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Müller-Weiss Disease: A Topical Review

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Müller-Weiss disease (MWD) is a painful foot condition characterized by deformity, sclerosis, and fragmentation of the navicular. The diseased navicular is characteristically comma shaped with varying degrees of arthritis present at the talonavicular and naviculocuneiform joints.[17,19,27] Other names for MWD include Brailsford disease,[37] adult tarsal scaphoiditis,[26] spontaneous adult navicular osteonecrosis,[34] and listhesis navicularis.[23] There is substantial controversy regarding the etiology, pathophysiology, and natural history of MWD, as well as optimal methods of treatment. This article reviews the historical and current literature regarding MWD, including the latest surgical interventions that have been reported.

Historical Background

Despite being named after Müller and Weiss, Schmidt was the first to report a similar condition in a patient with pluriglandular insufficiency syndrome in 1925.[23] Walther Müller,[28] a German surgeon, reported a case of MWD in 1927 and attributed it to mechanical collapse from compressive forces. One year later, he proposed a congenital theory as the cause of the condition.[29] Konrad Weiss,[42] an Austrian radiologist, presented 2 cases with similar findings. However, based on radiographic signs of increased bone sclerosis and adjacent joint space narrowing, he attributed the condition to osteonecrosis. Brailsford identified MWD as osteochondritis of the navicular bone or listhesis navicularis.[23,31]

Anatomical and Biomechanical Considerations

The healthy navicular bone is typically boat shaped with convex distal and concave proximal articular surfaces. It articulates proximally with the talar head, distally with the cuneiforms, and inferolaterally with the cuboid. Proximally, the talocalcaneonavicular articulation is also known as the acetabulum pedis for morphologic similarity to the hip joint. It is a ball-socket synovial joint allowing for rotatory and gliding movements. The talocalcaneonavicular and the naviculocuneiform joints sustain the greatest load transmission in comparison to other foot joints.[11]

The navicular is the latest tarsal bone to ossify. Ossification occurs during the period of increased mobility and activity in children (at the end of the second year in girls and at the beginning of the fourth year in boys). With suboptimal ossification of the navicular, it may sustain higher shearing forces at the level of the lateral cuneiforms.[36]

The navicular is perfused by 2 arteries. The dorsalis pedis artery supplies the dorsal and lateral one-third of the bone while the medial plantar artery supplies the plantar aspect and some of the medial aspect of the bone. The arterial supply has a circumferential pattern resulting in a central osseous zone that has a diminished blood supply that may even decrease with age.[40]

Being the keystone of the medial column of the foot, the navicular contributes to the integrity of both the medial longitudinal and the transverse arches of the foot.[35] In the case of dorsolateral fragmentation and collapse of the navicular, functional malalignment and progressive deformities of the midfoot and the hindfoot occur.[23,41]

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Any lateral shift of the compression forces on the navicular may then lead to further flattening and fragmentation of the navicular, often with the formation of a cleft between the medial and dorsolateral fragments. This collapse may result in secondary lateral talar head shift and hindfoot varus. In late stages, further collapse and fragmentation result in direct articulation of the talus with the lateral cuneiforms, creating enough space to permit plantarflexion of the talar head and consequently paradoxical pes planovarus.[23,43] However, it is not known whether the planus deformity in MWD is a cause or a result of the navicular collapse and fragmentation.[38]

Relative hypertrophy of the second metatarsal and a short first ray have been reported to be common findings in MWD.[34] The short first ray could be attributed to primary first metatarsal shortening, or it may be secondary to relative shortening of the medial column because of internal rotation of the navicular.[23,24] The short first ray may lead to abnormal force distribution with lateralization of stance phase compressive forces toward the second ray and lateral navicular.[24]

Hetsroni et al[13] studied the plantar pressure distribution in patients with MWD and found increased midfoot plantar pressures with reduction in toe pressures. Pain and discomfort could be attributed to this abnormal pressure distribution.

Epidemiology

The true incidence of MWD is unknown. It is more frequently bilateral and demonstrates a female predominance.[45] The female to male ratio was 6:1 in 1 study and 2:1 in another.[13,45] Several studies have reported that the age of patients at the time of diagnosis of MWD was over 40 years.[13,26,44] However, in a large multicenter study of 191 cases (101 patients), the age at diagnosis ranged from 13 to 91 years, with an average of 47.6 years.[23] In the series of 12 cases reported by Doyle et al,[7] 1 patient was 14 years old. Patients with MWD may also have a have a higher body mass index (BMI).[27] Fornaciari et al[10] reported a mean BMI of 29.6 kg/m^2 in their study of 10 patients while Hetsroni et al[13] reported an average BMI of 27 kg/m^2.

Etiology and Pathogenesis

Several etiological theories of MWD have been proposed, including primary osteonecrosis, posttraumatic necrosis, osteochondritis, congenital theory, and the abnormal evolution of Köhler's.[23] Despite its description as osteonecrosis of the navicular, most of the histopathological studies do not provide conclusive evidence of osteonecrosis (empty lacunae).[6,17,27,39] Tan et al[38] presented a single case report with histological evidence of osteonecrosis. Other microscopic studies, however, have reported normal bone.[22,25,46] Moreover, the central (not the lateral) middle third of the navicular has a relatively poor blood supply.[6,20] Therefore, osteonecrosis would theoretically start in the central zone in contrast to the lateral collapse and fragmentation seen with MWD.

Mohiuddin et al[27] recently surmised that MWD is a sequelae of undiagnosed navicular stress fractures with the hypothesis that the central one-third of the navicular bone is subjected to the maximum shear stresses. Once again, their theory is about the middle rather than the lateral third of the bone, and there are no available reports of MWD complicating a diagnosed navicular stress fracture.

The etiology of MWD may be multifactorial and associated with uneven loading of a suboptimally ossified navicular that is at risk for central ischemia due to its vascularity.[34] Maceira and Rochera[23] believed that 2 prerequisites are necessary for MWD: delayed ossification of the navicular and an abnormal force distribution pattern leading to compression of the lateral part of the bone. Delayed ossification of the navicular may be due to a localized or generalized developmental disturbance.

Clinical Presentation

The typical presentation is chronic pain on the dorsum of the midfoot and/or hindfoot.[23,27,39] There may be a delay in the diagnosis, and a stiff deformity is observed at presentation in most cases (Figure 1).[26]

Tenderness is usually located over the dorsomedial aspect of the midfoot. The medial longitudinal arch may be normal or low depending on the severity of the disease.[27,43] With regard to hindfoot alignment, a false impression of hindfoot valgus may occur due to prominence of the navicular on the medial aspect of the foot.[34,43] Maceira and Rochera[23] considered fixed hindfoot varus a constant finding in MWD. Cases in which this is accompanied by flattening of the longitudinal arch may be said to demonstrate "paradoxical pes planovarus." The paradoxical heel varus deformity with a concomitant pes planus is considered a hallmark of MWD.[6,43] However, this is controversial and descriptions of hindfoot position in MWD have included slight heel varus,[19] flatfoot without hindfoot varus,[45] neutral hindfoot,[41] and flatfoot without comment on hindfoot position.[4,5] Haller et al[12] reported 5 cases of MWD with flatfeet and hindfoot valgus. Only few published studies commented on the subtalar motion, and both reduced motion[7,23,27,43] and normal motion have been described.[30,32,39] Hetsroni et al[13] reported that the subtalar motion was not significantly limited.

Patients with MWD may complain of anterior knee pain because the tibia is forced into external rotation secondary to pes planovarus with posterior positioning of the fibula that could theoretically lead to altered knee biomechanics and patellar maltracking.[23,27]

Figure 1. Plain radiographs of a patient having Müller-Weiss disease (that was accidentally discovered on routine radiographs after trivial trauma) showing the characteristic comma-shaped navicular bone with compression of its lateral part in addition to the development of talonavicular osteoarthritis.

Figure 2. Plain radiographs comparing the foot of 2 different patients to compare between (A) the flatfoot in Müller-Weiss disease (MWD) and (B) flexible flatfoot. Note that the medial foot prominence in MWD is formed by the navicular and by the talar head in flexible flatfoot.

Differential Diagnosis

MWD should always be considered when assessing patients with chronic midfoot or hindfoot pain. It should not be confounded with Köhler disease, which is unilateral in 75% to 80% of cases, typically occurs between the ages of 3 and 7 years, produces minor symptoms, and has a male preponderance. MWD is usually bilateral with a characteristic painful clinical course and progressive deformity. Moreover, MWD is seen predominantly in females.[16,32] MWD can lead to disabling foot deformities, while Köhler disease is a self-limiting disease and usually has a favorable outcome.[27]

Secondary osteonecrosis of the navicular that is associated with trauma, renal failure, rheumatoid arthritis, and systemic lupus erythematosus is differentiated by a unilateral distribution and more extensive morphologic changes than those seen in patients with MWD.[32] Furthermore, the other clinical manifestations of these diagnoses are absent in MWD.

MWD has characteristic radiographic signs that are different from the findings seen in stress fracture of the navicular and Charcot arthropathy.[9] Moreover, patients with Charcot arthropathy of the midfoot have an insensate limb without acute pain due to peripheral neuropathy such as in diabetes mellitus.[44]

There are several causes for acquired flatfoot, including posterior tibial tendon dysfunction, trauma, tarsal coalition, arthritis, neurologic disorders, and iatrogenic causes. MWD may also lead to flatfoot.[41] However, flatfoot with MWD is differentiated from these by its characteristic comma-shaped navicular bone and by the paradoxical hindfoot varus. The prominence on the medial side of the foot in MWD is from the navicular tuberosity in contrast to the flexible flatfoot where that prominence is caused by the talar head following partial uncovering by the navicular (Figure 2).

Imaging Studies

Weightbearing radiographs of the foot and ankle are considered the mainstay of investigation. Assessment of the contralateral foot is also helpful.[8,31] Navicular fragmentation, foot deformity, and the presence or absence arthritic changes should be assessed.[43] The radiographic hallmark of MWD is a comma-shaped navicular on the anteroposterior (AP) view of the foot, associated with narrowing and sclerosis on the lateral view.

On the AP radiograph, the navicular is typically comma shaped with increased density of its lateral part, and there may be medial subluxation of cuboid with respect to the calcaneus ("cuboid sign").[34] The talar head may also appear wide due to its altered rotation,[43] and the talocalcaneal angle may be reduced.[2,43] The cyma line, an S-shaped line created by well-aligned talonavicular and calcaneocuboid joints,

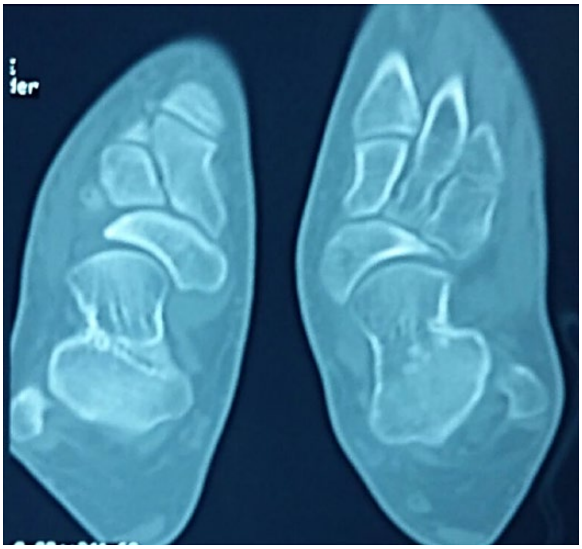

Figure 3. Long-axis computed tomography image of both feet with Müller-Weiss disease showing the comma-shaped navicular with collapse and sclerosis of its lateral part, lateral subluxation of the left talar head or medial subluxation of navicular tuberosity, and beginnings of new articulation between the talar head and the lateral cuneiform in the right foot.

may be altered or disrupted.[34] Contact between lateral talar head and lateral cuneiforms may occur.[43] There may also be a parallel orientation of the metatarsals,[34] hypertrophy of the second metatarsal, and short first metatarsal.[43]

On the lateral weightbearing radiographs, there is typically an increased calcaneal pitch angle,[2,43] a decreased talocalcaneal angle,[34] false impression of a capacious sinus tarsi due to hindfoot varus (see-through sign), an abnormal cyma line, double talar dome shadow, and posterior positioning of the fibula due to external rotation of the hindfoot and ankle.[43] The navicular may be shortened and extruded dorsally. There may also be varying degrees of perinavicular arthritis.

Computed tomography (CT) is helpful for evaluation of the bone stock (Figure 3), as well as the assessment of deformity and arthritis.[26,27,31,32,43] However, standard CT scan is not useful for evaluation of dynamic deformity and does not provide a functional appreciation of the hindfoot in relation to the midfoot under functional load.[43] This information may be obtained with weightbearing CT, which visualizes bony alignment in the loaded condition. It also allows for 3-dimensional reconstruction, as well as standard axial, sagittal, and coronal reformations.[33] Other advanced imaging modalities such as magnetic resonance imaging (MRI), ultrasonography, and bone scan have a limited role in the workup and the management of MWD.[26] MRI is helpful for early detection of the disease as it shows bone marrow edema, homogeneous loss of signal intensity in the dorsolateral bone marrow, and effusion in adjacent joints (Figure 4).[3,12,16,31] It is also helpful in detection of early perinavicular arthritic changes, assessment of soft tissue structures, and excluding other conditions such as stress fracture and infection.[27]

Radiographic Staging

Maceira and Rochera[23] presented a staging system for MWD based on the weightbearing lateral radiograph (Table 1). This system was determined by the appearance of the navicular and the Meary-Tomeno (M-T) angle (between the longitudinal axes of the talus and the first metatarsal). Normally, these 2 axes are aligned. With pes planus, this angle is more than 4 degrees of plantar apex angulation.[34]

Familiarity with this staging system may help in understanding MWD.[34] However, this staging is descriptive and has no prognostic value.[23] Furthermore, the severity of the symptoms may not correlate with the radiographic findings of destruction/deformity of the navicular or the stage of MWD.[27,34]

Treatment

Nonoperative Treatment

An initial trial of nonoperative treatment has been proposed by many authors for MWD and may include nonsteroidal anti-inflammatory drugs (NSAIDs), patient education, activity modification, weight reduction, shoe modification, orthotics, bracing, and casting.[26,32] The goals of shoe modification, orthotics, and bracing are the reduction of midfoot motion and offloading the talonavicular joint during heel rise. Shoe modification may entail a stiff sole or the incorporation of a midfoot rocker.[26] With regard to orthotics, a rigid or semirigid foot orthosis with a medial arch support and a valgus heel post may be of value. A more rigid orthosis that controls peritalar motion should be considered in cases where symptomatic talonavicular arthritis is felt to be the primary pain generator.[14] The suggested duration for conservative treatment ranges from 2 to 60 months.[9,21] However, poor responses were reported before surgical interventions in different studies.[10,19,39,41,43]

Operative Treatment

Surgical treatment is indicated for persistent symptoms after an adequate trial of conservative management.[26,34] Most authors consider surgery on the basis of the severity of the symptoms, rather than the degree of the deformity.[16,18,27]

The goal of operative treatment is a plantigrade, well-aligned foot with restoration of medial column height. While seemingly straightforward, achievement of these

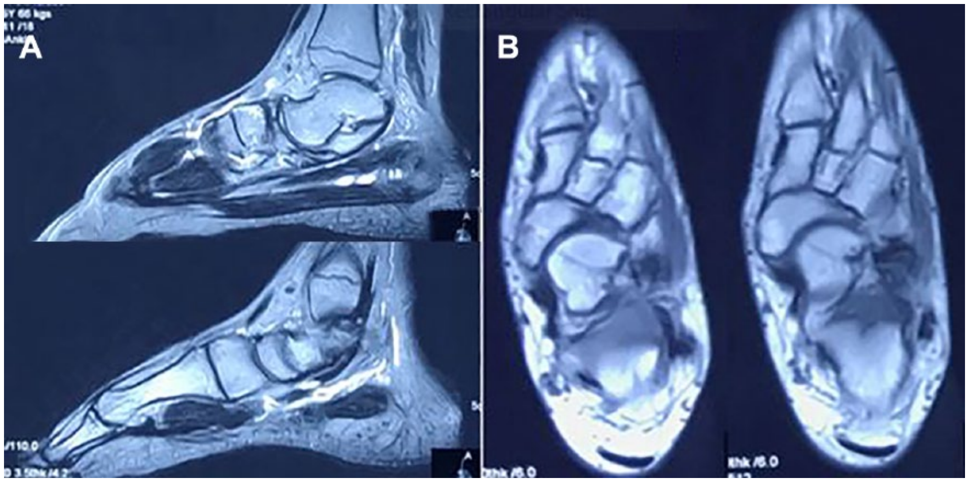

Figure 4. T2-weighted images from magnetic resonance imaging of a left foot with Müller-Weiss disease. (A) Sagittal images show (top) compression and splitting of the lateral part of the navicular, whereas (bottom) the medial part is broad. (B) Long-axis images show the characteristic comma-shaped navicular with compression and fragmentation of its lateral part.

Table 1. Maceira and Rochera Radiological Staging.[23]

Stage	Radiological Description
1	Normal plain film radiographs
	Bone scan/MRI typically demonstrates the disease
2	Subtle dorsolateral subluxation of the talus on the navicular
	Dorsal angulation of M-T line
	CT/MRI show initial stages of the structural injury to the navicular
3	Medial column height loss (space between the talar head and the medial and the intermediate cuneiforms) through a fragmented/split navicular
	Arch height loss (increased talocuboid overlap on the lateral view)
	Hindfoot varus
	M-T alignment is neutral
4	Increasing medial column collapse with arch height loss
	Hindfoot equinus
	Paradoxical pes plano varus
	M-T lines intersect on the plantar side
	Degeneration of the subtalar joint (typically the anterior facet) on CT scan
5	Formation of talocuneiform articulation
	Complete extrusion of navicular
	Significant/progressed heel varus, with paradoxical near-complete arch loss

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging; M-T, Meary-Tomeno.

goals in patients with MWD is often a complex endeavor.[26,44] Currently, there is no available consensus with regard to the optimal surgical procedure for treating MWD.[27,34] A variety of surgical options have been described in a limited number of case series.[27]

Operative treatment typically entails arthrodesis. However, joint-sparing calcaneal osteotomies as well as other miscellaneous procedures have recently been reported. The latter primarily entail techniques that have been described in single case reports. The need for adjuvant percutaneous lengthening of the Achilles tendon in MWD has also been reported.[9,27]

Arthrodesis

Arthrodesis is indicated for patients with MWD and painful perinavicular arthritis.[6] Variable techniques have been described, including talonavicular arthrodesis (TNA), talonaviculocuneiform arthrodesis (TNCA), double arthrodesis, and triple arthrodesis.[5,7,10,19,21,41,44,45] An additional calcaneal osteotomy should be considered if significant varus malalignment is observed.[9] Owing to the limited evidence and the considerable variation in the characteristics of MWD, there is no consensus with regard to recommending a single operation for this disease.[26,27,39] The functional assessment by the American Orthopaedic Foot & Ankle Society (AOFAS) Ankle-Hindfoot score varied among different studies from 79 to 90.9 (Table 2).

With MWD, there is considerable variation with regard to the degree of arthritis present, the extent of navicular fragmentation, and the associated remaining bone stock available for fixation. As such, meticulous preoperative planning is required. Important issues to consider include determination of which joints will require fusion, assessment of the bone stock available for fixation, assessment of the degree of medial column shortening, and the need for bone graft and bone graft substitutes.[26] Bone graft is typically required, and the choice of graft type (structural vs morselized, autograft vs allograft) is made on a

Table 2. Some Studies Reporting Outcome of Müller-Weiss Disease Treatment.

Study	Year	Patients/Feet	Mean Age, y	Sex	Feet/Stage	Treatment	Follow-up	AOFAS Outcome
Ahmed et al[1]	2019	13 feet/7 patients	15.6	2 males/5 females	All/S4	Calcaneus lengthening osteotomy	37.8 mo	94.2
Zhang et al[45]	2017	11 feet/10 patients	48.1	1 males/9 females	All/S4	A. 5 open triple A B. 6 TNCA	7.5 mo	A. 79 B. 86.2
Li et al[19]	2017	14 feet/13 patients	56	6 males/7 females	5 feet/S2 4 feet/S3 1 foot/S5	Calcaneus osteotomy	3.7 y	79
Cao et al[4]	2017	30 feet/30 patients	A. 50.3 B. 49.2	6 males/24 females	25 feet/S3 5 feet/S4	A. 16 TNA B. 14 TNCA	A. 39.8 mo B. 51.7 mo	A. 88.9 B. 90.1
Fornaciari et al[10]	2014	10 feet/10 patients	63	2 males/8 females	3 feet/S3 7 feet/S4	TNA	24 mo	88.3
Yu et al[44]	2012	7 feet/7 patients	55	1 males/6 females	4 feet/S3 1 foot/S4 2 feet/S5	TNCA	22 mo	82
Wang et al[41]	2012	7 feet/6 patients	54	1 males/5 females	5 feet/S4 2 feet/S5	5 TNA 2 triple A	23.2 mo	89.8
Doyle et al[7]	2012	19 feet/12 patients	57.9	4 males/8 females	6 feet/S1 1 foot/S2 8 feet/S3 3 feet/S4 1 foot/S5	5 triple A 1 triple A + NCA 1 pantalar A 1 TAR + calcaneus osteotomy	Up to 2 y	NA
Cao et al[5]	2012	9 feet/9 patients	48.2	4 males/5 females	All/S3	Perinavicular arthrodesis	22.4 mo	90.9
Lui[21]	2009	6 feet/6 patients	67.75	All females	2 feet/S4 4 feet/S5	Arthroscopic triple A	43.5 mo	81.5

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society; NA, not available; NCA, naviculocuneiform arthrodesis; S, stage; TAR, total ankle replacement; TNA, talonavicular arthrodesis; TNCA, talonaviculocuneiform arthrodesis; triple A, triple arthrodesis.

case-by-case basis. Successful outcomes have been reported using both allograft and autograft.[27,30] Structural graft is often required given the presence of bone fragmentation, resorption, and deformity.

With regard to internal fixation, the remaining bone stock is a critical consideration. For MWD stages 2 to 4, there is often a defect present laterally but viable bone present medially, so a mixture of both compressive and spanning fixation can be used. For MWD stages 4 and 5, there may be no viable bone remaining at all, and a more rigid construct with structural graft may be required. Spanning fixation may also be required in these cases. Fixation may include the use of screws, staples, and/or plates.[27] On the contrary, Fernández et al[9] reported that internal fixation is not required for TNCA if the graft is stable and self-locking.

With relatively healthy calcaneocuboid and subtalar joints, isolated TNA is an option for cases that are resistant to conservative treatment.[20] Fornaciari et al[10] treated 10 feet in 10 patients with TNA by the tension band technique using a dorsolateral compression plate and 2 medial transfixing screws (Figure 5). The stable lateral hinge theoretically transforms the tension effects of the tibialis posterior tendon into compression forces at the arthrodesis site. These authors reported a satisfactory outcome with an average postoperative AOFAS of 88.3 compared to 33 preoperatively. Solid fusion was achieved in 9 cases, and 1 nonunion with implant failure needed a revision. A fusion rate of 76.9% was reported by Lu et al[20] in a series of 13 cases treated by TNA. The average AOFAS Ankle-Hindfoot score improved from 48.5 preoperatively to 87.2 at final follow-up. One of the three nonunions was treated by double fusion (talonavicular and calcaneocuboid arthrodesis). Two cases of prominent implants underwent removal after solid arthrodesis, and 8 cases (61.5%) showed radiographic adjacent arthritic changes after a mean follow-up of 51 months. Meanwhile, Cao et al[4] recently reported a 100% fusion rate in 16 patients undergoing arthrodesis with 4.0-mm headless cannulated screws.

Some authors have criticized isolated TNA for not addressing the incongruence of the naviculocuneiform joint.[5,9,27] TNCA has provided satisfactory results in several published studies.[5,9,44,45] Fernández et al[9] reported the use of a trapezoid tricortical iliac crest autograft inserted into a reciprocal bed in the 3 bones to achieve arthrodesis and desired medial arch height. Meanwhile, Cao et al[5] described

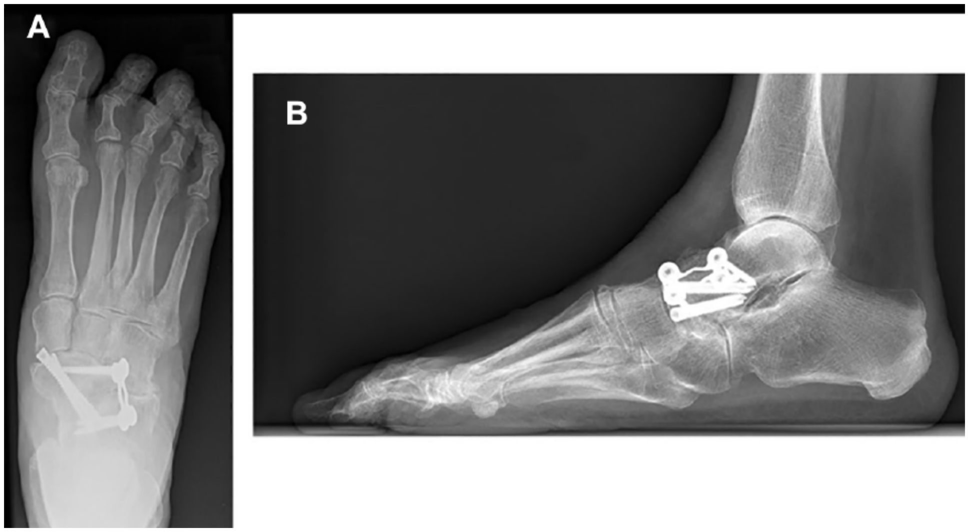

Figure 5. Postoperative plain radiograph (A) anteroposterior and (B) lateral showing isolated talonavicular fusion with tension band technique using compression plate. Reproduced by permission from Fornaciari et al.[10]

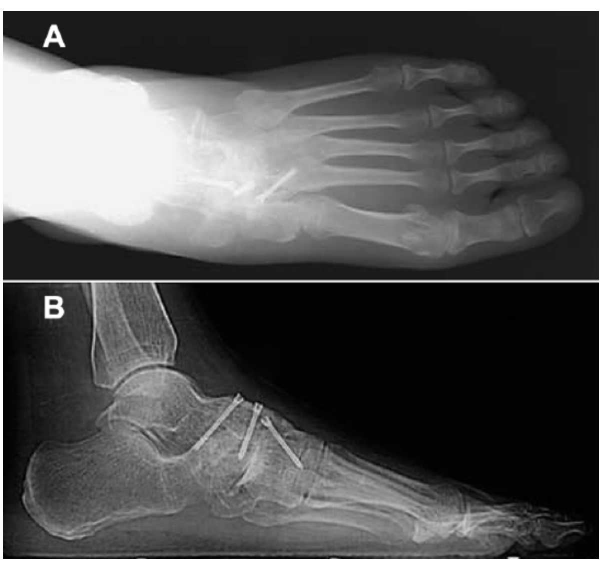

Figure 6. Postoperative (A) anteroposterior and (B) lateral weightbearing radiographs showing talonaviculocuneiform arthrodesis using 3 cannulated titanium screws for fixation and autogenous iliac bone graft with a reverse "V"-shaped osteotomy in the talonavicular joint to restore the height of the medial longitudinal arch. Reproduced by permission from Cao et al.[5]

the use of a reverse, V-shaped osteotomy in the talonavicular joint for restoring the height of medial longitudinal arch in addition to a dorsal tricortical iliac crest autograft inserted in a rectangular bed (Figure 6). Fusion was successful in all 9 cases with a mean postoperative AOFAS Ankle-Hindfoot score of 90.9 compared to 40.1 preoperatively. A similar complete rate of fusion was reported by Yu et al,[44] who treated 7 cases with TNCA by tricortical autologous iliac graft fixated by plate and screws with an AOFAS Ankle-Hindfoot score of 82 at last follow-up. Zhang et al[45] compared the outcomes of open triple arthrodesis (5 feet) and TNCA (6 feet) and achieved AOFAS scores of 79 and 86.2, respectively. Fusion was achieved in all cases. However, the mean follow-up duration was only 7.5 months. These authors highlighted the importance of preoperative radiological assessment of the involved joints to choose the appropriate method for different cases.

Triple arthrodesis is indicated for advanced stage of the disease with degenerative arthritic changes observed in the subtalar and/or calcaneocuboid joints (Figure 7).[7,45] Arthroscopic and open techniques have been described with satisfactory outcomes.[21,45] Lui[21] treated 6 feet by arthroscopic triple arthrodesis and achieved solid fusion in all cases and an average postoperative AOFAS score of 81.5. One patient had lateral foot pain upon walking due to varus deformity. Arthroscopic findings detected a significant incidence of calcaneocuboid degeneration that could not be detected by preoperative radiographs. Triple arthrodesis fails to address naviculocuneiform arthrosis–related symptoms. If the naviculocuneiform joint is involved, triple arthrodesis can be extended to include the naviculocuneiform arthrodesis.[7,45]

Some authors have attempted to provide a treatment algorithm based on Maceria staging. Lu et al[20] suggested simple excision or drilling decompression for early stage (1 or 2) MWD, isolated TNA for moderate stage (3 or 4) MWD, and triple arthrodesis, TNCA, or double fusion for

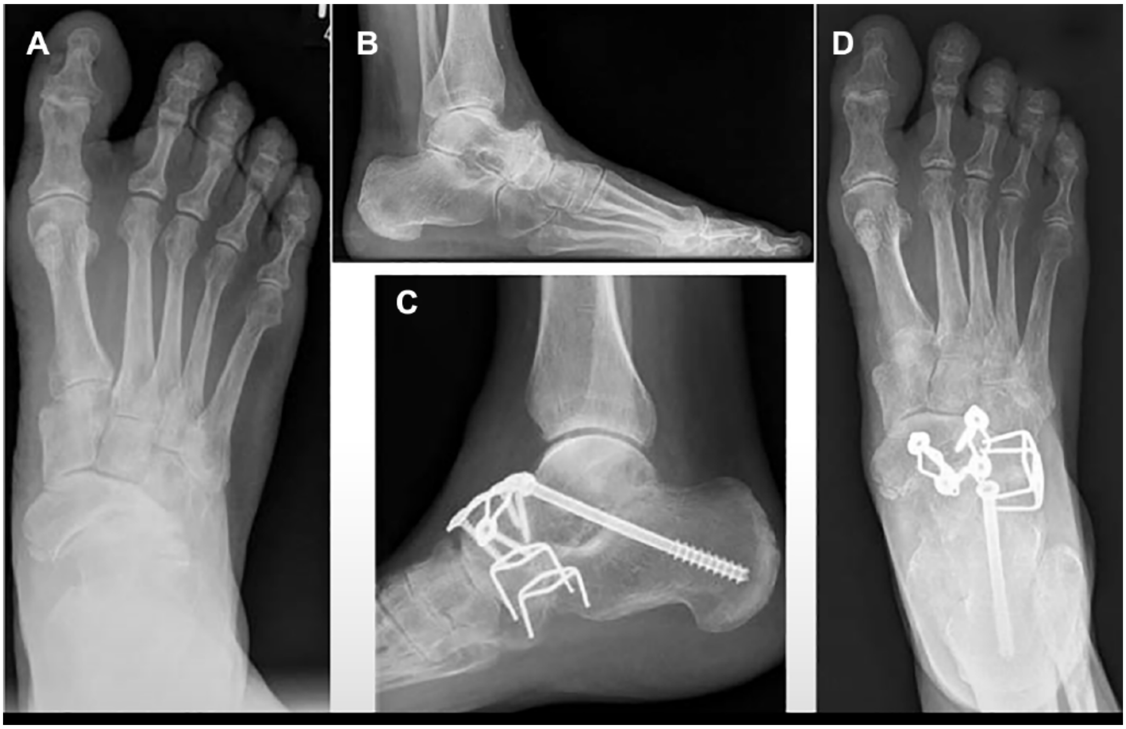

Figure 7. Preoperative (A) anteroposterior and (B) weightbearing lateral radiographs of Müller-Weiss disease. Postoperative radiographs (C, D) showing triple arthrodesis using plate, screws, and staples for fixation. Reproduced by permission from Doyle et al.[7]

more advanced MWD (stage 5). Mayich[26] recommended TNCA for stage 3 MWD and triple fusion for stage 4.

Calcaneal Osteotomy

The concept of joint arthrodesis focuses primarily on treating arthritis and restoring the medial arch of the foot.[19] However, pain in MWD may not only be caused by degeneration of the involved joints but also by impaired biomechanics due to medial arch collapse and varus hindfoot malalignment that lead to uneven load distribution on the foot.[13,19] Surgical correction of hindfoot malalignment may be considered when varus deformity is observed.[9,19] Recently, Li et al[19] treated 14 feet in 13 adult patients with an osteotomy combining lateral displacement and a lateral closing wedge to correct the hindfoot varus deformity. The disease was stage 2 in 5 feet (35.7%), stage 3 in 4 feet (28.6%), stage 4 in 4 feet (28.6%), and stage 5 in 1 foot (6.7%). After an average of 3.7 years follow-up, there was significant improvement in clinical and functional outcomes. The mean VAS score improved from 8 preoperatively to 2 postoperatively, and the mean AOFAS score improved from 29 preoperatively to 79 postoperatively. No patients required arthrodesis. The patients' subjective outcomes were rated as excellent in 4 feet, good in 8 feet, and fair in 2 feet. The authors reported that there was no progression of the arthritis or the stage of the disease during follow-up and that there was no correlation between the outcomes and the presence or the grade of arthritis. They concluded that lateral displacement calcaneal osteotomy is a satisfactory alternative treatment option even in advanced stages of the disease with severe arthritis. They assumed that there were changes in the forces around the perinavicular joints with lateral displacement calcaneal osteotomy, but they did not provide a biomechanical proof for this. Further studies are required to elucidate the role of calcaneal displacement osteotomy in the subset of MWD with varus heel either alone or as an adjunct procedure combined with joint fusion.

Most recently, Ahmed et al[1] treated 13 flatfeet in 7 adolescents with MWD without osteoarthritis by calcaneal lengthening osteotomy (Figure 8). They reported improvement in the radiographic parameters such as the talus-first metatarsal and the calcaneal pitch angles with improvement of the mean AOFAS Ankle-Hindfoot score from 61.9 preoperatively to 94.2 postoperatively. After an average follow-up of 37.8 months, none of their cases needed a secondary arthrodesis. Their rationale was that calcaneal lengthening would correct flatfoot while preserving the joint motion and would result in distraction, which might

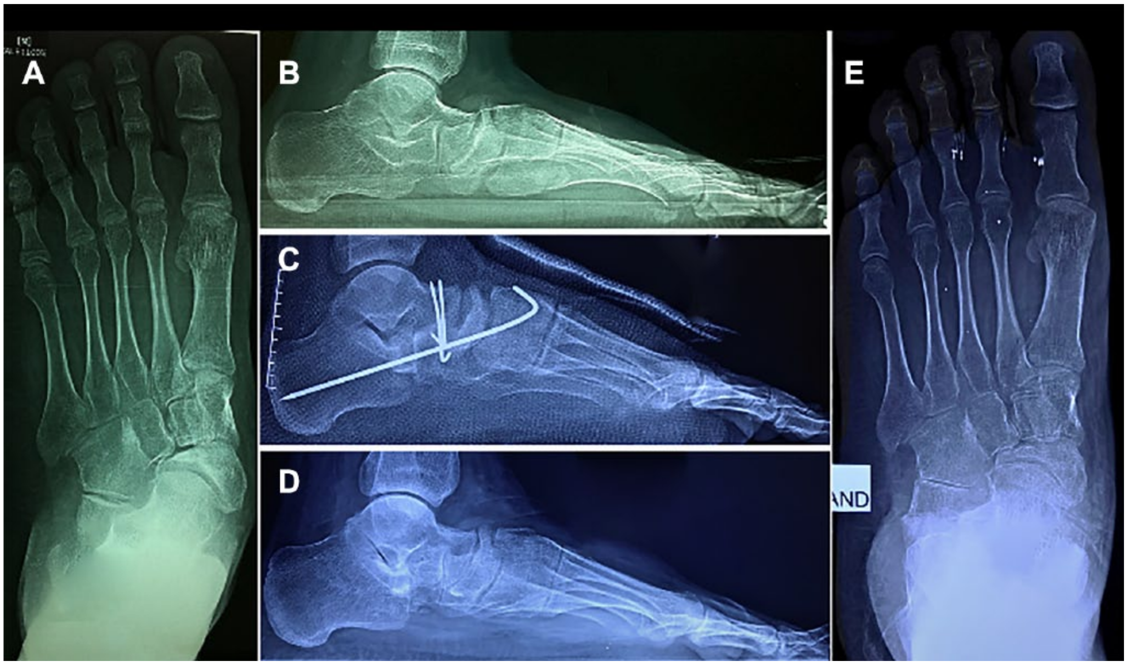

Figure 8. A case of Müller-Weiss disease. (A, B) Preoperative radiographs showing the comma-shaped navicular with forefoot abduction and arch collapse without osteoarthritis. (C) Immediate postoperative lateral radiograph after calcaneal lengthening osteotomy with fixation by K-wires. (D, E) Postoperative radiographs after 2 years showing restoration of the arch.

relieve pressure on the lateral navicular part. Moreover, this technique will not be an obstacle to future arthrodesis if arthritis developed.

Miscellaneous Procedures

Several case reports have described various joint-sparing treatment modalities such as percutaneous decompression,[16] removal of the necrotic bone and replacement with autologous iliac cancellous bone graft,[39] debridement and free medial femoral condyle vascularized bone grafting,[18] and navicular excision with reconstruction of the medial column using a remodeled femoral head allograft for interposition arthrodesis stabilized by a plate.[38]

Percutaneous decompression of the navicular bone is a minimally invasive surgical option in the treatment of early stage MWD. Janositz et al[16] presented 1 case report with a satisfactory result of this technique. Seven months postoperatively, MRI showed demarcation of the previously detected necrotic area of the navicular bone with absence of high-intensity areas, and at 8 years, MRI showed remodeling of the navicula. However, most patients with MWD presented with established arthritic changes and foot deformity, and at this stage, core decompression is less likely to be of benefit.[27,34]

Tan et al[38] reported navicular excision with reconstruction of the medial column using a remodeled femoral head allograft for interposition arthrodesis stabilized by a plate. Although this operative treatment results in lower donor site morbidity, inflammatory reactions and osteolysis may occur.

Tosun et al[39] used autologous iliac bone grafting packed inside the navicular cortical shell in treatment of early stages of MWD and reported full recovery for 3 years postoperatively. Levinson et al[18] reported a satisfactory functional outcome of use of the free medial femoral condyle vascular bone graft in treatment of MWD in a single case report. At 18-month follow-up, the patient had an excellent outcome and returned to his previous recreational and work-related activities. The medial femoral condyle vascularized bone graft has several theoretical advantages, including rapid bone healing with a direct vascular supply, ease of harvest with minimal donor site morbidity, and higher mechanical stability allowing early weightbearing.[15,18]

Although internal fixation of the navicular bone has been described as a treatment option for MWD, there is no single case series presenting the rationale, technique, or outcomes. It is not a feasible option in advanced stages of the disease due to loss of the lateral navicular bone stock.[27] The results of internal fixation in the cases reported in a review by Fernández et al[9] were poor, and the authors considered any arthritis to be a contraindication for the procedure.

Conclusion

MWD remains a complex foot disorder with a spectrum of clinical and radiographic presentations. Consequently, there is no standard treatment protocol. A thorough assessment of the navicular fragmentation, available bone stock, and degree of arthritis present in adjacent joints is critical to determining optimal treatment. To this end, treatment should be individualized for each case whether considering nonoperative measures, joint-sparing procedures, or arthrodesis.

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