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RESEARCH

Standardizing Joint-Line determination on anteroposterior knee radiographs: multicenter validation of the adductor ratio and a novel composite index in 3000 knees

Serhat Akcaalan[1] · Ismail Duran[2] · Mahmut Ugurlu[1] · Salahulddin Abuljadail[3] · Lina AlMudayris[3] · Antonio Russo[4] · Mattia Forgini[5] · Moez Zeiton[6] · Alexander Yan[7] · Felipo Forero[8] · Elliot Patarroyo[8] · María Belén López Villagra[9] · Ana Laura Bogado[9] · Julius G. Pallera[10] · Dexter R. Ramos[10] · Daniela Seidel[11] · Jorge Izquierdo[11] · Kushal Hippalgaonkar[12] · Niranjan Ghag[12] · Gunes Ates[13] · Mustafa Fatih Dasci[14] · Mustafa Citak[15]

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Abstract

Objective To quantify how sex, age, and region affect radiographic joint-line (JL) measurements and indices on standardized anteroposterior knee radiographs across ten countries, and to identify a demography-resistant metric set for reliable JL restoration.

Methods Multicenter retrospective study of 3,000 AP knee radiographs obtained from ten countries. Standardized acquisition (SID 100 cm; AP, full extension, no rotation). Exclusions: prior peri-knee fracture/surgery, KL 3–4 OA, neurovascular deficit, septic arthritis, rheumatologic disease, BMI > 30, inadequate AP. Measurements: ATJL, FHJL, MEJL, LEJL, FW. Derived indices: literature-based ATJL/FW, FHJL/FW, MEJL/FW, LEJL/FW, JL1, JL2; newly defined JL-AF, JL-Combine, JL-Symmetry, JL-Ratio, JL3. Statistics: t-tests, one-/two-way ANOVA, multiple regression; effect sizes (Cohen's d, η^2); variability (CoV). $\alpha = 0.05$.

Results Men showed higher FW (92.83 ± 11.15 vs 81.38 ± 8.54), ATJL (52.16 ± 6.31 vs 46.07 ± 5.46), FHJL (20.74 ± 4.05 vs 19.13 ± 4.04), MEJL (38.22 ± 8.96 vs 34.62 ± 7.67), and LEJL (35.35 ± 8.90 vs 32.07 ± 7.64); all $p < 0.001$. With aging, FHJL, MEJL, and LEJL decreased ($p < 0.001$); FW and ATJL showed no relevant age effect ($p > 0.05$). Region strongly impacted all variables (largest η^2: LEJL 0.583, MEJL 0.561, FW 0.493). Among derived metrics, ATJL/FW ($\eta^2 = 0.016$, CoV = 0.228) and JL3 ($\eta^2 = 0.023$, CoV = 0.235) were the most stable across demographics. JL-AF ($\eta^2 = 0.036$), JL-Combine (0.028), and JL-Symmetry (0.028) were low-dependency validators. FW-based JL1 ($\eta^2 = 0.899$) and JL2 (0.702) were demography-sensitive and unreliable as stand-alone predictors.

Conclusion Basic anatomic distances are demography-dependent and poor single guides for JL restoration. A normalize-and-combine strategy—using ATJL/FW as the anchor and JL3 as the composite confirmatory index (optionally cross-checked by JL-AF/JL-Combine/JL-Symmetry)—provides robust, transferable radiographic estimation across centers. Avoid single-variable FW models (e. g., JL1) in routine planning. Larger, population-level datasets should support personalized thresholds.

Keywords Joint line · Knee arthroplasty · Adductor tubercle · Normalized ratio · Composite index · Multicenter radiography

Introduction

Restoring the joint line to its normal anatomical shape after both primary and revision knee arthroplasty has a significant effect on the knee joint [1, 2]. A joint line (JL) that is more distal or proximal than normal can lead to worsening clinical and functional outcomes [3]. This is because even a small change of 5 mm in the JL can cause instability, and clinical changes can occur with a JL change of more than 2 mm [3–6]. From a mechanical perspective, the displacement of

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the JL distally or proximally also has different effects on the knee joint. When the JL shifts proximally, patellofemoral compression forces increase, anterior knee pain occurs, polyethylene wear increases, joint range of motion becomes limited, and the risk of aseptic loosening increases [1, 4, 7, 8]. When the JL displaces distally, it can cause mid-flexion instability, restriction of knee joint range of motion, and again, an increased risk of aseptic loosening [9].

JL measurements can be performed using direct anterior–posterior (AP) knee radiographs. Different anatomical landmarks are used for these measurements. These are the fibular head [10, 11], medial and lateral femoral epicondyles [12], and adductor tubercle [10–13]. Unlike measurements taken directly from these landmarks, some authors have defined indices used to calculate JL, which they have shown to be more reliable, using these landmarks and femoral width [11, 13–16]. Recent evidence has also demonstrated that lower-extremity anatomical parameters, such as intermalleolar distance, can influence knee joint line orientation independently of arthrosis severity, further highlighting the importance of comprehensive anatomical assessment in radiographic joint line evaluation [17]. In addition to femoral-based landmarks, recent studies have highlighted the potential role of tibial landmarks such as Gerdy's tubercle, particularly in knees with advanced degenerative changes where conventional reference points may be less reliable [18]. Despite all these studies and different findings, there is still no JL measurement method whose validity is accepted by all sections.

The authors designed this study because there is no universally accepted method in the literature and to investigate whether other accepted methods show differences based on gender, age, and region. The authors hypothesized that the parameters and existing indices used to determine JL in the literature would differ depending on age, gender, and region variables, and that a new index with limited influence from these variables should be defined.

Materials and methods

Following the approval of the ethics committee of our hospital (E1-23-4329), the data collection phase of the study was initiated. Digital archiving and communication systems of orthopedics and traumatology clinics in ten different countries (Turkey, Saudi Arabia, Italy, United Kingdom, Colombia, Argentina, Philippines, Mexico, India, Germany) were used to access the knee radiographs that were analyzed. All radiographs used for measurement were numbered instead of marked with the names of the patients to protect patient privacy. Measurements were performed on AP knee x-rays. As this was a retrospective multicenter study, radiographs were not obtained using a prospective standardized protocol. Instead, previously acquired anteroposterior knee radiographs were retrospectively reviewed, and only those meeting predefined quality criteria were included. Inclusion criteria for radiographic suitability were full knee extension without apparent rotation, appropriate centering at the knee joint, and symmetric appearance of the femoral and tibial condyles, with slight superimposition of the fibular head over the lateral tibial condyle. Radiographic suitability was independently evaluated by two orthopedic surgeons. Centering for the image was performed at the center of the knee joint, 1. 5 cm distal to the patella apex. The image was adjusted to fully include the femur superiorly, the proximal tibia and fibula inferiorly, and the medial–lateral skin borders bilaterally. In this process, the tube cassette distance was adjusted to 100 cm. Those with a history of fracture around the knee or arthroscopic/open surgery, those with advanced arthritic findings in the knee (Kellgren–Lawrence stage 3–4), those with neurovascular deficits in the upper extremities, those with a history of septic arthritis, those diagnosed with rheumatological diseases, those with a body mass index > 30 kg/m2, and those who could not have a full AP knee radiograph taken due to flexion contracture of the knee were excluded from the study.

Patients were categorized according to sex, age, and region. A total of 3,000 anteroposterior knee radiographs were included from ten countries, with 300 radiographs obtained from each country. The study population consisted of 1,500 female and 1,500 male knees. Patients were stratified into six age groups (20–29, 30–39, 40–49, 50–59, 60–69, and 70–79 years), with each age group comprising 500 knees in total. Only one knee per patient was included in the analysis.

To ensure balanced representation across regions, a quota of 300 knee radiographs per country was applied; within each center, eligible radiographs meeting the inclusion criteria were randomly selected from institutional archives until the predefined quota was reached.

All measurements were performed by two different orthopedists at the relevant clinics. The mean of the measurements taken was used for statistical analysis.

All measurements described below were taken on knee AP x-rays and recorded separately for each patient (Fig. 1).

- **Adductor tubercle to the joint line distance (ATJL):** Perpendicular distance between the adductor tubercle and joint line. The adductor tubercle was identified on the radiograph as the distal point on the medial supracondylar slope.
- **Femoral width (FW):** Distance between the most external points of the medial and lateral epicondyles.

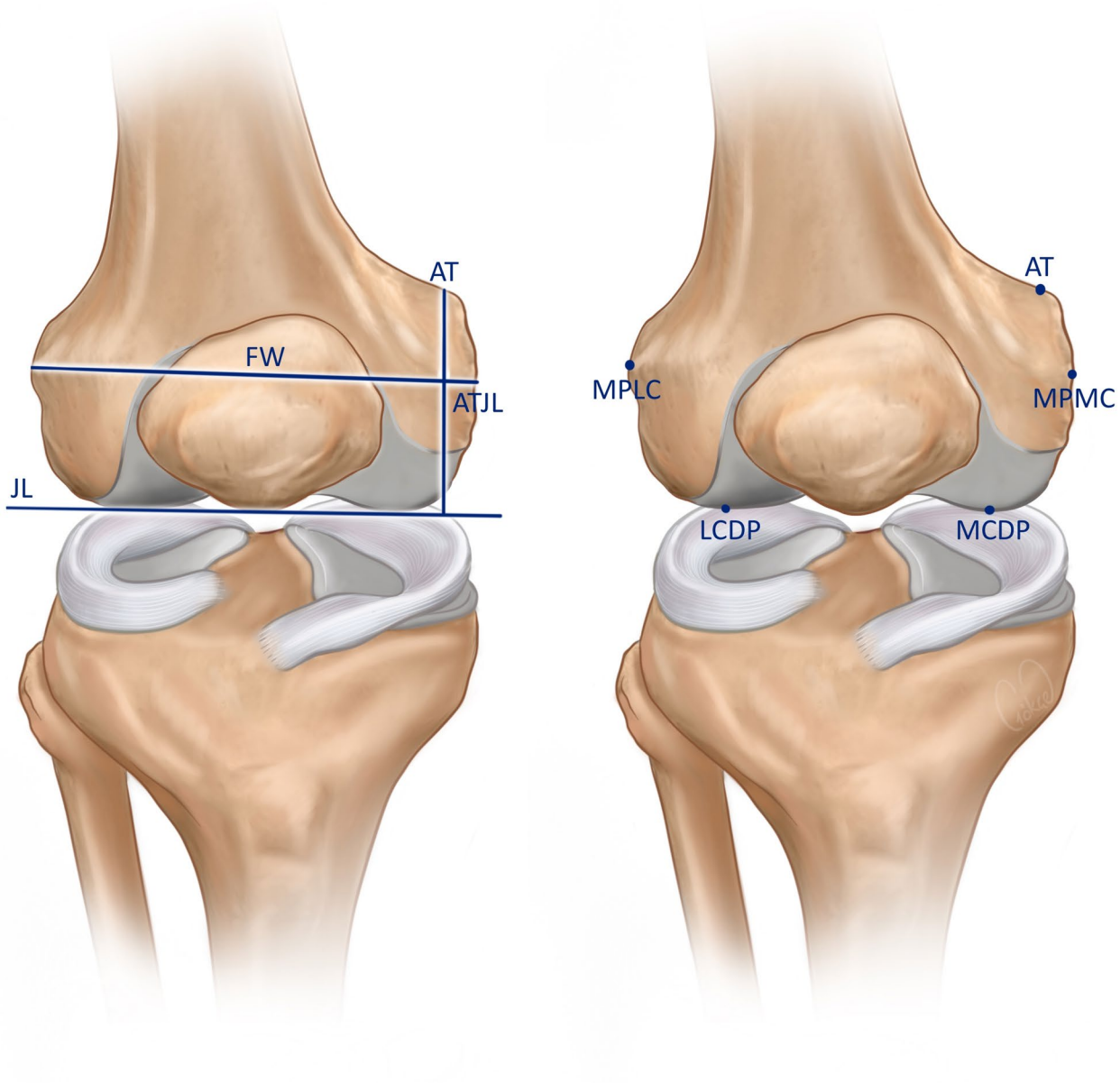

Fig. 1 Schematic illustration of the radiographic and anatomical landmarks used for joint-line assessment. (Left) Standardized anteroposterior knee view showing femoral width (FW), adductor tubercle–joint line distance (ATJL), and reference joint-line (JL). The adductor tubercle (AT) is used as the proximal landmark for ATJL measurement. (Right) Anatomical points relevant for mediolateral joint-line evaluation, including the medial proximal lateral condylar point (MPLC), medial proximal medial condylar point (MPMC), lateral condylar distal point (LCDP), and medial condylar distal point (MCDP). These landmarks form the basis for derived indices and composite measurements used in joint-line restoration analysis

- **Fibular head to joint line distance (FHJL):** Perpendicular distance between the most proximal point of the fibular head and the femoral joint line
- **Distance from medial epicondyle to medial most distal point (MEJL):** Perpendicular distance between the medial epicondyle and the joint line
- **Distance from lateral epicondyle to lateral most distal point (LEJL):** Perpendicular distance between the lateral epicondyle and the femoral joint line

Using the measurements specified above, the indices defined in the literature for determining the JL, along with their references listed below, were calculated in the second stage and recorded separately for all patients.

- ATJL/FW [19]
- FHJL/FW [20]
- MEJL/FW [20]

- LEJL/FW [20]

Derivation of composite indices

In addition to previously described ratio-based indices, several composite indices were developed to evaluate joint-line estimation while minimizing demographic dependency. JL-AF and JL-Combine were calculated as arithmetic combinations of anatomically relevant joint-line distances normalized to femoral width, with the aim of reducing the influence of absolute bone size. JL-Symmetry was defined to reflect mediolateral balance between the distal femoral condyles. JL-Ratio was calculated as the ratio of two normalized indices (ATJL/FW and FHJL/FW). JL1 and JL3 were derived using linear regression models based on femoral and periarticular joint-line measurements, with regression coefficients obtained from the overall study population. These indices were not intended as predictive models for individual patients but as composite metrics to compare demographic sensitivity across different joint-line estimation approaches.

All data were recorded in an electronic data program (Microsoft Excel) for statistical analysis.

Statistical analysis

Data analysis was performed using the SPSS 27. 0 program and conducted at a 95% confidence level. For categorical (qualitative) variables, frequency (n) and percentage (%) were provided, while for numerical (quantitative) variables, mean (Mean), standard deviation (SD), minimum, and maximum statistics were provided. Independent groups t-tests, one-way ANOVA, two-way ANOVA, and multiple linear regression analyses were used in the study. In addition, LSD (for homogeneous variance) and Tamhane (for non-homogeneous variance) tests were used for within-group comparisons, and effect size (Cohen's d and Eta^2) was calculated to examine group effects. Independent groups t; a test technique used to compare two groups in terms of a numerical variable. One-way ANOVA; a test technique used to compare two groups in terms of a numerical variable. Two-way ANOVA; a test technique used to determine the effects on a numerical variable in an ANOVA model of an experimental design involving two or more groups of variables. Multiple linear regression is a type of analysis that examines the effect of more than one independent variable on a numerical dependent variable.

Given the exploratory and multicenter nature of the study, no formal a priori power analysis was performed. The sample size was determined based on the availability of balanced and high-quality radiographs across participating centers, allowing robust estimation of demographic effects and effect sizes.

Results

A total of 3000 patients, including 1500 (50%) men and 1500 (50%) women, were included in the study. 300 knee AP x-rays were included, 150 from women and 150 from men from each country.

FW was found to be 81. 38±8. 54 in women and 92. 83±11. 15 in men. FW was found to be statistically higher in men ($p<0.001$). ATJL was found to be 46. 07±5. 46 in women and 52. 16±6. 31 in men. Statistically, a higher mean value was found in men ($p<0.001$). FHJL was 19. 13±4. 04 in women and 20. 74±4. 052 in men. FHJL values in men were found to be statistically significantly higher ($p<0.001$). MEJL was 34. 62±7. 67 in women and 38. 22±8. 96 in men. A statistically significant increase was found in men ($p<0.001$). LEJL was 32. 07±7. 64 in women and 38. 22±8. 96 in men. A statistically significant increase was found in men ($p<0.001$).

The data from the analysis of the measurements according to age groups are shared in Table 1.

Data from the analysis of measurements by country is shared in Table 2.

Values shown in bold represent statistically significant results ($p < 0.05$).Following the analysis of basic measurements and indices previously used in the literature to determine JL according to gender, age, and region variables, new indices were created. These are:

- JL AF: (ATJL+FHJL) / (2*FW)
- JL Combine: (ATJL+FHJL+MEJL+LEJL) / (4*FW)
- JL Symmetry: (MEJL – LEJL) / FW
- JL Ratio: (ATJL/FW) / (FHJL/FW)
- JL 1: 0. 27 * FW+13. 5
- JL 2: 0. 3 * ATJL+0. 4 * FHJL+0. 3 * MEJL
- JL 3: 1. 004×ATJL+0. 093×FHJL – 0. 070×MEJL+0. 391×LEJL

In the variance analysis conducted by gender, statistically significant differences were found in FW, ATJL, FHJL, MEJL, LEJL, FHJL/FW, MEJL/FW, and LEJL/FW, as well as in JL AF, JL 1, and JL Index 2 ($p<0.05$). In contrast, the effect of gender was not statistically significant in ATJL/FW, JL Average Index, JL Combine, JL Symmetry, and JL 3 ($p>0.05$). When examining effect sizes, the highest Cohen's d values were observed in MEJL ($d=0.057$) and LEJL ($d=0.052$) measurements, followed by JL 2 ($d=0.023$). Effect sizes remained low in all other measurements ($d<0.02$). In the analyses conducted in terms of age, statistically significant

Table 1 Analysis of measurements according to age groups in the study

Variables	Age	n	Mean	sd	F	p	Eta2	Post Hoc
FW	20–29(1)	500	85.67	10.57	2,084	0.064	0.003	x
	30–39(2)	500	87.10	11.07				
	40–49(3)	500	87.19	11.68				
	50–59(4)	500	87.70	12.11				
	60–69(5)	500	87.40	11.29				
	70–79(6)	500	87.58	11.93				
ATJL	20–29(1)	500	48.47	6.41	1,403	0.220	0.002	x
	30–39(2)	500	49.02	6.72				
	40–49(3)	500	49.15	6.23				
	50–59(4)	500	49.21	6.68				
	60–69(5)	500	49.40	6.85				
	70–79(6)	500	49.43	6.90				
FHJL	20–29(1)	500	20.40	4.03	6,208	**0.000**	0.010	1–31–4 1–51–6 2–32–4 2–52–6
	30–39(2)	500	20.57	3.97				
	40–49(3)	500	19.38	4.06				
	50–59(4)	500	19.84	4.20				
	60–69(5)	500	19.79	4.25				
	70–79(6)	500	19.62	4.14				
MEJL	20–29(1)	500	37.76	7.54	15,205	**0.000**	0.025	1–31–4 1–51–6 2–32–4 2–52–6
	30–39(2)	500	38.62	7.75				
	40–49(3)	500	36.22	8.48				
	50–59(4)	500	35.38	8.68				
	60–69(5)	500	35.78	9.05				
	70–79(6)	500	34.78	8.98				
LEJL	20–29(1)	500	34.55	7.31	12,092	**0.000**	0.020	6−16–2 6–32–4 2–5
	30–39(2)	500	35.54	7.66				
	40–49(3)	500	34.14	8.49				
	50–59(4)	500	33.10	8.78				
	60–69(5)	500	33.07	9.14				
	70–79(6)	500	31.85	8.75				

differences were found in FW, ATJL, FHJL, MEJL, LEJL, FHJL/FW, MEJL/FW, and LEJL/FW, as well as JL AF, JL 1, and JL 2 ($p<0.05$). In contrast, no age-related significant difference was found for ATJL/FW, JL Ratio, JL Combine, JL Symmetry, and JL 3 ($p>0.05$). When examining effect sizes, the highest η^2 values were observed in FW ($\eta2=0.397$), ATJL ($\eta2=0.319$), and JL 2 ($\eta2=0.240$). Significant but lower-level effects were also detected in MEJL ($\eta2=0.098$) and LEJL ($\eta2=0.095$) measurements. In normalized indices, effect sizes remained quite low ($\eta2<0.01$). In the analyses based on the country factor, statistically significant differences were found in all raw measurements (FW, ATJL, FHJL, MEJL, LEJL), normalized measurements (ATJL/FW, FHJL/FW, MEJL/FW, LEJL/FW), and all indices (JL AF, JL Combine, JL Symetri, JL Ratio, JL 1, JL 2, JL 3) were statistically significant ($p<0.05$). When examining effect sizes, the highest η^2 values were observed in LEJL ($\eta2=0.619$), MEJL ($\eta2=0.561$), FW ($\eta2=0.493$), and JL Index 1 ($\eta2=0.493$). Furthermore, ATJL ($\eta2=0.428$) and JL 2 ($\eta2=0.439$) were also among the measurements strongly affected by the country factor. Among the normalized measurements, the most significant differences were found in the LEJL/FW ($\eta2=0.206$), MEJL/FW ($\eta2=0.175$), and FHJL/FW ($\eta2=0.125$) ratios.

A comparison of the measurements made in the study with previously established and newly created indices is provided in Table 3.

According to the data in Table 3, FW and basic measurements (ATJL, MEJL, LEJL) are highly influenced by demographic factors and are limited in terms of stability. Normalized ratios (especially ATJL/FW) and combined indices (JL AF, JL Combine, JL Symmetry, JL 3) emerged as the most reliable measures with low StabilityScore values. Specifically, JL 3 and JL AF/Combined indices have been identified as the most stable indicators, independent of demographic factors and with a low coefficient of variation.

Table 2 Analysis of measurements by country in the study

Variables	Region	n	Mean	sd	F	p	Eta2	Post Hoc
FW	Argentina	300	87.20	9.10	193,443	**0.000**	0.368	**
	Colombia	300	88.48	8.70				
	Germany	300	91.96	9.28				
	India	300	66.79	5.27				
	Italy	300	89.71	12.52				
	Mexico	300	91.00	8.84				
	Philippines	300	88.04	9.67				
	SaudiArabia	300	90.09	8.78				
	Turkey	300	86.98	7.69				
	UK	300	90.81	9.80				
ATJL	Argentina	300	48.94	5.22	168,731	**0.000**	0.337	**
	Colombia	300	47.66	5.48				
	Germany	300	52.03	5.33				
	India	300	38.37	4.24				
	Italy	300	51.67	6.21				
	Mexico	300	52.08	5.81				
	Philippines	300	49.51	5.61				
	SaudiArabia	300	51.42	5.44				
	Turkey	300	49.09	4.74				
	UK	300	50.37	5.80				
FHJL	Argentina	300	18.62	4.14	7,879	**0.000**	0.023	**
	Colombia	300	19.76	4.46				
	Germany	300	20.90	4.57				
	India	300	20.31	3.04				
	Italy	300	20.48	3.97				
	Mexico	300	19.91	4.32				
	Philippines	300	19.82	3.85				
	SaudiArabia	300	20.47	4.43				
	Turkey	300	19.24	3.55				
	UK	300	19.82	4.29				
MEJL	Argentina	300	40.54	4.33	363,384	**0.000**	0.522	**
	Colombia	300	34.95	4.13				
	Germany	300	37.66	4.57				
	India	300	23.80	2.85				
	Italy	300	36.20	8.21				
	Mexico	300	33.74	3.47				
	Philippines	300	40.50	6.94				
	SaudiArabia	300	46.50	4.67				
	Turkey	300	29.20	10.77				
	UK	300	41.16	4.29				
LEJL	Argentina	300	37.42	4.72	465,038	**0.000**	0.583	**
	Colombia	300	32.32	3.66				
	Germany	300	33.80	3.67				
	India	300	19.20	1.81				
	Italy	300	35.46	8.49				
	Mexico	300	31.60	3.33				
	Philippines	300	38.04	6.50				
	SaudiArabia	300	41.97	4.48				
	Turkey	300	26.70	9.16				
	UK	300	40.58	4.11				

Table 3 Joint line measurements and derived indices in AP knee radiographs: mean (SD), effect size (η^2), coefficient of variation (CoV), and stability score

Variables	Mean	sd	Eta2	CoV	StabilityScore
FW	87.11	11.46	0.899	0.132	1.000
ATJL	49.11	6.64	0.752	0.135	0.887
FHJL	19.93	4.13	0.074	0.207	0.281
MEJL	36.42	8.53	0.716	0.234	0.950
LEJL	33.71	8.46	0.766	0.251	1,000
ATJL/FW	0.57	0.13	0.016	0.228	0.244
FHJL/FW	0.23	0.07	0.136	0.305	0.441
MEJL/FW	0.42	0.13	0.195	0.309	0.504
LEJL/FW	0.39	0.13	0.223	0.333	0.556
JLAF	0.40	0.09	0.036	0.230	0.266
JLCombine	0.40	0.09	0.028	0.233	0.261
JLSymmetry	0.77	0.19	0.028	0.241	0.269
JLRatio	0.40	0.10	0.074	0.254	0.328
JL1	0.37	0.03	0.899	0.084	0.983
JL2	0.34	0.05	0.702	0.137	0.839
JL3	0.71	0.17	0.023	0.235	0.258

Discussion

The most important finding of this study is that Basic anatomical measurements used to determine JL, such as FW, ATJL, FHJL, MEJL, and LEJL, are greatly affected by demographic variables and cannot be used alone to determine JL. The most reliable parameters for determining JL, which are least affected by demographic data, are ATJL/FW and JL 3. Furthermore, this study demonstrated that different indices previously defined in the literature as normalized ratios and considered reliable may vary depending on demographic data and therefore cannot be used reliably.

Iacano and colleagues, in their study to identify methods that could be used to determine JL, compared radiographic measurements with intraoperative measurements [13]. As a result, they found that the ATJL/FW ratio showed the highest agreement between radiographic measurement and intraoperative measurement. In their study evaluating full-leg standing x-rays of 100 healthy volunteers, Luyckx and colleagues demonstrated, similarly to the previous study, that the ATJL/FW ratio could be reliable and accurate for JL reconstruction, particularly in revision total knee arthroplasty [19]. Akça and colleagues also used both traditional and ratio-based methods to determine the JL in revision total knee arthroplasty () in their study, where they compared their radiographic measurements with intraoperative measurements. In this study, which used data from 16 revision knee arthroplasty patients, the Adductor Tubercle-Ratios method was shown to be a more reliable and usable method for determining the JL [21]. Yüksel and colleagues, in a retrospective study involving 186 patients [22] stated that the AT is a reliable landmark for determining the JL [In another study, anatomical landmarks that could be used to determine the JL were evaluated comparatively. This study also stated that the AT is a suitable anatomical landmark for determining the JL in revision surgeries [[23]In another study, Iacona demonstrated that the ATJL/FW ratio can be appropriately used to determine the JL in revision knee surgeries using an intraoperative control method [24]. Unlike these radiographic and intraoperative measurements, Maderbacher and colleagues conducted an MRI-based study to determine the JL. In this study, different measurements of FH, AT, ME, and LE were used; as a result, they showed that a healthy JL restoration cannot be achieved with direct bone-based measurements and that an index such as "6. 40+(width femur [mm]×0. 49) to the AT" can be used [25]. In their study on JL determination in the Chinese population, Gao and colleagues stated that different formulations should be created for women and men for reliable JL detection and concluded that the formulation "ATJL=0. 562×FW" could be used for women and "ATJL=0. 548×FW" for men [26]. In their study using 50 X-rays taken with a standardized protocol, Xia and colleagues emphasized that AT is a reliable landmark and demonstrated that combinations with FW can be used [26]. Fan and colleagues, in their study on the Chinese population, emphasized that ME and LE are also usable landmarks besides AT, but warned that ratios need to be established according to different races [20]. There are numerous studies in the literature related to determining JL, which include different results, but most of them have not revealed the effect of demographic variables such as age, gender, and region. In contrast, our study has detailed the effects of these variables and determined how JL can be identified using parameters that are least affected by these variables. Although our study draws conclusions based on a broader analysis than other studies, it is not possible to know the natural JL of every individual. Therefore, as stated by Hirschmann et al. [29], larger databases should be created and a transition to personalized medicine should be made, using individualized values for coronal plane deformity analysis and preoperative planning.

This study is methodologically robust due to its multicenter, large, and balanced sample (n=3000; 10 countries), standard AP imaging following a single protocol (SID=100 cm, full extension, no rotation), strict exclusion criteria, and use of the average measurements of two observers; beyond p-values, it systematically maps effect sizes (η^2, d) and coefficients of variation with demographic sensitivity, defines JL3 and other composite or normalized indices in addition to literature-based ratios, and provides an applicable framework for a demographic-resistant decision metric. However, the retrospective cross-sectional design, lack of external validation with intraoperative or clinical outcomes, absence of interobserver reliability analysis, and

potential imaging-related artifacts despite SID standardization may limit interpretation. The exclusion of patients with a body mass index greater than 30 kg/m^2, while intended to reduce radiographic landmark obscuration and measurement bias, may limit the generalizability of the findings to obese populations in whom soft tissue thickness can hinder reliable identification of adductor tubercle–based landmarks.

Conclusion

Consequently, basic measurements such as ATJL, FHJL, MEJL, LEJL, and FW, which are performed using direct landmarks, should not be used for JL detection because they show significant variations depending on demographic parameters. The ATJL/FW and JL 1 indices, which are the parameters least affected by demographic data, can be used reliably together or separately for JL detection. However, both primary and revision surgeries require broader and more personalized data for the anatomical restoration of JL.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval Ethical approval has been obtained and will be uploaded as an additional file.

Informed consent This study is a retrospective screening study; informed consent was not applicable.

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Authors and Affiliations

Serhat Akcaalan[1] · Ismail Duran[2] · Mahmut Ugurlu[1] · Salahulddin Abuljadail[3] · Lina AlMudayris[3] · Antonio Russo[4] · Mattia Forgini[5] · Moez Zeiton[6] · Alexander Yan[7] · Felipo Forero[8] · Elliot Patarroyo[8] · María Belén López Villagra[9] · Ana Laura Bogado[9] · Julius G. Pallera[10] · Dexter R. Ramos[10] · Daniela Seidel[11] · Jorge Izquierdo[11] · Kushal Hippalgaonkar[12] · Niranjan Ghag[12] · Gunes Ates[13] · Mustafa Fatih Dasci[14] · Mustafa Citak[15]

✉ Mustafa Citak
mcitak@gmx.de

Serhat Akcaalan
akcaalanserhat@gmail.com

Ismail Duran
ismailduran33@gmail.com

Mahmut Ugurlu
mugurlu@gmail.com

Salahulddin Abuljadail
sabuljadail@kfu.edu.sa

Lina AlMudayris
leenaalmudaires@gmail.com

Antonio Russo
russo.antonio.92@gmail.com

Mattia Forgini
mattia.forgini@gmail.com

Moez Zeiton
moezaz@gmail.com

Alexander Yan
Alex.yan@doctors.org.uk

Felipo Forero
fforero1997@gmail.com

Elliot Patarroyo
elliottdinesh@hotmail.com

María Belén López Villagra
Mblopez@sanatorioallende.com

Ana Laura Bogado
Albogado@sanatorioallende.com

Julius G. Pallera
juliuspallera@gmail.com

Dexter R. Ramos
dexterlloydrr@gmail.com

Daniela Seidel
Danscarrera@gmail.com

Jorge Izquierdo
jaizquierdol@gmail.com

Kushal Hippalgaonkar
kushalhippal@gmail.com

Niranjan Ghag
niranjanghag95@gmail.com

Gunes Ates
gunesatees@gmail.com

Mustafa Fatih Dasci
mfatihdasci@gmail.com

[1] Ankara City Hospital, Çankaya, Turkey

[2] Dr Lütfi Kırdar Kartal Eğitim ve Araştırma Hastanesi, Istanbul, Turkey

[3] King Faisal University, Al Hufūf, Saudi Arabia

[4] Humanitas Torino, Turin, Italy

[5] University of Turin, Turin, Italy

[6] Royal Bolton Hospital, Farnworth, UK

[7] Health Education North West, Manchester, UK

[8] Los Comuneros Hospital Universitario de Bucaramanga, Bucaramanga, Colombia

[9] Sanatorio Allende, Cordoba, Argentina

[10] De La Salle University, Manila, Philippines

[11] Centro Médico ABC, Mexico City, Mexico

[12] Sunshine Bone and Joint Institute, Hyderabad, India

[13] Gazi University, Ankara, Turkey

[14] Istanbul Medipol University, Istanbul, Turkey

[15] Helios Endo-Klinik Hamburg, Hamburg, Germany