Bridging the Gap: The Influence of Foot and Ankle Pathomechanics in Total Knee Arthroplasty

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ABSTRACT

Altered spinopelvic mechanics can have dramatic influences on the success of hip arthroplasty as seen with concomitant hip and spine disease. Interestingly, limited focus has been directed toward a similar codependent relationship between concurrent knee and foot deformities. By bridging this interdisciplinary gap, we attempt to explore the current understanding and clinical implications of concomitant knee and foot pathology while reviewing management options for addressing this unique yet ubiquitous patient population. Multiple authors have demonstrated an inverse relationship between progressive coronal plane deformities concerning the knee and hindfoot. The utility of a conventional mechanical axis during total knee arthroplasty may be limited in the presence of foot deformity where ground reactive forces often markedly deviate with the hindfoot, potentially leading to eccentric knee loading. The use of alternative indices, such as ground mechanical axis deviation, may offer a more reliable metric for achieving an accurate neutral mechanical axis. In addition, although foot deformity and compensation can often improve to a limited degree after total knee arthroplasty, residual deformity may have deleterious effects on the success of the procedure. A comprehensive understanding of the functional relationship between the foot and the knee can allow surgeons to better guide appropriate treatment sequence, often beginning with the more symptomatic deformity. Future research is needed to further elucidate the implications and appropriate management of concomitant knee and foot deformity.

Our understanding of total joint arthroplasty continues to evolve, leading to improved perioperative management, enhanced surgical techniques, and superior clinical outcomes. Bridging the interdisciplinary knowledge gap through research collaboration has proven fundamental in this process. For example, the spinopelvic relationship has recently received notable attention, drawing important perspective and research with wide applicability across both the hip arthroplasty and spine surgery specialties.[1]

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Importantly, the spinopelvic discussion recognizes the dependent functional relationship between adjacent anatomic regions. To that end, relatively little attention has been directed toward the potential concomitant pathomechanic dysfunction of more caudal associations, specifically the knee and foot.[2,3]

The importance of achieving a neutral mechanical alignment remains a cornerstone for lower extremity orthopaedic surgeons, particularly when planning reconstructive procedures.[4] However, the conventional mechanical axis angle (CMAA), with vectors traversing the center of the hip, knee, and ankle joints, is predicated on the calcaneal ground contact point (CGCP) and ground reactive force (GRF) aligning with these joint centers. Failure to recognize deviation of this axis through coronal hindfoot deformity, for example, can impose adverse effects on knee mechanics after total knee arthroplasty (TKA). Additionally, TKA may potentially expose, or lead to, symptomatic foot deformity.[5]

With the increased projection in TKA procedures,[6] and patient satisfaction and outcomes data often trailing that of total hip arthroplasty,[7] it remains important to investigate confounding variables. A comprehensive understanding of the functional relationship between the foot and the knee will better guide appropriate treatment. Here, we endeavor to explore the current understanding and clinical implications of concomitant knee and foot coronal plane deformity while proposing a guide to managing this unique patient population.

Two Sides of the Tibia

Concomitant knee and foot discomfort are ubiquitous within the orthopaedic population. Roughly, 25% of those presenting with knee osteoarthritis (OA) report symptomatic foot pathology.[8] Furthermore, patients with flatfoot deformity, classically involving a valgus hindfoot position, have a 1.3 odds of also reporting knee pain and 1.4 times the risk of presenting with medial tibiofemoral cartilage damage when compared with those with neutral plantigrade feet.[9] In fact, Lee et al[10] noted 35.2% of those undergoing TKA presented with radiographic signs of ankle OA.

Patients with knee OA often have more severe foot deformities when compared with asymptomatic control subjects. Levinger et al[11] compared those with and without medial OA using various static foot measurements. Those patients with knee OA were found to have markedly greater foot pronation and decreased arches versus normal control subjects. In a retrospective study, Norton et al[2] sought to identify the compensatory hindfoot alignment and where it occurs among those with end-stage OA undergoing TKA. Full-length lower extremity radiographs were obtained in 401 patients to evaluate the mechanical axis, Saltzman hindfoot alignment and angle, anatomic lateral distal tibial angle, and ankle joint line convergence angle. Because the mechanical axis angle developed further into varus or valgus, the hindfoot shifted into a more valgus or varus position, respectively. Quantitatively, the hindfoot shifted into varus by approximately 0.43° for each degree of increasing knee valgus measured by the mechanical axis angle. Conversely, a 0.49° increase in hindfoot valgus was noted with each additional degree of mechanical axis varus. Importantly, most hindfoot compensation was found to originate from the subtalar joint. Chandler et al[3] further supported the presence of hindfoot deformity in coronal plane knee deformity; however, the authors were unable to identify a direct correlation with the mechanical axis. However, using weight-bearing CT analysis, Burssens et al[12] noted that the direction of concomitant deformity may depend largely on tibiotalar pathology, where the authors found the same deviation of both the knee and the hindfoot (eg, valgus and valgus) in the absence of tibiotalar arthritis compared with opposite deviations in those with arthritis.

Van Gueluwe et al[13] expanded on the static radiographic findings by evaluating dynamic changes in foot position with simulated genu valgum and varum. The kinetic gait study based on GRFs predicted that genu varum would cause subtalar pronation to increase during the contact and propulsion phases of walking. Interestingly, genu valgum also demonstrated pronation during the stance phase but exhibited instead hindfoot varus through subtalar supination during propulsion. An additional dynamic gait analysis revealed a relatively everted and rigid hindfoot in those with valgus knee OA along with a greater internally rotated and laterally tilted tibia.[14] Notably, the presence of a rigid hindfoot may help explain the lack of favorable outcomes using lateral heel wedges for knee OA in the presence of coronal plane deformity.[15]

Classically, the development of hindfoot valgus and pronation in medial OA functions to deviate the ground contact pressure laterally. This lateral translation is believed to result from a compensatory mechanism attempting to normalize the mechanical alignment, thereby shifting pathologic knee forces toward the lateral

Figure 1

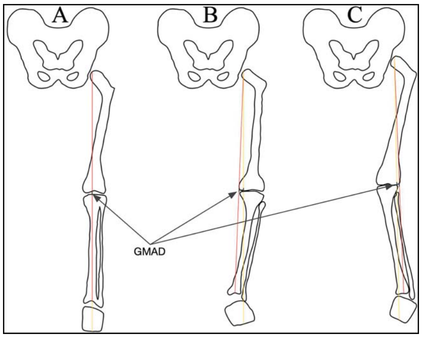
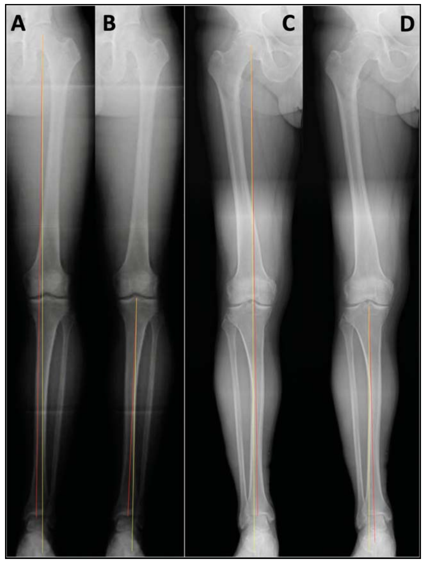


Illustration demonstrating the ground mechanical axis deviation as measured between the conventional mechanical axis (red line) and the ground mechanical axis (yellow line) at the knee level in a neutral aligned (**A**), varus (**B**), and valgus knee (**C**).

Figure 2



Long-leg radiographs both comparing conventional (red line) versus ground (yellow line) mechanical axis (**A** and **C**) and tibia anatomic axis calcaneal deviation (**B** and **D**). Note the similarity in calcaneal deviation between full-length films and tibia-only referencing.

compartment.[2] However, although varus knee OA and hindfoot valgus are the most common concurrent deformity, other combinations are not mutually exclusive. Occasionally, those with genu valgus and lateral OA will also demonstrate some degree of hindfoot valgus, although presenting as a relative hindfoot varus when measured from the long axis of the tibia.[9,13,16]

The understanding of the altered mechanical axis and its influence on knee OA led to multiple developments believed to alter the knee and GRFs. A classic early approach for managing medial knee OA was to reduce medial compartment loading using a lateral heel wedge.[17] These wedges were designed to shift loads to the lateral border of the foot and lateral knee, thereby reducing pathologic forces in the medial compartment. Alternative options such as unloader braces also act to reduce the increased pressures of the involved knee compartment.[18] However, the current literature regarding these interventions remains limited and/or controversial. As a result, the American Academy of Orthopaedic Surgeons does not recommend the use of lateral heel wedges and the consensus remains inconclusive regarding the use of unloader braces.[19] Although these interventions have demonstrated limited success in those with knee deformity, the underlying problem remains: a deviation in the CGCP from the mechanical axis leads to pathologic knee forces.[20] However, to our knowledge, the utility of lateral heel wedges in the treatment of those with concomitant foot and ankle coronal plane deformity has not been studied.

From these findings, we can begin to infer a natural history of knee OA and foot deformity occurring together in an often predictable manner. Because medial pressures on the knee increase and varus OA begins to develop, the subtalar joint compensates by deforming into valgus. This ultimately helps to salvage the conventional mechanical axis through displacement of the CGCP. However, with advancing deformity, a threshold is reached where subtalar compensation is no longer feasible.[14] With advancing foot deformity, the distal kinetic chain will continue to decline leading to sequelae from coronal hindfoot deformity. Planovalgus deformity, for example, can result in posterior tibialis insufficiency and lateral ankle impingement, whereas cavovarus deformity is often associated with metatarsalgia and ankle instability.[5,21]

Surgical Implications: What to Expect

TKA remains a reliable option for those with end-stage degenerative joint disease who have failed nonsurgical treatment. The popularity of TKA continues to rise, with the incidence expected to increase roughly 140% by 2050.[22] Unfortunately, patient satisfaction continues to lag behind that of hip arthroplasty, with only approximately 80% of patients reporting satisfaction with their outcomes.[23] As value-based care and meeting patient expectations become more prevalent, the search for improvement in clinical outcomes continues.

Figure 3

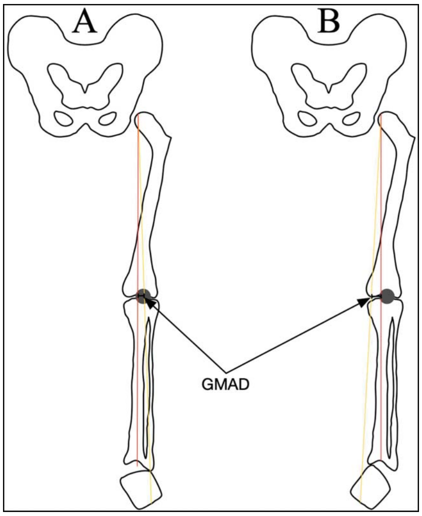


Illustration demonstrating the effect of residual foot deformity after total knee arthroplasty (TKA) with hindfoot valgus (**A**) and varus (**B**) and the resulting ground mechanical axis deviation as measured between the conventional mechanical axis (red line) and the ground mechanical axis (yellow line) at the knee level.

Practical concerns when performing TKA in those with concomitant foot deformity are as follows: (1) Will the arthroplasty alter the hindfoot deformity and potentially lead to symptomatic deformity? (2) Will the foot deformity and potential future treatments influence the success of the TKA? With the knowledge of native pathologic relationships between native foot and knee deformities, as reported above, and critical evaluation of those having undergone TKA, we can begin to objectively approach these questions.

Restoring a neutral knee alignment remains one of the fundamental goals for a successful TKA.[24] Accurate alignment is believed to balance the adductor or abductor moment and frontal plane lever arm about the knee, often increased in those with OA deformity.[25] The CMAA, which uses a vector traversing the hip, knee, and ankle center, is frequently used by surgeons as a proxy for the knee alignment because it relates to GRFs.[26] With advancing coronal knee deformity, the CMAA further deviates from neutral. However, this common measurement neglects the axis because it relates to ground contact through the foot, particularly the CGCP, where the GRF originates. Peritalar deformity, whether at the distal tibia (lateral distal tibia angle) and tibiotalar (ankle joint line convergence angle), or subtalar joint deformity can markedly deviate ground contact pressures from the traditional lower extremity mechanical axis.[2]

Recently, the ground mechanical axis deviation (GMAD) has been found to be a reliable indicator of lower extremity deformity and true mechanical axis alignment by enhancing the conventional mechanical axis to also include ground contact forces (Figures 1 and 2).[27,28] Mullaji et al[20] investigated the influence of TKA on preoperative hindfoot alignment and the clinical importance of the GMAD versus the CMAA. Although the investigators were able to demonstrate a decrease in hindfoot valgus after TKA, 29% of limbs had a residual postoperative GMAD of 10 mm or greater lateral to the knee center, where the CMAA was otherwise normalized. The implications of these findings suggest that although hindfoot valgus did improve after TKA in 31% of their cohort, residual hindfoot valgus continued to distort the weight-bearing axis of the lower extremity. The altered joint mechanics and alignment axis, specifically involving the GMAD, may help to explain

Table 1. Management of Concurrent Knee and Hindfoot Deformity

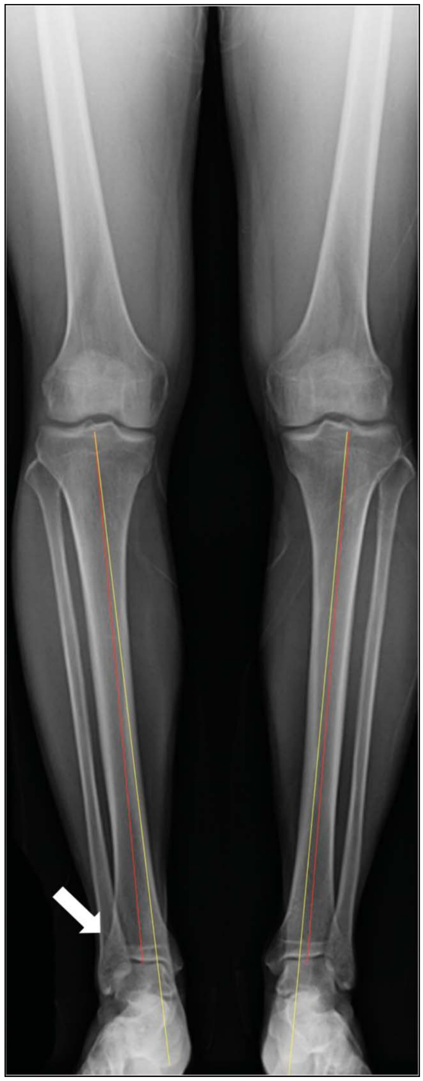
Examination	Imaging	Treatment
• Remove shoes • Gait evaluation • Standing evaluation (including posterior) • Single-leg heel rise (PTT integrity for hindfoot valgus) • Foot palpation for callus and tenderness • Assess hindfoot motion and Achilles tendons for correctability (plantigrade foot to TAA) • Standard knee examination	• Standard knee radiographs (standing AP, lateral, merchant, and sunrise) • Standing bilateral 3-joint long-leg radiographs • Long-axis hindfoot radiograph • Consider bilateral weight-bearing 3-view ankle radiographs • Consider bilateral weight-bearing 3-view foot radiographs • Consider weight-bearing CT	• Dependent on symptom and deformity severity/correctability • Trial conservative treatment • Shoe modification/hindfoot posting or ASO • More proximal or symptomatic joint treated first • Consult F&A specialist for chronic pain and/or uncorrectable deformity • Consider brace or custom orthotics after TKA to decrease GMAD

ASO = ankle-stabilizing orthosis, F&A = foot and ankle, GMAD = ground mechanical axis deviation, PTT = posterior tibial tendon, TAA = tibia anatomic axis, TKA = total knee arthroplasty

Figure 4

Radiograph showing calcaneal visualization (curved arrow) on anterior-posterior ankle radiographs, which is essential to determine the coronal calcaneal deviation and calcaneal ground contact point.

Figure 5



Radiograph showing tibia anatomic axis calcaneal deviation, and thus ground mechanical axis deviation, which is influenced by radiographic rotation. Note the relative external rotation of the right leg as indicated by increases tibia-fibula overlap (white arrow), resulting in a falsely increased calcaneal deviation.

higher revisions in TKA associated with coronal plane hindfoot deformities.[5,29]

Fortunately, minimal biomechanical foot alterations should be expected after TKA in those with limited coronal knee deformity.[30] However, in those with moderate to severe concomitant deformities, a notable improvement of 31% to 50% in foot alignment after knee reconstruction can be anticipated, particularly in the presence of relatively flexible deformity.[3,20] Therefore, notable compensatory changes to the ankle, subtalar joint, and foot should be expected and planned for when correcting a knee deformity through TKA.[31] However, although we can expect improvement in flexible peritalar coronal plane deformities, a neutral ground mechanical axis is infrequently achieved. Mullaji et al[20] noted most patients (96%) demonstrated hindfoot valgus before TKA. After the procedure, 87% remained in valgus, but to a lesser degree. Furthermore, variable correctability occurs depending on the presenting foot deformity. Notable improvement in hindfoot valgus as early as 3 weeks after TKA has been reported, whereas minimal to no improvement was seen in the commonly rigid varus hindfoot.[32] This residual deformity may forecast adverse consequences to the TKA.[5] Equally important, as Lee et al[10] noted, roughly 22% of patients will experience new or progressive ankle arthritis after TKA.

Figure 6

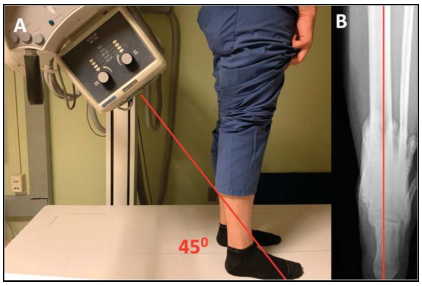


Image showing the long-axis view of the hindfoot (**A** and **B**), which provides the arthroplasty surgeon a simple additional radiographic image to assess hindfoot deformity.

Figure 7

Image showing a 61-year-old man with concomitant coronal hindfoot and knee deformity. The severe flatfoot deformity has resulted in a notable lateral calcaneal deviation (**A** and **B**), as measured on coronal computed tomography (**C**). The concurrent knee osteoarthritis and deformity (**D** and **E**) was reconstructed with total knee arthroplasty (**F**).

Management

Patients presenting with both knee and foot deformity pose a unique and often challenging problem for arthroplasty surgeons. Every effort should be made to prepare for, and prevent, potential complications related to these interdependent anatomic regions. Those undergoing TKA may have exacerbation of foot or ankle symptoms because of adapted and/or rigid deformities with limited correction postoperatively. Indeed, correcting a valgus knee with previous rigid hindfoot varus can lead to increasing lateral foot loading and symptom exacerbation (Figure 3). In essence, the objective when treating these patients is to remain cognizant to the concurrent deformities, particularly the flexibility, severity, and symptomatology of the foot deformity. The astute surgeon can thus avoid the scenario where a deformity correction surgery is adversely affected by continued malalignment or subsequent interventions, whether at the foot or knee. Here, we propose several key aspects to the comprehensive workup and management of this unique patient population (Table 1).

Workup

A comprehensive understanding of a patient's complaint begins with a well-executed history and physical examination. An initial workup for knee pain should include a focused foot and ankle history assessing the presence of discomfort and deformity, as well as any previous injuries or surgery. The use of orthotics, shoe modifications, and braces should also be documented.

Integral to a ground mechanical axis assessment is simply visualizing the patient's gait, standing posture, and leg length which will allow clinicians to assess knee and foot deformities in tandem. The knee may demonstrate coronal plane deformity with an associated thrust during normal gait. Sagittal deformities, including flexion contracture and recurvatum, should also be documented. Observing the weight-bearing patient from behind will provide a rapid assessment of existing hindfoot deformities. For example, the "too many toes" sign is often positive in those with pes planovalgus or flat feet. In those with flat feet, a single-leg heel raise can assist in determining the functionality of the posterior tibial tendon, where degeneration is the leading cause of adult acquired flatfoot deformity.[33]

In addition to a detailed hip and knee examination, palpation of the foot will provide clues regarding areas of increased load transfer, such as callus formation or tenderness, as can be seen with altered foot pressures in OA.[34,35] Both feet should be examined because bilateral deformity is associated with worsening knee OA symptoms.[36] Range of motion of both the ankle and subtalar joints is critical to assess deformity correctability and tight Achilles tendons. The goal of evaluating deformity correctability in the context of a planned TKA is to ensure that a plantigrade foot can be achieved when the neutral mechanical axis is reestablished. To do so, a good rule is to confirm that the foot can achieve plantigrade positioning relative to the tibia anatomic axis, not the precorrected patient long axis as is often used. Furthermore, sufficient dorsiflexion and flatfeet are often seen in the presence of knee OA, whereas high arches and limited dorsiflexion are generally noted in those with hip OA.[37] In those with limited dorsiflexion and tight Achilles tendons, the Silverskiold test can help determine the etiology of the restriction. In addition,

Figure 8

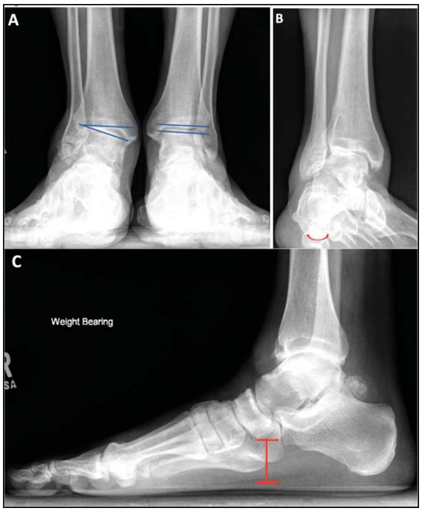


Image showing a 61-year-old man with chronic right tibiotalar arthritis. Note the relative increased ankle joint line convergence angle (**A**), identifying the tibiotalar joint disease as the etiology of the hindfoot deformity (**B**). The lateral radiograph (**C**) demonstrates an otherwise normal medial cuneiform height.

tarsometatarsal instability can occasionally conceal equinus contracture; thus, radiographic correlation is recommended. Again, in either case, the examiner should ensure that a plantigrade foot is achievable both at the time of the examination and with the prospect of future knee coronal plane correction.

In the presence of notable concomitant deformity, a weight-bearing bilateral 3-joint leg length radiograph should be obtained along with the consideration of dedicated bilateral weight-bearing ankle and foot radiographs. Importantly, radiographic calcaneal visualization is essential for proper alignment evaluation (Figure 4). Together, these images will help develop an objective evaluation of the ground mechanical axis and any associated deformity when planning correction. In institutions where full-length films are unavailable, tibia-only referencing can provide similar calcaneal deviation evaluation (Figure 4). In addition, focused foot and ankle radiographs can further assess foot alignment and help to expose underlying causes of the distal deformity. However, a proper radiographic assessment of the hindfoot alignment is rotation-dependent because the calcaneus contacts the ground posterior to the tibia plafond. Therefore, malrotated imaging may falsely accentuate the hindfoot deformity (Figure 5). The addition of a long-axis view of the foot can help determine the true hindfoot alignment with a high level of intraobserver and interobserver reliability (Figure 6).[38] Recently, weight-bearing computed tomography has been used with measurable success at several centers and may allow for improved concurrent knee and foot multipolar deformity evaluation; however, the availability of this technology remains limited in North America.[39]

Treatment

Regrettably, at this time, there are no clear guidelines or consensus regarding the management of those with concomitant symptomatic foot and knee deformity, thus underscoring an inherent limitation of this article. Furthermore, our treatment approach to this unique patient population depends both on the severity of pain and on the deformity, which are merely suggestions based on the aforementioned concepts and principles. In essence, it is sensible to seek treatment first for the more symptomatic joint. However, if both are equally symptomatic, as with the hip and knee, the more proximal joint should be reconstructed first (Figure 7). Attempting to reconstruct foot and ankle pathology with proximal deformities, specifically at the knee, poses several inherent challenges, especially when the proximal deformity is asymptomatic. Infrequently, however, the patient may benefit from surgical treatment of the foot or ankle before TKA, often using a combination of tendon transfers, osteotomies, fusions, or ankle arthroplasty. Indeed, it is our preference to await foot and ankle management and resolution before TKA when possible for patients with knee pain as the secondary complaint. In either case, we strive to remain cognizant of both the potential future reconstruction of the adjacent joint, which will invariably alter the GMA, and the implications on the success of the respective surgery.

In the presence of mild knee deformity and pain with an asymptomatic foot deformity, observation with conservative knee treatment is instituted, which includes activity modification, weight loss, injections, and NSAIDs. During the conservative treatment of knee OA, those with mild and minimally symptomatic foot deformity may benefit from early foot and ankle evaluation for preventive measures such as managing early stages of pes planovalgus related to posterior tibialis tendon insufficiency or ankle instability with developing arthritis (Figure 8). However, simple measures such as ensuring appropriate shoes and recommending home exercise programs are often sufficient. Medial hindfoot posting for those with hindfoot valgus and lateral hindfoot posting for hindfoot varus can potentially reduce the GMAD.[40] In some cases, an ankle stabilizing orthoses may provide additional support; however, compliance can pose a limiting factor. Custom orthotics may be helpful in those with additional midfoot and forefoot deformities.

Because knee deformity and pain increases despite conservative measures, arthroplasty should be considered, with particular attention to the severity of foot symptoms. Occasionally, if TKA is planned, simple postoperative foot observation may be sufficient, leading to resolution of symptoms and obviating the need for additional foot and ankle management. Should foot and ankle symptoms with residual deformity persist beyond 3 to 6 months after TKA, evaluation and treatment is suggested. However, collaboration and recommendations from those specializing in foot and ankle reconstruction should be sought before surgery for those patients presenting with an equal or greater symptomatic foot deformity, with consideration given to surgical timing and sequence if foot and ankle surgery is, in fact, recommended. Correction of a coronal plane foot or ankle deformity before TKA would effectively decrease the GMAD, potentially reducing eccentric forces seen within the knee prosthesis.

When planning TKA, it is essential to quantify the correctability of the hindfoot deformity. In general, the authors feel that obtaining a plantigrade foot relative to the tibia anatomic axis is sufficient to accommodate daily activities after the reconstruction of a neutral ground mechanical axis. When passive hindfoot correction, and thus a plantigrade foot, is not feasible, custom bracing is recommended after TKA. This is because the foot will be unable to compensate properly, leading to (1) potential off-axis implant loading and (2) acceleration of degenerative changes about the foot and ankle. Although small adjustments in femoral and tibial implant coronal plane positioning are possible during the TKA procedure, potentially accommodating notable rigid hindfoot deformities while decreasing the GMAD, we do not currently recommend this practice, particularly if future foot and ankle procedures are probable. In either scenario, those with rigid and/or symptomatic foot and ankle deformities should be counseled regarding the expectations after TKA, including unresolved foot and ankle deformity, increasing foot pain, and potential early TKA failure.

Summary

Orthopaedic patients presenting with concomitant knee and foot deformity have become ubiquitous. Armed with an improved understanding regarding the interplay between lower extremity joint functions, we can be better equipped to properly reconstruct a balanced and neutral mechanical alignment. As reported, residual deviation of the GMA with a resulting eccentric load on the arthroplasty implant can occur despite the restoration of the conventional mechanical axis. Alternatively, through normalization of the GMAD based on the knowledge of hindfoot deformities before knee arthroplasty and the subsequent influence of foot deformities after reconstruction, we can potentially improve patient satisfaction, reduce reoperation, and avoid future related foot and ankle symptoms. We hope that this review will serve as nidus for future research involving this complex topic. Particularly, prospective biomechanical studies with long-term outcomes are needed to improve our understanding and management of the pathologic interplay between concomitant knee and foot deformities.

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