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## Quantification of axial alignment of the lower extremity on conventional and digital total leg radiographs

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**Abstract** The purpose was to assess axial alignment of the lower limb using mechanical axis measurements on conventional and digital radiographs. Total-leg radiographs of 24 patients, 8 male and 16 female, with a mean age of  $68.6 \pm 10.2$  years, were performed in a standardized anterior-posterior projection and standing position using a conventional and digital phosphor storage film screen radiography system. Knee joint angulation was assessed by measuring the angle between a line drawn from the center of the femoral head to the middle of the femoral condyles and a line drawn from the middle of the tibial condyles to the midpoint of the malleolus. On conventional leg radiographs, line drawing and angle measurement were performed manually with a transparent goniometer. Angle measurement on digital leg radiographs was performed on a PACS workstation using computer-assisted measurement software (IMPAX, AGFA-GEVAERT, Belgium). Evaluation time for both measurements

was recorded. We diagnosed 14 varus and 10 valgus angulations of the knee joint. The mean individual difference between axis deviation of conventional digital leg radiographs was  $0.93 \pm 0.6^\circ$  (min  $0^\circ$ , max  $2^\circ$ ), the mean difference in varus angulation was  $1.13 \pm 0.45^\circ$  (min  $0.3^\circ$ , max  $2^\circ$ ), and the mean difference in valgus angulation was  $0.65 \pm 0.71^\circ$  (min  $0^\circ$ , max  $2^\circ$ ). Angle measurements on conventional and digital radiographs did not show any statistically significant difference. Mean time exposure was 4.9 min/patient for manual and 1.08 min/patient for computer-assisted angle measurement ( $P < 0.001$ ). Computer-assisted angle measurement on digital total-leg radiographs represents a reliable method with no significant angle differences compared to conventional radiographic systems and offers a significantly lower evaluation time.

**Keywords** Digital radiography · Lower limb alignment · Computer-assisted angle measurement

### Introduction

Standing anteroposterior long-leg radiographs using a conventional film screen system are part of a standardized protocol to evaluate axial alignment of the lower limb [1]. Assessment and quantification of lower limb alignment are important in the patient work-up in orthopedics and traumatology, especially when planning total knee arthroplasty [2–4]. Knowledge of the alignment of

the lower extremity is also important in postoperative follow-up.

Several indices of lower limb alignment have been described [5–9], but in the recent literature, there are no data about the evaluation and measurement of lower limb axial deviation using digital methods and about its applicability and reliability for clinical use. In this study, we measured the axial alignment of the lower limb on both conventional and digital radiographs. The following

points were considered to be potential causes for differences in the measurements acquired by conventional and digital measurements:

- Manual measurement deviations in angle evaluation on conventional radiographs.
- Errors in the localization of the dedicated measurement points on digital radiographs because of a smaller image size on the workstation screen.
- Inherent problems with the default use and application of the dedicated measurement software.

According to those points, the aim of this study was to compare a conventional standardized manual angle measurement procedure with a digital, computer-assisted method and to evaluate the required measurement time.

## Materials and methods

This study included 24 patients, 8 male and 16 female, with a mean age  $68.6 \pm 10.2$  years and a broad range of pathology. Fourteen patients had prior total knee arthroplasty, seven patients had total hip arthroplasty, and three patients suffered from valgus or varus gonarthrosis. Each patient underwent long-leg radiography of the lower limb (13 right, 11 left), the side according to the described pathology, using a conventional and a digital radiography system. All radiographs had been clinically indicated and served for diagnostic purposes or follow up. The mean time between both radiographs was 42 days; none of the patients underwent surgery between the two radiographs.

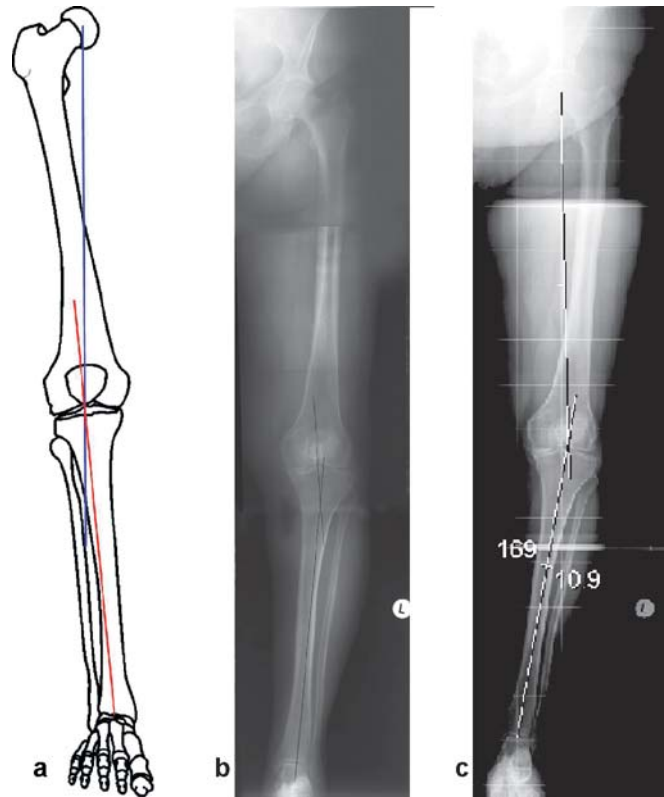
Radiographs were performed after informed patient consent in a standardized anteroposterior and standing position with normal footwear and the extremities positioned so that the patellae were facing forward. The gonads of male patients were shielded.

We used a conventional film screen radiography system (size  $20 \times 96$  cm or  $30 \times 120$  cm) for original size radiographs with a measurement grid, and an ADC (AGFA Diagnostic Center) full-body cassette holder with three overlapping ADCC/MD (AGFA Diagnostic Center Cassette, medium) phosphor storage plates ( $35 \times 43$  cm) for digital radiographs (AGFA-GEVAERT, Belgium) in the same patients. A 129.5- by 25.6-mm graduated grid was employed to filter the collimated X-ray beam in a graduated manner for equivalent visualization of the hip and the ankle. According to individual patient constitution, a setting of 77–96 kV and of 40–100 mA s was used for both conventional and digital imaging.

Lower limb alignment was measured according to axial deviation of the mechanical axes of the femur and the tibia. Measurement was performed by three board-certified radiologists. During the study-related image evaluation, patient data on the hard copy and the digital images were obscured and not available to the readers. All readers performed measurement on both conventional and digital long-leg radiographs. The mean angles were taken for further evaluation.

The mechanical axis of the femur was represented by a line from the center of the femoral head to the center of the distal femur, equivalent to the center of the intercondylar femoral notch. The mechanical axis of the tibia was represented by a line from the center of the knee, equivalent to the middle of the intercondylar eminentia, to the center of the talus. In patients with total knee arthroplasty, the intercondylar notch was considered equivalent to the midpoint of the femoral endoprosthesis trochlea, the tibial intercondylar eminentia equivalent to the midpoint of the tibial endoprosthesis plate.

Measurement on conventional radiographs was performed by drawing lines directly on the radiograph in the manner described above. Radiographs were copied for each reader. The center of the



**Fig. 1** a Anatomic drawing of the lower limb: the blue line for the mechanical axis of the femur, the red line for the mechanical axis of the tibia. b Conventional long-leg radiograph; the equivalent axes are drawn for manual measurement with the goniometer. Measured varus deviation was  $8.3^\circ$ . c Digital long-leg radiograph of the same patient; anatomic intersection points were chosen with mouse click; drawing of the equivalent mechanical axes and angle measurement was automatically performed by the PACS integrated software and showed a varus deviation of  $10.6^\circ$

femoral head was easily found using a Moses circle, and other essential points were detected based on the equivalent anatomic structures. For angle measurements on conventional radiographs, a goniometer was used. Angle measurements on digital leg radiographs were performed on a PACS workstation using dedicated computer-assisted measurement software (IMPAX, AGFA-GEVAERT, Belgium) with the identical anatomic landmarks that had to be chosen manually by mouse-click. The software automatically drew the mechanical axes of both femur and tibia and automatically showed the measured angle. We compared deviations of mean axial alignment and recorded required time exposure.

Statistical analysis was performed using the Student's *t*-test on SPSS for Windows (version 7.5), with a level of  $P > 0.005$  regarded as statistically significant. Interobserver reliability was evaluated by Spearman's correlation (Fig. 1).

## Results

Measurement of axial alignment was successful in all patients. All readers performed successful use of the dedicated measurement software. Location of the described anatomical landmarks was not limited by the presence of

total hip or knee arthroplasty. We diagnosed 14 varus and 10 valgus angulations of the knee joint. The mean total axis deviation on conventional radiographs was  $6.71 \pm 3.84^\circ$  (min  $1^\circ$ , max  $14^\circ$ ), with a mean varus angulation of  $5.36 \pm 3.80^\circ$  (min  $1^\circ$ , max  $11^\circ$ ), and a mean valgus angulation of  $8.6 \pm 3.20^\circ$  (min  $1.0^\circ$ , max  $3.0^\circ$ ). Equivalent data for the digital radiographs were  $6.08 \pm 3.67^\circ$  (min  $1^\circ$ , max  $13.9^\circ$ ), with a mean varus angulation of  $4.71 \pm 3.36^\circ$  (min  $1^\circ$ , max  $10^\circ$ ) or a mean valgus angulation of  $8.0 \pm 3.32^\circ$  (min  $2.3^\circ$ , max  $13.9^\circ$ ). The mean individual difference between axis deviations on conventional digital leg radiographs was  $0.93 \pm 0.6^\circ$  (min  $0^\circ$ , max  $2^\circ$ ), the mean difference in varus angulation was  $1.13 \pm 0.45^\circ$  (min  $0.3^\circ$ , max  $2^\circ$ ), and the mean difference in valgus angulation was  $0.65 \pm 0.71^\circ$  (min  $0^\circ$ , max  $2^\circ$ ). Angle measurements on conventional and digital radiographs showed no statistically significant differences. The Spearman's correlation coefficient for interobserver variability was 0.74 for manual angle measurement and 0.91 for computer-assisted evaluation. Total mean time exposure for all exams was 118 min (mean, 4.9 min/patient) for manual and 26 min (mean, 1.08 min/patient) for computer-assisted angle measurement ( $P < 0.001$ ).

## Discussion

Long-leg radiographs provide an approved and excellent method for quantification of axial alignment of the lower limb, which is especially important for preoperative and postoperative assessment in patients with total knee replacement [3, 4]. Line-drawing according to the mechanical axes of the femur and tibia with consecutive standardized manual angle measurement provides reliable and reproducible data and can be considered the "gold standard" [1]. The ongoing use of digital radiographic systems in clinical routine has led to increasing implementation of computer-assisted measurement software. However, there is a lack of data about this in the recent literature. Implementation of phosphor storage systems and digital integration of the technique rather than the use of conventional radiographs leads to a shortening of the work process, and image processing can be shortened by more than 30%. The major advantages of the implementation of integrated PACS and digital radiography systems are increased quality, reduction of mistakes in picture labeling, easier handling without the need for cassettes and hardcopies and the possibility of image postprocessing [10–14].

When comparing axial deviation of the lower limb on conventional and digital radiographs, we found no significant differences. Suspected causes for significance, especially the difference in image size between digital and conventional radiographs, could not be identified. Readers did not see any disadvantage in the smaller enlargement factor of the digital long-leg radiograph on the screen. A correlation coefficient of 0.91 allows the interpretation of an excellent interobserver reliability for the computer-assisted angle evaluation. The correlation coefficient of 0.74 for the manual evaluation on conventional radiographs was rather weak and might be interpreted by errors that occurred in manual angle measurement.

The computer-assisted measurement process on digital radiographs was subjectively considered by all three readers in consensus more simple and feasible than the manual evaluation, as it does not require time-consuming line drawings on the films. Accordingly, evaluation time was significantly lower when using the computer-assisted software. The time requirement of a mean of 1.08 min/patient is definitely acceptable and leads to the possibility of including quantification of axial alignment of the lower limb in the radiological routine report.

One weak point of our study might be the fact that the study required the patients to undergo an additional radiation exposure for the second long-leg radiograph. Conventional and digital imaging was not performed on the same day, with the intention to reduce additional radiation exposure to a minimum. The missing examination was performed within the scope of a clinically indicated radiological follow-up investigation of the knee or the hip and was extended to a long-leg radiograph after informed patient consent. The interval between conventional and digital imaging did not exceed 4 weeks in all patients.

Our results lead to the conclusion that our dedicated PACS integrated computer-assisted measurement software produces data at least as reliable as the manual "gold standard" and can therefore be recommended for use in the clinical practice without reservation. In conclusion, computer-assisted angle measurement on digital long-leg radiographs can be considered a precise and especially time-saving method for the evaluation of axial alignment of the lower limb. Its use will definitely be essential, given the increasing use of digital radiography systems and PACS and will certainly be a standard feature used every day in the next years.

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