Original Article

Novel method for evaluation of frontal plane knee alignment using bony prominences in patients with osteoarthritis

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Abstract. [Purpose] Angle measurement using images of bony prominences (AMI) determines frontal plane knee alignment from the skin surface without using radiation. The purpose of this study was to assess the validity and reliability of images obtained with the AMI method. [Participants and Methods] The study included 21 patients with osteoarthritis. We measured the functional axis of the lower limb, obtained via full-leg radiography and correlated the findings with the angle of dissection and the angle measured with the AMI method. Additionally, we assessed the reliability of the AMI method. [Results] The angle obtained using the AMI method and the radiographic anatomic axis (the full-leg radiograph)/the mechanical axis were well correlated. The AMI method also showed high reliability. [Conclusion] The AMI method is a valid and reliable alternative to full-leg radiography for imaging of functional and anatomical knee axes. As AMI does not use special equipment or involve radiation exposure, the method can be used in outside medical facilities and can be repeated over time without increased risk to patients.

Key words: Frontal plane knee alignment, Skin surface measure, Osteoarthritis

INTRODUCTION

Knee osteoarthritis (OA) is a common degenerative disease. Therefore, early disease diagnosis or prevention before is essential1). However, the lack of an epidemiological approach for knee osteoarthritis has rendered prevention difficult. Progression of knee OA and the resultant changes in alignment usually reflect bone and cartilage abrasion or narrowing within the articular cavity2). Sharma et al. examined 230 patients with knee OA and concluded that knee varus malalignment increased progression risk in the medial compartment3). Additionally, narrowing in medial articular cavity increased due to progression of varus malalignment and grade4). Moreover, progression of varus malalignment relates to narrowing in the articular cavity and increased risk of osteophytes5). Thus, knee malalignment is an independent risk factor for progression of knee OA6). For these reasons, evaluations of lower limb alignment are thought to be important for understanding and predicting progression of knee OA.

The gold standard method for examining knee alignment is the weight-bearing full-leg radiograph. Medical staff can verify both the mechanical3) and anatomical axes7) in the lower limb using this method. However, full-length radiography is costly, and requires specialized equipment that may not be readily available. Additionally, the procedure necessitates
radiation exposure to capture continuous changes in lower limb alignment. Because of this, the weight-bearing full-leg radiograph is rarely implemented as a tool for preventative management of knee OA. Rather, a goniometer is routinely used as an expedient means of screening knee alignment. Kraus et al.\textsuperscript{50} reported that the mechanical axis was strongly correlated with the goniometer reading; however, on the other hand, Hinman et al.\textsuperscript{50} found there was no correlation. Regardless, the goniometer is only used by clinicians and is not used by non-medical staff.

We devised the angle measurement method by image using bony prominences (AMI), a new and novel measurement method for allowing non-medical staff or other novices to easily evaluate articular deformities. This method uses markers which are placed on particular sites (bony prominences). These markers allow us to evaluate lower limb alignment using filmed images. This study sought to investigate the correlation between the weight-bearing full-leg radiograph (considered the gold standard for evaluating knee alignment) and the AMI method, from the skin surface, for measurement of the anatomic and mechanical axes of the knee. Additionally, we investigated the reliability of the AMI method by repeated measures in a patient with knee OA.

**PARTICIPANTS AND METHODS**

Participants were patients with knee osteoarthritis followed at a hospital affiliated with this investigation. All participants received full-leg radiographs or full-length radiographs. Exclusion criteria were: (1) past surgery involving the lower leg, (2) inability to maintain the knee joint(s) in an extended position, and (3) unable to perform symmetrical total body weight-bearing while standing. All participants provided voluntary, written informed consent for study participation. Ethical Review Boards at Showa Inan General Hospital (No. 2014-25) and Tatsuno Hospital (No. 2014.11) approved all aspects of this study.

We obtained a single full-leg, anteroposterior, weight-bearing radiograph on the symptomatic lower limb in each participant, using a 0.356 m × 1.067 m cassette. The femoral head, knee joint and talus were captured on all images. Participants stood barefoot with full knee extension and were positioned with the tibial tuberosity facing the X-ray beam. The X-ray tube was positioned 2.50 m from the cassette and set to 12.5 mA/sec and 58 kilovolts. From an anatomical and functional point of view, the femorotibial angle (FTA) and hip-knee-ankle angle (HKA) were considered parameters of lower limb alignment. FTA was also measured in two different ways. First, the short view (FTA-short) was used as a general knee alignment measure. The second, full-length radiograph (FTA-long) was used as a more accurate measurement of the anatomical axis. Before the measures were taken, each participant stood on a scale to attain balance using both legs. The between-leg difference was defined as within ± 3 kg of half the bodyweight. Then, the participant stood with his/her feet parallel to each other at a distance of 0.10 m in order to standardize the radiographic posture.

The mechanical axis was the angle between the femoral and tibial functional axes, defined using methods described by Sharma et al.\textsuperscript{3}. The femoral functional angle was drawn from the center of femoral head to the center of the femoral intercondylar incisures. HKA was measured as the angle between the femoral and tibial functional axes. Knee alignment measurements from the functional axis were shown as deviations from 180 degrees, with a positive deviation indicating valgus and a negative deviation indicating varus. Knee joint alignment from the anatomical axis was determined via the following two methods. In the first method, the Moreland procedure\textsuperscript{7} was used to define the anatomical axis. For FTA-short, the anatomical axis was defined as the angle between the two lines connecting the center of the tibial spine to two bisection points, 0.10 m superior and inferior, to the tibial spine on the femur and tibia (Fig. 1).

The second method used FTA-long and two lines drawn on full-scale X-ray films. The first line was defined as the anatomical axis on the femur which connected the bisection point on the narrowest aspect of the femoral endosteum cortex to the bisection point on the femur, 0.10 m superior to the knee joint. The second line was defined as the anatomical axis on the tibia which connected the bisection point on the center of tibial midshaft to the bisection point on the tibia, 0.10 m inferior to the knee joint\textsuperscript{7}. The FTA-long was defined as the intervening angle to the anatomical axis on the femur and tibia (Fig. 1).

AMI method is a lower limb alignment evaluation method based on measures taken from the skin surface. AMI method is a three-step procedure: 1) Application of markers on lower limb landmarks; 2) Photographing of the lower limb using a camera; and 3) Measurement of knee joint alignment on the photograph of the lower limb image using image processing software.

Markers (0.008 m in diameter) were applied to lower limb landmarks by physical therapists with over five years clinical experience. Lower limb landmarks were on the greater trochanter, femoral lateral condyle, head of the fibula, lateral malleolus, and center of the patella (Fig. 2).

To evenly capture every marker, a digital camera (Canon Power Shot SX500IS, pixel number: 1.6M, focal distance: 4.3 (W) – 129.0 (T) mm) was positioned 1.0 m from each participant. The camera was placed horizontally using a level, facing the participant to reduce image distortion from positional displacement. The camera was placed horizontally using a level and located directly in front of the knee joint using a laser beam, facing the participant to reduce image distortion from positional displacement.

In short, participants were photographed in the same posture used during full-leg radiography. Specialized software was developed to measure alignment (Lab VIEW2114, NI). Lower limb pictures were taken and uploaded into the program, when then recognized the markers on specific lower limb locations. The software calculated angles on the lateral side, between the line connecting the greater trochanter and femoral lateral condyle, and the line connecting the head of fibula and the lateral malleolus using recognized markers (Fig. 3).
Reliability of AMI method was examined by calculating the intra-class correlation coefficient (ICC) for both intra-rater and inter-rater reliability. Examiners were two non-medical postgraduate students without specialized anatomical knowledge. Reliability measures were performed on seven male patients (mean age 23.8 ± 0.2) without lower limb deformity, injury, or surgical history. Two examiners applied markers five times to a single participant and reliability measures were calculated from the results.

SPSS20.0 was used for all statistical analyses. Correlation between AMI method and gold standard radiographs were analyzed using the Spearman correlation coefficient.

Correlation coefficients of 0.41–0.60 were regarded as moderate, 0.61–0.80 were regarded as substantial and values over 0.81 were regarded as almost perfect\(^1\). P values less than 0.01 were regarded as significant. The angle of a participant’s knee joint was measured by each examiner, and the intra-rater reliability ICC (1,1) and the inter-rater reliability ICC (2, 1) were determined from the resultant data. For intra-rater reliability, each measure was performed five times per participant. For the inter-rater reliability, a single measure was taken for each participant.

**RESULTS**

Participants were the 21 individuals (total 39 limbs) with knee osteoarthritis. Participant characteristics are shown in Table 1. An almost perfect correlation of at least 0.9 was observed between AMI method and both HKA, anatomical axis (FTA-short) (r=0.94, r=0.90, p<0.001). A moderate correlation was observed between AMI method and the anatomical axis (FTA-
However, this correlation was weaker than the one observed between AMI method and the anatomical axis (FTA-long) ($r=0.55, p<0.01$). For evaluating the agreement between AMI method and the gold standard radiograph, an almost perfect correlation was observed between the anatomical axis (FTA-long) and HKA ($r=0.93, p<0.001$) (Table 2).

The ICCs for the intra-rater reliability for AMI method were 0.81 and 0.88 (Table 3). The ICC for inter-rater reliability for AMI method was 0.81.

**DISCUSSION**

AMI method, a novel method for evaluating frontal plane knee alignment during weight-bearing, exhibited almost perfect correlation with both the mechanical (HKA) and anatomical (FTA-long) axes. These findings show that AMI is a reliable method for determining knee alignment, using skin surface markers and without exposure to radiation. A moderate correlation was observed between AMI method and the anatomical axis (FTA-short). This correlation was weaker than the one between AMI method and anatomical axis (FTA-long). In general, FTA is measured from knee short views. However, these short views are limited in their ability to define the anatomical axes of bones. It is especially difficult to predict proximal and distal deformities in the femur just using the anatomical and mechanical axes observed using the FTA-short. Therefore, bone malalignment like coxa vara will be omitted from this measurement. Also, some researchers reported a low possibility...
of errors on the anatomical and mechanical axes using the FTA-long, compared with the FTA-short\textsuperscript{(15)}. This means that the AMI method reflects overall lower limb alignment. A previous study from Hinman et al. showed a strong correlation between the mechanical axis and the caliper method or inclinometer measurement\textsuperscript{(9)} ($r=0.76$, $r=0.80$). AMI may hold an advantage over these measurement methods for reflecting the mechanical axis.

Additionally, the intra-rater and inter-rater reliability were over 0.8, indicating significantly high reliability. This level of reliability is the highest (almost perfect) according to the Landis standard\textsuperscript{(11)}. One reason for this may be that all landmarks were on bony prominences, making it easier for examiners to palpate proper landmarks without advanced anatomical knowledge. Practitioners often use goniometers for lower limb alignment evaluations; however, general non-medical postgraduate students showed significant reliability using AMI. This means reliable measurement can be achieved by individuals without extensive medical knowledge, in non-hospital settings. In the future, we will attempt to standardize the AMI landmarks to make this method even more reliable, so ordinary people could measure lower limb alignment without a physical therapist or medical doctor. We also plan on developing novel application software for calculating angles using a portable information device. Regular measures of lower limb alignment using AMI may emerge as a novel, quantitative evaluation for knee OA, potentially lessening risk of knee OA progression in at-risk patients. One limitation to this investigation was that the participants varied with regard to varus deformity. Also, there were no participants classified as K-L grade 1. Future research should include participants with valgus deformities, and also those classified as grade 1, in order to further confirm the validity of AMI.

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**Conflict of interest**

None.

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