

# Prevalence of Tibia Valga Morphology in Valgus Knees and its Implications for Primary Total Knee Arthroplasty

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## Research Article

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# Abstract

## Introduction

Tibia valga, an extra-articular valgus deformity of the tibia, is common in valgus knees and can result in component misplacement and early total knee arthroplasty (TKA) failure. However, the prevalence and importance of tibia valga in TKA has been seldom reported. This study aims to describe the prevalence and characteristics of tibia valga morphology in valgus knees and describes implications for surgical planning in primary TKA.

## Methods

We prospectively examined pre-operative weightbearing whole-body EOS digital radiographs of patients with knee osteoarthritis listed for TKA between December 2018 and December 2020. Hip-knee-ankle angle (HKA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), joint line convergence angle (JLCA) and tibial morphology with centre of rotation of angulation of tibia (CORA-tibia) were measured and analysed.

## Results

In 830 knees, 253 (30%) and 577 (70%) were classified as valgus and varus respectively. In valgus knees, 89 knees (35%) had tibia valga. Median CORA-tibia was  $2.8^\circ$  (range  $0.2-10.9^\circ$ ). Tibia valga knees had no difference in mLDFA, higher HKA ( $5.0^\circ$  versus  $3.0^\circ$ ,  $p=0.002$ ) and mMPTA ( $89.6^\circ$  versus  $88.1^\circ$ ,  $p<0.01$ ), and lower JLCA ( $2.1^\circ$  versus  $2.3^\circ$ ,  $p<0.01$ ) compared to non-tibia valga knees. Tibia valga deformity was weakly positively correlated with valgus HKA ( $\rho=0.23$ ,  $p<0.001$ ) and mMPTA ( $\rho=0.38$ ,  $p<0.001$ ). In varus knees, there were 52 cases of tibia valga (9%) with median CORA-tibia of  $3.0^\circ$  (range  $0.5-5.5^\circ$ ). Tibia valga knees had higher mMPTA ( $87.0^\circ$  versus  $85.2^\circ$ ,  $p<0.05$ ) and no difference in HKA, mLDFA and JLCA. CORA-tibia was weakly positively correlated with mMPTA.

## Conclusions

Tibia valga is common in valgus knees, occurring in 35% of this population. Extra-articular tibial rather than distal femoral anatomy contributes most to valgus HKA. To detect the deformity, full leg-length radiographs should be acquired pre-operatively. Intramedullary instrumentation should be used cautiously in knees with tibia valga when performing TKA.

## Introduction

Coronal alignment of prosthetic components is a critical variable in determining the success of a total knee arthroplasty (TKA).<sup>1-4</sup> Achieving proper alignment permits balance of soft tissues and reduced shear and mechanical stresses on the femoral and tibial components as well as degradation of the

prosthetic articular surface.<sup>4-8</sup> Poor alignment of TKA components results in poor functional outcomes and survivorship of the implants which are common in valgus knees.<sup>4,5,8,9</sup>

Correction of valgus deformity to neutral alignment remains a challenge.<sup>3</sup> Approximately 10% of patients undergoing total knee arthroplasty (TKA) present with a valgus deformity.<sup>10</sup> The technical challenges associated with correcting a valgus deformity in TKA arise due to two main reasons: firstly, a unique combination of bone-tissue and soft-tissue anatomical variations make it difficult to ensure proper post-surgical alignment; secondly, the lack of adequate pre-operative imaging in the planning phase of TKA which results in less than optimal tibial component placement.<sup>2</sup> The importance of recognising tibial morphology has been previously demonstrated in varus knees where tibial bowing can result in suboptimal tibial cuts in TKA, which increases the risk of varus placement of tibial components.<sup>11</sup>

In the literature, it has been historically documented that the majority of knee valgus are primarily due to deformities in the femur, with the conjecture that correction should therefore take place at the femur.<sup>12</sup> However, recently there has been a shift in this theory, suggesting that an isolated deformity in the tibia contributes to the majority of cases with valgus knees.<sup>12</sup>

Tibia valga, an extra-articular deformity of the tibia, has been suggested to be a common implicating anatomical variation in valgus knees. Utilisation of intramedullary jigs and tibial stems in valgus knees with such a morphology have been demonstrated to result in malpositioning and cortical impingement, and therefore increase the risk of an iatrogenic tibial fracture if pre-operative planning is inadequate.<sup>13</sup> To date, the literature on the subject is limited, with only two studies using full lower-limb weightbearing x-rays examining this morphology in detail despite its potential implications on tibial component placement in TKA.<sup>12,14</sup>

This study aims to describe the prevalence and characteristics of tibia valga morphology in osteoarthritic knees. We also draw implications from these findings to inform and improve pre-operative planning for TKA.

## Methods

This single-centre study protocol was approved by the hospital ethics committee (HREA – SS000359). Patients undergoing primary TKA between December 2018 and December 2020 were drawn from our prospective database and reviewed against the eligibility criteria.

## Inclusion criteria

Patients diagnosed with idiopathic knee osteoarthritis requiring primary TKA by one of the two arthroplasty surgeons (DF, RK) in the above-mentioned timeframe were included. Furthermore, pre-operative imaging of their knees using weightbearing whole body low radiation biplanar EOS digital radiographs had to be available.

# Exclusion criteria

Exclusion criteria included patients with knee osteoarthritis secondary to a traumatic or congenital pathology, history of previous femoral or tibial osteotomy, fracture of the femur or tibia with or without internal fixation, partial arthroplasty of the knee or TKA.

## Radiographic measurements

Digital radiographs were accessed with the hospital's imaging archiving and communication system (IntelePACS) and measurements were performed with its software (InteleViewer, Intelrad Medical Systems Incorporated, Montreal, Canada). This software contains a ruler, circle and goniometer tools which allows identification of anatomical landmarks to make measurements. Previous studies have demonstrated excellent accuracy, reliability and reproducibility of digital orthopaedic measurements relative to manual modalities.<sup>15,16</sup> The following pre-operative knee radiographic angles (°) were measured to determine the prevalence and characteristics of tibia valga morphology. All measurements were performed by an experienced arthroplasty fellow (MF):

1. *Hip-knee-ankle (HKA) angle*. Used as a measure of lower limb alignment to determine if the knee joint is either in varus or valgus, defined as the angle between the mechanical axes of the femur and tibia.<sup>17</sup> The mechanical axes of the femur and tibia were defined by a line from cortical centre of the femoral head to the cortical centre of the femoral intercondylar notch and a line from the cortical centre of the talus to the centre of the tibial plateau respectively (**Fig. 1**).<sup>18-20</sup> In healthy adults, neutral alignment is between 1.0° and 1.5° of varus.<sup>17</sup>
2. *Mechanical lateral distal femoral angle (mLDFA)*. Used as a measure of deformity for the distal femur. Defined by the angle between the mechanical axis of the femur described above and the articular surface of the femur (**Fig. 2**).<sup>18-20</sup> In normal knees, the mean mLDFA is 87.5° valgus with a range of 85° to 90°.<sup>20</sup>
3. *Mechanical medial proximal tibial angle (mMPTA)*. A measure of deformity for the proximal tibia which was defined by the angle between the mechanical axis of the tibia described above and the articular surface of the proximal tibia (**Fig. 3**).<sup>18-20</sup> In normal knees, the mean mMPTA is 87.5° varus with a range of 85° to 90°.<sup>20</sup>
4. *Joint line convergence angle (JLCA)*. Measured to evaluate knee joint congruity. Defined as the angle of the two articular surface lines of the distal femur and the proximal tibia. The angle was determined by the femoral condylar joint and the tibial plateau joint line (**Fig. 4**).<sup>20,21</sup>
5. *Centre of rotation angulation of proximal tibia (CORA-tibia)*. Used as a measure of tibia valga. The anatomic axis of the tibia in the frontal plane was determined by a line drawn proximal to distal in the intramedullary canal passing the bicortical centre of the tibial shaft at 20cm below the tibial plateau, bisecting the tibia in half and should be parallel to its mechanical axis.<sup>5,14,22</sup> The CORA-tibia was utilised when the mechanical and anatomical axes are not parallel and is defined by using a line originating proximally at the mid-point of the tibia plateau and another distally from the anatomic

bicortical centre of the distal tibia shaft.<sup>14,20</sup> The angle formed by the convergence of these two lines defined the CORA-tibia (Fig. 5).<sup>14,20</sup>

## Statistical analysis

Statistical analyses were performed using R (V4.0.0; R Core Team, Vienna, Austria). Knee radiographs were stratified into valgus and varus knee groups according to their HKA angle measurements and further subdivided as tibia valga or non-tibia valga according to their CORA-tibia measurement. Shapiro-Wilk tests on angular measurements revealed that they were not parametric. Unpaired two-samples Mann-Whitney U tests were performed for univariate analyses and correlation matrices using Spearman's rho values.  $p < 0.05$  was considered statistically significant.

## Results

A total of 830 knees from 520 patients satisfied the criteria for analysis. Measurement of the HKA angle revealed that 253 (30%) and 830 (70%) knees were classified as valgus and varus, respectively. Radiographic characteristics of the valgus and varus knee groups respectively are described in Table 1 and Table 2.

### Valgus knee group radiographic analysis

CORA-tibia measurements revealed 35% (89 out of 253) of the valgus knees demonstrated a tibia valga morphology. Overall, there was no difference in mL DFA when comparing valgus knees with and without a tibia valga morphology ( $p > 0.05$ ). Valgus knees with tibia valga had greater angular deformity (HKA) compared to non-tibia valga knees ( $5.0^\circ$  versus  $3.0^\circ$ ,  $p = 0.002$ ). The average mMPTA in valgus knees ( $89.6^\circ$ ) with tibia valga was within the normal reference range and was found to be significantly higher than those valgus knees without a tibia valga morphology ( $p < 0.001$ ). Convergence of the knee joint (JLCA) was significantly lower in valgus knees with tibia valga compared to those without tibia valga ( $p < 0.05$ ). No valgus knees demonstrated a tibia vara morphology. Furthermore, CORA-Tibia was shown to be positively but weakly correlated with HKA ( $p < 0.001$ ) and mMPTA ( $p < 0.001$ ) respectively (Table 3).

### Varus knee group radiographic analysis

CORA-tibia measurements revealed that 9% (52 out of 577) varus knees demonstrated a tibia valga morphology. There was no difference in mL DFA and JLCA when comparing varus knees with and without a tibia valga morphology ( $p > 0.05$ ). Varus knees with tibia valga had a lower HKA compared to non-tibia valga knees ( $4.0^\circ$  versus  $5.0^\circ$ ,  $p = 0.039$ ). Furthermore, the average mMPTA in varus knee with tibia valga was found to be significantly higher than those varus knees without a tibia valga morphology although the mMPTA in these knees was within the normal reference range ( $p < 0.05$ ). In this group, CORA-tibia was shown to be weakly positively correlated with mMPTA ( $p < 0.05$ ) (Table 4).

## Discussion

Our study illustrates the prevalence and characteristics of tibia valga in a cohort of patients with knee osteoarthritis using EOS imaging technology. Firstly, we showed that tibia valga morphology is common in valgus knees, with 35% of knees demonstrating this anatomical variant. Secondly, we showed that the distal femur in valgus knees with tibia valga is within the normal anatomical range. Thirdly, we demonstrated that the degree of tibia valga is positively correlated to the overall angular deformity of patients with valgus knees. Therefore, we can conclude that a significant proportion of valgus knees have an extra-articular deformity of the tibia which might be the primary contributor of this deformity rather than the distal femoral anatomy.

The results of our study are consistent with the only two other studies<sup>13,14</sup> which have radiographically analysed tibia valga morphology in valgus knees. Alghamdi et al's<sup>14</sup> (2014) retrospective review of 97 osteoarthritic valgus knees prior to TKA via full lower limb weightbearing x-rays demonstrated a similar prevalence of tibia valga to ours, with 53% of valgus knees illustrating a tibia valga. Furthermore, they also demonstrated that the extra-articular tibia valga deformity was an isolated deformity, with mLDFA reported to be within normal limits and contributed significantly to the overall mechanical femorotibial alignment.<sup>14,20</sup> This is also consistent with Eberbach et al's<sup>19</sup> (2016) study challenging the previously accepted dogma that the primary deformity of valgus knees originates in the femur. Our results not only demonstrate the characteristics of tibia valga morphology, but we also demonstrate that there is a positive correlation between the magnitude of the deformity (CORA-tibia) and the overall HKA valgus deformity of the knee.

Our results demonstrate the importance of screening for tibia valga as part of pre-operative planning as it can have implications for the TKA procedure. Restoring the mechanical axis of the lower limb and ensuring accurate cuts of the femur and tibia are critical in determining the success and survivorship of a TKA.<sup>23</sup> Restoration of the mechanical axis is achieved through bone cuts perpendicular to the mechanical axes of the femur and tibia respectively. It has been previously demonstrated that usual tolerance of error for bone cuts is approximately 3° from its ideal position.<sup>24</sup> The correct placement of cutting jigs and alignment guides are critical in ensuring accurate placement of femoral and tibial components in TKA.<sup>25</sup> Although intra-articular causes of valgus deformities can be managed intra-operatively, extra-articular deformities of the lower limb may be overlooked both clinically and surgically. Figure 6 illustrates such an example, where tibia valga can be overlooked if only knee x-rays for operative planning. Given the small window for error for component placement in TKA means that presence of a tibia valga deformity can significantly mislead the orthopaedic surgeon in their tibial cuts.<sup>24</sup> Therefore, we recommend that the surgeon adequately plan their TKA with pre-operative lower limb weightbearing radiographs to screen for extra-articular deformities which may contribute to the angular deformity of the knee, given their common prevalence. Previous studies have demonstrated the benefit of standing lower limb films compared to short-leg films which many orthopaedic surgeons still utilise in the pre-operative planning phase, with their greater accuracy in determining overall tibiofemoral alignment.<sup>26-28</sup>

Furthermore, the common prevalence of tibia valga morphology in valgus knees suggests implications regarding the optimal approach for tibial component placement in TKA. On average in non-arthritic knees, the articular surface of the tibia is 3° varus to its mechanical axis.<sup>13</sup> However studies have demonstrated that tibial component placement in TKA should be 90° to the mechanical axis as this allows the prosthetic component to evenly distribute its weight across the tibia and therefore prolong the survivorship of the implant.<sup>14,25,29</sup> The literature has differing evidence regarding the use of intramedullary and extramedullary tibial cutting guides in TKA. Although Reed et al's<sup>30</sup> (2002) randomised-controlled trial comparing intramedullary and extramedullary cutting guides for tibial resection in 135 TKAs demonstrated that intramedullary cutting guides resulted in a significantly better tibial alignment compared to extramedullary cutting guides, Ko et al (2007)<sup>31</sup> and Yau et al (2007)<sup>32</sup> demonstrated that intramedullary cutting guides in varus knees performed poorly with up to 30% of patients receiving unacceptable tibial cuts. Additionally, Dennis et al<sup>33</sup> (1993) demonstrated that the use of extramedullary cutting guides in TKA resulted in better tibial component alignment compared to intramedullary cutting guides (88% versus 72%). Given the increased likelihood of cortical impingement of the intramedullary cutting guide which can result in less accurate tibial cuts in a valgus knee with significant tibia valga, we suggest the utilisation of extramedullary cutting guides in these knees. Palanisami et al's<sup>13</sup> (2019) study reaffirms this suggestion, demonstrating that excellent prosthetic component placement can be achieved in valgus knees with tibia valga using extramedullary cutting guides. Additionally, we recommend post-TKA lower limb weightbearing radiographs to ensure adequate component placement, especially in cases of tibia valga where tibial component placement may appear in varus relative to the proximal tibia.

## Limitations

This study must be viewed in consideration of its limitations. We included all patients with EOS scans, irrespective of rotation, therefore scans where the patella was not visible over the femoral condyles were included. This may reduce the accuracy of the geometric values which were obtained in this study; however, we used an experienced arthroplasty fellow to ensure the most consistent and reproducible measurements were made. Secondly, given the cross-sectional nature of this study, it does not highlight the aetiology and progression of tibia valga (for example, if it is due to lateral compartment knee osteoarthritis or a congenital or developmental deformity). Furthermore, our results demonstrated that tibia valga is also an uncommon occurrence in varus knees. What we know from the literature is that when lower-limb alignment changes, the of distribution of stress forces on the tibia can change and result in bone-remodelling which may account for this observation.<sup>34</sup> Therefore, longitudinal radiographic studies of patients experiencing knee osteoarthritis can help to address this gap in the literature.

## Conclusions

Tibia valga is a common anatomical morphology occurring in 35% of patients with valgus knee osteoarthritis, whereas it is uncommon in varus knees. Our findings suggest that in this cohort, the extra-

articular tibial rather than distal femoral anatomy contributes most to valgus HKA. To detect the deformity, full leg-length radiographs should be acquired pre-operatively. Intramedullary instrumentation should be used with caution in knees with significant tibia valga when performing TKA.

## Declarations

**Conflict of interest statement:** None

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## Tables

**Table 1.** Radiographic analysis of valgus knees according to presence of tibia valga.

<i>Parameter</i>	<b>Tibia Valga</b> (89/253 = 35%)			<b>Non-Tibia Valga</b> (164/253 = 65%)			<i>P-value</i>
	<i>Median</i>	<i>Q1-Q3</i>	<i>Min-Max</i>	<i>Median</i>	<i>Q1-Q3</i>	<i>Min-Max</i>	
<b>HKA</b>	5.0	2.0-8.0	0.0-14.0	3.0	1.0-6.0	1.0-6.0	<b>0.002</b>
<b>mLDFA</b>	85.5	84.1-91.0	79.9-97,6	85.5	84.2-86.8	79.7-97.1	0.97
<b>mMPTA</b>	89.6	88.3-89.6	84.1-94.8	88.1	86.9-89.3	84.0-95.4	<b>&lt;0.001</b>
<b>JLCA</b>	2.1	0.7-2.87	0.0-9.43	2.3	0.9-3.3	0.0-8.8	<b>0.045</b>
<b>CORA-Tibia</b>	2.8	2.0-3.73	0.23-10.9	0.0	0.0-0.0	0.0-0.0	<b>&lt;0.001</b>

Q1-Q3: Interquartile range; HKA: Hip-knee-ankle; mLDFA: mechanical lateral distal femoral angle (° in valgus); mMPTA: mechanical medial proximal tibial angle (° in varus); JLCA: joint line convergence angle; CORA-Tibia: centre of rotation angulation of tibia.

**Table 2.** Radiographic analysis of varus knees according to presence of tibia valga.

<i>Parameter</i>	<b>Tibia Valga</b> (52/577 = 9%)			<b>Non-Tibia Valga</b> (525/577 = 91%)			<i>P-value</i>
	<i>Median</i>	<i>Q1-Q3</i>	<i>Min-Max</i>	<i>Median</i>	<i>Q1-Q3</i>	<i>Min-Max</i>	
<b>HKA</b>	4.0	2.0-7.0	0.0-17.0	5.0	3.0-9.0	0.0-25.0	0.039
<b>mLDFA</b>	87.8	86.4-89.0	83.1-93.9	87.7	86.4-89.0	81.2-103	0.79
<b>mMPTA</b>	87.0	85.50-88.6	81.4-92.6	85.2	83.8-86.7	69.6-94.1	<b>&lt;0.001</b>
<b>JLCA</b>	4.3	2.8-5.8	0.2-10.0	3.9	2.2-5.5	0.0-11.1	0.23
<b>CORA-tibia</b>	3.0	2.3-3.9	0.5-5.5	0	0.0-0.0	0.0-4.2	<b>&lt;0.001</b>

Q1-Q3: Interquartile range; HKA: Hip-knee-ankle; mLDFA: mechanical lateral distal femoral angle (° in valgus); mMPTA: mechanical medial proximal tibial angle (° in varus); JLCA: joint line convergence angle; CORA-Tibia: centre of rotation angulation of tibia in varus.

**Table 3.** Correlation matrix of knee alignment variables in valgus knees with tibia valga.

		HKA	mLDFA	mMPTA	JLCA	CORA-Tibia
<b>HKA</b>	Spearman's rho	-	-	-	-	-
	<i>P</i> -value	-	-	-	-	-
<b>mLDFA</b>	Spearman's rho	<b>-0.4208</b>	-	-	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	-	-	-	-
<b>mMPTA</b>	Spearman's rho	<b>0.2633</b>	-0.0063	-	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	0.920	-	-	-
<b>JLCA</b>	Spearman's rho	<b>0.3565</b>	<b>-0.1438</b>	-0.0489	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	<b>0.022</b>	0.438	-	-
<b>CORA-Tibia</b>	Spearman's rho	<b>0.2278</b>	0.0017	<b>0.3812</b>	0.135	-
	<i>P</i> -value	<b>&lt; 0.001</b>	0.979	<b>&lt; 0.001</b>	0.592	-

HKA: Hip-knee-ankle; mLDFA: mechanical lateral distal femoral angle; mMPTA: mechanical medial proximal tibial angle; JLCA: joint line convergence angle; CORA-Tibia: centre of rotation angulation of tibia in varus.

**Table 4.** Correlation matrix of knee alignment variables in varus knees with tibia valga.

		HKA	mLDFA	mMPTA	JLCA	CORA-Tibia
<b>HKA</b>	Spearman's rho	-	-	-	-	-
	<i>P</i> -value	-	-	-	-	-
<b>mLDFA</b>	Spearman's rho	<b>0.3284</b>	-	-	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	-	-	-	-
<b>mMPTA</b>	Spearman's rho	<b>-0.5990</b>	-0.0167	-	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	0.690	-	-	-
<b>JLCA</b>	Spearman's rho	<b>0.5932</b>	0.0526	<b>-0.2046</b>	-	-
	<i>P</i> -value	<b>&lt; 0.001</b>	0.208	<b>&lt; .001</b>	-	-
<b>CORA-Tibia</b>	Spearman's rho	-0.0412	-0.0056	<b>0.1185</b>	0.0721	-
	<i>P</i> -value	0.325	0.894	<b>0.004</b>	0.084	-

HKA: Hip-knee-ankle; mL DFA: mechanical lateral distal femoral angle; mMPTA: mechanical medial proximal tibial angle; JLCA: joint line convergence angle; CORA-Tibia: centre of rotation angulation of tibia in varus.

## Figures



Figure 1

**Hip-knee-ankle (HKA) angle.** A pre-operative weightbearing lower-limb anteroposterior EOS digital radiograph is shown. The HKA is the angle between the femoral and tibial mechanical axes. Varus, negative; valgus, positive.



**Figure 2**

**Mechanical lateral distal femoral angle (mLDFA).** A pre-operative weightbearing lower-limb anteroposterior EOS digital radiograph is shown. The mLDFA is the angle between the mechanical axis of the femur and its articular surface.



**Figure 3**

**Mechanical medial proximal tibial angle (mMPTA).** Pre-operative weightbearing lower-limb anteroposterior EOS digital radiograph is shown. The mL DFA is the angle between the mechanical axis of the femur and its articular surface.



**Figure 4**

**Joint line convergence angle (JLCA).**

Close-up of the knee joint of a pre-operative, weightbearing lower-limb anteroposterior EOS digital radiograph is shown. The JLCA is the angle formed by the articular surfaces of the femur and tibia.



**Figure 5**

**EOS radiograph demonstrating measurement of extra-articular tibial deformity in valgus knee.** Close-up of the knee joint and leg of a pre-operative, weightbearing lower-limb anteroposterior EOS digital radiograph is shown. The angle formed by the proximal and distal tibial mechanical axes is the centre of rotation angulation (CORA-tibia).

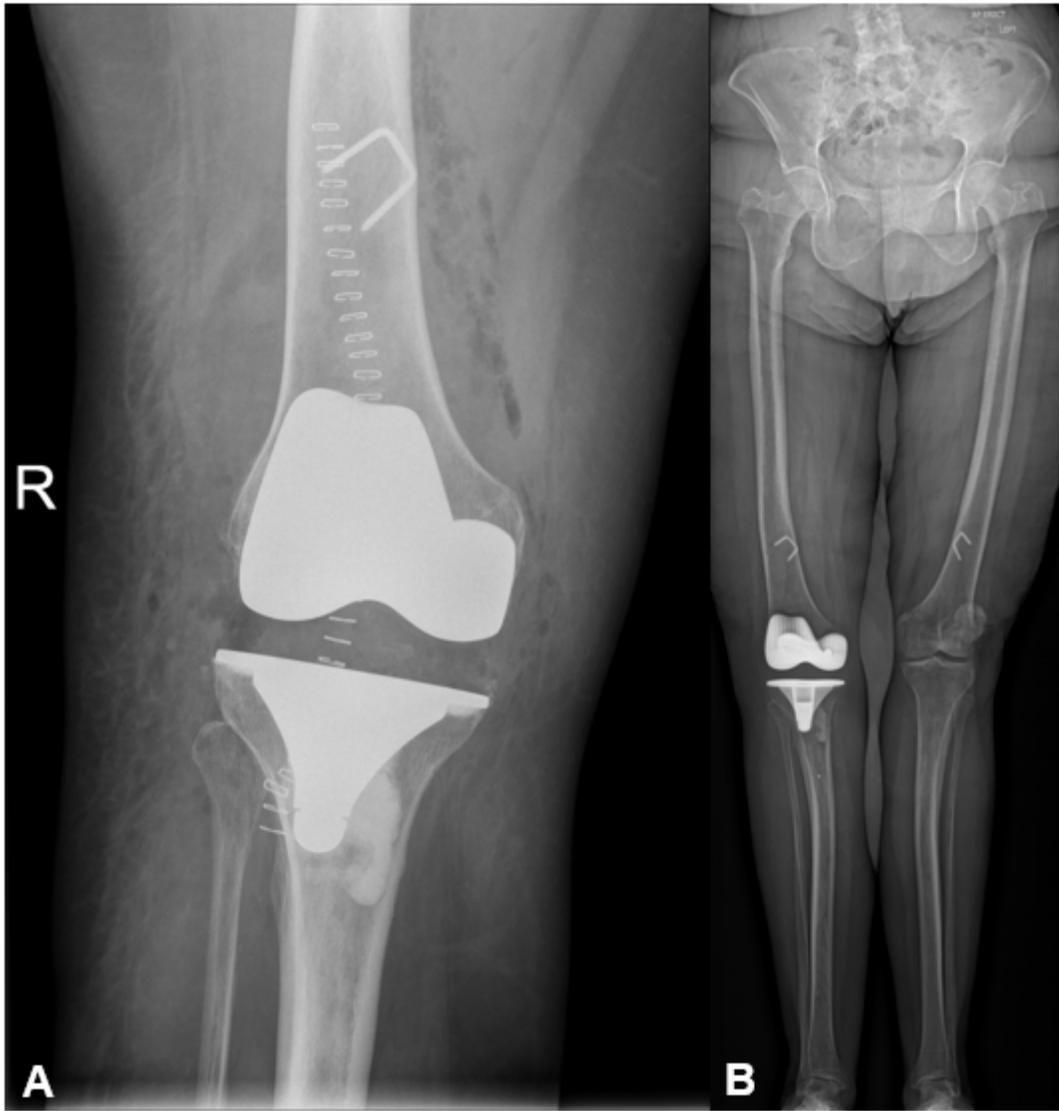


Figure 6

**Clinical significance of full lower limb weightbearing radiographs in total knee arthroplasty (TKA).** (A) Post-TKA anteroposterior radiograph of the right knee demonstrating satisfactory position. (B) Same patient with a post-TKA weightbearing lower-limb anteroposterior EOS digital radiograph, demonstrating a persisting tibia valga deformity and post-operative valgus alignment of the right lower limb.