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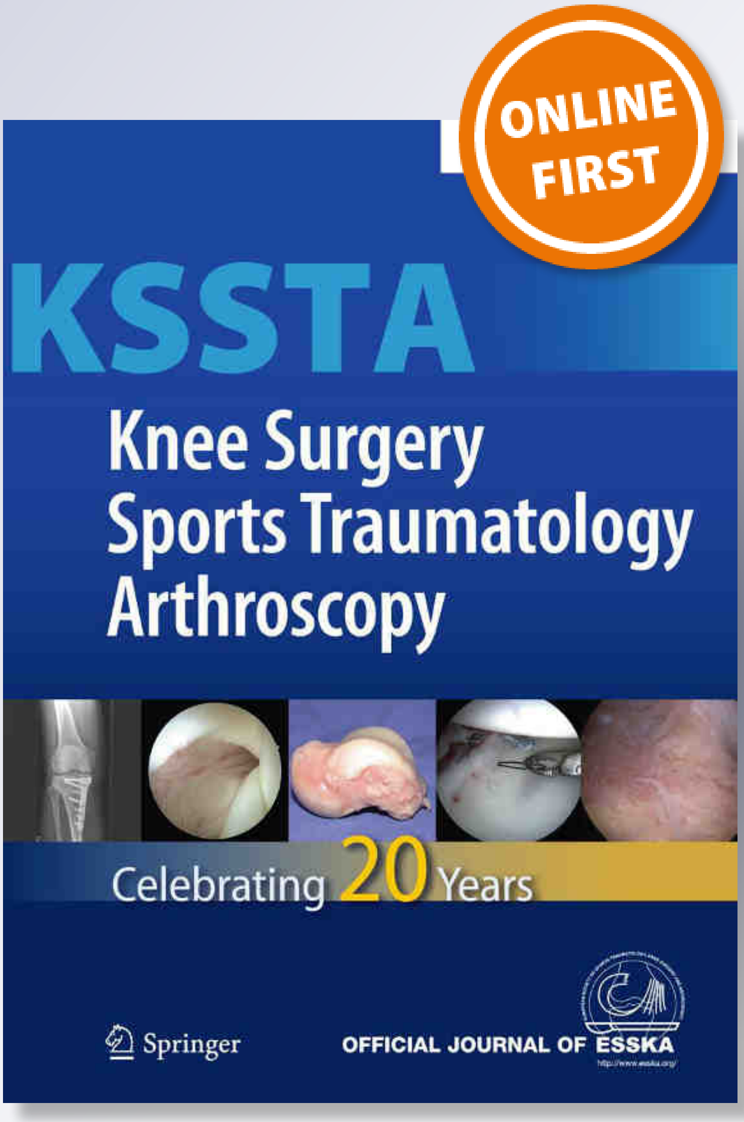

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Digital planning of high tibial osteotomy. Interrater reliability by using two different software

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Abstract

Purpose The purpose of the study was to determine the interrater reliability as well as the correlation of mediCAD® and PreOPlan® in deformity analysis and digital planning of osteotomies.

Methods Digital radiographs were obtained from 81 patients planned to undergo an open wedge high tibial osteotomy. The JPEG files of the radiographs were imported to landmark-based software. Deformity analysis and planning of correction were performed by 1 experienced and 2 unexperienced observers. Osteotomy planning was aimed at correction to the predefined mechanical tibiofemoral angle of 3° valgus leg alignment. The interrater reliability of measurements was assessed using intraclass correlation coefficients (ICCs) and the confidence interval.

Results The ICC of PreOPlan® was from 0.841 (mechanical lateral distal femur angle) to 0.993 (wedge-angle) and from 0.896 (joint line convergence angle) to 0.995 (mechanical tibiofemoral angle) of mediCAD®. The ICC of height of wedge-base was 0.979 with PreOPlan® and 0.969 with mediCAD®. Comparing PreOPlan® and mediCAD®, the ICC of the height of wedge-base of the observers was 0.966, 0.956 and 0.969, respectively.

Conclusions The results show a high interrater reliability of digital planning software. Experience of the observer had no influence on results. Furthermore, a high interrater reliability and correlation of digital planning specific parameters was found. Surgeons need to master limb geometry measurements and osteotomy planning on digital radiographs as digital planning reports are used for intercolleagual correspondence, teaching purposes and as medicolegal documents. The digital planning software tested agrees with the actual demands and could be recommended for deformity analysis and planning of osteotomies.

Level of evidence Diagnostic studies, Level I.

Keywords Digital planning · Osteotomy · Open wedge HTO · Limb deformity · Planning software

Introduction

Open wedge high tibial osteotomies (OWHTO) are well-established and commonly used in patients with varus malalignment and medial compartment osteoarthritis [1, 8, 10, 16]. In general, the aim of an OWHTO is the realignment of the lower limb into a 3 degrees valgus overcorrection, which is considered the mean optimal angle of correction for valgisation HTO [2, 6, 7].

Knowledge of deformity analysis including accurate measurement of limb segments and joint angles and a

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correct planning of correction including height of wedge-base and osteotomy correction angle is mandatory to prepare for limb realignment surgery [11]. Radiology departments nowadays are almost fully digitized and picture archiving, and communication systems (PACS) for medical imaging are in widespread use. Accuracy of measurements and intraobserver reliability has improved with the introduction of computer-assisted limb geometry measurements as compared to measurements of previously used plain radiographs [14, 15]. Surgeons nowadays need to master limb geometry measurements and osteotomy planning on digital radiographs.

To assist the surgeon in deformity analysis and planning of deformity correction, different software programs are available. FDA-approved and landmark-based medical planning software mediCAD® (Hectec GmbH, Germany) is well known [4, 5, 13] and considered the gold standard in planning software. Recently, a more versatile new digital planning software PreOPlan® (Siemens, Germany/Synthes, Switzerland) was developed for computer-assisted deformity analysis, osteotomy simulation and planning of fixation. Interrater correctness in application of landmarks as a measure of intraobserver and interrater reliability of limb geometry measurements becomes increasingly important as planning reports are used for intercolleagual correspondence, teaching purposes and as medicolegal documents. Literature on interrater correctness in landmarks application is lacking. Besides that, no reports were found to determine the reliability of specific parameters of digital planning, that is, height of wedge-base or wedge-angle.

The purposes of this study were to determine the interrater correctness of landmarks application using mediCAD® and PreOPlan® programs and the correlation of mediCAD® and PreOPlan® in measurement and planning of radiographs including digital planning specific parameters. We hypothesized that planning software (mediCADv and PreOPlan®) has a high interrater reliability in planning and measuring as well as a high correlation in digital planning specific parameters.

Materials and methods

Digital radiographs were obtained from 81 patients planned to undergo an OWHTO. All patients had been diagnosed with medial compartment knee osteoarthritis and varus leg alignment. Full-weight bearing long-leg radiographs of the whole lower extremity were obtained according to the method of Paley et al. [11] including a reference ball (Ø 25 mm) for calibration. A 124.5 × 35.4 cm cassette was used, and the X-ray beam was centered at the level of the knee line at a distance of 3.18 m. Depending on lower extremity size, settings of 40–70 mA/s and 73–90 kV were applied. Patients stood with full-weight bearing on both legs.

Table 1 Abbreviations

mTFA	Mechanical tibiofemoral angle
mPLFA	Mechanical proximal lateral femur angle
mLDFA	Mechanical lateral distal femur angle
MPTA	(Mechanical) medial proximal tibia angle
mLDTA	Mechanical lateral distal tibia angle
JLCA	Joint line convergence angle
Leg length	Leg length
MAD %	Mechanical axis deviation, medial tibial plateau 0 %, lateral 100 %
Wedge-angle	Opening angle of osteotomy
Height of wedge-base	Height of opening medial cortex

Each radiograph was exported as JPEG file from IMPAX version 6.3.1.3811 (Agfa HealthCare N.V., Mortsel, Belgium) to an external hard drive. Three observers (observer 1: Experienced with digital osteotomy planning, observer 2: Unexperienced, observer 3: Unexperienced) measured each radiograph on a separate laptop with the digital planning software programs (mediCAD® and PreOPlan®). These programs both use landmark-based approaches for alignment and deformity analysis. All preoperative radiographs were planned to an mTFA = 3° (valgus). Table 1 shows the abbreviations of angles and distance measurements.

In addition, to test measurement accuracy, an independent measurement parameter on the femur (mLDFA) was measured on different radiographs of the same patient. For this, the preoperative radiographs measurement (mLDFA) was compared with the 6-week follow-up radiographs measurement of the individual patients after HTO. The measured values were examined by an equivalence test for agreement. On clinical grounds, an equivalent range of ± 2° was defined to be acceptable.

Measuring and planning alignment with mediCAD®

The JPEG files of the radiographs were imported to mediCAD® version 2.20 module osteotomy (Hectec GmbH, Germany). Calibration was performed based on the reference ball and three-point method (three points define a circle). The hip-center was determined using the three-point method too. The apex of the greater trochanter, medial/lateral condyle and epicondyles of femur and tibia were marked, respectively. Then, the medial and lateral limits of the talus as well as the joint line were marked. Secondary correction of marked points is not possible. The angles of the lower extremity were issued by the software. The wedge-base was measured separately. All angles were

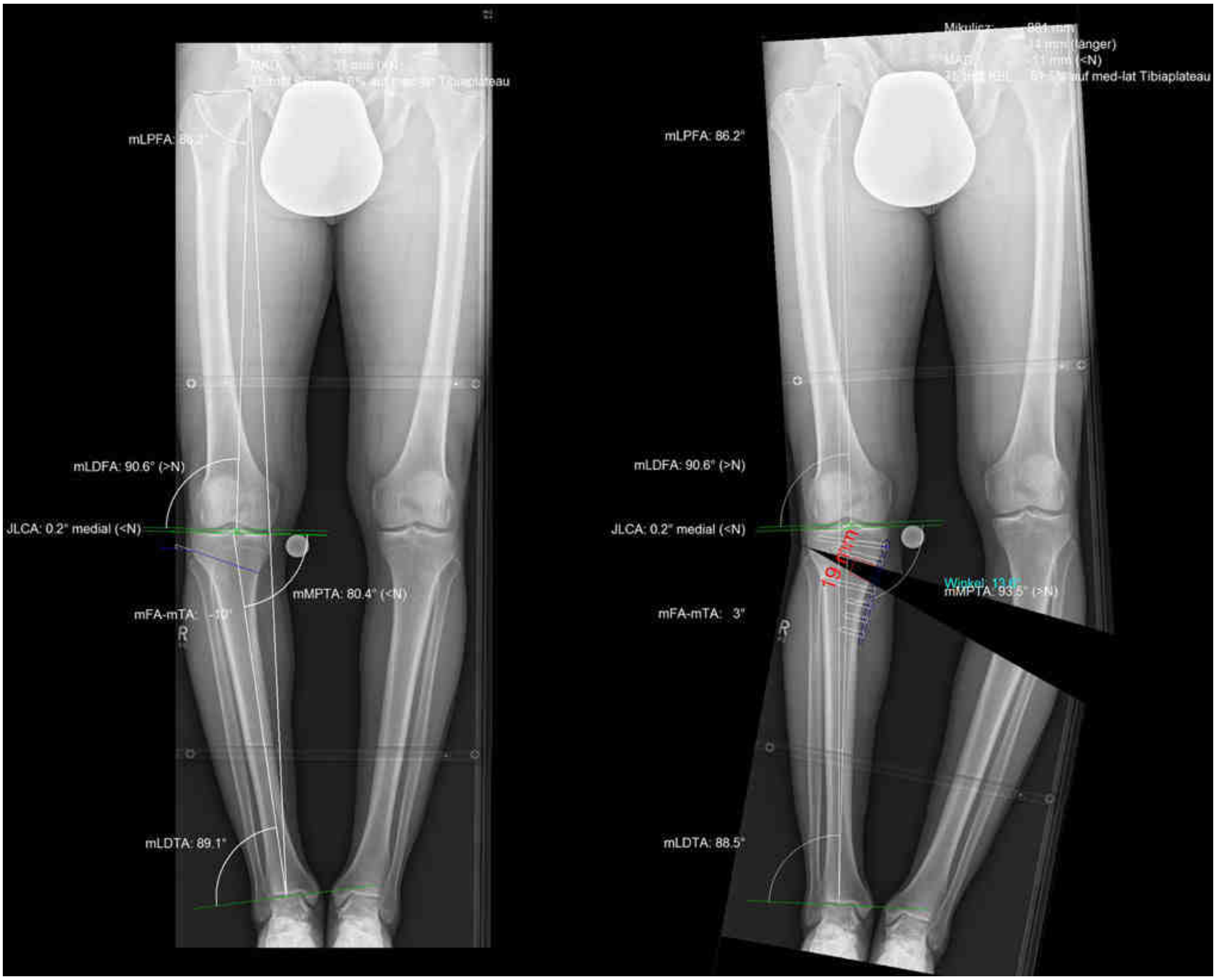

Fig. 1 Screenshots mediCAD®. *mLPFA* mechanical lateral proximal femur angle, *MAD* mechanical axis deviation, *mLDFA* mechanical lateral distal femur angle, *JLCA* joint line convergence angle, *mMPTA* (mechanical) medial proximal tibia angle, *mFA-mTA* = *mTFA* mechanical tibiofemoral angle, *mLDTA* mechanical distal tibia angle

shown at the axis on the radiographs. Subsequently, the osteotomy and the hinge point were located. The planning was executed to the pre-defined mTFA of 3° in each case (Fig. 1).

Measuring and planning alignment with PreOPlan®

Using PreOPlan® module osteotomy (Siemens, Germany/Synthes, Switzerland), the JPEG file from all patients were imported, and calibration was carried out with the two-point method. The hip-center was determined with the two-point method. Subsequently, the greater trochanter, the intercondylar notch, lateral and medial edge of femoral condyles, eminences, the proximal tibia edges were marked as well as the medial and the lateral edge of the talar dome. A graphic help window assists in optimal landmark positioning and a fine tuning of each mark point after positioning is possible. A split-screen display enables monitoring of the effects of consecutive planning steps. On the left side of the screen, radiograph axis and angles on the right side, a table with each relevant angle was displayed. As part of the planning process, graphic help windows assist in accurate positioning of the osteotomy hinge point. The wedge-base could be located inside the radiograph and adapted if aimed for. The opening-size was carried out to the pre-defined angle of mTFA = 3° (Fig. 2).

All data were entered into a data base for further analysis.

Statistical analysis

Repeated measurements of three observers and two different softwares were available. Interrater variability of systematic deviation of factors software and observers with

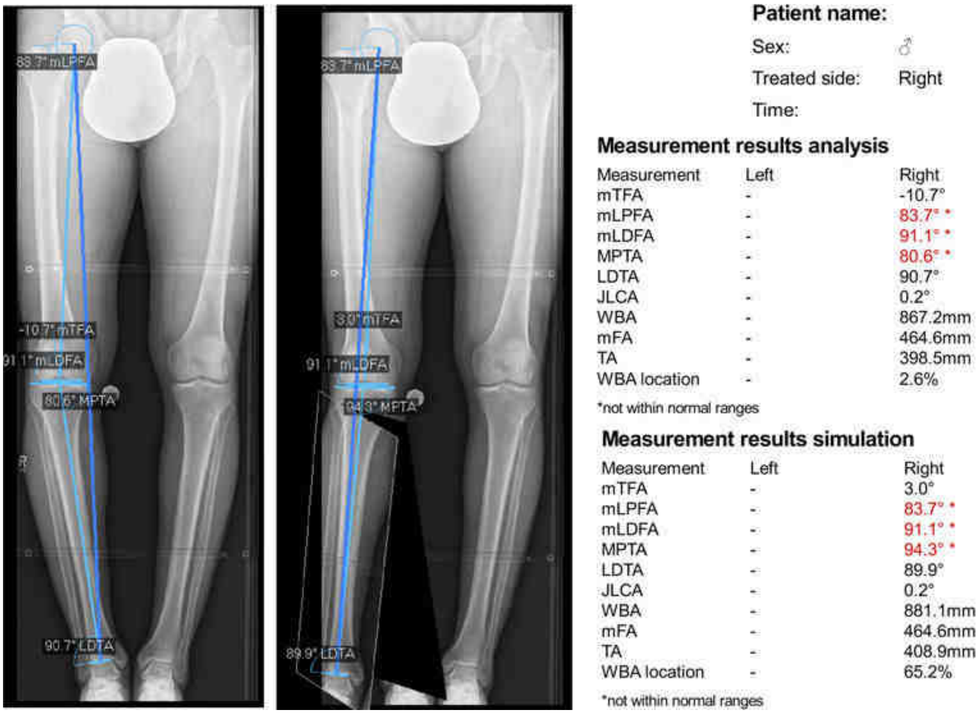

Fig. 2 Report PreOPlan®. *mTFA* mechanical tibiofemoral angle, *mLPFA* mechanical proximal femur angle, *mLDFA* mechanical lateral distal femur angle, *MPTA* (mechanical) medial proximal tibia angle, *LDFA* mechanical medial lateral distal femur angle, *JLCA* joint line convergence angle, *WBA* length of weight bearing axis = Mikulicz line, *mFA* length of mechanical femur axis, *TA* length of tibia axis, *WBA location* = *MAD* mechanical axis deviation

Patient name:
Sex: ♂
Treated side: Right
Time:

Measurement results analysis

Measurement	Left	Right
mTFA	-	-10.7°
mLPFA	-	83.7° *
mLDFA	-	91.1° *
MPTA	-	80.6° *
LDTA	-	90.7°
JLCA	-	0.2°
WBA	-	867.2mm
mFA	-	464.6mm
TA	-	398.5mm
WBA location	-	2.6%

*not within normal ranges

Measurement results simulation

Measurement	Left	Right
mTFA	-	3.0°
mLPFA	-	83.7° *
mLDFA	-	91.1° *
MPTA	-	94.3° *
LDTA	-	89.9°
JLCA	-	0.2°
WBA	-	881.1mm
mFA	-	464.6mm
TA	-	408.9mm
WBA location	-	65.2%

*not within normal ranges

a two-factorial analysis to repeated measurements were determined. If there was inhomogeneous variance (according to Mauchly test of sphericity), degrees of freedom of the F-statistics within the repeated measures comparisons after Greenhouse-Geisser were corrected.

The agreement (interrater reliability) of landmark application measurements was assessed using intraclass correlation coefficients [library irr in R (R, version 2.12.1, www.r-project.org, R Development Core Team)]. According to the results from the variance analysis in this case, the two factors have been analyzed separately. Comparisons of the ICC with each other have been performed on the 95 % CI. Equivalence analysis was based on a significance level of $\alpha = .05$ and tested two-sided. The calculations were made with SPSS version 19 (IBM Company, Chicago, IL, USA).

Results

Interrater reliability statistics (observer 1–3) of PreOPlan® and mediCAD® regarding preoperative radiographs are displayed in Table 2. High agreement was found for all measurements in both software and all observers, respectively (Fig. 3). The intraclass correlation coefficients (ICC) for defined angular measurements of PreOPlan® were from 0.841 (mLDFA) to 0.993 (wedge-angle) and from 0.8956 (JLCA) to 0.995 (mTFA) of mediCAD®.

Table 2 Evaluation of Interrater reliability of PreOPlan® and mediCAD® using the intraclass correlation coefficient (ICC) and 95 %-CI ($n = 81$ radiographs)

	PreOPlan		mediCAD	
	ICC	95 %-CI	ICC	95 %-CI
mTFA pre-OP	0.994	0.991–0.996	0.995	0.993–0.997
mPLFA pre-OP	0.935	0.876–0.963	0.971	0.958–0.980
mLDFA pre-OP	0.841	0.780–0.889	0.947	0.925–0.964
MPTA pre-OP	0.974	0.963–0.983	0.974	0.961–0.983
mLDTA pre-OP	0.901	0.861–0.932	0.943	0.919–0.961
JLCA	0.886	0.841–0.921	0.896	0.854–0.928
Leg length	0.981	0.965–0.989	0.974	0.962–0.982
MAD %	0.990	0.986–0.994	0.976	0.904–0.990
Wedge-angle	0.993	0.990–0.995	0.995	0.992–0.996
Height of wedge-base	0.979	0.969–0.986	0.969	0.956–0.979

Abbreviations see Table 1

Regarding digital planning specific parameters, the ICC (95 %-CI) of mTFA was 0.994 (0.991–0.9956) and 0.995 (0.993–0.997) with PreOPlan® and mediCAD®, respectively. The ICC (95 %-CI) of height of wedge-base was 0.979 (0.969–0.986) and 0.969 (0.956–0.979) with PreOPlan® and mediCAD®, respectively.

The means of each variable are presented in Table 3. The mTFA was −5.4° to −5.6° (varus) in the preoperative radiographs, and the MPTA was 85.9°–86.2° depending on software and observer. Each planning was found to have

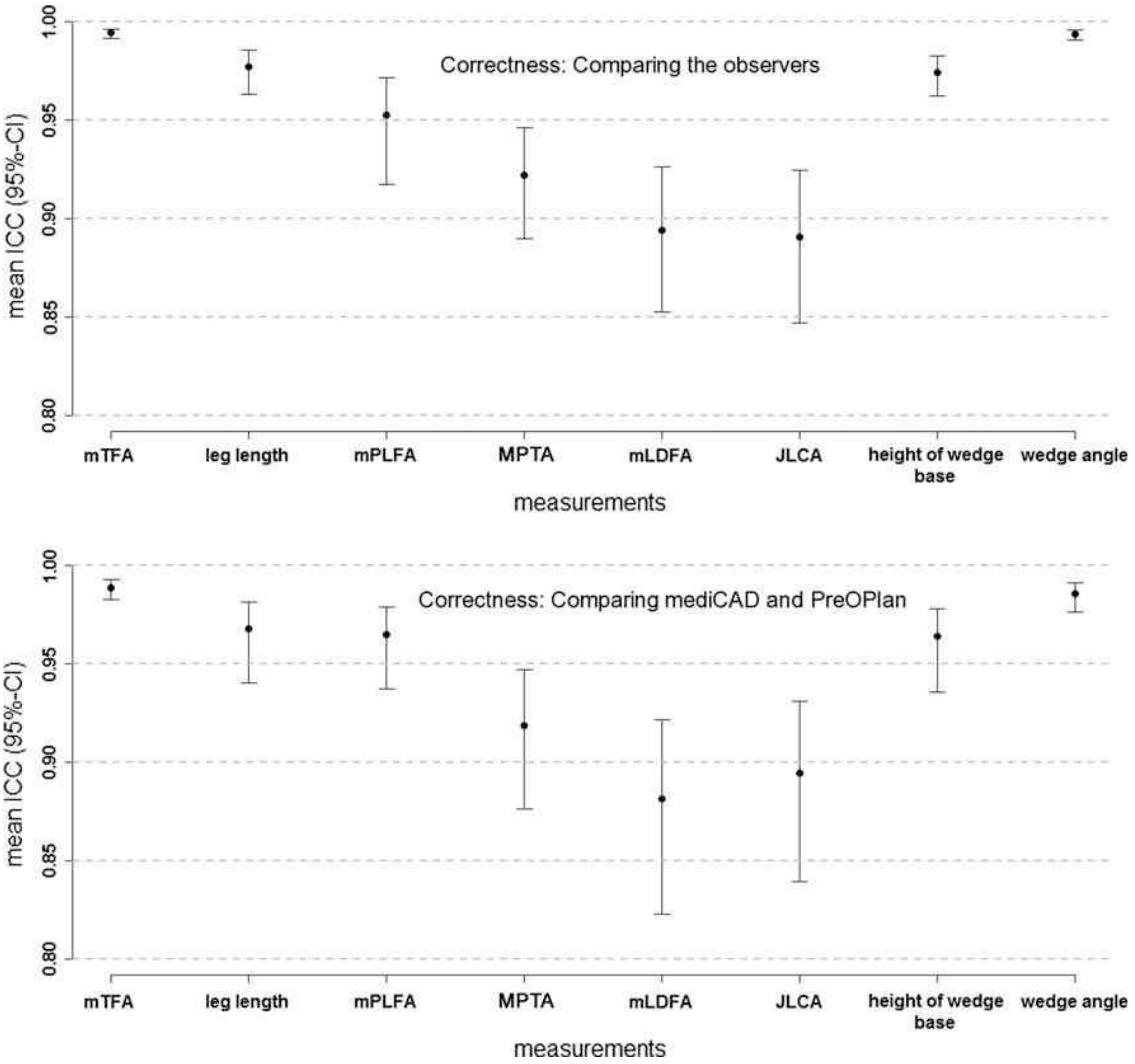

Fig. 3 Intraclass correlation coefficients (ICC) with the 95 %-CI (95 %-CI) of the correctness: Comparing the observers; comparing mediCAD and PreOPlan. For all measurements of the X-rays, the ICC were analyzed. *mLPFA* mechanical lateral proximal femur angle, *MAD* mechanical axis deviation, *mLDFA* mechanical lateral distal femur angle, *JLCA* joint line convergence angle, *mMPTA* (mechanical) medial proximal tibia angle, *mFA-mTA* = *mTFA* mechanical tibiofemoral angle, *mLDTA* mechanical distal tibia angle

been performed to the pre-defined mTFA of 3° (valgus) by all observers. The mean height of wedge-base was 9.9–10.2 mm with PreOPlan$^{®}$ and 9.7–9.9 mm with mediCAD$^{®}$.

Comparing the two planning software, a high correlation was found in the landmark-based measurements of the radiographs (Table 4). The ICC (95 %-CI) of observer 1, 2 and 3 in the mTFA was 0.987 (0.980–0.997), 0.988 (0.981–0.992) and 0.991 (0.986–0.994), respectively. The ICC (95 %-CI) of the height of the wedge-base of observer 1, 2 and 3 was 0.966 (9.45–0.979), 0.956 (0.933–0.972) and 0.969 (0.929–0.984), respectively. Each 95 %-CI was very close (Fig. 3).

In the equivalence measurement comparing preoperative radiographs with the 6-week follow-up radiographs, the preoperative mLDFA compared with 6-week follow-up mLDFA was significantly equal ($p < .05$). A small bias of 0.43° was found (Fig. 4).

Discussion

The most important finding of the present study was the high interrater reliability of 2 digital planning programs even if used by inexperienced users and the correlation of both programs in radiographic deformity analysis and osteotomy planning. The hypothesis that planning software (mediCAD$^{®}$ and PreOPlan$^{®}$) have a high interrater reliability (measured by the interrater correctness of landmarks applications) in planning and measuring as well as a high correlation was confirmed in this study. A high level of agreement was found with the intraclass correlation

Table 3 Descriptive statistics

	PreOPlan observer 1	PreOPlan observer 2	PreOPlan observer 3	mediCAD observer 1	mediCAD observer 2	mediCAD observer 3
mTFA (°)	−5.5 ± 2.7	−5.5 ± 2.7	−5.4 ± 2.7	−5.6 ± 2.7	−5.5 ± 2.7	−5.4 ± 2.7
mPLFA (°)	90.1 ± 5.5	91.5 ± 5.3	91.1 ± 5.4	90.9 ± 5.2	91.2 ± 5.5	91.1 ± 5.3
mLDFA (°)	89.3 ± 2.2	89.0 ± 2.2	89.0 ± 2.0	89.0 ± 2.1	89.1 ± 2.1	89.1 ± 2.1
MPTA (°)	86.2 ± 2.4	86.2 ± 2.4	86.2 ± 2.5	85.9 ± 2.4	86.1 ± 2.1	86.1 ± 2.4
mLDTA (°)	88.0 ± 3.7	88.1 ± 3.5	88.0 ± 3.7	87.8 ± 3.6	87.8 ± 3.7	87.7 ± 3.3
JLCA (°)	2.6 ± 1.7	2.7 ± 1.8	2.7 ± 1.7	2.6 ± 1.7	2.7 ± 1.7	2.5 ± 1.7
Leg length [mm]	831 ± 49	824 ± 48	827 ± 51	823 ± 52	821 ± 50	825 ± 51
MAD (%)	23 ± 11	23 ± 11	23 ± 11	24 ± 11	26 ± 11	26 ± 11
Wedge-angle	8.5 ± 2.8	8.5 ± 2.8	8.5 ± 2.9	8.3 ± 2.8	8.3 ± 2.8	8.3 ± 2.8
Height of wedge-base (mm)	10.2 ± 3.8	9.9 ± 3.6	10.2 ± 3.7	9.9 ± 3.5	9.9 ± 3.4	9.7 ± 3.4

Means ± SD of measurements (*n* = 81 radiographs). Abbreviations see Table 1

Table 4 Correlation of PreOPlan® and mediCAD®

	Observer 1		Observer 2		Observer 3	
	ICC	95 %-CI	ICC	95 %-CI	ICC	95 %-CI
mTFA	0.987	0.980–0.997	0.988	0.981–0.992	0.991	0.986–0.994
mPLFA	0.940	0.883–0.967	0.972	0.957–0.982	0.981	0.971–0.988
mLDFA	0.803	0.708–0.869	0.882	0.822–0.922	0.960	0.939–0.974
MPTA	0.970	0.928–0.984	0.967	0.949–0.979	0.982	0.972–0.989
mLDTA	0.949	0.921–0.967	0.896	0.842–0.932	0.912	0.866–0.942
JLCA	0.890	0.834–0.928	0.854	0.782–0.904	0.939	0.902–0.96
Leg length	0.942	0.881–0.968	0.978	0.966–0.986	0.983	0.974–0.989
MAD %	0.987	0.967–0.994	0.950	0.297–0.986	0.946	0.333–0.985
Wedge-angle	0.993	0.990–0.995	0.995	0.992–0.996	0.983	0.973–0.989
Height of wedge-base	0.966	0.945–0.979	0.956	0.933–0.972	0.969	0.929–0.984

Abbreviations see Table 1

coefficients of 0.841 (mLDFA) to 0.993 (wedge-angle) in PreOPlan and of 0.896 (JLCA) to 0.995 (mTFA) in mediCAD. In addition, a high correlation was found in the measurements of the radiographs irrespective of the experience of the observer (Table 2).

The results using PreOPlan® and mediCAD® are similar to findings from previous studies using other digital planning software. Sled et al. [14] evaluated AutoCAD® by comparing interrater reliability and intra rater reliability between measurements of alignment of full-weight bearing long-leg standing anterior posterior radiographs of the whole lower extremity. In this study, another nomenclature of joint orientation was used. HKA (hip-knee-ankle) angle was equal to mTFA in the presented report. An ICC (95 %-CI) of 0.995 (0.994–1.000) was described. Using the software The HTO Pro, a ICC (95 %-CI) of 0.98 (0.91–0.99) was reported [15]. These results were inferior as compared to PreOPlan® and mediCAD® results (Table 2). Marx et al. [9] reported a high interrater reliability of the mechanical axis with a ICC 0.97–0.99 using the PACS system for measuring. However, ICC for hard copies are 0.87–0.98. Sled et al. [14] reported a mLDFA (CH: condylar-hip angle) with a ICC (95 %-CI) of 0.960 (0.953–1). The ICC (95 %-CI) of leg length with PreOPlan® and with mediCAD®, however, were slightly inferior to AutoCAD® with an ICC (95 %-CI) of 0.995 (95 %-CI, 0.993–1) [14]. Hankemeier et al. [3] compared digital measurements of mediCAD® and manual methods. In that study, a different statistical method to determine the reliability was used, that is, the mean of standard deviation (SD) after five measurements of the alignment and angles was compared. The reported means of SDs are lower than the SD of each measurement in the present study. Repeated measurements could be a cause for this difference. Moreover, the same working group reports.

Comparing the new digital planning software PreOPlan® and mediCAD®, a high correlation was found (Table 4). These results illustrated a high level of

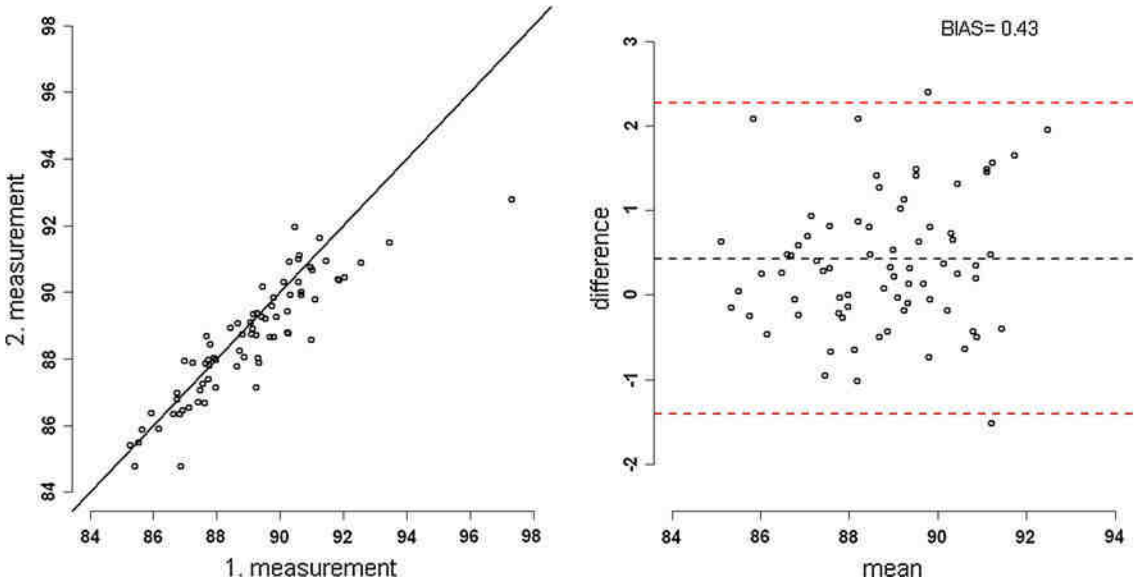

Fig. 4 Preoperative mechanical lateral distal femur angle (mLDFA) compared with 6-week follow-up mLDFA. Significant equality ($p < .05$). A small bias of 0.43° was found

agreement with both software and are in accordance with or superior to computer-assisted measurements and manual measurements of leg alignment by others [3, 12, 15]. Both planning programs are landmark-based, user-defined nomenclature for deformity analysis and enable simulation of osteotomy planning and fixation. PreOPlan® is more versatile in changes of landmark positioning, has graphic help windows for optimal landmark and osteotomy hinge point positioning, and a split-screen presentation of planning steps. These factors may be an advantage over mediCAD®, which could have resulted in a more accurate planning especially for unexperienced users visible in a higher level of agreement for PreOPlan measurements. However, no significant differences were found.

Limitations of this study are that out of different methods to measure interrater reliability in this study, we limited the measurement of interrater reliability to the interrater correctness of landmark application. This method was chosen as differences in landmark positioning were found to be the main cause of inaccuracy in our practices. Repeated measurements to analyze intra-observer reliability may be a better format to investigate the differences between the programs. Further limitations of this study are that measurements were performed by only three observers with different experience in digital planning who performed each measurement only once. This study design was chosen because it accommodates best increasingly important demands for digital planning reports.

As digitization of medical practice progresses not only in radiological departments but in electronic patients files and intercolleagual correspondence as well, research on reliability of digital planning programs becomes of greater clinical relevance. Surgeons need to master limb geometry measurements and osteotomy planning on digital radiographs as digital planning reports are used nowadays for intercolleagual correspondence, teaching purposes and as medicolegal documents.

Conclusion

The results show a high interrater reliability of digital planning software as measured by interrater correctness of landmarks application. Experience of the observer had no influence on results. Furthermore, a high interrater reliability and correlation of digital planning specific parameters was found. The digital planning software tested agrees with the actual demands and could be recommended for deformity analysis and planning of osteotomies. Surgeons need to master limb geometry measurements and osteotomy planning on digital radiographs as digital planning reports are used for intercolleagual correspondence, teaching purposes and as medicolegal documents. The digital planning software tested agrees with the actual demands and could be recommended for deformity analysis and planning of osteotomies.

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Conflict of interest The senior author (RvH) has been involved in the development of the PreOPlan® software; however, he has received no financial benefits. The other authors report no conflict of interest. SS, PL and RvH are members of the AO Joint Preservation Expert Group. The other authors report no conflict of interest.

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