Original Article
Clinics in Orthopedic Surgery 2024;16:125-133 • https://doi.org/10.4055/cios22359

Radiographic Evaluation of the Association between Foot Deformities and Ankle Medial Osteoarthritis

Ji Hye Choi, MD, Kwon Seok Noh, MD*, Dong Yeon Lee, MD†, Yoon Hyo Choi, MD*, Taeyong Lee, PhD‡, Kyoung Min Lee, MD*

Department of Orthopedic Surgery, Anam Hospital, Korea University College of Medicine, Seoul,
**Department of Orthopedic Surgery, Seoul National University Bundang Hospital, Seongnam,*
†Department of Orthopedic Surgery, Seoul National University Hospital, Seoul,
‡Division of Mechanical and Biomedical Engineering, Ewha Womans University, Seoul, Korea

Background: Foot deformities can cause abnormal biomechanics of the ankle joint and the development of osteoarthritis. It was hypothesized that foot deformities would be related to medial ankle osteoarthritis, and this study investigated this relationship using radiographic measurements.

Methods: Seventy-six ankles of 76 patients (32 men and 44 women; mean age, 69.0 years) with medial ankle osteoarthritis were included. Eleven radiographic measurements evaluated ankle joint orientation (tibial plafond inclination [TPI], medial distal tibial angle [MDTA], and anterior distal tibial angle [ADTA]), ankle joint incongruency (tibiotalar tilt [TT]), foot deformities (lateral talo-first metatarsal angle [Lat talo-1MT], anteroposterior talo-first metatarsal angle [AP talo-1MT], and talonavicular coverage), talar body migration (medial talar center migration [MTCM] and anterior talar center migration [ATCM]), internal rotation (IR) of the talus, and mechanical tibiofemoral angle. All were statistically analyzed using Pearson's correlation coefficients and regression analyses.

Results: Ankle joint orientation to the ground (TPI, $p = 0.002$), increased foot arch (Lat talo-1MT, $p < 0.001$), and IR of the talus ($p = 0.001$) were significantly associated with ankle joint incongruency (TT) in linear regression analysis. Ankle joint incongruency (TT, $p = 0.003$), medial talar body migration (MTCM, $p = 0.042$), and increased foot arch (Lat talo-1MT, $p = 0.022$) were significantly associated with IR of the talus in the binary logistic regression analysis. MTCM was significantly correlated with TPI ($r = 0.251$, $p = 0.029$), TT ($r = 0.269$, $p = 0.019$), MDTA ($r = 0.359$, $p = 0.001$), ATCM ($r = -0.522$, $p < 0.001$), and AP talo-1MT ($r = 0.296$, $p = 0.015$). ATCM was significantly correlated with TPI ($r = -0.253$, $p = 0.027$), ADTA ($r = 0.349$, $p = 0.002$), and Lat talo-1MT ($r = -0.344$, $p = 0.002$).

Conclusions: Ankle joint orientation, foot deformities, and talar rotation were associated with ankle joint incongruency in medial ankle osteoarthritis when evaluated radiographically. These findings need to be considered during surgical treatment for medial ankle osteoarthritis. However, the biomechanical significance of these radiographic measurements requires further investigation.

Keywords: *Medial ankle osteoarthritis, Radiographs, Foot, Foot deformities*

Ankle osteoarthritis (OA) is a debilitating condition that usually affects elderly individuals.[1)] Although the prevalence of ankle OA is lower than that of hip or knee OA, ankle OA is reported to cause as much disability as hip OA.[2)] In addition, the increasing prevalence of ankle OA in aging societies[3)] and the complex anatomy of the ankle joint have drawn increasing interest and attention from orthopedic surgeons.

Received November 9, 2022; Revised April 11, 2023;
Accepted August 20, 2023
Correspondence to: Kyoung Min Lee, MD
Department of Orthopedic Surgery, Seoul National University Bundang Hospital, 82 Gumi-ro 173beon-gil, Bundang-gu, Seongnam 13620, Korea
Tel: +82-31-787-7205, Fax: +82-31-787-4056
E-mail: oasis100@empal.com

Eccentric wear of the cartilage on the medial or lateral side of the ankle joint is usually concomitant with heel varus or valgus deformities,[4,5] and it imposes additional difficulties in the biomechanical balancing of the ankle joint during motion-preservation surgeries such as supramalleolar osteotomy or total ankle arthroplasty.[6] Although these surgeries involved the correction of fixed-foot deformities, previous studies on this topic did not sufficiently clarify the relationship between the characteristics of ankle OA and any concomitant foot deformities.

Correction of ankle-joint deformities by supramalleolar osteotomy has been reported to cause both favorable and unfavorable outcomes.[7-9] These contradictory reports are considered to be caused at least in part by compensatory correction of concomitant foot deformities. However, it is not clear whether foot deformities are true pathologies or secondary compensations and whether they are rigid or flexible. A recent study reported radiographic and clinical improvements following the correction of flatfoot for posterior ankle arthritis,[10] which raised interest in anteroposterior (AP) cartilage wear as well as mediolateral wear along with concomitant foot deformities. Therefore, it was hypothesized that foot deformities would be related to medial ankle OA, and this study investigated this relationship using radiographic measurements.

METHODS

This retrospective study was approved by The Institutional Review Board of Seoul National University Bundang Hospital (No. B-2201-733-103). The requirement for informed consent was waived due to the retrospective nature of the study.

Participants

We reviewed the medical records and radiographs of consecutive patients 50 years of age and older who had visited our hospital for ankle pain between September 2020 and March 2021. Of these, patients with medial ankle OA who underwent weight-bearing ankle and foot radiography along with a teleradiogram were included. Exclusion criteria were as follows: (1) neuromuscular disease, (2) congenital anomaly, (3) previous foot and ankle fracture history, (4) infection or tumor, (5) previous lower-extremity surgery, (6) inflammatory arthritis, (7) avascular necrosis, or (8) any condition other than foot and ankle degenerative changes that could have changed the anatomy of the lower extremity (Fig. 1).

Radiographic Examination and Measurements

Radiographs were obtained with a UT 2000 X-ray machine (Philips Research, Eindhoven, Netherlands) in accordance with our protocol. Radiographs in the ankle AP weight-bearing view were obtained with a horizontal beam centered between the ankle joints at the joint level with the film cassette behind the heels. Radiographs in the foot and ankle lateral weight-bearing view were obtained with the beam focused on the lateral malleolus and the cassette positioned between patients' feet. Radiography was performed in the ankle mortise non-weight-bearing view with the leg internally rotated 15°–20° so that the beam was perpendicular to the inter-malleolar line. Radiographs in the foot AP weight-bearing view were obtained with the patient in the standing position barefoot at a source-to-image distance of approximately 100 cm. Standing full-limb AP radiographs (teleradiographs) were obtained on a 14 × 51-inch grid cassette, at a source-to-image distance of 240 cm. All radiographic images were acquired using a picture archiving and communication system (PACS; Infinitt Healthcare, Seoul, Korea), and radiographic measurements were performed using the PACS software.

The following radiographic indices were selected and measured for evaluating the anatomical structures of the foot and ankle and the lower-extremity alignment: tibial plafond inclination (TPI), tibiotalar tilt (TT) angle, medial distal tibial angle (MDTA), and medial talar center migration (MTCM) on the ankle AP standing view; anterior distal tibial angle (ADTA), lateral talo-first metatarsal angle (Lat talo-1MT), and anterior talar center migration (ATCM) on the foot and ankle lateral standing view; AP talo-first metatarsal angle (AP talo-1MT) and talonavicu-

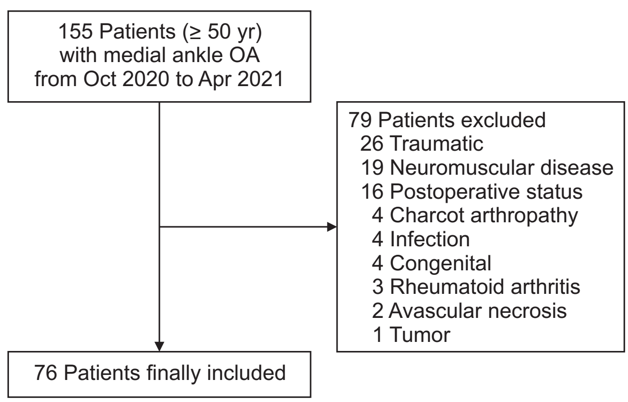

Fig. 1. Flow diagram showing the study inclusion and exclusion criteria. OA: osteoarthritis.

lar (TN) coverage angle on the foot standing AP view; and the mechanical tibiofemoral angle (MTFA) on the teleradiogram.

In the ankle AP view, TPI was measured between the tibial plafond and the horizontal line parallel to the floor.[11] The TT was consecutively measured between lines parallel to the tibial plafond and talar dome.[12] The MDTA was measured between the tibial axis and the straight-line tangent to the distal tibial articular surface.[13] The MTCM was defined as the shortest distance between the center of the talus and the long axis of the tibia. The center of rotation was defined as the center of a circle adjusted to the

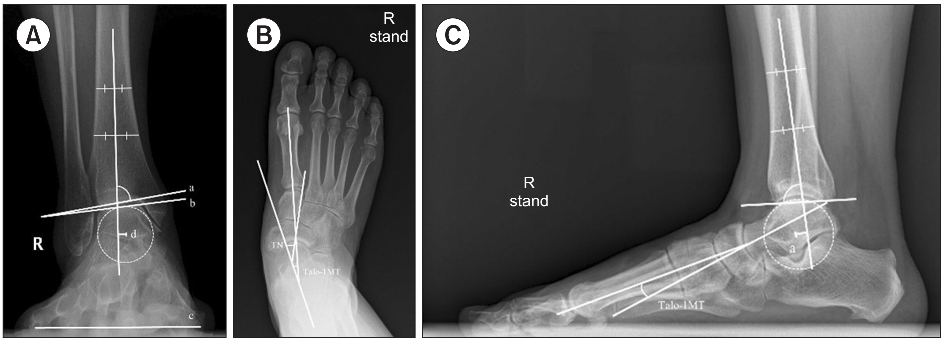

Fig. 2. Radiographic measurements. (A) Anteroposterior (AP) view of the weight-bearing ankle. Tibial plafond inclination is measured between the tibial plafond (a) and the floor (c). Tibiotalar tilt is the angle between the tibial plafond (a) and the talar dome (b). Medial distal tibial angle is the angle between the tibial long axis and the tibial plafond (fan shape). Medial displacement of the talar body is the shortest distance (d) between the tibial long axis and the talar center, defined as the center of a circle adjusted to the talar body. (B) AP view of the weight-bearing foot. AP talo-first metatarsal angle (talo-1MT) is the angle between the long axis of the first metatarsal and that of the talus. Talonavicular (TN) coverage angle is measured between a line bisecting the articular surface of the talar head and another line bisecting the proximal articular surface of the navicular. (C) Lateral view of the weight-bearing foot and ankle. Anterior distal tibial angle is the angle (fan shape) between the long axis of the tibia and a line connecting the most anterior and posterior points of the distal tibial articular surface. Lat talo-1MT is measured between the long axis of the first metatarsal and the talus (talo-1MT). Anterior talar center migration is the shortest distance (a) between the tibial long axis and the center of talus, defined as the center of a circle adjusted to the talar body.

Fig. 3. Radiographic signs of talar internal rotation. (A) Anteroposterior (AP) view of the weight-bearing ankle. The talar head (dotted curved lines) is medialized (arrow) compared to the contralateral ankle. (B) Mortise view of the non-weight-bearing ankle. Erosion of the articular surface of the medial malleolus (arrows) is shown compared to the contralateral side. (C) Lateral view of the weight-bearing foot and ankle. The talar head and neck are not well discriminated (arrow), and the length of the talus is short compared to the contralateral side. (D) AP view of the weight-bearing foot. Articular surfaces of the talus and lateral malleolus (dotted lines) are more divergent (arrow) compared to the contralateral side.

talar dome. Medial and lateral displacements were considered positive and negative, respectively.[14)]

In the foot standing AP view, the AP talo-1MT was measured between a line bisecting the anterior articular surface of the talus and a line along the first metatarsal long axis.[15)] The TN coverage angle was measured between a line bisecting the anterior articular surface of the talus and another line bisecting the proximal articular surface of the navicular.[15)] In the foot and ankle lateral standing view, the ADTA was measured between the long axis of the tibia and a line connecting the most anterior and posterior points of the distal tibia, while ignoring osteophytes.[10)] The Lat talo-1MT was measured between a line of the long axis of the first metatarsal bone and a line drawn through the midpoints of the talar head and neck.[15)] The ATCM was measured as the shortest distance between the line of the long axis of the tibia and the center of rotation of the talus; the center of rotation was defined as the center of a circle adjusted to the talar dome (Fig. 2).[10)]

Talus internal rotation was measured qualitatively by evaluating multiple signs in various radiographs. Erosion of the medial malleolus (in the ankle mortis view) and the contour of the talar head seen on the medial ankle (in the ankle standing AP view) was thought to be a sign of talus internal rotation. In the foot standing AP view, the divergent angle between the articular surfaces of the talus and lateral malleolus in the lateral gutter was measured to evaluate talus rotation. In the foot and ankle lateral standing view, the length of the talus was compared with that in the normal ankle radiograph, and a short talus was thought to be a sign of talus internal rotation. Considering these signs together, talus rotation was qualitatively categorized as neutral talus and internal rotation (Fig. 3). The MTFA was defined as the angle between the mechanical axis of the femur and the mechanical axis of the tibia on teleradiograms.[16)]

After a consensus-building session, two orthopedic surgeons with 6 and 2 years of experience in orthopedics (JHC and KSN) participated in an interobserver reliability test and measured the radiographic indices for a predetermined number of 15 images. After establishing the interobserver reliability of the radiographic measurements, the orthopedic surgeon with 6 years of experience obtained measurements of all radiographic images for all the patients.

Statistical Analysis

Descriptive statistical analysis included measurements of the mean, standard deviation (SD), and proportion. The Kolmogorov-Smirnov test was used to verify the normality of the distribution of continuous variables. The Student *t*-test was used for comparison of means between the two groups. The correlation between the continuous variables of radiographic measurements was analyzed using Pearson's correlation coefficients. Interobserver reliability was tested using intraclass correlation coefficient values with a two-way random effect model, assuming single measurements and absolute agreement. Linear regression analysis was performed to identify radiographic measurements associated with the TT (ankle-joint incongruency). Binary logistic regression analysis was used to analyze radiographic factors associated with talus internal rotation. All statistical analyses were performed using IBM SPSS statistics ver. 26 (IBM Corp.), and statistical significance was defined as $p < 0.05$.

Table 1. Patient Characteristics

Variable	Value
No. of patients	76
Age (yr)	69.0 ± 7.9
Male : female	32 : 44
Height (cm)	159.7 ± 9.3
Weight (kg)	67.5 ± 10.5
BMI (kg/m^2)	26.4 ± 2.5
Side (right : left)	40 : 36
Radiographic measurements	
TPI (°)	5.9 ± 3.7, varus (+)
TT (°)	4.3 ± 5.0, varus (+)
MDTA (°)	2.3 ± 2.9, varus (+)
MTCM (mm)	3.2 ± 3.1, medial displacement (+)
ADTA (°)	12.1 ± 2.8, anterior slope (+)
Lat talo-1MT (°)	8.4 ± 11.5, arch collapse (+)
ATCM (mm)	1.1 ± 2.4, anterior displacement (+)
AP talo-1MT (°)	11.9 ± 7.6, forefoot abduction (+)
Talonavicular coverage (°)	16.0 ± 11.0, forefoot abduction (+)
Mechanical TFA (°)	2.0 ± 3.2, varus (+)
Talar axial rotation (neutral: IR)	48 : 28

Values are presented as mean ± standard deviation.
BMI: body mass index, TPI: tibial plafond inclination, TT: tibiotalar tilt, MDTA: medial distal tibial angle, MTCM: medial talar center migration, ADTA: anterior distal tibial angle, Lat talo-1MT: lateral talo-first metatarsal angle, ATCM: anterior talar center migration, AP talo-1MT: anteroposterior talo-first metatarsal angle, TFA: tibiofemoral angle, IR: internal rotation.

RESULTS

Seventy-six patients (32 men and 44 women) with medial ankle OA were included in this study. The mean age of the patients was 69.0 years (SD, 7.9 years). The mean body mass index was 26.4 kg/m^2 (SD, 2.5 kg/m^2). A total of 40 right and 36 left ankles were included in the final analysis (Table 1). All radiographic measurements showed satisfactory interobserver reliabilities (Supplementary Table 1).

TT (ankle joint incongruency) was significantly correlated with TPI (varus orientation of the tibial plafond to the ground; $r = -0.238$, $p = 0.038$), Lat talo-1MT (foot arch

Table 2. Correlations among Radiographic Measurements

	TT	MDTA	MTCM	ADTA	Lat talo-1MT	ATCM	AP talo-1MT	TN coverage	Mechanical TFA
TPI	–0.238 (p = 0.038)	0.634 (p < 0.001)	0.251 (p = 0.029)	–0.159 (p = 0.171)	–0.128 (p = 0.271)	–0.253 (p = 0.027)	0.155 (p = 0.211)	0.069 (p = 0.581)	0.525 (p < 0.001)
TT		–0.069 (p = 0.555)	0.269 (p = 0.019)	0.163 (p = 0.160)	–0.335 (p = 0.003)	0.094 (p = 0.420)	–0.276 (p = 0.024)	–0.324 (p = 0.008)	–0.121 (p = 0.301)
MDTA			0.359 (p = 0.001)	–0.175 (p = 0.132)	–0.353 (p = 0.002)	–0.172 (p = 0.138)	–0.085 (p = 0.492)	–0.162 (p = 0.191)	–0.023 (p = 0.440)
MTCM				–0.198 (p = 0.086)	0.069 (p = 0.553)	–0.522 (p < 0.001)	0.296 (p = 0.015)	0.077 (p = 0.537)	0.170 (p = 0.144)
ADTA					–0.114 (p = 0.329)	0.349 (p = 0.002)	–0.195 (p = 0.115)	–0.178 (p = 0.149)	0.042 (p = 0.722)
Lat talo-1MT						–0.344 (p = 0.002)	0.578 (p < 0.001)	0.623 (p < 0.001)	0.165 (p = 0.157)
ATCM							–0.323 (p = 0.008)	–0.264 (p = 0.031)	–0.206 (p = 0.077)
AP talo-1MT								0.568 (p < 0.001)	0.137 (p = 0.268)
TN coverage									0.129 (p = 0.297)

TT: tibiotalar tilt, MDTA: medial distal tibial angle, MTCM: medial talar center migration, ADTA: anterior distal tibial angle, Lat talo-1MT: lateral talo-first metatarsal angle, ATCM: anterior talar center migration, AP talo-1MT: anteroposterior talo-first metatarsal angle, TN: talonavicular, TFA: tibiofemoral angle, TPI: tibial plafond inclination.

Table 3. Significant Radiographic Measurements Associated with Tibiotalar Tilt in Linear Regression Analysis

	Non-standardized		Standardized beta	t	p-value
	B	Standard error			
TPI	–0.446	0.135	–0.335	–3.299	0.002
MTCM	0.232	0.188	0.137	1.236	0.221
Lat talo-1MT	–0.218	0.058	–0.513	–3.773	< 0.001
AP talo-1MT	–0.085	0.089	–0.127	–0.954	0.344
TN coverage	0.005	0.059	0.010	0.079	0.937
IR of talus	4.237	1.180	0.404	3.589	0.001
Coefficient	7 .260	1.136	-	6.393	< 0.001

$R^2 = 0.481$.
TPI: tibial plafond inclination, MTCM: medial talar center migration, Lat talo-1MT: lateral talo-first metatarsal angle, AP talo-1MT: anteroposterior talo-first metatarsal angle, TN: talonavicular, IR: internal rotation.

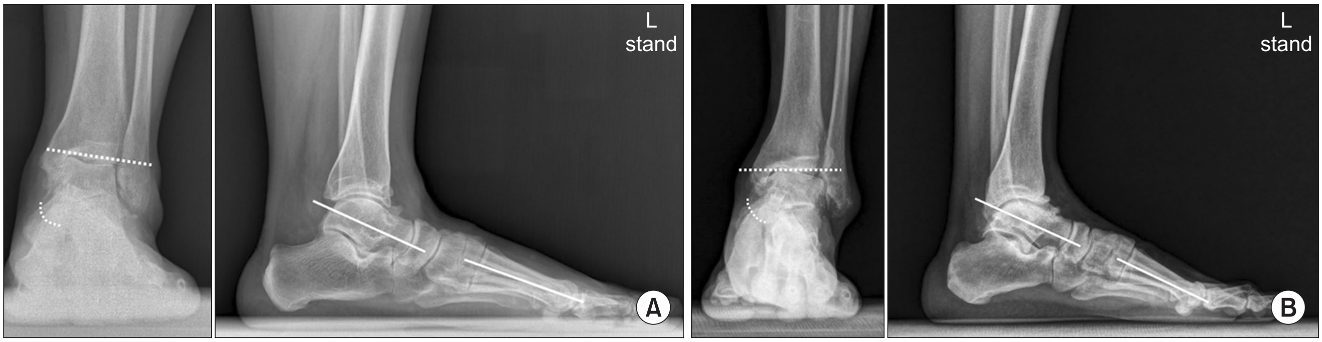

Fig. 4. Comparison between medial ankle osteoarthritis with normal tibiotalar tilt (TT; a 55-year-old woman) (A) and increased TT (a 60-year-old man) (B). A medial ankle with increased TT (B) shows a smaller tibial plafond inclination (straight dotted line), an internally rotated talar head (curved dotted line), and a decreased foot arch (straight lines on lateral view) compared to an ankle without a TT increase (A).

Table 4. Radiographic Factors Associated with an Internally Rotated Talus in Binary Logistic Regression Analysis

	B	Standard error	Wald	*p*-value	Exp(B)
TT	0.335	0.113	8.752	0.003	1.398
MTCM	0.360	0.177	4.120	0.042	1.433
Lat talo-1MT	0.111	0.049	5.236	0.022	1.118
ATCM	0.006	0.237	0.001	0.980	1.006
AP talo-1MT	0.107	0.066	2.666	0.103	1.113
Coefficient	–5.623	1.450	15.046	< 0.001	0.004

TT: tibiotalar tilt, MTCM: medial talar center migration, Lat talo-1MT: lateral talo-first metatarsal angle, ATCM: anterior talar center migration, AP talo-1MT: anteroposterior talo-first metatarsal angle.

collapse; $r = -0.335$, $p = 0.003$), AP talo-1MT (forefoot abduction; $r = -0.276$, $p = 0.024$), and TN coverage angle ($r = -0.324$, $p = 0.008$). MTCM (medial displacement of the talar body) was significantly correlated with TPI ($r = 0.251$, $p = 0.029$), TT ($r = 0.269$, $p = 0.019$), MDTA (varus orientation of the tibial plafond to the tibial shaft; $r = 0.359$, $p = 0.001$), ATCM (anterior displacement of the talar body; $r = -0.522$, $p < 0.001$), and AP talo-1MT ($r = 0.296$, $p = 0.015$). Additionally, ATCM was significantly correlated with TPI ($r = -0.253$, $p = 0.027$), ADTA (anterior inclination of the tibial plafond; $r = 0.349$, $p = 0.002$), and Lat talo-1MT ($r = -0.344$, $p = 0.002$) (Table 2).

The internal talus rotation group showed a significantly larger TT, larger MTCM, smaller ATCM, and larger AP talo-1MT and Lat talo-1MT than the neutral talus group ($p = 0.004$, $p < 0.001$, $p = 0.039$, $p = 0.002$, and $p = 0.008$, respectively) (Supplementary Table 2). Linear regression analysis showed that a decreased TPI ($p = 0.002$), decreased Lat talo-1MT ($p < 0.001$), and talus internal rotation ($p = 0.001$) were the radiographic measurements significantly associated with the TT (Table 3, Fig. 4). In contrast, an increased TT ($p = 0.003$), increased MTCM ($p = 0.042$), and increased Lat talo-1MT ($p = 0.022$) were significant factors associated with talus internal rotation (Table 4).

DISCUSSION

This study investigated the relationship between foot shape and medial ankle OA by evaluating comprehensive radiographic measurements. Foot shape showed complex associations with the degree of ankle joint incongruency (TT), tibial plafond orientation (TPI), and displacement (MTCM and ATCM) and rotation of the talus in medial ankle OA.

Medial migration of the talar body (MTCM) was significantly correlated with the varus slope of the distal tibial articular surface (TPI and MDTA), varus incongruency of the ankle joint (TT), posterior migration of the talar body (ATCM), and forefoot abduction (AP talo-1MT). In contrast, anterior migration of the talar body (ATCM) was significantly correlated with the anterior slope of the distal tibial articular surface (ADTA), increasing medial foot arch (Lat talo-1MT), forefoot adduction (AP talo-1MT), and decreased varus slope of the distal articular surface (TPI). Thus, the position of the talar body within the ankle mortise may change according to the foot shape in medial ankle OA, and surgeons should consider this when planning surgical treatment. Specifically, this information may provide surgeons with insight into which soft tissues need to be released, reconstructed, or transferred during the operation for medial ankle OA.

Ankle-joint incongruency (TT) was significantly associated with a decreasing varus slope of the distal tibial articular surface (TPI), increased medial foot arch (Lat talo-1MT), and internal rotation of the talus in linear regression analysis. An increasing varus slope of the distal tibial articular surface (TPI) has been considered to compensate and neutralize the varus movement of the talus from the foot shape, which led to the negative association between TT and TPI (Fig. 5). Therefore, supramalleolar osteotomy could aggravate ankle joint incongruency in patients with increased varus moment.[17,18)]

Increased ankle-joint incongruency (TT), medial migration of the talar body (MTCM), and collapse of the medial foot arch (Lat talo-1MT) were significantly associated with the internal rotation of the talus in binary logistic regression in our patients with medial ankle OA.

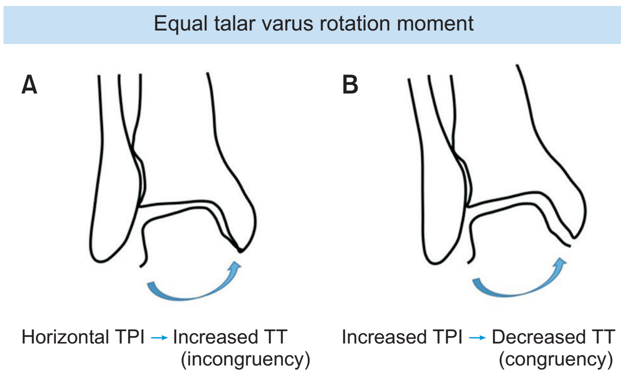

Fig. 5. With the same degree of talar varus tilt and moment, the tibiotalar tilt (TT) is greater (ankle joint is more incongruent) when the tibial plafond inclination (TPI) is more horizontal (A) compared to the greater TPI (B).

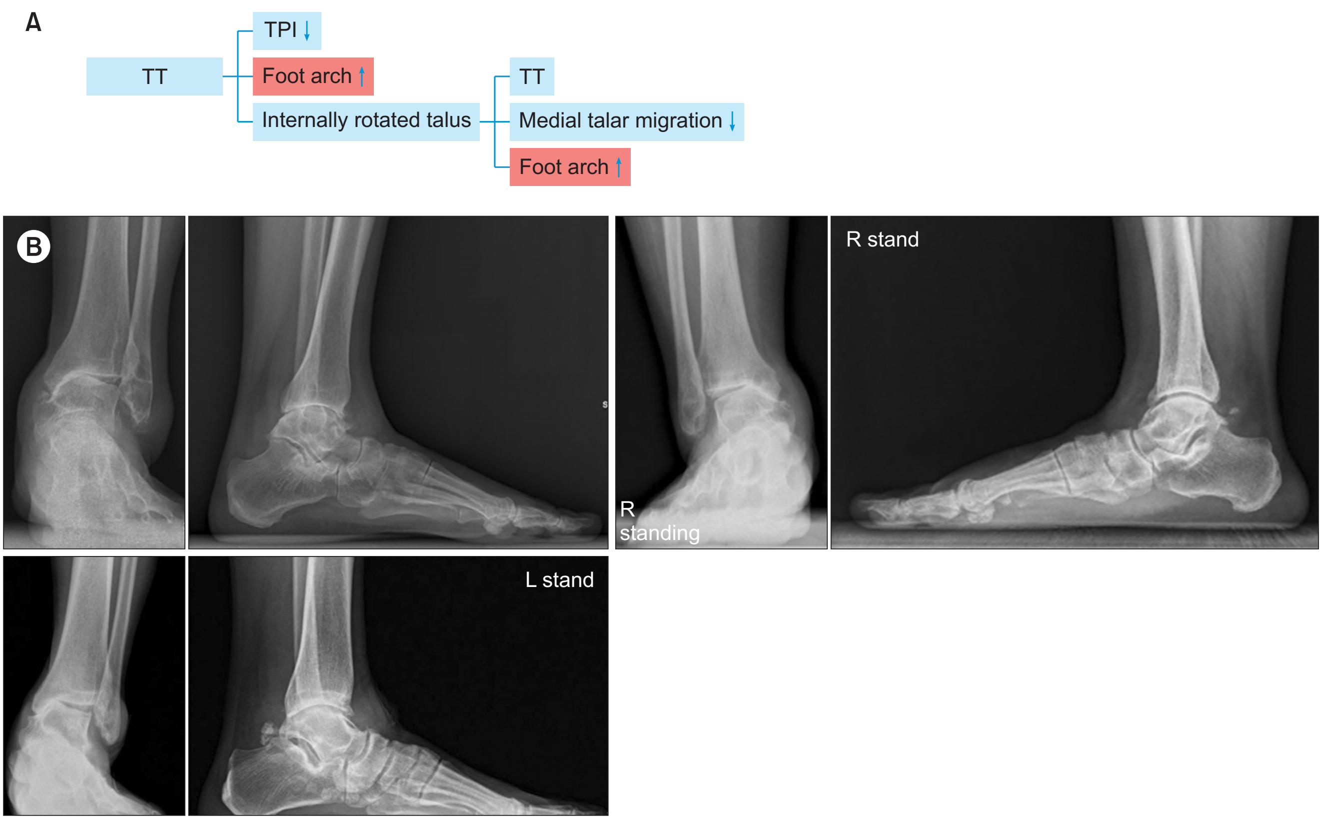

Fig. 6. (A) Diagram showing the regression analysis results. The tibiotalar tilt (TT) is significantly associated with decreased tibial plafond inclination (TPI), increased foot arch, and internal rotation of the talus while internal rotation of the talus is significantly associated with decreased foot arch. These regression results are paradoxical in terms of their relationship with the foot arch. (B) Cases were frequently observed in which increased TT, internal rotation of the talus, and medial displacement of the talar body were concurrent with a decreased foot arch (lateral talo-first metatarsal angle).

Thus, since an increased medial foot arch was significantly associated with TT in linear regression analysis while a decreased medial foot arch was significantly associated with internal rotation of the talus, the correlation of the foot arch with TT and internal rotation of the talus may appear to be paradoxical (Fig. 6). According to the current anatomical knowledge, flatfoot deformity leads to plantar flexion and internal rotation of the talus. The posterior side of the talar body is narrower than the anterior talar body width, and plantar flexion of the talus allows more space and motion, which could eventually cause greater incongruency and deformities at the ankle joint. However, the studies to date have been unable to distinguish between the causative factors and the compensatory outcomes because of the complex and paradoxical relationships among radiographic measurements representing the two-dimensional deformity. Serial weight-bearing computed tomography measurements could help discriminate the causes and compensatory outcomes of the progression of medial ankle OA in a future study.

A recent novel study reported that posterior ankle arthritis concomitant with flatfoot deformity is improved by correcting flatfoot deformities by subtalar arthrodesis. This study highlighted the role of foot deformities and concomitant biomechanics in the development and progression of ankle OA.[9] Traditionally, flatfoot deformity has been considered to be associated with valgus ankle arthritis and a cavus foot with varus ankle arthritis.[19,20] Our study results suggest that flatfoot deformities could be associated with varus ankle arthritis as our patients with medial ankle OA grossly showed arch collapse (Lat talo-1MT) and forefoot abduction despite varus ankle incongruencies (TT). However, this requires further validation in future studies.

Our study has some limitations that have to be addressed. First, our analysis was based on plain radiographic measurements obtained from two-dimensional images. However, the ankle joint is a complex three-dimensional structure, and our two-dimensional analysis may not have been sufficient to evaluate the complex foot and ankle structures. Second, talar rotation was not measured quantitatively, and further studies with weight-bearing CT may be required to obtain more accurate insight into talar rotation. Third, our study was retrospective in nature, and unknown biases may have influenced the study results. Fourth, the number of cases might be insufficient to generalize the study results. Fifth, our study did not compare data between normal feet and those with medial ankle OA, which would have provided us with more comprehensive insight into discriminating the true pathologic components.

In conclusion, medial ankle OA was associated with foot deformities, ankle-joint incongruencies, and talar body displacement. These findings should help orthopedic surgeons when planning surgical treatment for medial ankle OA in terms of soft-tissue balancing and normalizing ankle anatomy. The role of foot deformities in the development and progression of medial ankle OA needs to be validated in further biomechanical research.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Ji Hye Choi https://orcid.org/0000-0002-0062-4222
Kwon Seok Noh https://orcid.org/0000-0003-2215-2657
Dong Yeon Lee https://orcid.org/0000-0001-8233-6285
Yoon Hyo Choi https://orcid.org/0000-0003-2386-1594
Taeyong Lee https://orcid.org/0000-0002-0176-0525
Kyoung Min Lee https://orcid.org/0000-0002-2372-7339

SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org

REFERENCES

1. Murray C, Marshall M, Rathod T, Bowen CJ, Menz HB, Roddy E. Population prevalence and distribution of ankle pain and symptomatic radiographic ankle osteoarthritis in community dwelling older adults: a systematic review and cross-sectional study. PLoS One. 2018;13(4):e0193662.

2. Glazebrook M, Daniels T, Younger A, et al. Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. J Bone Joint Surg Am. 2008;90(3): 499-505.

3. Saltzman CL, Zimmerman MB, O'Rourke M, Brown TD, Buckwalter JA, Johnston R. Impact of comorbidities on the measurement of health in patients with ankle osteoarthritis. J Bone Joint Surg Am. 2006;88(11):2366-72.

4. Knupp M, Stufkens SA, van Bergen CJ, et al. Effect of su-

pramalleolar varus and valgus deformities on the tibiotalar joint: a cadaveric study. Foot Ankle Int. 2011;32(6):609-15.

5. Pagenstert G, Knupp M, Valderrabano V, Hintermann B. Realignment surgery for valgus ankle osteoarthritis. Oper Orthop Traumatol. 2009;21(1):77-87.
6. Usuelli FG, Di Silvestri CA, D'Ambrosi R, Orenti A, Randelli F. Total ankle replacement: is pre-operative varus deformity a predictor of poor survival rate and clinical and radiological outcomes? Int Orthop. 2019;43(1):243-9.
7. Lee WC, Moon JS, Lee K, Byun WJ, Lee SH. Indications for supramalleolar osteotomy in patients with ankle osteoarthritis and varus deformity. J Bone Joint Surg Am. 2011;93(13):1243-8.
8. Krahenbuhl N, Akkaya M, Deforth M, Zwicky L, Barg A, Hintermann B. Extraarticular supramalleolar osteotomy in asymmetric varus ankle osteoarthritis. Foot Ankle Int. 2019;40(8):936-47.
9. Lim JW, Eom JS, Kang SJ, Lee DO, Kang HJ, Jung HG. The effect of supramalleolar osteotomy without marrow stimulation for medial ankle osteoarthritis: second-look arthroscopic evaluation of 29 ankles. J Bone Joint Surg Am. 2021;103(19):1844-51.
10. Kim J, Kim JB, Lee WC. Clinical and radiographic results of ankle joint preservation surgery in posterior ankle arthritis. Foot Ankle Int. 2021;42(10):1260-9.
11. Xie K, Jiang X, Han X, Ai S, Qu X, Yan M. Association between knee malalignment and ankle degeneration in patients with end-stage knee osteoarthritis. J Arthroplasty. 2018;33(12):3694-8.
12. Barg A, Saltzman CL. Joint-preserving procedures in patients with varus deformity: role of supramalleolar osteotomies. Foot Ankle Clin. 2019;24(2):239-64.
13. Barg A, Harris MD, Henninger HB, et al. Medial distal tibial angle: comparison between weightbearing mortise view and hindfoot alignment view. Foot Ankle Int. 2012;33(8):655-61.
14. Ahn TK, Yi Y, Cho JH, Lee WC. A cohort study of patients undergoing distal tibial osteotomy without fibular osteotomy for medial ankle arthritis with mortise widening. J Bone Joint Surg Am. 2015;97(5):381-8.
15. Lee KM, Chung CY, Park MS, Lee SH, Cho JH, Choi IH. Reliability and validity of radiographic measurements in hindfoot varus and valgus. J Bone Joint Surg Am. 2010;92(13):2319-27.
16. Lee SA, Choi SH, Chang MJ. How accurate is anatomic limb alignment in predicting mechanical limb alignment after total knee arthroplasty? BMC Musculoskelet Disord. 2015;16:323.
17. Choi W, Chung CY, Park MS, Lee S, Lee KM. Radiographic differences in the concomitant deformities in two types of medial ankle osteoarthritis. PLoS One. 2021;16(3):e0247816.
18. Choi JH, Han HS, Park YJ, Koo S, Lee T, Lee KM. Relationship between ankle varus moment during gait and radiographic measurements in patients with medial ankle osteoarthritis. PLoS One. 2021;16(6):e0253570.
19. Barg A, Pagenstert GI, Leumann AG, Muller AM, Henninger HB, Valderrabano V. Treatment of the arthritic valgus ankle. Foot Ankle Clin. 2012;17(4):647-63.
20. Grice J, Willmott H, Taylor H. Assessment and management of cavus foot deformity. Orthop Trauma. 2016;30(1):68-74.