Beam Projection Effect in the Radiographic Evaluation of Ankle Valgus Deformity Associated With Fibular Shortening

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Background: Fibular shortening is one of the most common causes of ankle valgus deformity in children, and is frequently observed in patients with hereditary multiple exostoses (HME). It has been observed that the lateral distal tibial angle (LDTA) measured on the teleoradiograph differs from that on the ankle anteroposterior (AP) radiograph. The effect of the beam projection angle in the measurement of ankle valgus deformity associated with fibular shortening in HME patients was investigated.

Methods: Fourteen ankles showing valgus deformity associated with fibular shortening from 14 HME patients comprised the short fibula group. Nineteen ankles with normal ankle alignment from 19 patients comprised the control group. The LDTA on the AP radiograph, teleoradiograph, and 3 coronal planes of 3-dimensional computed tomographic scans were measured and compared.

Results: In the short fibula group, the LDTA measured on the ankle AP radiograph was significantly larger than that on the teleoradiograph (79.6 ± 4.3 vs. 75.0 ± 6.2 degrees, $P = 0.001$), whereas there was no significant difference in the control group ($P = 0.36$). In the short fibula group, the LDTAs measured on the 3 coronal planes of 3-dimensional computed tomography showed that the ankle valgus measurement significantly increased from anterior to posterior planes ($P = 0.001$), whereas there was no significant difference in the control group ($P = 0.85$).

Conclusions: Measurement of ankle valgus deformity depends on the direction of beam projection and ankle valgus deformity is more severe in the posterior coronal plane of the ankle joint. This discrepancy should be taken into consideration in the planning of ankle valgus deformity management.

Level of Evidence: Level IV—diagnostic.

Key Words: ankle valgus deformity, fibular shortening, beam projection

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Ankle valgus deformity in children develops from a variety of etiologies.[1–8] Fibular shortening is one of the most common causes of ankle valgus deformity and is frequently observed in patients with hereditary multiple exostoses (HME).[9,10] Many authors have used the plain ankle anteroposterior (AP) radiograph to measure the ankle valgus tilt angle,[2,6,9,11,12] but some have used the teleoradiograph.[9] While evaluating the alignment of lower limb in HME patients, the authors have frequently observed that the lateral distal tibial angle (LDTA) measured on the teleoradiograph differs from that on the ankle AP radiograph (Fig. 1), which confused us in planning the management of ankle valgus deformity. Ebraheim et al[13] reported that the ankle AP radiograph provides an accurate representation of the anterior part of the joint surface, but little information regarding the posterior joint line. Hence, we investigated the effect of the beam projection angle in the measurement of ankle valgus deformity associated with fibular shortening in HME patients.

METHODS

This study was approved by the institutional review board. From 158 HME patients who were examined by the authors from January 2001 to October 2014, 14 ankles were selected to comprise the short fibula group as subjects of this study. All 14 patients of the short fibula group had osteochondromas at the ankle. The number of osteochondromas in each patient varied from 1 to 14 with the median number of 4. Inclusion criteria were the ankles: (1) showing valgus deformity as defined by LDTA[14] < 86 degrees; (2) with fibular shortening of Malhotra class I[6] or more; and (3) of which ankle AP radiograph, lower extremity teleoradiograph, and ankle 3-dimensional computed tomography (3D-CT) were available for analysis. The patients were 12 men and 2 women. Both ankles in 5 patients fulfilled the inclusion criteria, but only 1 side ankle were randomly selected and

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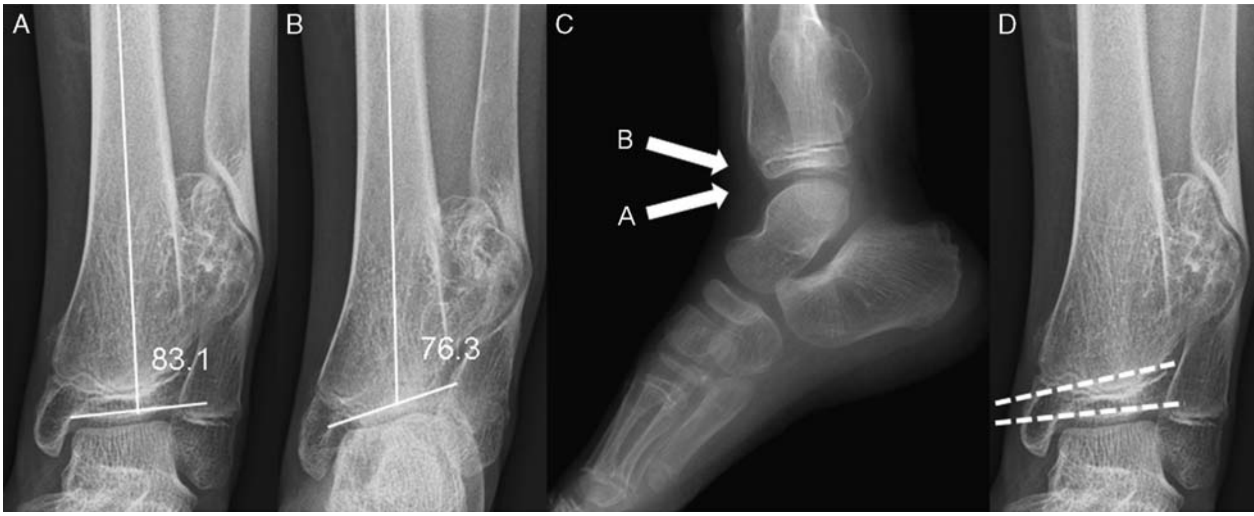

FIGURE 1. Lateral distal tibial angle of a 14-year-old boy with hereditary multiple exostoses, measured on the teleoradiograph of the whole lower extremity (A) and that measured on the ankle anteroposterior (AP) radiograph (B). C, Beam projections of these 2 plain radiographies are shown by the respective arrows. D, The articular surface and the growth plate are indicated by the dashed lines from which the epiphyseal wedge angle was measured.

included in the study. The mean age at the time of radiographic evaluation was 12.3 years (range, 6 to 17 y).

During the same period, 19 ankles were selected to comprise the normal control group. These ankles had normal ankle alignment (LDTA between 86 and 92 degrees[15]); did not show any sign of osteoarthritis; and had available ankle AP radiograph, lower extremity teleoradiograph, and 3D-CT data. They were the contralateral unaffected ankles of 4 men and 15 women who underwent ankle operations such as arthroplasty, ligament repair, or arthroscopy. The mean age at the time of radiographic evaluation was 59.7 years (range, 41 to 77 y).

The ankle AP radiograph was taken with focal receptor distance of 1.1 m and with the central beam focusing on the center of the ankle joint. The teleoradiograph was taken in the patella-facing-forward position, with focal receptor distance of 1.8 m and with the central beam focusing on the center of the patella. Fibular shortening was assessed with the Malhotra classification in the short fibula group. Briefly, it was classified as grade 0 when the distal fibular physis was at the level of talar plateau, grade 1 when between the talar plateau and the distal tibial physis, grade 2 when in line with the distal tibial physis, and grade 3 when proximal to the distal tibial physis. In the control group, the talocrural angle[16] was measured to assess fibular shortening because all subjects had achieved skeletal maturity and Malhorta classification could not be applied.

The LDTA was defined as the lateral angle between the long axis of the tibial diaphysis and the distal tibial articular surface.[14] It was measured on the AP radiograph and teleoradiograph (Fig. 1). The LDTA was also measured on the 3 coronal planes of 3D-CT—at the midpoint, anterior one-quarter point, and posterior one-quarter point in the AP depth of ankle mortise in the short fibula group as well as in the control group (Fig. 2).

The epiphyseal wedge angle (EWA) defined as the angle between the articular surface and growth plate (Fig. 1D) was measured on the ankle AP radiograph, teleoradiograph, and 3 coronal planes of 3D-CT in the short fibula group.

The paired t test was used to compare the LDTAs measured on ankle AP radiographs and teleoradiographs. Mann-Whitney U test was used to compare the difference between LDTA on the ankle AP radiograph versus that on the teleoradiograph according to the fibular station. Repeated measures analysis of variance test was used to compare the LDTAs measured on the 3 coronal planes of 3D-CT. Individual comparisons were conducted using post hoc Bonferroni method. Nonparametric test was performed to analyze EWA, which does not follow a normal distribution. Wilcoxon signed-rank test was used to compare differences between the EWA on the ankle AP versus that on the teleoradiograph. Friedman test was used to analyze the EWAs measured on the 3 coronal planes of 3D-CT. Individual comparisons were conducted using post hoc Bonferroni method. The statistical analyses were performed with SPSS software (Ver. 17.0, Chicago, IL). A $P < 0.05$ was considered as statistically significant.

RESULTS

Among 14 ankles in the short fibula group, no ankle was in station I of the Malhotra classification, 4 in station II, and 10 in station III. The talocrural angle in the control group measured 82.4 ± 1.4 degrees, all of which were within normal range (from 75 to 86 degrees).[17]

In all cases of the short fibula group, the LDTA measured on the ankle AP radiograph was significantly larger than that on the teleoradiograph (79.6 ± 4.3 vs. 74.4 ± 6.2 degrees; $P = 0.001$). In the normal control

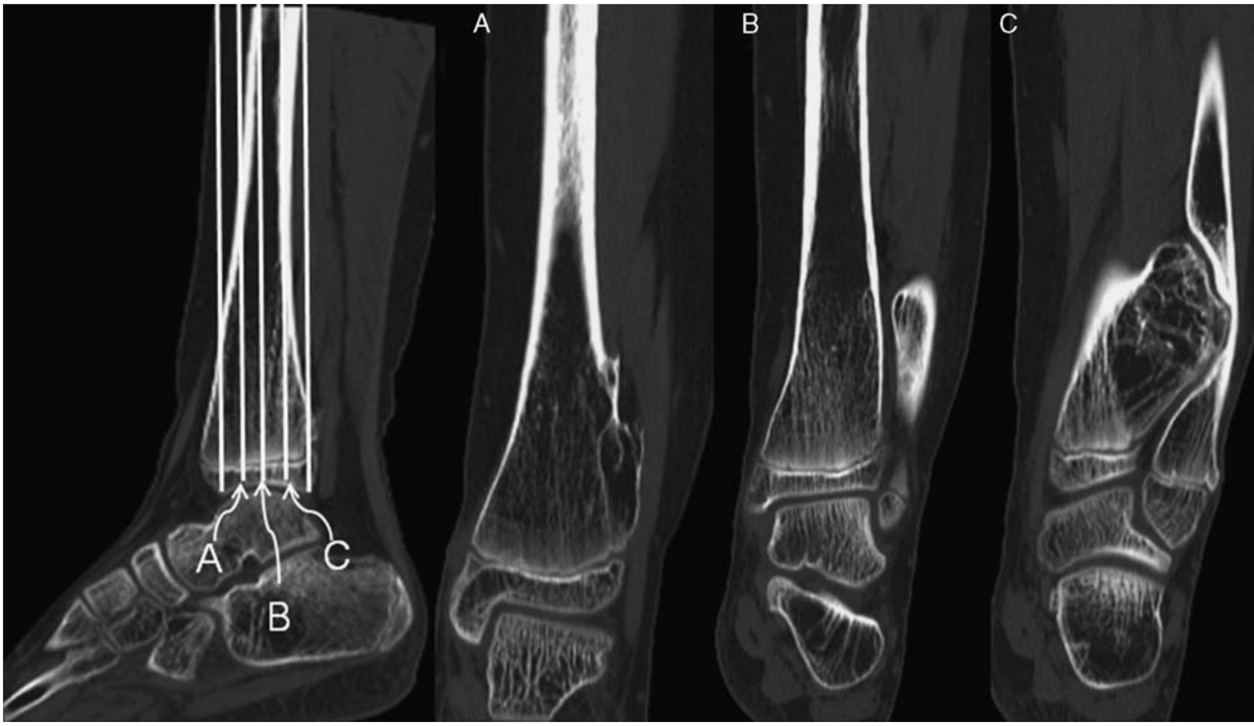

FIGURE 2. Multiplanar reconstruction (MPR) 2-dimensional images on the coronal plane were selected at anterior one-quarter (A), the midpoint (B) and posterior one-quarter (C) of the anteroposterior diameter. The computed tomographic-lateral distal tibial angle was also measured on these 2 MPR images.

group there was no significant difference between the LDTAs measured on the ankle AP radiograph and teleoradiograph (90.7 ± 1.7 vs. 90.4 ± 2.0 degrees; $P = 0.36$). The difference in LDTA between ankle AP radiograph versus teleoradiograph tended to increase between Malhotra station II and III, although it failed to show statistical significance ($P = 0.42$, Fig. 3).

In the short fibula group, the LDTAs measured on the 3 coronal planes of 3D-CT showed that the ankle valgus measurement significantly decreased from anterior to posterior planes ($P = 0.001$), being 89.8 ± 3.2 degrees on the anterior one-quarter plane, 80.9 ± 6.7 degrees at the midpoint plane, and 72.1 ± 6.1 degrees at the posterior one-quarter plane (Fig. 4). Post hoc Bonferroni method showed that all LDTAs on the 3 planes significantly differed from each other. In contrast, in the control group there was no significant difference in the LDTAs measured on the 3 coronal planes (anterior one-quarter plane: 91.53 ± 1.95 degrees, midpoint plane: 90.14 ± 1.56 degrees, posterior one-quarter plane: 90.08 ± 1.50 degrees, $P = 0.85$).

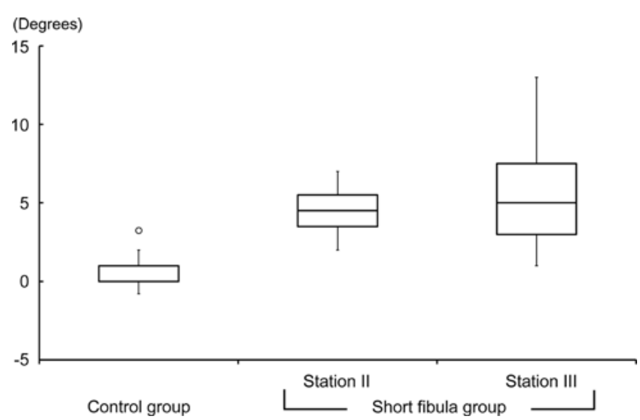

FIGURE 3. Differences in lateral distal tibial angle according to fibular shortening. Stations indicate those of Malhotra classification[6] in short fibular group.

In the 14 ankles of the short fibula group, EWA measured on the teleoradiographs was significantly larger than that on ankle AP radiographs (12.9 ± 4.3 or 8.5 ± 3.4 degrees, respectively; $P = 0.001$). The mean EWAs on the 3 coronal planes of 3D-CT increased from anterior to posterior, being 1.6 ± 2.9 degrees at the anterior one-quarter point, 8.6 ± 3.9 degrees at the midpoint, and 15.8 ± 4.3 degrees at the posterior one-quarter point, respectively ($P = 0.001$, post hoc Bonferroni method).

DISCUSSION

Radiographic measurements of ankle valgus deformity associated with fibular shortening differed significantly between ankle AP radiographs and teleoradiographs. It appeared larger on the teleoradiographs than on AP radiographs by an average of 5.1 ± 3.4 degrees in this series. Such a difference may affect the clinical decision in the management of ankle deformity. In some patients of this series, the authors considered surgical correction of the ankle deformity based upon teleoradiographic finding, but changed our mind on

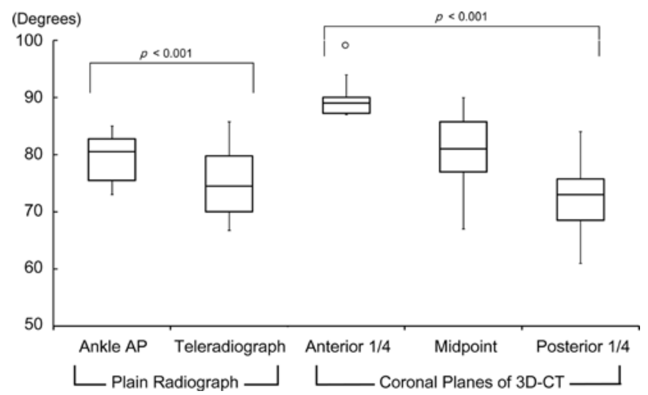

FIGURE 4. Lateral distal tibial angles (LDTAs) measured on the different radiographic images. The LDTA of ankle anteroposterior radiograph was similar to that of midpoint coronal planes of 3-dimensional computed tomography (3D-CT) and the LDTA of teleoradiograph was similar to that of posterior one-quarter coronal plane of 3D-CT.

reviewing the ankle AP radiograph because the deformity was less on this image. Furthermore, awareness of this difference according to the projection angle is important in follow-up examination with or without surgical correction of the deformity.

Scrutinizing the 3D-CT data revealed that the slope of the distal tibial plafond was steeper to the posterolateral corner, where the fibula was located, in the short fibula group. Tendency of increasing difference in LDTAs with increasing severity of fibular shortening, although failed to show statistical significance, seems to further support the association of ankle valgus and fibular shortening. Increasing tendency of the EWA from anterior to posterior coronal planes of 3D-CT implies that the growth retardation is more severe posteriorly than anteriorly. The reason for this growth retardation of the distal tibial epiphysis is considered to be associated with the short fibula that is located on the posterolateral side of the tibia. Therefore, we believe that the posterolateral growth retardation of the distal tibial epiphysis is present in ankle valgus deformity associated with short fibula. Mechanism of ankle valgus deformity in association with fibular shortening is not clear. It might involve tethering of the distal tibial longitudinal growth at the posterolateral corner by short fibula or suppression of the posterolateral distal tibial epiphysis growth from loss of fibular support at this corner.

The LDTA measured on ankle AP radiograph was close to that on the midpoint coronal plane of 3D-CT, whereas the LDTA of the teleoradiograph was close to that of the posterior one-quarter coronal planes in the short fibula group. We believe that the distinct concordance of the ankle AP radiograph and the teleoradiograph to the coronal planes of 3D-CT is due to the effect of x-ray beam projection. The tibial plafond is dome-shaped on the sagittal plane. The x-ray beam of the ankle AP radiograph is projected perpendicular to the tibial axis, so is tangential to the midpoint of the plafond dome. Thus, the LDTA on this image represents that of the midpoint coronal plane. In contrast, in teleoradiography the x-ray beam passes through the ankle joint in a cephalocaudal direction. Thus, the LDTA on the teleoradiograph represents the posterior part of the plafond dome, which is close to the posterior one-quarter coronal plane. Hence, the difference between the LDTAs on teleoradiographs versus ankle AP radiographs reflects the difference in ankle valgus on these 2 different coronal planes. Interestingly, correction of the ankle valgus deformity by transphyseal screw was faster in studies using ankle AP radiograph[11,15] than a study using teleoradiograph.[9] It is conceivable that the transphyseal screw, inserted at the midpoint coronal plane, may affect more the midpoint deformity represented on ankle AP radiograph than the posterior coronal plane deformity represented on teleoradiograph. However, it could not be proven in our study, but remains to be investigated in future studies.

Many previous reports have described the effects of the x-ray beam projection angle. Ankle AP radiographs characterize the anterior portion of the joint, whereas it can poorly assess the posterior portion of the joint.[13] For this reason, the assessment of fracture anatomy at the posterior tibial margin based on the ankle AP radiograph may be underestimated, with additional oblique views recommended to assess fractures of the posterior portion of the tibial plafond.[13,18,19] However, no study has yet investigated the x-ray beam effect in the measurement of ankle valgus deformity. The authors use teleoradiographs at the regular follow-up for the lower extremity angular deformity and leg-length discrepancy. If ankle valgus deformity is noticed on the teleoradiograph, an ankle AP radiograph is taken for further evaluation. The ankle valgus deformities measured on both projections are taken into consideration in surgical planning. We put more importance on the angle measured on ankle AP radiograph in making a surgical decision, but it remains to be further investigated which angle of the 2 measurements are biomechanically more important.

The present study has several limitations. First, all the study subjects were HME patients. We purposefully recruited HME patients to make a homogenous subject group. Effects of osteochondromas on growth plate and consequent ankle valgus deformity need to be taken into consideration in HME patients. According to previous reports,[3] however, fibular shortening, by any causes, is related to ankle valgus deformity. Therefore, we believe that the findings are pertinent in any case of ankle valgus deformity associated with fibular shortening. Second, the normal control group was not age matched with the short fibula group because 3D-CT images of age-matched normal ankles were not available in this retrospective study. However, the effects of age should be negligible because this study investigated only the radiographic appearance.

In summary, measurement of ankle valgus deformity associated with fibular shortening is different according to the direction of x-ray projection. The ankle valgus deformity measured on the teleoradiograph is larger than those on the ankle AP radiograph. Analysis of changes in the ankle valgus on coronal planes of 3D-CT revealed that the ankle valgus deformity along with more severe epiphyseal wedging is more severe on the posterior coronal plane. This may be attributed to the posterolateral location of the fibula at the ankle mortise. This discrepancy in the measurement in ankle valgus deformity should be taken into consideration in planning management for the ankle valgus deformity.

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