mechanical axis in the coronal plane, whereas the reliability of the lateral cortex of the proximal fibula was less satisfactory, especially in patients with BMI <25.3 kg/m^2.

It is believed that the results of this study provide a new perspective on the evaluation of the tibial mechanical axis, with lower radiation exposure for the routine evaluation of outpatients with knee degeneration, which is especially meaningful in community hospitals and developing countries that do not have the special device required for full-leg standing digital AP radiography. For arthroplasty patients, fibular references could be used for orthopedists to intraoperatively determine tibial mechanical axis with fluoroscopy, which is particularly beneficial for tibia-first gap techniques in complicated cases. However, based on current evidence, fibular references should be used as a useful auxiliary method rather than a replacement for the conventional intra-medullary or extra-medullary guide. More well-designed and large-sample studies are needed to confirm the reliability of these references. Before that, full-leg standing AP radiographs are still necessary for TKA and osteotomy surgery.

This study had several limitations. First, it was a female-dominant study, and all participants were Chinese; thus, the results may not be generalizable to patients from different ethnic groups. Second, it was a radiologic study based on measurements from full-leg standing digital AP radiographs, and the results may not be generalizable to standard knee radiographs. Third, the results may not be generalized to patients with early-stage knee OA or valgus knee deformity. Fourth, severe bone wear on the proximal tibia and distal femur are common in TKA patients, which could have affected the accuracy of the measurement of HKA and MPTA. Fifth, only the coronal variation between proximal fibular references and tibial mechanical axis was evaluated. Given the satisfactory results, it is recommended for the future that careful examination in the sagittal plane is performed. Finally, among all radiological measurements, the ICCs showed excellent reliability, and measurement errors may exist because of the measurement method.

5. Conclusions

In patients with knee OA, the proximal fibular shaft and its medial cortex are reliable landmarks for the mechanical axis of the tibia in the coronal view. However, the reliability of the lateral cortex of the proximal fibula is less satisfactory, especially in patients with BMI <25.3 kg/m^2. Current results provide a new perspective on the primary evaluation of the tibial mechanical axis with lower radiation exposure, especially for hospitals that do not have a special device required for full-leg standing digital AP radiography. More well-designed and large-sample studies are needed to confirm the reliability of these references in both sagittal and coronal planes.

Funding

This work was supported by Clinical Research Program of 9th People's Hospital affiliated to Shanghai Jiao Tong University School of Medicine (Grant No. JYLJ025); the Project of the Shanghai Collaborative Innovation Center for Translational Medicine (Grant No. TM201814); Technology and Innovation Fund (Chuang Ke) of the Ninth People's Hospital Shanghai Jiao Tong University School of Medicine (Grant No. CK2018011); National Natural Science Foundation of China (Grant No. 81772425); The Science and Technology Commission of Shanghai Municipality (Grant No. 16441908700); Shanghai "Rising Stars of Medical Talent" Youth Development Program (Youth Medical Talents – Specialist Program).

Ethical statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standard. Informed consent was obtained from all individual participants included in the study.

Declaration of competing interest

None.

Acknowledgments

Not applicable.

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