Analysis of Whole Limb Alignment in Ankle Arthritis

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KEYWORDS

• Whole limb alignment • Ankle arthritis • Hip-to-calcaneus radiograph
• Flatfoot deformity • Total ankle arthroplasty

KEY POINTS

- A full-length standing posteroanterior radiograph that includes the calcaneus (hip-to-calcaneus radiograph), obtained with the patient in a bipedal stance on a radiolucent platform and facing the long film cassette, can be used to evaluate the mechanical axis of the lower limb and hindfoot alignment.
- This simple radiograph clarifies various pathomechanical aspects of hindfoot disorders, facilitates preoperative surgical planning, and sheds light on factors contributing to unsatisfactory results of a particular operation.
- Knee realignment surgery influences hindfoot alignment and vice versa.
- It is essential to evaluate whole limb alignment in planning corrective lower limb surgery.

INTRODUCTION

Various hindfoot disorders, such as ankle osteoarthritis, flatfoot deformity, rheumatoid hindfoot, hindfoot deformity associated with cavus foot, posttraumatic deformity, congenital deformity, and paralytic foot, lead to hindfoot malalignment. With weight-bearing being the main function of the lower limbs, analyzing changes in the mechanical axis resulting from malalignment in the diagnosis and treatment of lower limb disorders is imperative.

The mechanical axis of the lower limb has, traditionally, been taken as a line on a full-length standing anteroposterior radiograph extending from the center of the femoral head to the center of the tibial plafond (Mikulicz line), and it has been considered key to understanding malalignment and deformity from the hip to the lowest part of the tibia. Assessing the mechanical axis of the lower limb based on this line is mandatory for reconstructive surgery on the lower limb, such as total knee replacement, high tibial osteotomy, or corrective osteotomy for a malunited fracture of the femur or tibia. However, use of the Mikuliczline does not allow for identification of the point at which the mechanical axis of the lower limb passes through the tibial plafond.

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A line from the center of the femoral head to the lowest point of the calcaneus, not to the center of the tibial plafond, should be taken as the true mechanical axis of the lower limb. Only by drawing such a line can the point at which the mechanical axis of the lower limb passes through the tibial plafond be determined. For this, a radiograph that extends from the center of the femoral head to the lowest point of the calcaneus, which itself must be clearly visualized, is needed (Fig. 1).

I have described use of a full-length standing posteroanterior radiograph that includes the calcaneus for assessment of both the mechanical axis of the lower limb and hindfoot alignment.[1] Use of this "hip-to-calcaneus radiograph" has clarified various pathomechanical aspects of hindfoot disorders. Herein I describe how such a radiograph is obtained, how the mechanical axis of the lower limb is identified, especially the point at which the mechanical axis passes through the ankle joint, and various conditions and procedures for which analyzing the mechanical axis of the lower limb is applicable.

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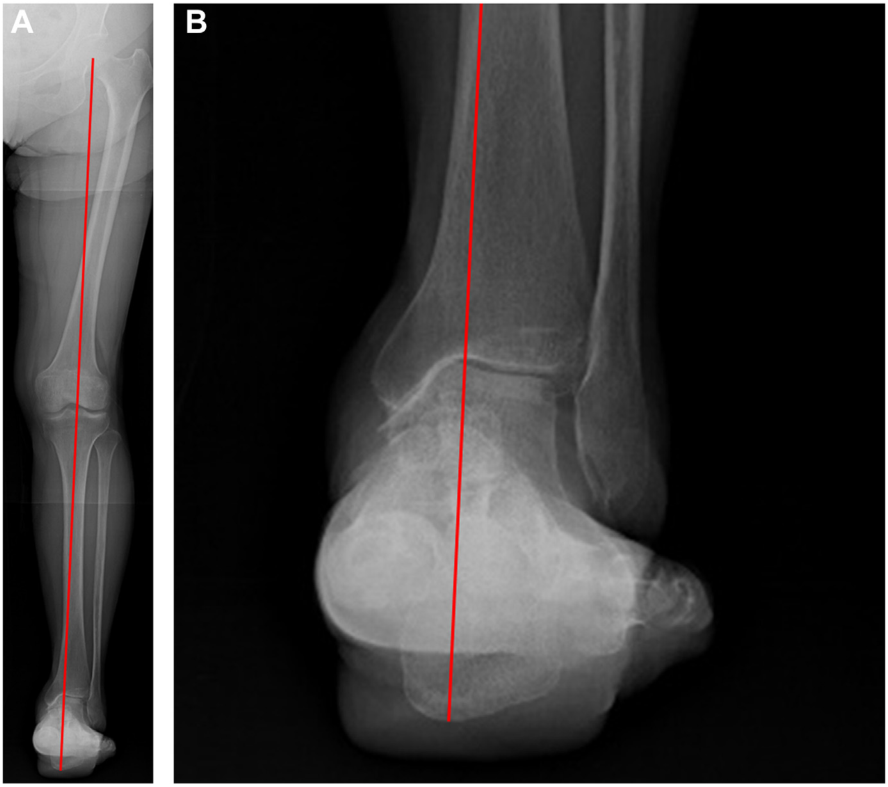

Fig. 1. Preoperative radiographs of a patient with varus ankle osteoarthritis. (*A*) Hip-to-calcaneus radiograph. (*B*) The lower part of the preoperative hip-to-calcaneus radiograph shows obliteration of the joint space between the medial malleolus and the medial facet of the talus with subchondral bone contact and that the mechanical axis (*red line*) passes through the medial part of the ankle joint.

OBTAINING THE HIP-TO-CALCANEUS RADIOGRAPH AND IDENTIFYING THE MECHANICAL AXIS OF THE LOWER LIMB, INCLUDING THE POINT AT WHICH IT PASSES THROUGH THE ANKLE JOINT

The hip-to-calcaneus radiograph is obtained with the patient maintaining a bipedal stance on a radiolucent platform and facing a so-called long-length film cassette,[1] as shown in **Fig. 2**. For the lowest point of the calcaneus to be captured on the radiograph, the cassette is slid into position, with its lower edge advanced beyond the edge of the platform. The patient's patella is oriented forward, and the x-ray beam is centered on the knee of the imaged leg from a distance of 2 m. Voltage is typically 200 mA, and current is typically 85 kV.

Once the radiograph is obtained, a line is drawn from the center of the femoral head to the lowest point of the calcaneus, and the point at which the mechanical axis crosses the tibial plafond is easily identified. This point, referred to as the mechanical

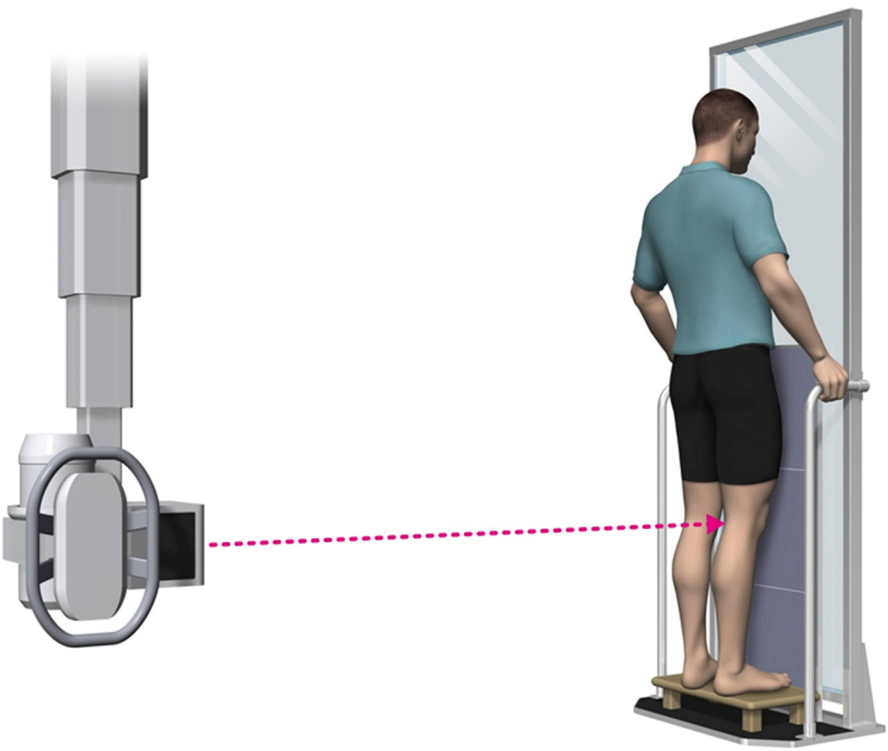

Fig. 2. Obtaining the hip-to-calcaneus radiograph. The patient maintains a bipedal stance on a radiolucent platform and faces the long film cassette. For the lowest point of the calcaneus to be visualized on the radiograph, the cassette is slid into position with its lower edge passing the edge of the platform. The patient's patella is oriented forward. The x-ray beam is centered on the knee of the imaged leg from a distance of 2 m. Voltage and current are 200 mA and 85 kV, respectively. It is important to confirm on the radiograph that the patella is centered between the femoral condyles. (Reprinted with permission from Haraguchi N, Ota K, Tsunoda N, Seike K, Kanetake Y, Tsutaya A. Weight-bearing-line analysis in supramalleolar osteotomy for varus-type osteoarthritis of the ankle. J Bone Joint Surg Am. 2015;97:333-339).

ankle joint axis point, is expressed as a percentage of the measured length of the plafond in the coronal plane (Fig. 3A), with the medial and lateral edges of the tibial plafond taken as 0% and 100%, respectively. Thus, a negative value indicates that the mechanical ankle joint axis point lies medially beyond the medial corner of the plafond, and a value of greater than 100% indicates that the point lies laterally beyond the lateral edge of the plafond (Fig. 3B).

The mechanical ankle joint axis point is affected by the position of the heel contact point, which is directly influenced by rotation of the lower limb. External rotation of the lower limb moves the heel contact point medially, and internal rotation of the lower limb moves the heel contact point laterally. Traditionally, the axis of the foot is used to control rotation of the lower limb in obtaining radiographs for hindfoot evaluation, for example, with the foot placed with its axis parallel to the x-ray beam. However, the long axis of the foot is often deviated in patients with foot and ankle malalignment. Likewise, if the transmalleolar axis is used to control limb rotation, by positioning the ankle so that the transmalleolar axis is perpendicular to the x-ray beam, the lower limb is rotated internally because the transmalleolar axis is rotated externally in relation to the transepicondylar axis of the femur. I have found it best to use the patella rather than the foot or ankle to control rotation of the lower limb. It is important to confirm on the radiograph that the patella is centered between the femoral condyles.

OSTEOTOMY FOR VARUS ANKLE OSTEOARTHRITIS

Varus ankle osteoarthritis is often treated by supramalleolar tibial osteotomy, a reliable joint-preserving procedure.[2–11] For some patients, however, clinical and radiological outcomes are not satisfactory. In performing this procedure, the tibial correction angle has been traditionally determined based on the tibial ankle surface (TAS) angle, defined as the angle between the tibial shaft and its distal joint surface on the anteroposterior radiograph.[8] Slight overcorrection is recommended for such osteotomy, but the target TAS angle is based primarily on the surgeon's experience, and it varies from one group to another.[3,6,8–10] The purpose of supramalleolar osteotomy for varus ankle osteoarthritis is transfer of the weight-bearing line from the medial to the lateral side of the ankle, which is expected to open the medial side of the ankle joint. However, there has been little preoperative and postoperative analysis of the weight-bearing line in the ankle. Thus, the target mechanical axis point at the ankle remains unknown.

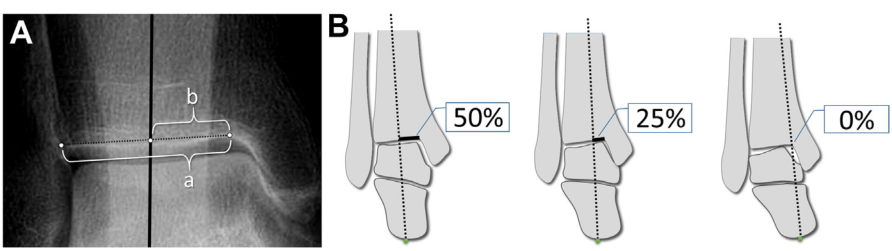

Fig. 3. Mechanical ankle joint axis point. (*A*) The mechanical ankle joint axis point is expressed as the ratio representing the division of the coronal length of the plafond by the axis and is a radiographic measure of the distance of this point from the medial corner of the plafond (ie, b/a × 100). (*B*) The medial and lateral edges of the tibial plafond are taken as 0% and 100%, respectively. Thus, a negative value indicates that the mechanical ankle joint axis point lies medially beyond the medial corner of the plafond, and a value of greater than 100% indicates that the point lies laterally beyond the lateral edge of the plafond.

For patients with varus ankle osteoarthritis, I have used our radiographic method to determine, both before and after traditional supramalleolar osteotomy, the mechanical ankle joint axis point.[1] I have assessed correlation between the mechanical ankle joint axis point and clinical outcomes of the surgery. I found marked postoperative variation in the location of the mechanical ankle joint axis point and that when this axis point was found, preoperatively, to be medial to the edge of the tibial plafond, the surgery resulted in insufficient lateral movement of the axis point and a less than satisfactory clinical outcome.

Factors that can contribute to the excessively medial position of the mechanical ankle joint axis point in cases of varus ankle osteoarthritis include varus tilt of the tibial plafond, varus tilt of the talus within the ankle mortise, wearing of the articular cartilage and subchondral bone of the medial part of the of the plafond and the medial gutter, and inward deviation of the medial malleolus resulting in an abnormally wide angle between the articular surfaces of the medial malleolus and tibial plafond. Thus, I continue to use a TAS angle of 98° as our supramalleolar osteotomy target, but in some patients I use a target TAS angle of a little more than 98° and add lateral sliding calcaneal osteotomy and/or opening-wedge medial malleolar osteotomy[12] (**Fig. 4**) to further move the mechanical axis laterally. The medial malleolar osteotomy is performed to prevent postoperative medial translation of the talus, which can lead to medial positioning of the mechanical axis point. Adding lateral sliding calcaneal osteotomy further moves the lowest point of the calcaneus laterally and contributes to proper lateral positioning of the mechanical axis point. These additional procedures also add a hindfoot valgus moment arm.

Thus far, I have found that adding these procedures for ankles for which the mechanical axis point is in an excessively medial position (mainly in cases of Takakura stage 3b ankle osteoarthritis) moves the mechanical axis point laterally, more so

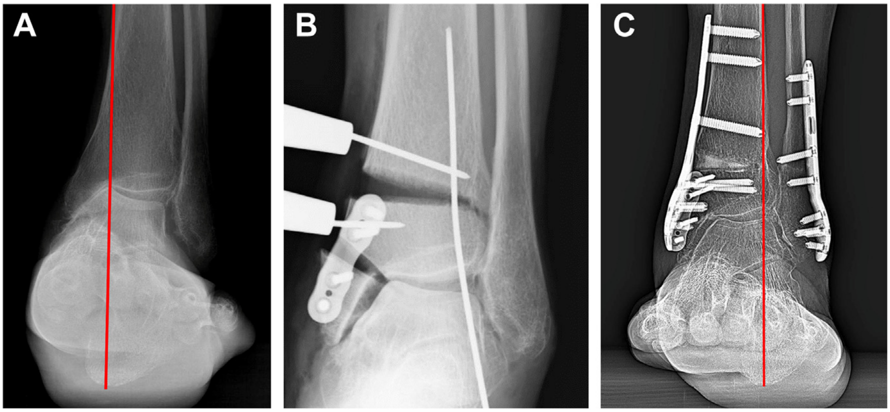

Fig. 4. Images of a patient who underwent supramalleolar osteotomy combined with ankle mortise reconstruction for varus ankle osteoarthritis. (*A*) The lower part of the preoperative hip-to-calcaneus radiograph shows subchondral bone contact that extends to the roof of the talar dome (Takakura stage 3b osteoarthritis). The mechanical ankle joint axis point is 0%. (*B*) Intraoperative image obtained during opening-wedge osteotomy of the medial malleolus performed to reconstruct the ankle mortise. (C) The lower part of the postoperative hip-to-calcaneus radiograph shows that the mechanical axis (*red line*) has been transferred to the lateral part of the ankle, with the mechanical ankle joint axis point being 100%, and the joint space has opened up.

than can be accomplished by traditional supramalleolar osteotomy alone, and thus better clinical outcomes are achieved. Correcting the talar tilt in ankles with stage 3b osteoarthritis is challenging. According to our experience, however, sufficient translation of the mechanical axis point is, with respect to long-term outcomes, much more influential than residual talar tilt.

Notably, evaluating the mechanical ankle joint axis point is also useful in cases of valgus ankle osteoarthritis (**Fig. 5**). An investigation aimed at determining the target mechanical ankle joint axis point when supramalleolar osteotomy is performed for valgus ankle osteoarthritis is under way.

RECONSTRUCTION OF STAGE IV-A ADULT-ACQUIRED FLATFOOT DEFORMITY

Hindfoot malalignment is seen in many individuals with adult-acquired flatfoot deformity. The valgus malalignment is especially severe in cases that have reached stage IV. In the original Myerson classification system, stage IV was defined as valgus angulation of the talus and early degeneration of the ankle joint.[13] Reconstruction in cases of stage IV deformity remains a substantial surgical challenge. Tibiotalocalcaneal arthrodesis has been recommended for stage IV deformity[13]; however, patient satisfaction tends to be quite low.

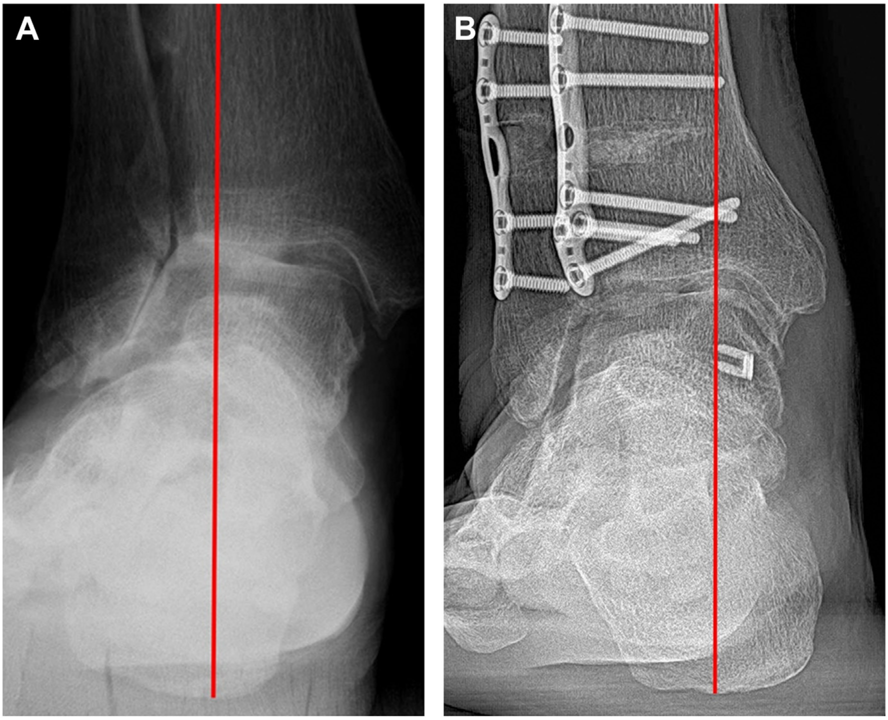

Fig. 5. Radiographs obtained in a case of valgus ankle osteoarthritis. (*A*) The lower part of the preoperative hip-to-calcaneus radiograph shows obliteration of the joint space in the lateral part of the ankle with subchondral bone contact and the mechanical axis (*red line*) passing through the lateral part of the ankle joint. (*B*) The lower part of the postoperative hip-to-calcaneus radiograph obtained 3 years after opening-wedge supramalleolar osteotomy for valgus ankle osteoarthritis shows that the mechanical axis (*red line*) has been transferred to the medal part of the ankle, and the joint space has opened up.

Stage IV adult-acquired flatfoot deformity[13] was eventually subdivided into stage IV-A, in which the ankle valgus is flexible, and stage IV-B, in which the valgus is rigid.[14,15] Stage IV-A deformity can sometimes be treated by means of a joint-sparing procedure such as deltoid ligament reconstruction in conjunction with triple arthrodesis[16] or deltoid ligament reconstruction in conjunction with calcaneal osteotomy, flexor digitorum longus tendon transfer, and lateral column lengthening[17]; however, clinical results of these procedures have been suboptimal. In some cases in which deltoid ligament reconstruction was performed in conjunction with triple arthrodesis, correction was lost over time, indicating that reconstruction of the deltoid ligament is not adequate for sustained correction of marked tibiotalar valgus deformity.[16]

In stage IV-A adult-acquired flatfoot deformity, the mechanical ankle joint axis point is in an excessively lateral position due to heel valgus and talar tilting. Furthermore, stage IV-A covers ankle osteoarthritis of various degrees. Because of these factors, I now perform supramalleolar osteotomy in addition to flatfoot reconstruction procedures, such as flexor digitorum longus tendon transfer, medializing calcaneal osteotomy, and/or Cotton osteotomy, for stage IV-A adult-acquired flatfoot deformity. In this operation, the distal aspect of the fibula and distal aspect of the tibia are exposed through a single incision on the anterolateral side of the ankle. Lateral opening-wedge tibial osteotomy is performed, along with oblique fibular osteotomy at the same level. A locking plate is used for tibial and fibular fixation. The gap created by the opening-wedge tibial osteotomy is filled with beta-tricalcium phosphate.

TOTAL ANKLE ARTHROPLASTY

One of the important technical principles of total knee arthroplasty (TKA) is restoration of neutral mechanical alignment, which is achieved when the mechanical axis of the lower extremity passes through the center of the knee joint.[18,19] In total ankle arthroplasty, as well, restoration of neutral mechanical alignment is important because increased edge loading due to hindfoot malalignment can lead to prosthesis loosening or breakage.[20,21] Yi and colleagues[22] reported association of medial malleolar impingement, delayed malleolar fracture, implant overhang, insert dislocation, and edge loading with talar translation, and that these factors are known causes of prosthetic failure after total ankle replacement. Deviation of the mechanical axis (angle between the mechanical axis of the lower limb and the tibial axis), lateral distal tibial angle, and hindfoot alignment are factors strongly associated with talar translation. Hence, the authors concluded that, in patients with a preoperative medial or lateral translation of the talus along with a great degree of hindfoot malalignment, simultaneous correction of the hindfoot malalignment should be considered.[22]

Studies of the mechanical axis at the ankle joint before and after total ankle arthroplasty are scarce. The mechanical ankle joint axis point reflects both mechanical axis deviation and hindfoot alignment. Hirao and colleagues,[23] in describing total ankle arthroplasty performed for patients with rheumatoid arthritis, reported that the angle that must be corrected for proper adjustment of the weight-bearing line in the ankle joint, is seen on the hip-to-calcaneus radiograph as the angle created by the lines connecting the center of the plafond and the calcaneal tip and the ideal loading axis (**Fig. 6**).

On rare occasion, I perform supramalleolar osteotomy after total ankle arthroplasty. This is needed in cases in which the postoperative hip-to-calcaneus radiograph shows malalignment of the ankle prosthesis, that is, deviation of the mechanical ankle joint axis point from the center of the ankle joint (**Fig. 7**).

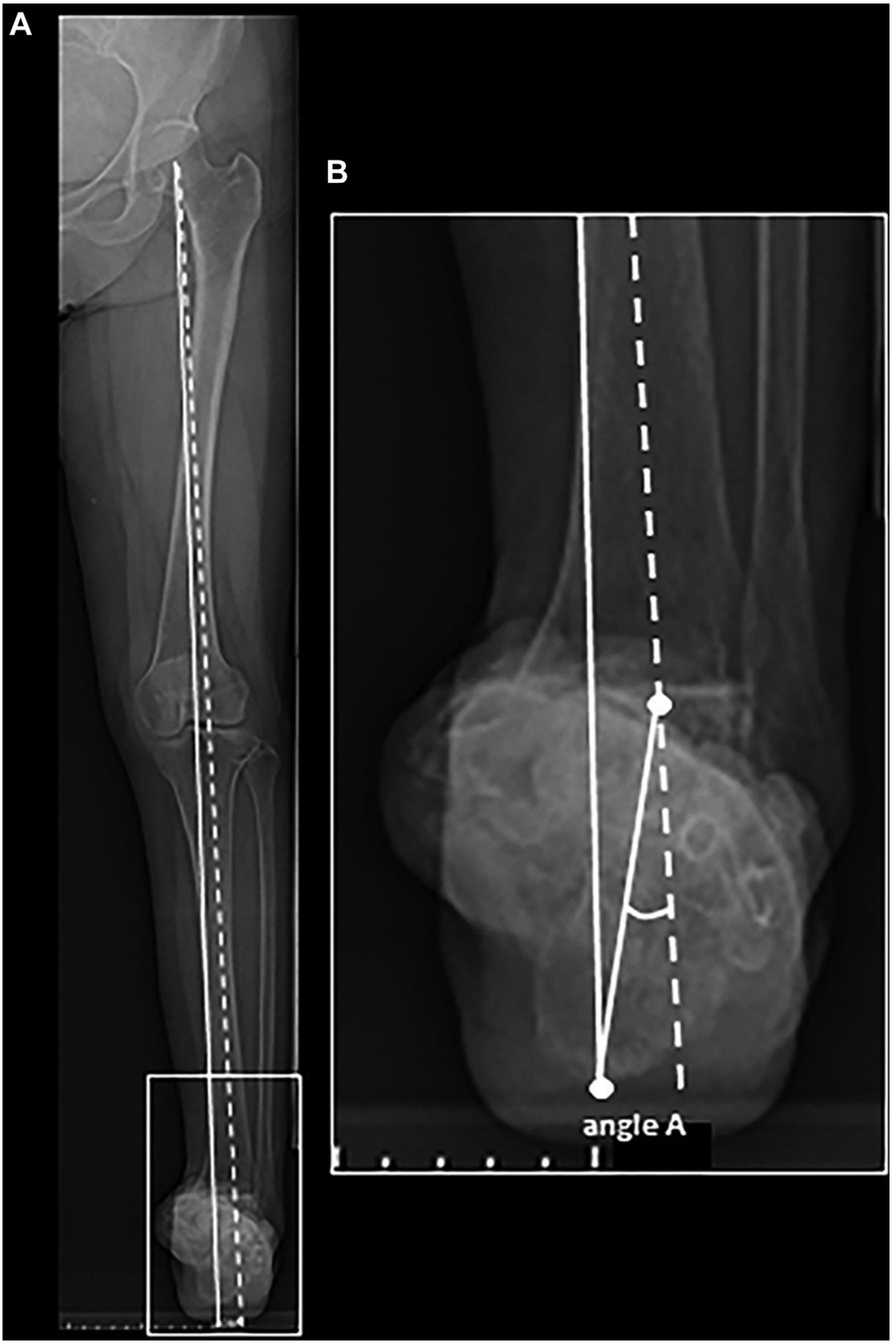

Fig. 6. Preoperative radiographs used in planning total ankle arthroplasty. (*A*) Hip-to-calcaneus radiograph. The solid line shows the preoperative calcaneal tip and loading axis. The dashed line shows the ideal loading axis, which passes through the center of the distal tibial plafond. (*B*) Angle A (created by the *lines* connecting the center of the plafond and the calcaneal tip and the ideal loading axis) is defined as the angle that must be

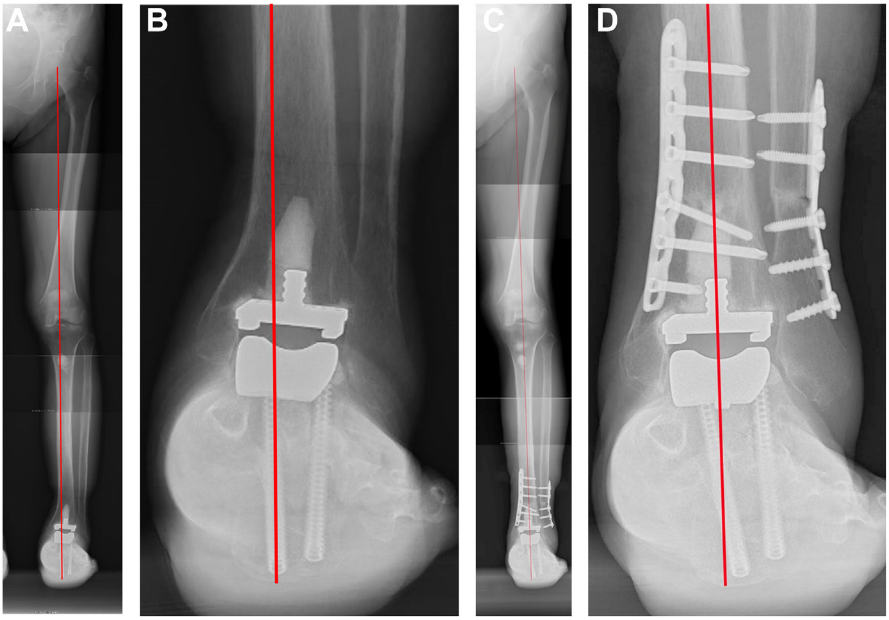

Fig. 7. Radiographs obtained before and after supramalleolar osteotomy for correction of malalignment after total ankle replacement in a patient with rheumatoid arthritis. (*A*) Preoperative hip-to-calcaneus radiograph. (*B*) The lower part of the preoperative hip-to-calcaneus radiograph shows that the mechanical axis (*red line*) passing through the lateral part of the ankle joint. (*C*) Postoperative hip-to-calcaneus radiograph. (*D*) The lower part of the postoperative hip-to-calcaneus radiograph shows the mechanical axis (red *line*) passing through the center of the ankle joint. (Reprinted with permission from Haraguchi N, Hip to calcaneus view for treatment planning and evaluation of hindfoot disorders. Bone Joint Nerve. 2012;2:569–575.)

REALIGNMENT OF THE OSTEOARTHRITIC KNEE AND ITS RELATION TO ANKLE JOINT ALIGNMENT

Ankle osteoarthritis is sometimes found in patients with knee osteoarthritis, and the ankle symptoms can either improve or worsen after knee surgery, such as total knee replacement or high tibial osteotomy. Norton and colleagues[24] showed compensatory hindfoot alignment for a given varus deformity of the knee; that is, as the mechanical axis angle becomes more varus, the hindfoot will subsequently become more valgus. They stated that patients undergoing TKA should be advised that their hindfoot symptoms might worsen afterward. Choi and colleagues[25] found that, after high tibial osteotomy performed in patients with medial compartment osteoarthritis with a varus deformity at the knee, the hindfoot valgus deviation observed preoperatively decreased significantly by 12 months, approaching normal values. Chang and

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corrected for proper alignment of the weight-bearing line in the ankle joint. (Reprinted with permission from Hirao M, Hashimoto J, Tsuboi H, Ebina K, Nampei A, Noguchi T, Tsuji S, Nishimoto N, Yoshikawa H. Total ankle arthroplasty for rheumatoid arthritis in Japanese patients: a retrospective study of intermediate to long-term follow-up. JB JS Open Access. 2017;2:e0033).

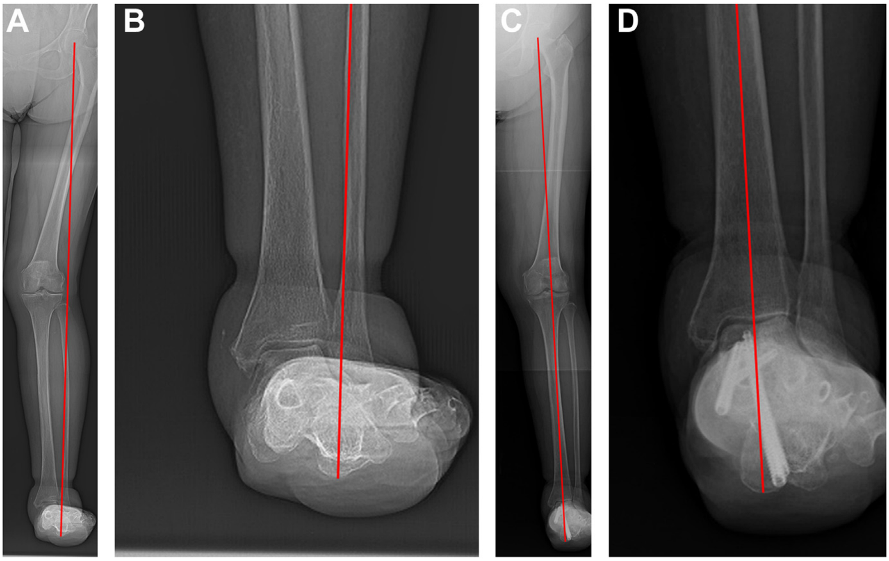

Fig. 8. Radiographs of a patient with stage-3 flatfoot combined with vulgus knee osteoarthritis. (*A*) Preoperative hip-to-calcaneus radiograph of a patient with stage 3 flatfoot and concomitant vulgus knee osteoarthritis. The hip-knee ankle angle is -10°. (*B*) The lower part of the preoperative hip-to-calcaneus radiograph shows hindfoot valgus and that the mechanical axis lies laterally beyond the lateral edge of the tibial plafond. (*C*) The knee vulgus resolved (hip-knee-ankle angle of-2°) as a result of triple arthrodesis performed for the flatfoot. (*D*) The lower part of the postoperative hip-to-calcaneus radiograph shows neutral hindfoot alignment and that the mechanical axis passes through the center of the tibial plafond.

colleagues[26] reviewed the cases of 24 patients who underwent TKA and had concomitant varus ankle osteoarthritis, and they found, as a result of the correction of the varus malalignment of the lower limb following TKA, that radiographic profiles of the ankle joint (eg, orientation of the joint line relative to the ground and medial joint space) had improved. However, although the radiographic features of the ankle joint had improved, many patients experienced increased ankle pain following TKA. The investigators speculated that drastic change in the alignment of the ankle joint could have an adverse effect on the tension of the ligaments that surround the ankle.[26] On the other hand, Takeuchi and colleagues[27] reported clinical outcomes of valgus high tibial osteotomy performed for patients with varus knee osteoarthritis accompanied by ipsilateral varus ankle osteoarthritis. The high tibial osteotomy led to improved American Orthopaedic Foot and Ankle Society Ankle-Hindfoot scores and ankle joint congruency in their patients.

I have found great variation in locations of the mechanical ankle joint axis point in patients with medial compartment osteoarthritis and almost no correlation between the hip-knee-ankle angle and the location of the mechanical ankle joint axis point (data unpublished). When undertaking knee surgery, surgeons should check the patient's mechanical ankle joint axis point preoperatively to evaluate whether the patient's ankle symptoms will worsen or improve.

Needless to say, lower limb alignment is influenced not only by the knee joint but also by the ankle joint. Knee realignment surgery influences hindfoot alignment and vice versa (**Fig. 8**).

SUMMARY

Analyzing the mechanical axis of the lower limb as a line from the center of the femoral head to the lowest point of the calcaneus clarifies the pathogenesis of various hindfoot disorders. Such analysis also facilitates surgical planning. Further, the analysis can clarify the cause of an unsatisfactory outcome of corrective surgery in particular cases. I believe it essential to analyze alignment of the whole limb when planning reconstructive surgery for lower limb conditions involving malalignment.

CLINICS CARE POINTS

- When planning reconstructive surgery of lower limbs with malalignment, it is essential to analyze the alignment of the whole limb prior to surgery.
- When obtaining hip-to-calcaneus radiographs, it is best to use the patella rather than the foot or ankle to control rotation of the lower limb. It is also important to confirm by radiograph that the patella is centered between the femoral condyles.
- When performing supramalleolar osteotomy for patients with a mechanical ankle joint axis point to be medial to the edge of the tibial plafond, use a target TAS angle slightly over 98° and add lateral sliding calcaneal osteotomy and/or opening-wedge medial malleolar osteotomy to further move the mechanical axis laterally.
- Before undertaking realignment surgery of the knee joint, surgeons should check the patient's mechanical ankle joint axis point to evaluate whether the patient's ankle condition will worsen or improve after surgery.

DISCLOSURE

The authors have nothing to disclose.

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