



Assessment of the tibial slope is highly dependent on the type and accuracy of the preceding acquisition

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Abstract

Background Precise measurement of the tibial slope (TS) is crucial for realignment surgery, ligament reconstruction, and arthroplasty. However, there is little consensus on the ideal assessment. It was hypothesized that the tibial slope changes according to the acquisition technique and both tibial length as well as femoral rotation serve as potential confounders.

Methods 104 patients (37 women, 67 men; range 12–66 years) were retrospectively selected, of which all patients underwent a 1.5-Tesla MRI and either additional standard lateral radiographs (SLR, $n=52$) or posterior stress radiographs (PSR, $n=52$) of the index knee. Two blinded observers evaluated the medial tibial slope as the medial TS is primarily used in clinical practice. Additionally, the length of the diaphyseal axis and the extent of radiographic malrotation were measured.

Results Mean TS on MRI was significantly lower compared to radiographs ($4.2^\circ \pm 2.9^\circ$ vs. $9.1^\circ \pm 3.6^\circ$; $p < 0.0001$). There was a significant correlation between MRI and PSR ($p < 0.0001$ with $r = 0.7$), but not with SLR ($p = 0.93$ with $r = 0.24$). Tibial length was a significant predictor for the difference between MRI and SLR (regression coefficient $\beta = -0.03$; $p = 0.035$), yet not between MRI and PSR ($\beta = -0.003$; $p = 0.9$). Femoral rotation proved to be a significant predictor for the agreement between both observers (PSR: $\beta = 0.14$; $p = 0.001$ and SLR: $\beta = 0.08$; $p = 0.04$). ICC indicated a high interrater agreement for the radiographic assessment ($ICC \geq 0.72$).

Conclusions There is a substantial variance between MRI and radiographic measurement of the tibial slope. However, as MRI assessment is time-consuming and requires specialized software, instrumented radiographs might be an alternative. Due care has to be taken to ensure that radiographs contain a sufficient tibial length, and femoral rotation is avoided.

Study design Case series (diagnosis); Level of evidence, 4.

Keywords Tibial slope · Knee · Measuring accuracy · MRI · Posterior stress radiographs

Introduction

Notwithstanding the contributions of soft tissue restraints on knee kinematics, there is an emerging consensus that the underlying tibial geometry has a comparable impact on

antero-posterior stability, center of rotation and loading of the cruciate ligaments [1–5].

More specifically, the dorsal inclination of the tibial plateau in the sagittal plane, namely the tibial slope (TS), has been shown to relate linearly to anterior tibial translation during simple weight-bearing activities [6]. Several authors have advocated that knowledge of the tibial slope is essential for anterior (ACL) [7–10] and posterior cruciate ligament (PCL) reconstruction [5, 11, 12], ACL and PCL graft failure [7, 12], high tibial osteotomies [13, 14], total knee arthroplasty (TKA) [15, 16] or prevention of knee injuries [17, 18].

Notably, there is little consensus on the ideal technique for the assessment of the tibial slope. Precise radiographic measurement usually requires a lateral radiograph, displaying the knee as well as the ankle joint, as short lateral

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radiographs might overestimate the tibial slope [19]. However, long-legged, lateral radiographs are rarely implemented in clinical routine and short lateral radiographs still serve, per definition of the American Knee Society, as the routine postoperative monitoring after TKA [20]. Malrotation of the knee in the x-ray beam may also result in additional measuring errors of the tibial slope [21]. These might be reduced in instrumented stress radiographs, as this technique enables to work with an orthogonal beam projection and a comparable tibial length. Albeit, computed tomography (CT) and magnetic resonance imaging (MRI) are advocated as the golden standard for TS assessment, as they allow an accurate assessment of the inherently complex anatomy of the proximal tibia. Furthermore cross sectional imaging facilitates precise multiplanar reconstruction, which mitigates measuring errors due to malrotation of the knee [22, 23].

By implication, the aim of the present study was to compare two different radiographic acquisition types with the golden standard MRI for the assessment of the tibial slope. The tested hypothesis was that instrumented stress radiographs yield in superior accuracy when compared to standard lateral radiographs. It was further sought to elucidate potential confounders during radiographic acquisition.

Methods

104 patients (37 women, 67 men; median age, 31 years; range 12–66) were retrospectively selected within a 2-year period (05/2014 to 05/2016). All patients underwent a 1.5-Tesla MRI, equipped with a dedicated 8-channel knee coil. Half of the cohort received either additional standard lateral radiographs (SLR; $n = 52$) or posterior stress radiographs (PSR; $n = 52$) of the index knee. Two blinded observers evaluated the posterior tibial slope on both modalities using a PACS workstation (Centricity RIS-I 4.2 Plus, GE Healthcare, Milwaukee, WI, USA). Each observer measured the tibial slope separately and the mean value of both observers was calculated, respectively.

Patients with realignment surgery, tumors or lower extremity fractures were excluded from analysis. The study protocol was approved by the institutional ethics commission (approval number: EA1/003/16 and EA2/067/17) and carried out in accordance with the Tenets of the Declaration of Helsinki. All patients (or the person having the care and custody of the child) gave informed consent.

Radiographic assessment

The tibial slope is defined as the angle formed at the intersection of the posterior inclination of the tibial plateau and a line perpendicular to the diaphyseal shaft axis of the tibia. TS was measured in the method by Dejour et al. [6]. As

the medial contour of the tibial plateau is commonly superimposed on lateral radiographs and thus primarily used in clinical practice, only the medial TS was measured on radiographs and MRI. The diaphyseal shaft axis was measured by two midpoints between the anterior and posterior tibial cortex at 5 cm below the tibial tuberosity and the most distal point below the tibial joint line. Subsequently, the TS is determined between the tangent line to the respective medial tibial plateau and the perpendicular to the established diaphyseal axis (Fig. 1).

Additionally, the length of the diaphyseal axis that was covered by the radiogram was measured. Peripheral bony landmarks were used to estimate the extent of radiographic malrotation. This was done in like manner to the technique proposed by Jacobsen et al. [24] for the assessment of posterior tibial translation. Perpendicular to the tangent of the joint line, the distance between the posterior femoral condyles was measured (Fig. 2).

MRI assessment

MRI was performed in supine position with the leg in full extension. The imaging protocol consisted of the following



Fig. 1 Measurement of the tibial slope. The TS is defined as the tangent line to the medial tibial plateau and to the longitudinal tibial axis



Fig. 2 Measurement of the extent of radiographic malrotation. Perpendicular to the joint line, the distance between the posterior femoral condyles was measured

sequences acquired at a 1.5 T whole-body MR system (MAGNETOM Avanto, Siemens, Erlangen, Germany) using a dedicated knee surface eight-channel receiver coil: coronal (TR/TE, 4100/37 ms; matrix, 320×320; bandwidth, 120 Hz/px), axial (TR/TE, 5310/47 ms; matrix, 320×272; bandwidth, 182 Hz/px) and sagittal (TR/TE, 5800/61 ms; matrix, 320×272; bandwidth, 120 Hz/px) fat saturated (FS) proton density two-dimensional (2D) turbo spin echo (TSE) sequences (slice thickness, 3 mm; field of view, 140 mm). Additionally, sagittal proton density 2D-TSE sequences without FS were used (slice thickness, 3 mm; TR/TE, 3000/20 ms; matrix, 384/384; bandwidth, 171 Hz/px).

For assessment of the tibial slope, the technique described by Hudek et al. [22] was applied using dedicated software (Visage 7, Visage Imaging Inc., Berlin, Germany). Briefly, multiplanar reconstruction was deployed to facilitate proper sagittal, axial, and coronal planes of the tibia and to determine the central sagittal image. A cranial as well as a caudal circle were positioned to fit the tibial head with the center of the caudal circle being located on the contour of the cranial one. Both circles were chosen as an overlay to remain in a fixed position on the complete image series. The diaphyseal

tibial axis was defined as the line connecting the midpoints of both circles. Taking this as a reference, the medial tibial slope was determined between a tangent line to the medial tibial plateau (Fig. 3).

Data analysis

Statistical analysis was performed using SPSS 22 (IBM Corporation, Armonk, NY, USA). Descriptive variables were either expressed as median, interquartile range (IQR) and range or as mean and standard deviation (SD)—depending on data distribution according to Shapiro–Wilk test. The comparison of parametric data was performed with a *t* test. Agreement between TS measured with MRI or radiographs as well as interrater agreement between both observers was rated with intraclass correlation ICC(2,1) according to Shrout and Fleiss [25] (absolute agreement). ICC benchmarks were used as proposed by Cicchetti [26] (poor, ICC < 0.4; fair, 0.4–0.59; good, 0.6–0.74; excellent, 0.75–1.0). The association of the quality of the acquired radiographs with TS differences between MRI and PSR/SLR or with the interrater agreement was analyzed with linear regression (independent variables: diaphyseal axis length, femoral rotation). Statistical significance was assumed at $p < 0.05$. Agreement between different methods was analyzed using Bland–Altman plots and 95% limits of agreement.

Results

Comparison of TS on MRI and radiographs

There was a significant difference between the mean TS on MRI and all radiographs ($4.2^\circ \pm 2.9^\circ$ vs. $9.1^\circ \pm 3.6^\circ$; $p < 0.0001$). The medial TS was by an average of $4.9^\circ \pm 3.3^\circ$ smaller on MRI compared to radiographs. This was evident for PSR ($4^\circ \pm 3.1^\circ$ vs. $8.9^\circ \pm 2.9^\circ$; $p < 0.0001$) and SLR ($4.4^\circ \pm 3.7^\circ$ vs. $9.3^\circ \pm 3.8^\circ$; $p < 0.0001$).

TS on MRI and PSR was significantly correlated ($p < 0.0001$ with $r = 0.7$) while no significant correlation could be established between MRI and SLR ($p = 0.93$ with $r = 0.24$). Corresponding Bland–Altman plots (Fig. 4) show smaller 95% limits of agreement for PSR (0.14° – 8.9°) than for SLR (-1.9° to 12.8°).

By average, the tibial length was 126 ± 16 mm for PSR and 119 ± 37 mm for SLR (n.s.). Femoral rotation was 2.7 ± 2 mm for PSR and 6.8 ± 5.1 mm for SLR ($p < 0.0001$). Linear regression analysis revealed that the length of the diaphyseal axis was a significant negative predictor for the difference of the medial TS between MRI and SLR [regression coefficient $\beta = -0.03$ (95% CI -0.06 to -0.002); $p = 0.035$]. The probability of exceeding a threshold of 4°

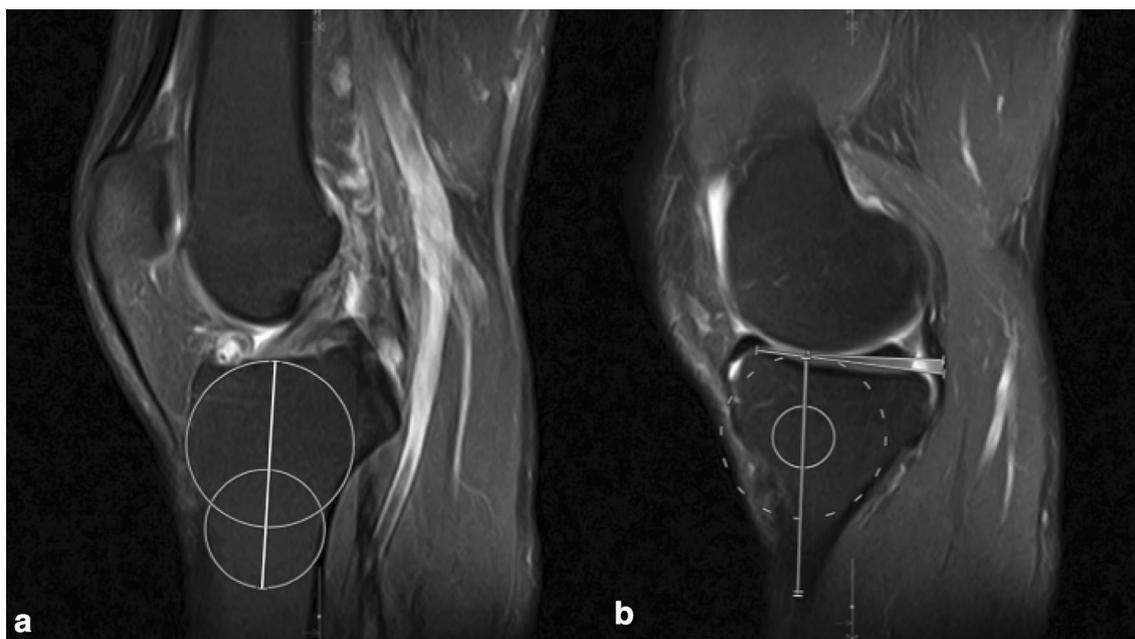


Fig. 3 Measurement of the medial TS according to Hudek et al. [22]. By connecting the centers of the cranial and the caudal circle the diaphyseal tibial axis is chosen (left). The tibial slope is determined as

the angle between the posterior inclination of the medial tibial plateau and a perpendicular line to the diaphyseal shaft axis (right)

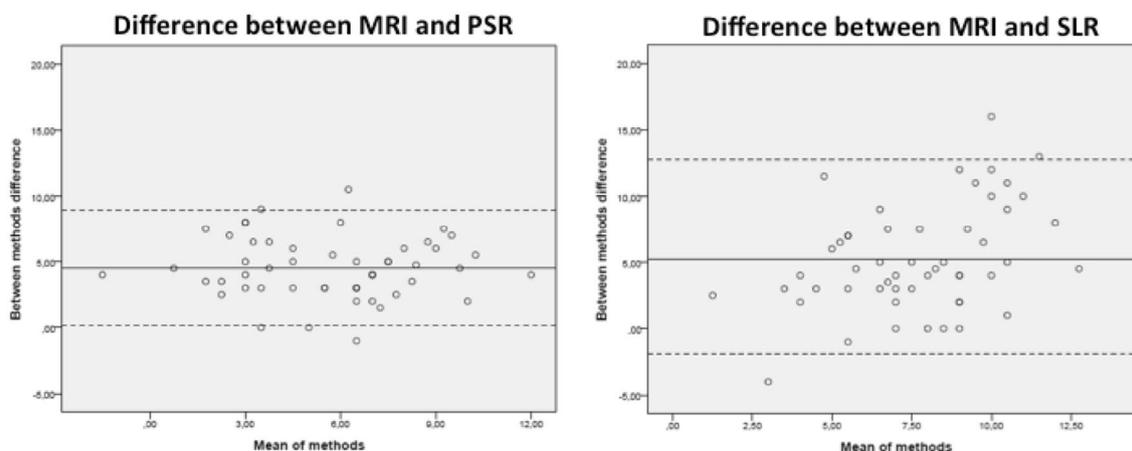


Fig. 4 Bland–Altman plots depicting smaller 95% limits of agreement for PSR (left) than for SLR (right)

difference between MRI and SLR (see Hudek et al. [22]) was considerably higher if the covered diaphyseal axis length was < 125 mm compared to ≥ 125 mm (probability, 62.5 vs. 35.0%). The length of the diaphyseal axis was not associated with TS differences between MRI and PSR [$\beta = -0.003$ (95% CI -0.04 to 0.04); $p = 0.9$]. The amount of femoral rotation was no significant predictor for the difference between MRI and both SLR as well as PSR.

MRI assessment of the tibial slope took significantly longer compared to its radiographic counterpart (147 ± 37 vs. 59 ± 8 s; $p < 0.0001$). ICC between the observers

indicated a high interrater agreement for the radiographic assessment (ICC > 0.75).

Interrater agreement in TS measurement on radiographs

ICC revealed an excellent agreement between the observers for PSR (ICC, 0.78; 95% CI, 0.65–0.87) and a good agreement for SLR (ICC, 0.72; 95% CI 0.53–0.84). The absolute TS difference between both observers was similar in PSR

(median, 2.0°; IQR, 1.0°–2.4°) compared to SLR (median 2.0°; IQR, 0°–4.0°; $p=0.16$).

Respective Bland–Altman plots (Fig. 5) illustrate smaller 95% limits of agreement for PSR (− 4.3° to 3.9°) compared to SLR (− 6.1° to 6.3°).

The amount of femoral rotation proved to be a significant positive predictor for higher differences between both observers [PSR: $\beta=0.24$ (95% CI 0.08–0.4); $p=0.005$ and SLR: $\beta=0.19$ (95% CI 0.08–0.29); $p=0.001$]. The probability of exceeding a threshold of 2° difference between both raters was considerably higher if femoral rotation was ≥ 5 mm compared to < 5 mm (probability for PSR, 36.4 vs. 22.0%; SLR, 47.8 vs. 23.5%). The length of the diaphyseal axis did not predict the interrater agreement.

Discussion

The most important finding of the present study is that measurement of the tibial slope is significantly influenced by the acquisition technique. In particular, assessment of the tibial slope on lateral knee radiographs yields in significantly different results compared to MRI. By average, the medial TS was $4.9^\circ \pm 3.3^\circ$ smaller on MRI compared to radiographs. As MRI analysis was shown to be significantly more time-consuming compared to radiographic assessment and required the use of specialized software, instrumented radiographs may serve as an alternative. There was significant agreement with the results of the MRI—as opposed to standard lateral radiographs. Thus the tested hypothesis was confirmed by the current results. The radiographic measurement of the tibial slope can further be improved by taking due care during acquisition. Femoral rotation, measured as the distance between the posterior aspects of the femoral

condyles, should fall below 5 mm. Furthermore, the radiogram should cover at least 125 mm of the diaphyseal axis length.

The tibial slope is awarded with increasing importance in current literature. To the best of the knowledge there has not been a quantitative definition of a nominal, physiological equivalent for the tibial slope. Quite the contrary, reports on the characteristics of the tibial slope vary considerably. Hoffmann et al. [27] reported the mean tibial slope to be 7° on knee radiographs. Matsuda advocated the mean medial tibial slope to be 10.7° in normal knees and 9.9° in varus knees, as measured on MRI [28]. Hudek et al. [22] determined a mean medial TS of 4.8° on MRI and 8.2° on lateral radiographs. In a cadaveric study, Weinberg postulated the mean medial TS to be 6.9° [29].

This variance can be mainly attributed to the method of measurement and the acquisition technique [30], which is also evident in the current study. Consequently, the tibial slope describes an acquisition-dependent tendency of the dorsal inclination of the tibial plateau and not a nominal figure. Notably, comparisons between cohorts, which are not measured by the same acquisition technique, will introduce considerable inaccuracy.

Regarded as a potential flaw, several studies have evaluated the impact of the tibial length on tibial slope measurement. The authors concluded, that long-legged x-rays are needed to accurately evaluate the tibial slope. The shorter the x-ray the “overestimated” the tibial slope is [19]. Of note, no institutional consensus has been reached on the necessary tibial length.

This was also evident in the current study. SLR, which showed a significantly higher femoral rotation than PSR, failed to agree with the gold standard MRI. As posterior stress radiographs facilitate both an orthogonal beam projection and a comparable tibial length, these factors may

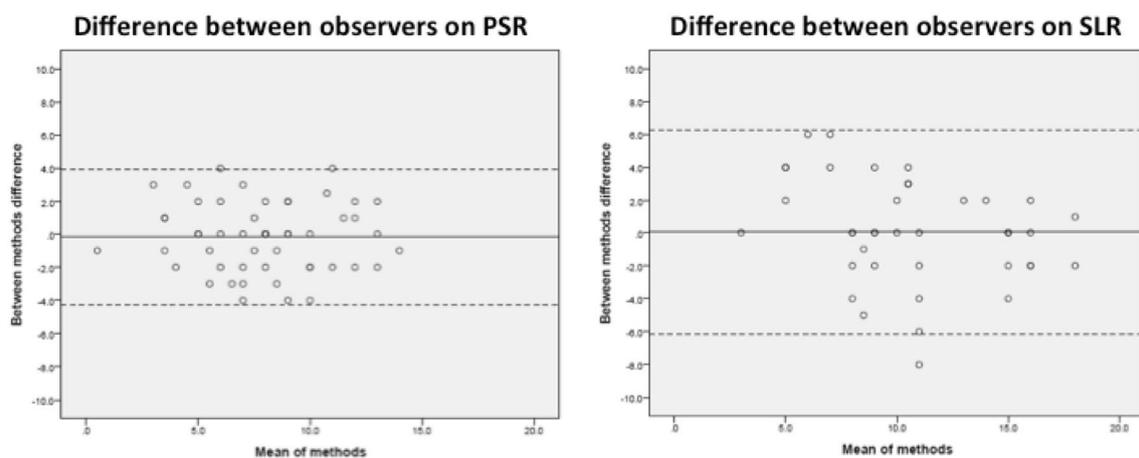


Fig. 5 Bland–Altman plots illustrate smaller 95% limits of agreement between both observers for PSR (left) compared to SLR (right)

have led to the superior results compared to SLR. Due to significant agreement between PSR and MRI, PSR—if available—may consequently serve as a viable alternative in clinical practice. In addition, radiographic evaluation of the tibial slope does not require specialized software and proved to be more time-efficient than MRI measurement. Hudek et al. [22] further stated that the ICCs for intra- and interobserver agreement on conventional lateral radiographs were superior to those on MRI. Correspondingly, the ICC between the observers indicated a high interrater agreement for all radiographic measurements in the current study.

We note several limitations to our study. First, only the medial tibial slope was measured, thereby ignoring a potential asymmetry of the medial and lateral slope. As the medial slope is usually superimposed on lateral radiographs, we focused on the evaluation of the medial slope both on radiographs and MRI [31]. Second, there are various measurement methods for the tibial axis in both radiographs [19, 32] and MRI [3, 22]. Thus, the current results may differ depending on the respective measurement technique. Third, demographic data, such as height, weight, body mass index, and ethnicity were not available for review. Thus, confounding effects of these factors could not be delineated.

In conclusion, the findings of the current study indicate that the assessment of the tibial slope is highly affected by the acquisition technique. By average, the medial TS is approximately 5° smaller on MRI compared to radiographs. In addition, measuring accuracy of lateral knee radiographs can be significantly improved. Best results are achieved if femoral rotation was below 5 mm and the radiogram covered at least 125 mm of the tibial diaphyseal axis.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest in the authorship and publication of this contribution.

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