Archives of Orthopaedic and Trauma Surgery (2019) 139:1455–1460
https://doi.org/10.1007/s00402-019-03256-x

KNEE ARTHROPLASTY

A whole leg radiograph is not necessary for postoperative determination of the mechanical leg axis after total knee arthroplasty

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Received: 24 April 2019 / Published online: 14 August 2019

Abstract

Background Anteroposterior (AP) whole leg radiographs (WLR) in the standing position for assessment of the mechanical leg axis are generally performed preoperatively for the planning of total knee replacement (TKR) and postoperatively to assess the leg axis. The objective of the present study was to investigate whether, if preoperative WLR are available, postoperative AP standard knee radiographs in the standing position are sufficient for calculating the mechanical leg axis.

Methods In the present prospective study, the mechanical and the anatomical leg axes were determined on the basis of WLR from 104 patients prior to implantation of a TKR and the difference was calculated. Twelve weeks postoperatively, standing long AP radiographs and WLR were prepared. In addition, the mechanical axis was calculated by adding the preoperative difference between the anatomical and mechanical axis to the anatomical axis from the postoperative AP radiographs. Accuracy, bias and level of agreement for calculated relative to measured mechanical alignment were determined.

Results Mean accuracy of calculated mechanical alignment was 0.5° ± 0.4°, and mean bias was 0.0° ± 0.6° ($p = 1.00$). Bland–Altman analysis revealed a 95% upper and lower level of agreement of − 1.3° and 1.3°, respectively.

Conclusion A preoperative WLR and a postoperative long AP knee standard radiograph are sufficient to determine the mechanical leg axis after TKR. If these are available, it is possible to do without WLR after TKR, particularly since they involve higher radiation exposure, are time-consuming, and are also prone to errors in the first postoperative weeks.

Level of evidence II diagnostic study.

Keywords Total knee arthroplasty · Radiography · Whole leg axis image · Mechanical leg axis

Introduction

Technical perfection of the implantation of a total knee replacement (TKR) has been considered to be prerequisite for the good functioning and survival of a TKR. Apart from the spatial alignment of the components, an as exact as possible reconstruction of the frontal plain is aimed at. The achievement of a straight mechanical leg axis of 0° with a tolerance of ± 3° remains the gold standard [1].

Within the context of the preoperative planning of the implantation of a TKR and for postoperative control and outcome assessment, there is thus a need to prepare whole leg radiographs (WLR) [2]. WLR are used for reliable determination of the postoperative leg axis [3]. However, this procedure has been the subject of considerable debate in recent times because of the markedly higher radiation exposure (about 75%) compared with standard images [long anteroposterior (AP)] and the partly increased susceptibility to errors [4]. Some authors have even questioned the utility of

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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radiological measurements on WLR of the knee [5, 6]. However, in the country of the authors, measurement of mechanical axis within the first 3 months postoperatively is required by regulations, and for this reason cannot be abandoned.

The objective of the present study was to investigate whether, if preoperative WLR are available, postoperative AP standard knee radiographs in the standing position are sufficient for calculation of the mechanical leg axis and thus postoperative WLR can be omitted for the purpose of axis determination.

The hypothesis was that there is no difference between measured (WLR) and calculated (standard image) mechanical leg axes 12 weeks after TKR.

Methods

Within the context of this prospective study, patients with primary osteoarthritis of the knee (Kellgren & Lawrence grade III, IV) who were due to undergo implantation of a TKR were consecutively recruited. Patients with an extension deficit of $< 20°$ were included. Patients with posttraumatic knee osteoarthritis and extraarticular deformities, periprosthetic fractures, simultaneous extraarticular axis corrections, bone structure anomalies, disorders of calcium and phosphate metabolism, or an extension deficit of $> 20°$ were excluded. Approval of the ethics committee of the Brandenburg Medical Association was obtained (AS 17(bB)/2015) prior to study commencement, and all patients provided informed consent before surgery.

The operations were all performed with the same endoprosthesis system (Journey BCS II, Smith & Nephew, Memphis, TN, USA) and the same surgical technique. Patient-specific instrumentation (Visionaire, Smith & Nephew) was used for the proximal tibial and the distal femoral cuts. A balancer device was used to create a symmetrical extension and flexion gap and to set femoral rotation [7]. All operations were aimed at achieving a neutral (0°) mechanical leg axis. After the operation, all patients underwent a standardised follow-up programme, including an individually adapted multimodal pain therapy, thromboembolism prophylaxis with a low-molecular-weight heparin, inpatient postoperative rehabilitation with full loading and free active and passive mobilisation of the knee joint [7].

All patients were examined clinically and radiologically prior to surgery and after 12 weeks. We chose 12 weeks, because there is no significant change of angle due to weight or function after this point [4]. We used the same radiographic technique used by Zahn et al. in their article about axis measurement after TKR [4]. At each examination, both a standardised WLR and a standardised long AP radiograph (30×60 cm) of the knee in the standing position were prepared, as far as possible at maximum extension. Attention was paid to an upright stance of the patient, to the central alignment of the patella in the image, and also to, as even as possible, a distribution of body weight over both legs [4]. We excluded all images in which the leg was not correctly imaged in the frontal plane, as well as images in which the head of the femur could not be clearly differentiated as a result of too high a degree of body fat.

The axes were determined with the validated and certified software mediCAD (Hectec GmbH, Altdorf, Germany).

The mechanical axis was defined as a line through the centre of the femoral head, the middle of the knee joint and the middle of the upper ankle. The anatomical knee axis was defined as the angle formed by the line through the center of the femur, the middle of the knee joint and the center of the tibia [8]. Valgus angles were noted as negative values throughout.

The center of the femur is defined by a line connecting two points each equidistant from the medial and lateral cortices along the femoral diaphysis on an AP radiograph, the center of the tibia is similarly defined by a line connecting two diaphyseal points [9]. Preoperatively, the mechanical and the anatomical axis were measured on the WLR and the difference was determined (Fig. 1). Twelve weeks postoperatively, the mechanical axis was measured on the WLR (Fig. 2) and the anatomical axis on the long AP radiographs (30×60 cm). This can be reliably determined on long AP images (Fig. 3) [10]. Then, the preoperatively determined difference was added to the values of the anatomical axis from the postoperative AP image to produce the calculated postoperative mechanical axis (Formula 1). Formula used to calculate the postoperative mechanical leg axis based on preoperative WLR and postoperative standing anteroposterior radiographs:

$$\begin{aligned}&\text{Calculated postoperative mechanical leg axis}\\&\quad = (\text{difference between preoperative mechanical axis WLR}\\&\quad \text{and preoperative anatomical axis WLR})\\&\quad + \text{postoperative anatomical axis AP.}\end{aligned} \tag{1}$$

The calculated postoperative mechanical leg axis was compared with the mechanical leg axis of the patient measured on the WLR (12 weeks postoperatively). An axial deviation of 3° was specified as threshold value for malalignment [11].

The reduction of the radiation exposure was calculated from the ratio of the average energy dose of the long AP images (1.48 cGy × cm^2) to the average energy dose of the whole leg images (5.92 cGy × cm^2).

The inter- and intra-rater reliability for determination of the mechanical and anatomical leg axes were determined. For determination of the intra-rater reliability, the measurements of the postoperative WLR were performed twice with

Fig. 1 Preoperative mechanical axis and difference between mechanical and anatomical axis (femoral)

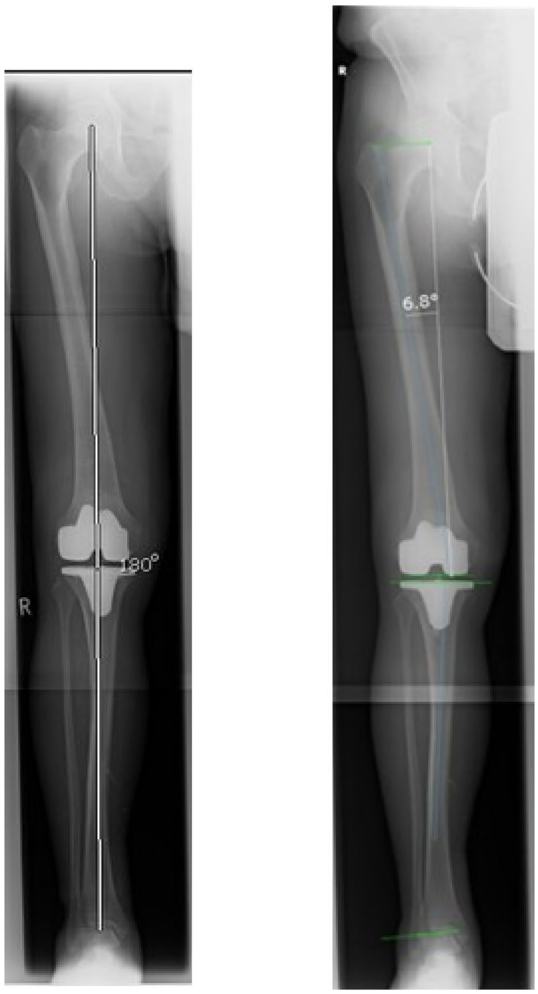

Fig. 2 Postoperative mechanical axis and difference between mechanical and anatomical axis (femoral)

a 6-week interval. For determination of the inter-rater reliability, the same measurements were performed independently by a second investigator (Table 1). Both investigators were experienced orthopaedic surgeons who had used the technique several times.

Statistics

The data are presented as mean ± standard deviation (SD) and as a range, as required. The testing for normal distribution of the data was done with the D'Agostino–Pearson normality test. The inter- and intra-rater reliability were determined with the Spearman (not normally distributed) or the Pearson (normally distributed) test as an intraclass correlation coefficient (ICC). Accuracy was defined as the absolute difference between the calculated value relative to the measured value. Precision was expressed as the 95% limits of agreement of the calculated value relative to the measured value [12]. Precision was also calculated by the percentage of patients with greater than 3° (alignment) deviation from the measured values. Bias was computed as the difference between the mean values from the intended values. A one-sample two-sided *t* test was performed to assess whether the calculated value significantly differed from the measured value. Multiple linear regression was performed to assess the association between difference between the two methods and age, gender, BMI, and postoperative mechanical alignment. The level of significance was set at $p < 5\%$. Stata/SE 15.1 (StataCorp, College Station, TX, USA) was used for analysis.

Results

Between III/2015 and VI/2015, 154 patients (154 knees) were assessed for eligibility. In total, 50 patients were excluded due to extra-articular deformity ($n = 12$), post-traumatic arthritis ($n = 24$) or a preoperative flexion contracture of more than 20° ($n = 14$). No patients were excluded

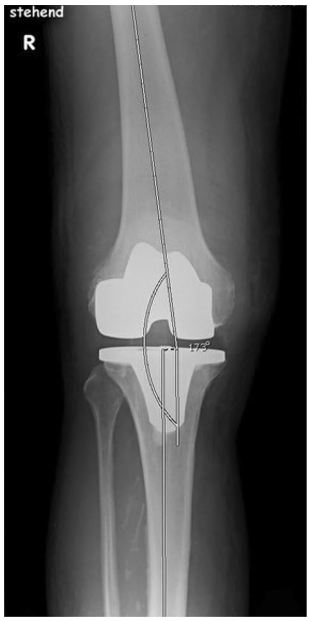

Fig. 3 Postoperative anatomical axis (femoral) 173° on long AP (30×60 cm) radiograph (same patient)

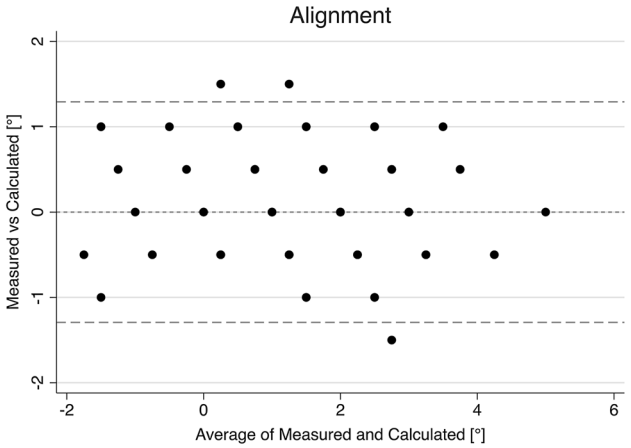

Fig. 4 Bland Altman plot for measured versus calculated mechanical alignment

for missing radiographs and due to the short follow-up time, there were no patients lost to follow-up. Of the 104 included patients, 48 were men and 56 were women. Their average age was 70 ± 7 years (range 53–85). Their BMI was 29.6 ± 2.6 kg/m^2. Mean preoperative alignment (± SD) was 5.1° ± 3.1° varus. Three patients had a preoperative valgus alignment, with a mean alignment of − 4.7° ± 2.5°. At 12 weeks postoperatively, there were no patients presenting a flexion contracture. Mean mechanical alignment at 12 weeks was 1.5° ± 1.5° varus and 1.5° ± 1.4° varus for measured and calculated mechanical alignment, respectively. In six patients (5.8%), mechanical axis alignment was outside of the target zone of ± 3°. For calculated mechanical alignment, there were 13 knees (12.5%) outside of the target zone. The mean accuracy of calculated mechanical alignment was 0.5° ± 0.4°, and mean bias was 0.0° ± 0.6°(range − 1.5° to 1.5°) (p = 1.00). There were no patients with greater than 3° deviation between the two methods. Bland–Altman analysis revealed a 95% upper and lower level of agreement of − 1.3° and 1.3°, respectively (Fig. 4). Multiple linear regression did not reveal a statistically significant association between the difference of measured and calculated mechanical alignment and age (p = 0.505), male gender (p = 0.175), BMI (p = 0.675), or preoperative mechanical alignment (p = 0.765).The radiation exposure was reduced to (1.48 cGy × cm^2: 5.92 cGy × cm^2) 25% when taking a 30 × 60 cm AP image, compared with a WLR.

Discussion

Overall, the study findings indicate that the accuracy for measuring and calculating lower leg alignment is similar. It was therefore shown that WLR are not necessary over the postoperative course if a preoperative WLR of the leg in the standing position and a standard AP standing radiograph of the knee are available. This means that the radiation exposure can be reduced for the patient, as can the economic and financial outlay involved in taking the radiographs. This finding will play an important role in the current discussion about the need for WLR.

The postoperative radiographic assessment of anatomic and mechanical lower leg alignment is considered state of the art, as the concepts of malalignment, instability, and loosening in TKA are closely interrelated [13]. The specifications on radiographic documentation before and after the implantation of a TKR for determination of the leg axes

Table 1 Inter- and intra-observer reliability of the postoperatively measured mechanical and anatomical leg axes

Radiographs	Inter-observer reliability (intraclass correlation coefficient)	Intra-observer reliability (intraclass correlation coefficient)
Mechanical axis on WLR	0.95	0.95
Anatomical axis WLR	0.95	0.97
Anatomical axis AP image	0.95	0.97

WLR whole leg radiograph, *AP* anteroposterior

are a matter of considerable discussion at present [14–16]. The exact postoperative determination of the mechanical axis and its documentation would appear to be more important than ever, especially for assessing the outcome of new surgical techniques for the alignment of knee replacements (anatomical versus mechanical versus kinematic alignment) [17]. These alignment options are an important subject of research at the moment, with their relative benefits not yet completely clarified but with an urgent need for reliable and comparable data [18–21]. Beside the extra time required for preparing the WLR, the WLR is always accompanied by an increased radiation exposure compared with AP standard images of the knee.

A mechanical WLR is suitable preoperatively for planning the correct position and size of the implant as well as the postoperative leg axis [22]. However, the present study shows that the renewed taking of a whole leg axis image postoperatively for determination of the mechanical leg axis is not necessary. If the difference between the anatomical and the mechanical leg axis has been determined preoperatively, the mechanical leg axis can be calculated with sufficient precision postoperatively on the basis of an AP standard image, assuming that a preoperative whole leg axis image is available. The anatomical axis can be determined reliably on the long AP radiographs [10].

Nevertheless, the reproducible technical performance of the WLR remains a difficulty, despite precise specifications [4]. The problem of exact radiological measurement and its importance [11] has been raised frequently. Measuring errors have been attributed to unrecognised rotation of the knee as a result of the two-dimensional imaging of a three-dimensional structure [23–25]. In addition, the axis values determined are dependent on the X-ray unit used [26], although there is no alternative technique available at present [27]. This results in the consistent exclusion of images in which the specifications on quality of the radiographs [26] were not met.

Solutions for better reproducibility might include special retaining devices for the leg, continuous measurement without loading in the supine position, or automated measurements [22, 28]. However, these have been applied rarely if at all in practice up to now.

The study presented here has limitations. The results of this study apply primarily to the hospital in which the images were prepared and its staff, who play an important role in instructing patients and precise compliance with the technical specifications, especially regarding positioning of the patients. The extent to which the results can be generalised and are generally valid must be shown in further studies at other institutions. The results are influenced by the experience of the examiners. The examiners of the radiographs had several years' experience in assessment. The transfer of the study results to patients with intra- and post-operative complications such as periprosthetic fractures, simultaneous extraarticular axis corrections, bone structure anomalies or disorders of calcium and phosphate metabolism is only possible to a limited degree. In such cases, the preparation of a WLR is still to be recommended at present [29].

Conclusion

Following TKR, a preoperative WLR and a postoperative long AP standing knee radiograph allow for adequate determination of the mechanical leg axis at 12 weeks postoperatively. In patients with primary knee OA without extraarticular deformity or severe flexion contractures, the routine performance of a postoperative WLR seems questionable considering the higher exposure to radiation.

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