Do Patients' Perceptions of Leg Length Correlate With Standing 2- and 3-Dimensional Radiographic Imaging?

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A B S T R A C T

Background: This study compared 2- and 3-dimensional (2D and 3D) radiographic measurements of anatomical and functional leg length and knee coronal and sagittal alignments and correlated these measurements with patients' leg-length perceptions.

Methods: Patients without symptomatic spinal pathology, previous surgery of the spine, and lower extremities (140 lower extremities) were evaluated on EOS images obtained in standing position. Numerous measurements of each limb were compared to the contralateral limb. All 2D/3D measures were evaluated and compared for repeatability and reproducibility.

Results: Mean 2D functional and anatomical lengths were 78.7 cm (64.7-88.4, confidence interval [CI] 95%: 77.4-80) and 78.3 cm (64.9-87.9, CI 95%: 77-79.6), respectively. Mean 3D functional and anatomical lengths were 78.9 cm (65.1-88.7, CI 95%: 77.6-80.2) and 78.9 cm (65.6-88.3, CI 95%: 77.8-80.5), respectively ($P < .001$). Mean 2D and 3D knee varus/valgus angles were $-1.9°$ (-26.4 to 9.1, CI 95%: -3.5 to -0.7) and $-0.9°$ (-19.2 to 11.8, CI 95%: -2.4 to 0.2), respectively ($P = .004$). Multiple regression analysis found that patients with $>10°$ of flexum/recurvatum were $2.1\times$ more likely to perceive unequal length ($P < .1$). Patients with irreducible varus/valgus knee deformity were $4\times$ more likely to perceive unequal length ($P < .04$).

Conclusion: EOS imaging allows more accurate assessment of anatomical and functional lengths. Patients' perceptions of lower extremity length may correlate more closely with coronal and sagittal alignments of the knee than with femoral or tibial length. This study highlights the importance of physical examination of all the joints and 3D measurements in functional standing position.

The accurate assessment of leg length is essential for planning the correction of deformities and limb-length discrepancy. Limb-length discrepancy is a common finding in degenerative hip and knee disorders and congenital or trauma-related lower extremity deformities. It is also a common postoperative complication after total hip and knee arthroplasty [1-4], which can result in patient dissatisfaction, limping, need for shoe lift, low back pain, hip instability, and revision surgery [5-11]. Limb-length discrepancy can also result in medicolegal complaints. Upadhyay et al. [12] surveyed members of the American Association of Hip and Knee Society regarding medical malpractice litigations. Limb-length discrepancy was the second most common reason for litigation, and 8% of surgeons had been a defendant in a legal case secondary to this complication.

Most radiographic analyses of arthroplasty patients are based on anteroposterior (AP) radiographs in the standing position and computed tomography (CT) scans in the supine position. Despite its better accuracy, CT measures anatomical length in the supine position but does not evaluate functional length in the standing position, the position in which limb-length discrepancy is perceived by patients. Functional length integrates both the lengths

of the femoral and tibial bones and the coronal (varus/valgus) and sagittal (genu flexum/recurvatum) knee alignments. It also integrates the spine-pelvis junction and its effect on the pelvic obliquity.

These questions were asked: (1) Do the 2- and 3-dimensional (2D and 3D) radiographic measurements of leg length and knee coronal and sagittal alignments differ substantially? (2) Do patients' perceptions of leg length correlate with the 2D and 3D anatomical and functional limb lengths or knee coronal and sagittal alignments?

Our hypotheses were that the anatomical and functional lengths would differ substantially between the 2D and 3D images and that genu flexum, genu recurvatum, severe varus, and valgus deformities, especially those that are correctable, would affect patient perception of functional leg length more than just anatomical length.

Methods

This was a nonrandomized, prospective study of the consecutive patients who were assessed with EOS imaging and met our inclusion and exclusion criteria. Patients were recruited in the Department of Orthopaedic and Trauma Surgery, Pitié-Salpêtrière Hospital, between January 2013 and December 2015.

We routinely evaluate all patients in clinic using the EOS imaging system for spine and lower extremity–related pain. The EOS system (EOS imaging SA, Paris, France) is an innovative slot-scanning radiograph system allowing the simultaneous acquisition of orthogonal AP and lateral radiographs while the patient is standing, sitting, or even squatting with less irradiation than standard imaging. After obtaining approval from our institutional review board, we reviewed 70 patients for bilateral lower extremity length assessment. We included all patients (aged 18-80 years) who were assessed in our clinic for hip and knee pain due to different degrees of degenerative joint disease. These patients were all treated nonoperatively for degenerative hip or knee pain before EOS imaging. All patients with symptomatic spinal pathology; previous spinal surgery; lower extremity open reduction; and external fixation, osteotomy, or arthroplasty (hip, knee, ankle) were excluded.

Each patient stood comfortably in the EOS machine. The position was specifically checked to avoid superimposition of anatomical structures on the lateral view (which would make 3D reconstruction impossible). We successively used the AP uniplanar acquisition (an equivalent of standard AP long-leg x-ray) and then the biplanar acquisition of the entire lower extremities (Fig. 1A and B). The biplanar acquisition was used to perform stereoradiographic 3D modeling of each lower extremity using specialized software (sterEOS 3D, EOS imaging SA) according to a previously described method [13]. The bony landmarks used to determine the femoral and tibial torsions in 3D images were identical to those used in the 2D measurements. The parameters measured in both 2D and 3D views were the hip-knee-ankle (HKA) angle and the femoral and tibial mechanical axes (FMA and TMA). The FMA was defined as the line connecting the center of the femoral head to the center of the femoral notch, and the TMA was defined as the line from the center of the tibial plateau (interspinous intercruciate midpoint) extending distally to the center of the tibial plafond (Fig. 2A and B). HKA angle was defined as the angle between the FMA and TMA. Neutral angle was defined as HKA angle of 0. The lengths of the femoral and tibial bones and the anatomical and functional lengths of the lower extremity were also measured. Tibial and femoral rotation and knee flexion/hyperextension angle were also derived from the 3D reconstruction [14].
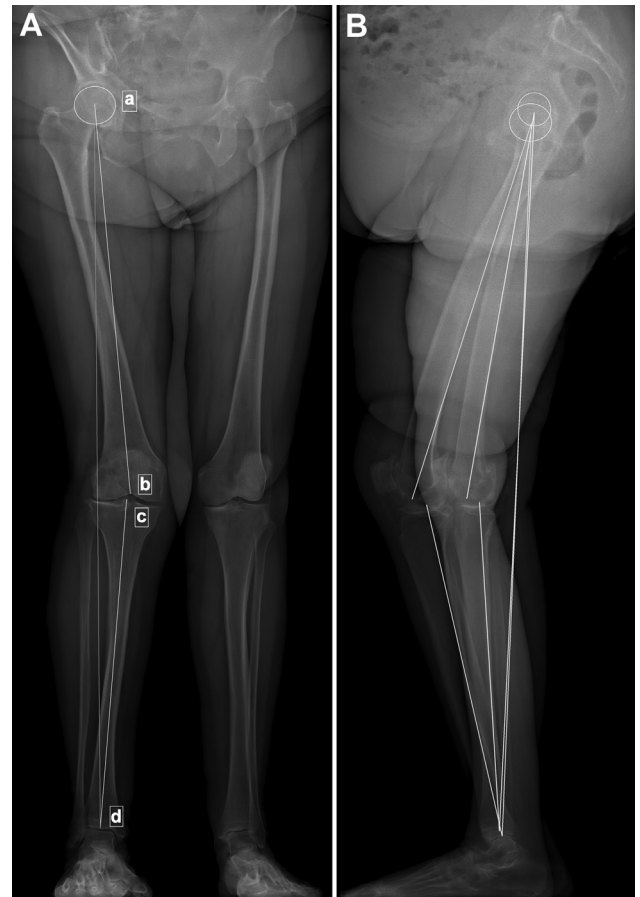

Fig. 1. (A and B) Two dimensional anteroposterior and lateral views of the lower extremity, showing the anatomical length of the femoral (ab) and tibial bones (cd) and the functional length (AD line in anteroposterior view and the line connecting the femoral head to ankle in the lateral view).

We used the following definitions (Fig. 1A):

- Anatomical femoral length: distance between the center of the femoral head (a) and the center of the trochlea (b).
- Anatomical tibial length: distance between the center of the tibial spine (intercondylar eminence) (c) and the center of the ankle joint (d).
- Functional length: distance between the center of the femoral head to the center of the ankle joint (ad).
- Anatomical length: sum of the anatomical femoral and tibial lengths (ab + cd).

Previous studies have shown that mean anatomical leg-length difference is about 5 mm in up to 90% of the general population. Some of these studies also looked into the clinical significance of the anatomical leg-length discrepancy and considered the threshold to be as low as 5 mm [15] and as high as 30 mm [16,17]. For this study, legs were considered to be of equal length when the difference between the anatomical and functional lengths of lower extremities was ≤5 mm.

All patients were asked if they perceived equal or unequal limb length. The knee coronal angle (varus/valgus) was also assessed during the physical examination by the senior author with manual varus and valgus stress to see if the varus/valgus deformity was correctable to neutral angle or not. This was done using a goniometer, as validated in previously published work [18]. Patients were categorized into 3 groups based on correctability of deformity: completely
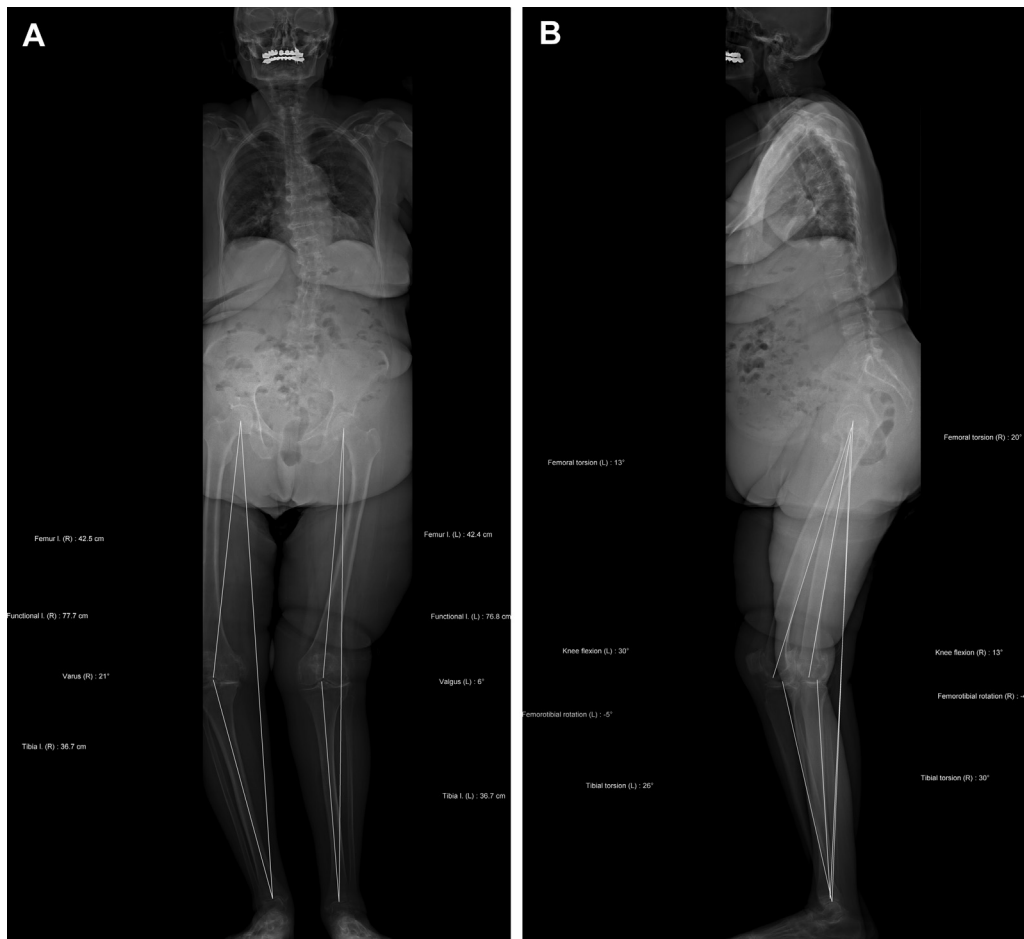
Fig. 2. (A and B) Measurement of the anatomical and functional length of both extremities in anteroposterior and lateral views in a patient.

correctable (within 5° of the neutral HKA angle), partially correctable (correctable but not within 5° of the neutral HKA angle), and non-correctable (unable to change the alignment with manual stress).

Statistical Analysis

For both the 2D and 3D methods, valgus angulation was considered positive and varus angulation negative. Each patient's 2D and 3D measurements were compared. The statistical analysis was performed with MedCalc (version 11.2.0.0, Mariakerke, Belgium). Along with descriptive statistics, the differences between measurements derived from the 2D and 3D methods were analyzed for repeatability and reproducibility. Student *t* test was used to determine if HKA angle measurement differed between these 2 methods and to assess the effect of flexion/hyperextension, femoral rotation, and tibial rotation on the 2D and 3D measurements. Cohen's Kappa test was used to assess the level of agreement between the patient's perception of limb-length discrepancy and objective measurement of limb length. Logistic regression was used to find any correlation between the patient's perception of the length and objective measurements of the length and different angles of the knee. The significance level was set at 5%.

Results

The descriptive measurement data are presented in Table 1. The mean 2D functional and anatomical lengths were 78.7 cm (64.7-88.4, confidence interval [CI] 95%: 77.4-80) and 78.3 cm

(64.9-87.9, CI 95%: 77-79.6), respectively. The mean 3D functional and anatomical lengths were 78.9 cm (65.1-88.7, CI 95%: 77.6-80.2) and 78.9 cm (65.6-88.3, CI 95%: 77.8-80.5), respectively ($P < .001$). The difference between 2D and 3D functional length measurements is only 2 mm. The difference in 2D and 3D anatomical length measurements is 6 mm.

The mean 2D knee varus/valgus angle was $-1.9°$ (-26.4 to 9.1, CI 95%: -3.5 to -0.7). The mean 3D knee varus/valgus angle was $-0.9°$ (-19.2 to 11.8, CI 95%: -2.4 to 0.2) ($P = .004$). There was no substantial difference between the 2D and 3D measurements of sagittal knee angle (flexum/recurvatum).

For patient perception of length, 45 of 70 patients (64.3%) felt that their lower limb lengths were equal (Table 2). For 2D measurements, functional leg-length discrepancy was <5 mm in 37 of 70 patients (52.9%) and anatomical length discrepancy was <5 mm in 40 of 70 patients (57.1%). For 3D measurements, functional leg-length discrepancy was <5 mm in 36 of 70 patients (51.4%) and anatomical length discrepancy was <5 mm in 45 of 70 patients (64.3%). Testing for agreement between patient perception and objective measurement of limb length is presented in Table 3. Interestingly, agreement is better for 2D measurements than for 3D, but the agreement is moderate at best.

In coronal knee angle measurements (Table 1), 35 of 70 patients (50%) were within 5° of neutral angle. Among those who were not, 18 patients were categorized as partially correctable and 17 patients were noncorrectable in physical examination.

For multiple logistic regression analysis, the knees (n = 140) were divided into 2 groups on the basis of coronal knee angle

Parameters	Mean	Standard Deviation	Minimum	Maximum	95% CI	*P* Value
2D functional length	78.7	5.5	64.7	88.4	77.4-80	<.001
3D functional length	78.9	5.5	65.1	88.7	77.6-80.2	
2D anatomical length	78.3	5.4	64.9	87.9	77-79.6	<.001
3D anatomical length	78.9	5.4	65.6	88.3	77.8-80.5	
2D hip-knee-ankle angle	4.9	1.9	0.6	9.3	4.8-5.7	.9
3D hip-knee-ankle angle	4.9	1.5	1.8	8.4	4.6-5.3	
2D knee varus/valgus	−1.9	6.5	−26.4	9.1	−3.5 to −0.7	.004
3D knee varus/valgus	−0.9	5.8	−19.2	11.8	−2.4 to 0.2	
2D knee flexum/recurvatum	7.4	12	−14.8	46.7	4.8-11.5	.39
3D knee flexum/recurvatum	7.3	11.9	−15.1	44.5	4.5-10.5	

Functional length: distance from the center of the femoral head to the center of the ankle joint (cm). Anatomical length: sum of the anatomical femoral and tibial lengths (cm). Varus knee angle (°) and genu recurvatum (°) are considered negative. Valgus knee angle (°) and genu flexum (°) are considered positive.
CI, confidence interval.

(varus-valgus): ±5° from the neutral angle for a first analysis and ±10° for a second analysis. The knees (n = 140) were also divided into 2 groups on the basis of sagittal knee angle: ±5° for a first analysis and ±10° for a second analysis. In simple regression, we found that patient perception of leg length was correlated with flexum-recurvatum angle >10° (*P* < .0001), 2D varus/valgus angle >5° (*P* = .001), and 3D varus/valgus angle >10° (*P* = .009). Two and 3D measurements of length were not found to correlate with limb-length perception (*P* > .1). We did not find any correlation between patient perception and femoral torsion (*P* = .674) and tibial torsion (*P* = .992). In multiple logistic regression analysis, we found that patients who had >10° degrees of flexum/recurvatum were 2.1 times more likely to perceive unequal leg length (95% CI: 0.9-5; *P* = .09). Those patients who had an uncorrectable varus/valgus knee deformity were 4 times more likely to perceive unequal leg length (95% CI: 1-15; *P* = .04).

Regarding repeatability and reproducibility, interclass correlation coefficients >0.95 were found for all measurements except tibial mechanical angle (0.91 for 2D and 0.92 for 3D; Tables 4 and 5).

Discussion

Leg-length discrepancy is a common finding in degenerative disease of the hip and knee, a common complaint after hip or knee arthroplasty, and sometimes results in costly litigation [19-21]. In one study, 30% of the patients perceived different leg length after total hip arthroplasty [22] and only 36% of these patients had a true limb-length discrepancy in imaging studies. This topic has been previously studied, yet much remains to be understood. Patients are aware of limb-length discrepancy in the standing position, but the limb-length discrepancy is mostly assessed by clinical examination in supine position or radiographic studies such as x-ray, CT, and magnetic resonance imaging that are also obtained in supine position. These methods do not take into account the sagittal or coronal knee deformities and their potential correctability or the spinal pathologies and their effect on coronal or sagittal pelvic tilt. The prevalence of anatomical leg-length discrepancy is diversely described in the literature [23-25]. Different authors report an anatomical limb-length discrepancy of 5 mm or more in 90% of the population [23-25]. They found that 20% of their patients had a discrepancy in leg length of 10 mm or more and 6%-8% had a difference of 14 mm or more [24-26]. Some of the other factors that could potentially affect the leg-length perception have been assessed, including gender [27-30] and height [27,31]. Factors such as coronal and sagittal knee alignment and its reducibility are not extensively studied.

Agreement of 2D and 3D Measurements of Leg Length and Knee Coronal and Sagittal Alignment

Most of the previously published studies did not use 3D imaging methods. The reliability of long-leg radiographic techniques such as orthoroentgenogram, scanogram, and computerized digital radiographs may not be very high due to parallax and magnification error or methodologic differences between publications [32]. Our study found that both functional and anatomical leg-length measurements were different between 3D and 2D imaging. In all measurements, the mean 3D imaging measurements were higher than the mean 2D measurements. We also found a difference between 2D and 3D measurements of knee coronal alignment (varus/valgus) and sagittal alignment (genu flexum/recurvatum). The 3D measurements are more accurate due to the consideration of the

3D Parameters	Perceived Equal Leg Length			Did Not Perceive Equal Leg Length			*P* Value
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
3D femoral length	42.5	35.4	47.3	41.9	35.2	47.3	.414
3D tibial length	41.9	35.2	47.3	36.1	30.4	41.3	.791
3D functional length	79.5	67.5	88.7	77.7	65.1	88.2	.993
3D anatomical length	79.4	67.1	88.2	78.1	65.6	88.3	.949
3D coronal knee alignment	−0.5	−14.1	11.8	−1.6	−19.2	10.7	.025
3D knee flexum/recurvatum	4.3	−15.1	36.2	12.6	−11	44.5	.04
Femoral torsion	14.9	−5.3	38.8	11.8	−45	40	.07
Tibial torsion	31.4	6.2	52.4	32.1	9.3	52.9	.375

Functional length: distance from the center of the femoral head to the center of the ankle joint (cm). Anatomical length: sum of the anatomical femoral and tibial lengths (cm). Varus knee angle (°) and genu recurvatum (°) are considered negative. Valgus knee angle (°) and genu flexum (°) are considered positive.
3D, three dimensional.

Table 3
Agreement Between Patients' Perceptions of the Limb Length and Objective Measurements.

Parameters	Percentage of Agreement	Fairness of the Agreement	Kappa Value
2D functional length	77	Moderate	0.535
2D anatomic length	73	Moderate	0.434
3D functional length	70	Fair	0.395
3D anatomic length	60	Slight	0.129

femoral and tibial torsion. This has been shown in other studies. Thelen et al. [33] assessed 2D and 3D images of the knee for the accuracy of the HKA angle. They measured the angle with the knee flexed 0°, 9°, and 18° and found 1.4°, 4.7°, and 6.8° error, respectively, between the 2D and 3D images. Of course, 3D imaging is not available in all centers and it might be more expensive to obtain. The orthopedic surgeons can assess the alignment of the lower extremity during the physical examination and consider 3D imaging in patients with severe malalignment or torsional deformities.

Correlation of Patients' Perceptions of Leg Length With 2D and 3D Imaging

To the best of our knowledge, no previous studies have assessed the correlation between the perception of limb-length discrepancy and the knee alignment or lower extremity torsion as possible factors influencing individual adaptation. In this study, we have demonstrated the influence of knee frontal and sagittal plane alignment deformities and the impact of the reducibility of these deformities on patient perception of leg length. Many patients who have degenerative hip arthritis also have degenerative knee disease with sagittal or coronal alignment deformity. The odds of having a perception of unequal leg length was 2.1 if patients had >10° of genu flexum/recurvatum. Those patients who had uncorrectable varus/valgus deformity of their knee were 4 times more likely to perceive unequal leg length. These malalignment or torsional deformities can be easily found during the physical examination, but these conditions are usually missed during clinic visits because orthopedic surgeons simply do not evaluate patients in standing position, while walking, or while wearing examination gown or shorts (instead of street clothes). Many orthopedic surgeons might be cautious in asking their patients about their perception of limb length because this may trigger concerns about postoperative limb-length discrepancy. It is important to inform patients about the normal differences in leg length in the general healthy population and discuss the other factors that can affect the perception of the leg length, such as disorders of the spine or other lower extremity joints.

Table 4
Interobserver Agreement Results From Bland and Altman Test for Two-Dimensional (2D) Images.

2D Parameters	ICC	95% Confidence	Interreader Agreement (Bland-Altman)
Femoral length (mm)	0.99	0.9989-0.9994	0.0 ± 2.3
Tibial length (mm)	0.99	0.9990-0.9995	0.1 ± 2.1
Anatomic length (mm)	0.99	0.9995-0.9997	0.2 ± 3.0
Functional length (mm)	0.99	0.9993-0.9996	0.0 ± 3.5
Femoral mechanical angle (°)	0.97	0.9639-0.9813	0.1 ± 1.6
Tibial mechanical angle (°)	0.91	0.8768-0.9349	−0.1 ± 2.8
HKS (°)	0.99	0.9880-0.9938	−0.02 ± 0.49
Flexum/recurvatum (°)	0.99	0.9989-0.9994	−0.03 ± 0.90
Hip-knee-ankle angle (°)	0.99	0.9984-0.9992	−0.07 ± 0.53

HKS, Hip-Knee-Shaft angle; ICC, interclass correlation coefficient.

Table 5
Interobserver Agreement Results From Bland and Altman Test for Three-Dimensional (3D) Images.

3D Parameters	ICC	95% Confidence	Interobserver Agreement (Bland-Altman)
Femoral length (mm)	0.99	0.9982-0.9991	0.0 ± 2.9
Tibial length (mm)	0.99	0.9978-0.9989	−0.1 ± 3.0
Anatomic length (mm)	0.99	0.9991-0.9995	−0.2 ± 3.7
Functional length (mm)	0.99	0.9994-0.9997	−0.3 ± 2.9
Femoral mechanical angle (°)	0.95	0.9432-0.9705	0.1 ± 1.6
Tibial mechanical angle (°)	0.92	0.8985-0.9466	−0.1 ± 2.9
HKS (°)	0.97	0.9663-0.9826	−0.01 ± 0.64
Flexum/recurvatum (°)	0.99	0.9986-0.9993	−0.0 ± 1.0
Hip-knee-ankle angle (°)	0.99	0.9963-0.9981	−0.01 ± 0.82

HKS, Hip-Knee-Shaft angle; ICC, interclass correlation coefficient.

Limitations

Our study has some shortcomings. The subjects did not have any hip or knee arthroplasties but were evaluated for hip or knee degenerative joint disease and treated nonoperatively. It would have been informative to assess the patients for limb-length discrepancy after arthroplasty surgery. We also assessed the correctability of the varus/valgus deformity by physical examination instead of radiograph to limit radiation exposure to the patient and surgeon. Although an experienced senior surgeon performed all measurements, there is still the possibility of inaccurate measurements. In addition, our study did not consider foot and ankle deformities.

Conclusions

The patient perception of limb length can be better correlated with the knee varus/valgus and flexum/recurvatum deformity and their correctability than with the objective anatomical lengths of the femur and tibia. This study opens new perspectives for better understanding of true and apparent limb-length discrepancy and improving the evaluation of medical legal issues after joint arthroplasty or trauma surgeries. This can help orthopedic surgeons in discussions of the causes of the apparent limb-length discrepancy with their patients. This study also emphasizes the importance of 3D measurements in outlier cases, such as severe varus or valgus deformity and severe genu flexum/recurvatum of the knee. Most of these outliers can be recognized with a thorough physical examination in standing position.

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