CLINICAL ARTICLE

Planning Results for High Tibial Osteotomies in Degenerative Varus Osteoarthritis Using Standing and Supine Whole Leg Radiographs

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Objective: In this study, we hypothesized that standing and supine X-rays lead to different preoperative planning results.

Methods: The present study included 168 pictures from 81 patients who were treated surgically with high tibial osteotomy (HTO) for varus deformity between January 2017 and February 2018. Each patient underwent whole leg X-ray examinations in both standing and supine position. On both images, the following parameters were measured: degree of axis deviation (DAD), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), width of medial (MJS) and lateral joint space (LJS), and the correction angle (CA). The results were correlated with the patients' age and body mass index (BMI). To analyze intra-observer reliability, the same researcher, blinded to the previous measurements, remeasured all X-rays from 10 patients 8 weeks after the initial measurements were carried out.

Results: While mLDFA ($P = 0.075$), mMPTA ($P = 0.435$), and MJS ($P = 0.119$) did not show any differences between the two modalities, LJS ($P = 0.016$) and DAD ($P < 0.001$) differed significantly, leading to different correction angles ($P < 0.001$). The mean difference of the CA was $1.7° ± 2.2°$ (range, $-2.6°$ to$-15.4°$). In 14 legs (17%), the standing X-ray led to a correction angle that was at least $3°$ larger than the calculation revealed in the supine X-ray; in 4 legs (5%), it was at least $5°$ larger. Increased BMI ($r = 0.191$, $P = 0.088$) and older age ($r = 0.057$, $P = 0.605$) did not show relevant correlation with DAD differences. However, more severe varus malalignment in the supine radiograph did correlate moderately with differences of correction angles between supine and weight-bearing radiographs ($r = 0.414$, $P < 0.001$). The analysis of the intra-rater reliability revealed mediocre to excellent intercorrelation coefficients between the measurements of the observer.

Conclusion: The use of supine and standing X-ray images leads to different planning results when performing high tibial osteotomies for varus gonarthrosis. To avoid potential overcorrection, surgeons might consider increased lateral joint spaces on standing radiographs in osteoarthritic knees with varus deviation.

Key words: Knee; Leg axis; Osteotomy; Tibia; Varus

Introduction

Corrective osteotomies of the knee joint are an established therapeutic option in joint-preserving, surgical therapy for varus knee osteoarthritis (OA)[1]. Particularly in patients with high levels of activity, return to sports can be achieved with this treatment option[2]. While the results of open wedge osteotomies of the proximal tibia for isolated medial OA of the knee are generally promising, undercorrection and overcorrection are known to be associated with inferior clinical outcomes and revisions to arthroplasty[3,4]. In addition, the conversion to total knee arthroplasty may be associated with more demanding surgery than primary arthroplasty and the clinical function may be impaired[5,6]. Successful osteotomy requires not only a strict indication but also accurate preoperative planning[4].

Here, both standing and lying whole leg images are used, on the basis of which the width of an osteotomy wedge can be calculated. The most common planning technique includes the positioning of the Miculicz line from the center of the femoral head to the center of the ankle[1]. Next, a line from the femoral head to the center of the knee is drawn. Then, an angle is drawn from the tip of these two lines to the lateral tibial plateau. This angle is called the correction angle and is of crucial importance for exact planning. In clinical practice, this line can vary in different imaging techniques and between different observers.

Some consider the standing X-ray a "gold standard," claiming that the assessment of the extent and localization of knee osteoarthritis is best using standing AP views[7]. Another argument is that it allows the most reproducible measurements of the mechanical axis[8]. Others argue that the use of standing radiographs is not appropriate for high tibial osteotomy (HTO) planning as the relative angle of the articular surfaces in the weight-bearing knee is changed by the osteotomy itself[9]. In addition, it has been shown that laxity of the lateral collateral ligament influences measurements of the mechanical leg axis in the standing position[10].

However, no previous work has examined the effect of weight-bearing on the planning results of an HTO. Therefore, the purpose of our work was to examine three hypothyses: (i) the first hypothesis was that the choice of the radiographic recording mode leads to significant differences in the measurement of the axis angle and subsequent planning of the correction angle; (ii) the second hypothesis was that mere usage of standing radiographs could possibly lead to overcorrection because of secondary laxity of the lateral collateral ligament in varus knees; and (iii) the third hypothesis was that age and body mass index (BMI) have a significant influence on the measurement results. These results could have a significant impact on future planning of HTO surgeries because exact measurement and good preoperative planning play a major role in this field.[11]

Methods

Inclusion Criteria

We included all patients that fulfilled the following criteria: (i) treatment for varus gonarthrosis at our unit between January 2017 and February 2018 with HTO; (ii) no or only mild chondral damages (Outerbridge I–II) in the lateral and retropatellar compartments; (iii) regular physical activity; and (iv) advanced OA of the medial compartment (Kellgreen–Lawrence score II and higher), as confirmed by MRI.

Exclusion criteria: (i) secondary, post-traumatic deformities; (ii) revision surgeries for previous osteotomies; and (iii) technical inaccessibility of either supine or standing radiographs.

To evaluate the indication for surgery, we also include the following factors: smoking, age, ligament stability, and side diagnoses such as osteoporosis.

Recruitment of Patients

All whole leg X-ray images of patients who were treated surgically at our unit for varus deformity between January 2017 and February 2018 were screened. In total, 88 patients were treated surgically at our unit during this period of time. For 7 patients, one of the radiographs could not be retrieved for technical reasons. Among the remaining 81 patients, 3 received surgery on both legs, resulting in a total of 168 images from 84 legs. Of the patients included, 60 (126 radiographs) were men and 21 (42 radiographs) were women.

Imaging Technique

For the patients included in this study, both standing and supine images were recorded for estimation of the correction potential. For the standing image, patients were bare-footed and advised to stand upright on a step with heels touching the posterior ridge of the step. The patients were instructed to fully extent the knees and the patella was oriented in the anterior direction. Three radiographs were taken and merged automatically (Fujifilm Digital Radiography Console, Fujifilm Holdings K.K., Minato; Philips Optimus Digital X-ray, Philips, Amsterdam). The supine images were taken with another device (Shimadzu General Radiographic System, Shimadzu, Kyoto), examining the patients lying on a designated bench. Again, the knees were brought to full extension, and the pictures were taken digitally as a total view without the need for merging.

After identification of both images of a patient, the X-rays were evaluated according to a standardized study protocol at a radiological workplace. For analysis, we used JiveX (JiveX Review Client 4.4.5, VISUS Technology Transfer GmbH, Bochum). This research has been approved by the institutional review board of the authors' affiliated institutions. With this approval, no informed consent was required for this retrospective study. A single observer (senior resident

MEASUREMENT OF LEG AXIS FOR HIGH TIBIAL OSTEOTOMY

TABLE 1 Results for the different anatomic planning parameters				
	N	Mean	Standard deviation	Significance
mLDFA (weight-bearing) [°]	84	90.2	2.8	$P = 0.075$
mLDFA (supine) [°]	84	89.8	2.6	
mMPTA (weight-bearing) [°]	84	85.8	3.2	$P = 0.435$
mMPTA (supine) [°]	84	85.6	3.0	
Medial joint space (weight-bearing) [mm]	84	4.3	1.4	$P = 0.119$
Medial joint space (supine) [mm]	84	4.5	1.2	
Lateral joint space (weight-bearing) [mm]	84	6.9	1.5	$P = 0.016$
Lateral joint space (supine) [mm]	84	6.6	1.5	
DAD (weight-bearing) [°]	84	7.3	3.6	$P < 0.001$
DAD (supine) [°]	84	6.2	3.2	
Correction angle (weight-bearing) [°]	84	10.9	4.2	$P < 0.001$
Correction angle (supine) [°]	84	9.2	3.4	
ΔDAD [°]	84	1.1	1.3	
ΔCA [°]	84	1.7	2.2	

CA, correction angle; DAD, degree of axis deviation; mLDFA, mechanical lateral distal femur angle; mMPTA, mechanical medial proximal tibia angle.
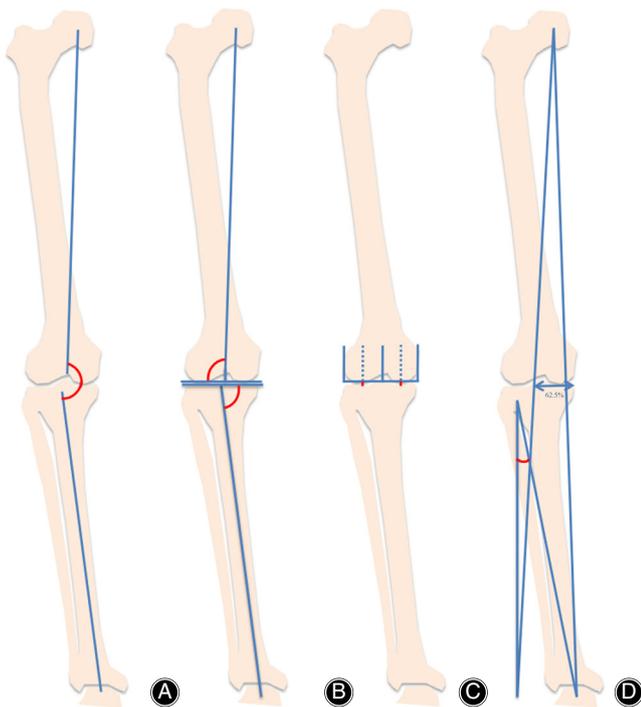
Fig 1 Measuring of X-ray images according to a standardized protocol. (A) The degree of axis deviation (DAD) was measured by drawing a line from the center of the hip to the intercondyle region[1]. Another line was drawn from the center of the tibial plateau to the center of the ankle. (B) The mechanical lateral distal femoral angle (mLDFA) and the mechanical medial proximal tibial angle (mMPTA) were measured as described in the literature[1]. (C) The lateral and medial width of the joint space were analyzed by grouping the space between the edges of the femoral epicondyles into four quadrants. Then, the width of the joint space was evaluated[12]. (D) The correction angle was analyzed as described in the literature[14].

in orthopaedic surgery familiar with the technique), who was not involved in the surgical treatment as a surgeon, carried out the evaluation of all images (Table 1).

Radiologic Parameters
The following quantitative parameters were determined for both standing and supine radiographs.

Mechanical Lateral Distal Femur Angle and Proximal Medial Tibial Angle
According to the nomenclature of Paley *et al.* (Fig. 1B), these angles are measured by drawing a line along the femur and tibia, respectively[1]. Then, the angles between these lines and the lateral femoral and medial tibial joint line are calculated. These angles indicate to the examiner if the deformity is situated at the tibia or at the femur.

Width of the Lateral and Medial Joint Space
According to Mehta *et al.* (Fig. 1C), the joint line is divided into quarters and the medial and lateral quarters are used as a reference[12]. These values express how much cartilage is missing.

The Degree of Axis Deviation
The degree of axis deviation (DAD) is defined as the difference between the leg axis measured and a straight 180° axis (Fig. 1A)[1]. For this parameter, a closed angle was placed along the femur and tibia. This parameter gives the examiner an impression of how severe the deformity really is.

Correction Angle for the Subsequent Planning of the Width of the Osteotomy Wedge
The correction line was placed through the Fujisawa point[13] and the base of the correction angle was projected at the level of the tibiofibular joint, as described by Miniaci

(Fig. 1D)[14]. This angle tells the examiner how much correction needs to be done.

After performing these measurements, the difference of the mechanical leg axis (ΔDAD) between both images was calculated (ΔDAD = DAD$_{weight-bearing}$ − DAD$_{supine}$).

Then, ΔDAD was correlated to the BMI and age of each patient.

In addition, the difference of the correction angle was calculated (ΔCA) using the same logic. Finally, DAD$_{supine}$ was correlated with ΔCA to see if a higher initial varus malalignment leads to larger differences in the following planning of the correction angle.

Statistical Calculation

All results were evaluated with SPSS (Version 25, IBM, Armonk, NY, USA). To analyze intra-observer reliability, the same researcher (blinded to the previous measurements) remeasured all X-rays from 10 patients 8 weeks after the initial measurements were carried out, as proposed in the literature[15]. These 10 cases were selected as a random sample using the case select function in SPSS. Afterwards, intercorrelation coefficients (ICC) were calculated.

For differences between the measurement results of one patient's images, we used the t-test for dependent samples. The correlation of different parameters was tested using the Pearson correlation coefficient. P-values lower than 0.05 were considered statistically significant.

Results

Radiologic Outcomes

Mechanical Lateral Distal Femur Angle and Proximal Medial Tibial Angle
The mechanical lateral distal femur angle (mLDFA) and the proximal medial tibial angle (mMPTA) did not show significant differences between weight-bearing and supine images (mLDFA [weight-bearing]: 90.2° ± 2.8°, mLDFA [supine]: 89.8° ± 2.6°, P = 0.075; mMPTA [weight-bearing]: 85.8° ± 3.2°, mMPTA [supine]: 85.6° ± 3.0°, P = 0.435).

Width of the Lateral and Medial Joint Space
The medial joint space did not show any significant differences, while the lateral joint space was significantly larger (discrepancy: 0.3 mm) in weight-bearing pictures (medial joint space [weight-bearing]: 4.3 ± 1.4 mm; medial joint space [supine]: 4.5 ± 1.2 mm, P = 0.119; lateral joint space [weight-bearing]: 6.9 ± 1.5 mm; lateral joint space [supine]: 6.6 ± 1.5 mm, P = 0.016).

The Degree of Axis Deviation
The leg axis showed a significantly larger deviation (discrepancy: 1.1°) in pictures that were taken under weight-bearing (DAD [weight-bearing]: 7.3° ± 3.6°, DAD [supine]: 6.2° ± 3.2°, P < 0.001).

Correction Angle for the Subsequent Planning of the Width of the Osteotomy Wedge
The estimated correction angles were significantly larger (discrepancy: 1.7°) when measured in weight-bearing pictures (correction angle [weight-bearing]: 10.9° ± 4.2°, correction angle [supine]: 9.2° ± 3.4°, P < 0.001).

In 14 legs (17%), the standing X-ray led to a correction angle that was at least 3° larger than the calculation in the supine X-ray; in 4 legs (5%), it was at least 5° larger (Fig. 2).

Influence of Body Mass Index and Age on ΔDAD
Increased BMI (r = 0.191, P = 0.088) and older age (r = 0. 057, P = 0. 605) did not show relevant correlation with ΔDAD. However, more severe varus malalignment in the supine radiograph did correlate moderately with differences of correction angles between supine and weight-bearing radiographs (r = 0.414, P < 0.001) (Fig. 3).

Inter-rater reliability
The analysis of the intra-rater reliability revealed mediocre to excellent intercorrelation coefficients between the measurements of the observer (ICC for weight-bearing radiographs: mLDFA = 0.786, mMPTA = 0.698, medial joint space [MJS] = 0.607, lateral joint space [LJS] = 0.704, DAD = 0.968, correction angle = 0.981; ICC for supine radiographs: mLDFA = 0.793, mMPTA = 0.421, MJS = 0.520, LJS = 0.682, DAD = 0.976, correction angle = 0.965).

Fig 2 Supine (left) and standing (right) images of a 51-year-old patient. The measurements of the axis angle (not shown) differ by 3.2°; as a result, the planning of the correction angle differs by 3.4°.
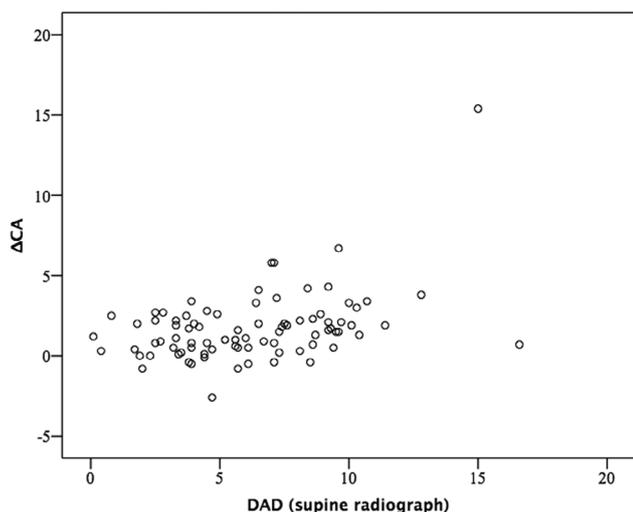
Fig 3 Correlation between degree of axis deviation (DAD) and differences in correction angle (ΔCA).

Discussion

Our study was able to prove the hypothesis that different X-ray modalities influence preoperative planning for HTO. Weight-bearing radiographs showed significantly larger deviations of the leg axis, increased correction angles, and larger lateral joint spaces compared to radiographs in the supine position. Furthermore, patients with larger initial varus deformities showed bigger differences in correction angles between both radiographs.

There has been an ongoing discussion about the best modality for preoperative evaluation of the leg anatomy[4,16,17]. While advocates of standing images claim to obtain a better visualization of the actual cartilage damage and the anatomy under weight-bearing conditions[7], others warn that these images are affected by lateral collateral ligament laxities[18]. In addition, the recording of weight-bearing images is said to be more time consuming and might cause inconveniences for the patients[18,19].

At our unit, we perform both radiographs to evaluate alignment of the leg with and without weight-bearing. Thus, the laxity of the lateral collateral ligament can be addressed. If standing and supine X-rays lead to similar planning results, lengthening of the lateral collateral ligament does not need to be considered. In cases of large planning differences, we tend to evaluate the average of both correction angles to achieve satisfactory functional results.

Potential discrepancies of leg axis analyses between different imaging modalities have been analyzed before. In a laboratory study, Specogna et al. evaluated the results for mechanical axis angle measurements in single-limb standing, double-limb standing, and supine positions and were able to show differences among these modalities[20]. Similarly, Sabharval et al. were able to reveal differences between preoperative standing radiographs and intraoperative fluoroscopy

in a cohort of different lower limb procedures[21]. Schoenemakers et al. (2017) compared preoperative and postoperative weight-bearing radiographs to non-weight-bearing imaging modalities such as navigation pictures and MRI in patients who received total knee arthroplasty. The authors concluded that these different modalities led to different results, too[15].

The results of these three studies are supported by our results, even if comparability is impeded by the different imaging modalities. For HTO, we assume that intraoperative controls are necessary and useful. Nevertheless, in our view, precise preoperative planning is essential and will increase safety. Furthermore, we use preoperative MRI scans to evaluate the cartilage situation of the knee to verify the need for HTO.

The question of how discrepancies between these modalities are generated is still under debate. While Sabharval et al.[21] were able to show an influence of increased BMI, Schoenemakers et al.[15] identified mediolateral instability, older age, and >3° varus malalignment as influencing factors for differences in measurements. The rationale behind these factors seems plausible: lateral ligament instability allows for an increase of the lateral joint space under weight-bearing conditions.

Our data supports the influence of severe deformities on lateral ligament laxity, because increased initial varus in supine position correlated with larger differences of correction angles between both radiographs.

The same effect might be induced by increased BMI, because a larger body weight poses more mechanical force on the lateral ligament. This effect, however, could not be shown in the present study, despite a reasonable cohort size and thorough statistical analysis. Older age did not have a significant influence in our study, either. However, it is generally associated with increased ligament laxity around the knee, which might be another factor that influences differences in leg axis measurements[22]. Our results were not able to prove this hypothesis. Future multicenter studies with larger cohorts might be helpful to sharpen the perspective on these confounding factors.

Limitations

The authors are aware of the limitations of the presented study. First, the retrospective study design might have influenced the results. A prospective study could have been more feasible in this context. However, this study presents a consecutive large cohort without selection bias due to prospective designs. Second, the standing and supine radiographs were taken at different time points. Still, the clinical evaluations did not indicate clinically relevant changes between the radiographs. The strength of our work is the large cohort of patients who exclusively presented with the diagnosis of varus gonarthrosis. To our knowledge, this is the first work examining the effects of standing and supine X-rays on the planning of corrective osteotomies.

Conclusion

The use of supine and standing X-ray images leads to different planning results when performing high tibial osteotomies for varus gonarthrosis. To avoid potential overcorrection, surgeons might consider increased lateral joint space on standing radiographs in osteoarthritic knees with varus deviation.

Acknowledgement

References

1. Paley D, Pfeil J. Principles of deformity correction around the knee. Orthopade, 2000, 29: 18–38.

2. Bastard C, Mirouse G, Potage D, et al. Return to sports and quality of life after high tibial osteotomy in patients under 60 years of age. Orthop Traumatol Surg Res, 2017, 103: 1189–1191.

3. Myrnerts R. Optimal correction in high tibial osteotomy for varus deformity. Acta Orthop Scand, 1980, 51: 689–694.

4. Schroter S, Gunzel J, Freude T, et al. Precision in the planning of open wedge HTO. Z Orthop Unfall, 2012, 150: 368–373.

5. Efe T, Heyse TJ, Boese C, et al. TKA following high tibial osteotomy versus primary TKA: a matched pair analysis. BMC Musculoskelet Disord, 2010, 11: 207.

6. Brouwer RW, Huizinga MR, Duivenvoorden T, et al. Osteotomy for treating knee osteoarthritis. Cochrane Database Syst Rev, 2014, 3: Cd004019.

7. van Heerwaarden R, Spruijt S, Niemeyer P, et al. Osteotomy: The Basics. ESSKA Instructional Course Lecture Book. Berlin: Springer, Berlin, Heidelberg: Geneva, 2012.

8. Odenbring S, Berggren AM, Peil L. Roentgenographic assessment of the hip-knee-ankle axis in medial gonarthrosis. A study of reproducibility. Clin Orthop Relat Res, 1993, 289: 195–196.

9. Ogata K, Yoshii I, Kawamura H, et al. Standing radiographs cannot determine the correction in high tibial osteotomy. J Bone Joint Surg Br, 1991, 73: 927–931.

10. Dugdale TW, Noyes FR, Styer D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clin Orthop Relat Res, 1992, 274: 248–264.

11. Patsch C, Dirisamer F. The basics of knee osteotomy: clinical examination, analysis of the deformity and correction planning. Orthopade, 2017, 46: 558–562.

12. Mehta N, Duryea J, Badger GJ, et al. Comparison of 2 radiographic techniques for measurement of tibiofemoral joint space width. Orthop J Sports Med, 2017, 5: 2325967117728675.

13. Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am, 1979, 10: 585–608.

14. Miniaci A, Ballmer FT, Ballmer PM, et al. Proximal tibial osteotomy. A new fixation device. Clin Orthop Relat Res, 1989, 246: 250–259.

15. Schoenmakers DAL, Feczko PZ, Boonen B, Schotanus MGM, Kort NP, Emans PJ. Measurement of lower limb alignment: there are within-person differences between weight-bearing and non-weight-bearing measurement modalities. Knee Surg Sports Traumatol Arthrosc, 2017, 25: 3569–3575.

16. Akamatsu Y, Sotozawa M, Kobayashi H, Kusayama Y, Kumagai K, Saito T. Usefulness of long tibial axis to measure medial tibial slope for opening wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc, 2016, 24: 3661–3667.

17. van Raaij TM, Takacs I, Reijman M, Verhaar JAN. Varus inclination of the proximal tibia or the distal femur does not influence high tibial osteotomy outcome. Knee Surg Sports Traumatol Arthrosc, 2009, 17: 390–395.

18. Brouwer RW, Jakma TS, Bierma-Zeinstra SM, Ginai A, Verhaar J. The whole leg radiograph: standing versus supine for determining axial alignment. Acta Orthop Scand, 2003, 74: 565–568.

19. Zampogna B, Vasta S, Amendola A, et al. Assessing lower limb alignment: comparison of standard knee Xray vs long leg view. Iowa Orthop J, 2015, 35: 49–54.

20. Specogna AV, Birmingham TB, Hunt MA, et al. Radiographic measures of knee alignment in patients with varus gonarthrosis: effect of weightbearing status and associations with dynamic joint load. Am J Sports Med, 2007, 35: 65–70.

21. Sabharwal S, Zhao C. Assessment of lower limb alignment: supine fluoroscopy compared with a standing full-length radiograph. J Bone Joint Surg Am, 2008, 90: 43–51.

22. Rudolph KS, Schmitt LC, Lewek MD. Age-related changes in strength, joint laxity, and walking patterns: are they related to knee osteoarthritis? Phys Ther, 2007, 87: 1422–1432.