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Special Article

Hallux rigidus

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Abstract

Hallux rigidus is a common disorder with a multifactorial etiology and is highly disabling in many cases. Factors associated with the condition include trauma, particularly in cases of unilateral involvement; metatarsophalangeal joint shape; and shortening of the soft-tissue structures of the posterior chain. Some studies have also associated excessive length and elevation of the first metatarsal with the disorder. Conservative treatment may provide temporary symptom relief, especially in the early stages, but cannot eliminate or reduce established degenerative changes. Surgical treatment depends on the patient's characteristics and expectations, as well as the clinical and radiographic stage of the disorder. Joint-preserving procedures, such as metatarsal and proximal phalanx osteotomies, are the preferred approach for less severe grades of the disorder, whereas interposition arthroplasty and arthrodesis are indicated for more advanced disease. When technical indications are followed, most cases expect good to excellent results.

Level of Evidence V; Narrative Revision.

Keywords: Hallux rigidus; Arthritis; Hallux; Hallux limitus; Bunion.

Introduction

Hallux rigidus is the second most common disorder affecting the first ray. Although less prevalent than hallux valgus, it is generally more disabling. It is the most common form of osteoarthritis in the foot and ankle, affecting approximately 2.5% of individuals older than 50 years and occurring twice as frequently in women[1-3].

Anatomy

The first metatarsophalangeal (MTP) joint represents a complex synovial articulation formed by the first metatarsal head and the base of the proximal phalanx, with the medial and lateral sesamoids constituting an integral component of its plantar functional unit. This highly specialized articulation withstands substantial loads while providing the mobility required for efficient propulsion during gait. The head of the first metatarsal is convex and asymmetric, being wider on its plantar than its dorsal aspect. Its plantar surface contains a longitudinal central ridge that separates the sesamoid grooves, which articulate with the medial and lateral sesamoid bones. The concave geometry of the proximal phalangeal base conforms to the convex metatarsal head, allowing articular motion while maintaining congruence. Plantarly, the paired sesamoids are incorporated within the flexor hallucis brevis tendon and articulate with the grooves along the inferior aspect of the metatarsal head. The sesamoid complex contributes to the distribution of plantar forces across the first ray and enhances the mechanical efficiency of the flexor mechanism. Its articulation with the plantar ridge contributes to joint stability and resistance to coronal plane deformity. The joint capsule is relatively lax dorsally and thicker on the plantar aspect, where it merges with the plantar plate. The collateral, metatarsosesamoid, intersesamoid, and phalangeosesamoid ligaments provide stability and maintain joint alignment during gait and other weight-bearing activities. Dynamic control of the first MTP joint is provided primarily by the flexor hallucis longus and brevis and the extensor hallucis longus and brevis. The flexor hallucis brevis divides into medial and lateral components

Study performed at the Moinhos de Vento Hospital, Porto Alegre, RS, Brazil.

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associated with the respective sesamoids. Together, these structures provide active hallux motion and play a critical role in propulsion during gait[1-4].

Pathologic anatomy

Hallux rigidus appears to arise from the interaction of multiple predisposing factors rather than from a single identifiable cause, including anatomic configuration, traumatic events, and hereditary predisposition, which may collectively influence disease onset and progression. A positive family history has been reported in approximately two-thirds of patients, whereas bilateral involvement is present in up to 79% of cases[1-3]. Coughlin and Shurnas[4] observed that hallux rigidus was unilateral in 78% of patients with a history of trauma.

Structural factors associated with hallux rigidus include the morphology of the first metatarsal head, contracture of the gastrocsoleus complex, metatarsus primus elevatus, an excessively long first metatarsal, and metatarsus adductus[4]. A flat or triangular first metatarsal head increases resistance to coronal plane deformity, particularly hallux valgus, but also concentrates axial loads, thereby predisposing the joint to first MTP osteoarthritis[1-4].

Contracture of the gastrocsoleus complex reduces sagittal plane mobility and increases dorsal loading across the first MTP joint, thereby promoting progressive cartilage degeneration. Hallux limitus, also referred to as functional hallux rigidus, represents an early stage of the disorder in which restricted dorsiflexion results primarily from increased tension in the plantar soft tissues, particularly the gastrocsoleus complex and the plantar fascia. On clinical examination, the limitation in dorsiflexion is characteristically more pronounced with the ankle in dorsiflexion and improves substantially with ankle plantarflexion, reflecting relaxation of the plantar soft tissues[5-8].

The association between metatarsus primus elevatus and hallux rigidus remains controversial, as several studies have failed to confirm this relationship[9-12]. One major limitation is the lack of a standardized method for assessing first metatarsal elevation across studies. Some investigators have measured its height relative to the ground, others relative to the second metatarsal, and still others relative to the proximal phalanx of the hallux. This methodological heterogeneity complicates comparisons among studies and limits interpretation of the available evidence[9]. Whether metatarsus primus elevatus represents a primary deformity predisposing to hallux rigidus or a secondary consequence of the disease also remains debated[9-12]. Fukushima et al.[11] compared first-ray elevation using weight-bearing computed tomography in 18 patients (21 feet) with early-stage hallux rigidus and 10 healthy volunteers (19 feet). Sagittal images demonstrated narrowing of the dorsal joint space and a more plantar location of the center of rotation in patients with hallux rigidus than in controls. These differences became progressively more pronounced with advancing disease severity. Based on these findings, the authors proposed that failure of the windlass mechanism occurs early in the disease process, resulting in progressive elevation of the first metatarsal[11]. Additional evidence suggests that metatarsus primus elevatus may improve following surgical treatment, even in the absence of a plantarflexion osteotomy of the first metatarsal. In a study of 27 patients who underwent implant-free interpositional arthroplasty, Sanchez et al.[13] found that first metatarsal elevation was more common in advanced stages of hallux rigidus and concluded that it was more likely a consequence than a cause of the disorder. Similarly, Horton et al.[10] compared lateral radiographs from 81 patients with hallux rigidus, 50 asymptomatic volunteers, and 64 patients with isolated Morton's neuroma. Mean first-ray elevation was virtually identical in patients with mild or moderate hallux rigidus and in asymptomatic controls, whereas patients with advanced radiographic disease exhibited only a modest increase in metatarsus primus elevatus.

Although Coughlin and Shurnas[14] found no difference in first metatarsal length between patients with hallux rigidus and the general population, Calvo et al.[15] reported contrasting findings in a case-control study involving 132 feet treated surgically for hallux rigidus (72 patients) and 132 control feet (66 healthy volunteers). They observed that the first metatarsal was significantly longer in patients with hallux rigidus than in controls.

Pathophysiology

Adequate first MTP joint mobility is essential for normal propulsion and requires nearly 60º of hallux dorsiflexion during gait. Mechanical demand on the joint increases markedly during push-off, when forces transmitted through this region can reach approximately 1.2 times body weight. Consequently, pain and loss of hallux motion from osteoarthritis alter both gait cadence and the biomechanics of walking and running[7].

Hallux rigidus is a progressive arthritic condition involving the first MTP joint characterized clinically by progressive pain and loss of range of motion. Unlike osteoarthritis affecting most other joints, restriction of motion typically precedes cartilage degeneration, underscoring the predominant biomechanical component of this condition[8]. Joint motion is closely coordinated with the windlass mechanism, in which hallux dorsiflexion tensions the plantar fascia and elevates the medial longitudinal arch, thereby increasing structural rigidity and creating a stable platform for push-off. Under physiological conditions, hallux dorsiflexion depends on coordinated rolling and gliding of the proximal phalanx over the first metatarsal head, allowing efficient load distribution during gait[1-8].

Functional hallux rigidus

Functional hallux rigidus refers to a dynamic limitation of the first MTP joint, with preserved mobility during unloaded examination but reduced dorsiflexion once weight is transferred through the first ray or the ankle moves into dorsiflexion (Figure 1). Mechanically, functional hallux rigidus is characterized by a predominance of rolling rather than the normal gliding contact between the articular surfaces.

The windlass mechanism is essential for maintaining the medial longitudinal arch and depends on the coordinated function of an osseous arch that resists compressive forces together with supporting soft tissues that resist tensile forces. Among these structures, the plantar fascia plays the dominant role because of its favorable mechanical lever arm. Elevation of the first metatarsal head and increased tension within the plantar fascia may alter first MTP joint kinematics, resulting in rolling rather than the physiological gliding motion of the articular surfaces.

Restricted dorsiflexion of either the ankle or the first MTP joint limits normal anterior progression of the tibia during the stance phase of gait. This impairment is compensated for by abnormal movements in other planes and adjacent body segments[6-8]. Contracture of the posterior chain, particularly the gastrocsoleus complex and plantar fascia, further disrupts this biomechanical sequence by impairing the synchronized motion between the proximal phalanx and the first metatarsal. Progressive loss of dorsiflexion results in abnormal concentration of compressive forces across the dorsal aspect of the first MTP joint. This process initiates cartilage degeneration, osteochondral irregularities, and progressive joint incongruity, ultimately leading to marginal osteophyte formation, one of the earliest radiographic manifestations of hallux rigidus. These osteophytes contribute substantially to pain and mechanical impingement during dorsiflexion.

Clinically, reduced first MTP joint mobility compromises the propulsive phase of gait, resulting in compensatory mechanisms such as decreased loading of the first ray and transfer of weight-bearing forces to the lateral border of the foot. In advanced stages, the disease progresses to marked stiffness, extensive cartilage loss, prominent osteophyte formation, and persistent pain, reflecting progressive biomechanical and functional failure of the first MTP joint[1-8].

Clinical examination

An antalgic gait and limping are common, particularly in advanced disease. During standing examination, the alignment of the hallux and the foot should be assessed, along with dorsal osteophyte formation (dorsal bunion).

Passive mobility of the first MTP joint should be examined with the patient sitting or lying supine, while varying the ankle between neutral alignment and plantarflexion. In an unaffected joint, approximately 75º-90º of dorsiflexion and 20º-30º of plantarflexion can typically be achieved without pain. Changes in hallux mobility associated with ankle dorsiflexion should be carefully assessed, and the Silfverskiöld test should be performed to evaluate gastrocnemius tightness.

During passive range-of-motion testing, the presence and distribution of pain provide important information regarding disease severity. Pain occurring throughout the arc of motion, rather than only at the extremes of dorsiflexion or plantarflexion, is generally indicative of more advanced disease.

Palpation of the dorsal joint line is typically painful and is frequently associated with palpable dorsal osteophytes, depending on disease stage. Osteophyte formation is characteristic of advanced disease and usually begins at the

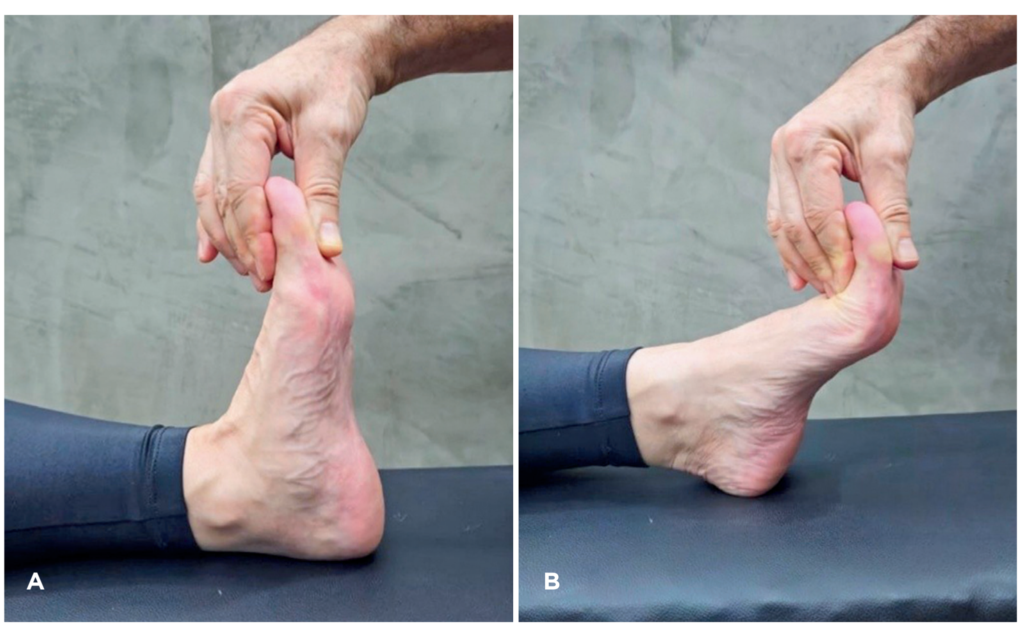

Figure 1. Lateral view of a foot with functional hallux rigidus. Note the restriction of hallux dorsiflexion with the ankle positioned at 90° (A) and the improvement in hallux dorsiflexion with the ankle in plantarflexion (B).

dorsolateral aspect of the joint, where it further contributes to restriction of joint motion.

Imaging evaluation

Initial imaging should consist of standing foot radiographs obtained in anteroposterior, lateral, oblique and axial sesamoid views. The anteroposterior view is the most appropriate for assessing the metatarsal formula and identifying medial and lateral osteophytes at the level of the first metatarsal head. Joint space width is best evaluated on the anteroposterior and oblique views. The lateral view demonstrates the degree of first metatarsal elevation and the presence of dorsal osteophytes involving the metatarsal head, the proximal phalanx, and the sesamoid complex. The sesamoid axial view is useful for assessing sesamoid involvement, which is common in advanced stages of the disease. Subchondral sclerosis and subchondral cysts involving the first metatarsal head and the base of the proximal phalanx are also common findings and are typically associated with advanced disease.

Computed tomography and magnetic resonance imaging may occasionally provide additional information; however, in most cases, they are unnecessary for therapeutic decision-making.

Classification

Pain severity, range of motion, and radiographic findings are all essential components in assessing the severity of hallux rigidus. Accordingly, the Coughlin and Shurnas[14] classification, the only system that incorporates all three parameters, is currently the most widely used. It comprises five stages, ranging from a periarthritis condition to advanced degenerative disease.

Grade 0 represents the earliest stage, with first MTP dorsiflexion remaining between 40º and 60º and showing no more than a 10%-20% reduction relative to the unaffected opposite foot when unilateral disease is present. Standard radiographs reveal preserved joint morphology, without measurable loss of articular space or osteophytes. Patients are asymptomatic, and the only clinical finding is mild restriction of joint motion detected on physical examination.

Grade 1 reflects early structural involvement and is characterized by 30°-40° of dorsiflexion, representing a 20%-50% decrease in physiological motion. The principal radiographic finding is a small dorsal osteophyte, while the articular space remains largely preserved despite subtle narrowing. Minor periarticular sclerosis and early loss of the normal contour of the first metatarsal head may also be present. Symptoms are usually mild and episodic, with slight restriction of motion and discomfort predominantly when the joint approaches the limits of dorsiflexion or plantarflexion.

Grade 2 reflects a substantial decline in first MTP mobility, with dorsiflexion restricted to 10°-30°, corresponding to a 50%-75% decrease in joint motion. Radiographs demonstrate osteophyte formation predominantly along the dorsal and lateral margins, with medial involvement occurring less consistently. Joint space narrowing is mild to moderate and is accompanied by subchondral sclerosis, whereas the sesamoids are generally preserved. Pain becomes moderate to severe and is often constant, occurring immediately before the extremes of dorsiflexion and plantarflexion.

Grade 3 denotes advanced functional impairment; it is characterized by dorsiflexion of 10° or less, accompanied by a 75%-100% decrease in joint motion. Plantarflexion is also substantially compromised and commonly remains below 10º. Imaging demonstrates pronounced degenerative changes, including substantial loss of articular space and periarticular cyst formation. On lateral radiographs, more than one-quarter of the dorsal joint surface may be affected. Degenerative involvement may also extend to the sesamoid complex which may manifest as enlargement, irregularity, or cystic degeneration. Patients experience severe pain at the extremes of joint motion.

Grade 4 demonstrates radiographic findings similar to those observed in Grade 3; however, patients experience pain throughout the entire arc of passive joint motion rather than only at the extremes of movement.

Despite its comprehensive nature, the Coughlin and Shurnas[14] classification has important limitations. Most notably, it does not account for clinicoradiographic discordance, as radiographic severity does not always correlate with symptom severity or degree of functional impairment. Nixon et al.[16] retrospectively reviewed weight-bearing foot radiographs and Foot and Ankle Ability Measure (FAAM) Activities of Daily Living subscale (FAAM-ADL) scores from 84 patients with hallux rigidus and found no association between radiographic severity and FAAM-ADL scores. Furthermore, progression of radiographic changes was not accompanied by worsening patient-reported symptoms as measured by the FAAM-ADL[16].

Conservative treatment

Early management, especially during the initial stages of the disease, typically consists of footwear modifications to accommodate dorsal osteophytes and reduce mechanical irritation, together with the prescription of orthotic devices to limit dorsiflexion and decrease mechanical loading across the first MTP joint. Rocker-soled footwear is an effective approach to limiting hallux motion during the toe-off phase of gait. Conservative treatment of hallux rigidus should be viewed primarily as a strategy for symptom control and biomechanical optimization rather than as an intervention intended to alter the natural history of the disease, as there is no consensus that nonoperative management can halt its clinical progression[17-20].

The available literature suggests that patients with early-stage disease, relatively preserved joint space, and pain predominantly occurring at the end of the dorsiflexion arc are more likely to respond favorably to conservative treatment, whereas those with more advanced disease and greater structural joint involvement generally achieve less satisfactory outcomes[18-22]. The rationale for conservative treatment is to reduce dorsiflexion of the first MTP joint, minimize dorsal impingement between the proximal phalanx and the first metatarsal head, and decrease mechanical irritation caused by dorsal osteophytes against footwear[18-22].

Nevertheless, the evidence supporting conservative treatment remains limited. A systematic review by Kon Kam King et al.[18] found no Grade A recommendation for any conservative intervention. Footwear modification, orthotic devices, and physical therapy were supported only by Grade C evidence, whereas Grade B evidence discouraged routine intra-articular injections[18]. Likewise, a systematic review by Munteanu et al.[17], including 547 participants, concluded that the benefits of nonoperative treatment remain uncertain. Although some studies have reported favorable outcomes, larger randomized clinical trials (RCTs) are needed to strengthen the level of evidence and better define indications for conservative versus surgical management[17].

General recommendations for conservative management include activity modification, appropriate footwear, weight reduction when indicated, analgesics, and nonsteroidal anti-inflammatory drugs tailored to the patient's clinical profile. Repetitive or forceful dorsiflexion of the first MTP joint may exacerbate symptoms, whereas weight loss reduces forefoot loading during gait and may decrease both mechanical demand and local pain[19-23]. Pharmacological therapy should be regarded as an adjunct to the other conservative measures, as robust evidence supporting medication alone for the treatment of hallux rigidus is lacking[18-21].

Appropriate footwear is intended to minimize painful dorsiflexion of the first MTP joint, minimize dorsal impingement, decrease irritation of dorsal osteophytes, and redistribute plantar loading. Shoes with rigid soles and a high, wide toe box are generally preferred. Regarding sole design, rocker-soled shoes facilitate rollover from the hindfoot to the forefoot without requiring full dorsiflexion of the first MTP joint, whereas rigid-soled shoes act as a splint by limiting forefoot flexion, achieving a similar biomechanical objective[19,20,22].

Orthotic treatment (e.g., rigid plates, Morton's extension, first-ray support orthoses, polypropylene devices, and custom-made orthoses) has yielded heterogeneous clinical outcomes. Retrospective studies and case series suggest symptomatic improvement in some patients, although controlled trials have substantially weakened this evidence[17-19,23,24]. Grady et al.[23] reported successful conservative treatment in 55% of 772 patients, most of whom (84%) were managed with orthotic devices. Similarly, Smith et al.[24] found that 75% of patients elected to continue nonoperative treatment despite radiographic progression in some cases, with the principal reason being that pain was not sufficiently severe to warrant surgery. In contrast, a multicenter trial of 88 participants comparing contoured foot orthoses with sham insoles found no significant differences in function or quality of life at 12 weeks. Likewise, an RCT including 100 participants comparing rigid shoe inserts with sham devices found no differences in pain, function, or quality of life after 12 weeks. Collectively, these findings suggest that the effectiveness of orthotic treatment depends more on appropriate patient selection, comfort, footwear characteristics, and individual biomechanical factors than on a universally reproducible therapeutic effect[17,19,20].

Physical therapy may serve as an adjunctive treatment for patients with early-stage disease, functional hallux rigidus, gait abnormalities, mechanical overload, posterior chain tightness, or first-ray dysfunction. Common interventions include mobilizing the first MTP joint and sesamoids, strengthening the flexor hallucis longus, gait retraining, stretching the gastrocnemius, soleus, and hamstring muscles, analgesic modalities, and patient education[18,25]. Shamus et al.[25] evaluated a rehabilitation protocol incorporating these interventions and reported short-term improvements in pain, muscle strength, and range of motion. However, because the study population consisted of young individuals without advanced disease, these findings cannot be readily extrapolated to patients with more severe hallux rigidus[25].

Intra-articular injections may provide temporary pain relief, particularly in patients with early or moderate-stage disease, clinically evident synovitis, acute symptom exacerbation, or a desire to postpone surgery. Corticosteroids and hyaluronic acid are the most commonly used injectable agents[17,18,26-31]. Solan et al.[26] investigated manipulation under anesthesia combined with intra-articular injection of a local anesthetic and corticosteroid and reported favorable outcomes, particularly in the early stages of the disease. In contrast, Munteanu et al.[27] found no clinically meaningful superiority of hyaluronic acid over saline in an RCT involving 151 patients. Similarly, Pons et al.[28] compared sodium hyaluronate with triamcinolone in an RCT and observed clinical improvement in both groups, but also a high rate of progression to surgical treatment within one year. More recently, the prospective, multicenter, uncontrolled REPAR study, published in 2022, evaluated image-guided injection of mannitol-modified cross-linked hyaluronic acid in 65 patients and showed a significant reduction in pain during walking at three months, with greater benefit in patients with mild to moderate radiographic disease[30,31]. However, robust evidence supporting sustained long-term benefit remains lacking. Collectively, these findings suggest that intra-articular injections may provide short-term symptomatic relief in selected patients, although larger, high-quality clinical trials are required before this intervention can be considered an established treatment for hallux rigidus.

Overall, nonoperative treatment should be offered to appropriately selected patients, particularly those with mild to moderate disease, because it is safe, minimally invasive, and may provide at least temporary symptom relief[17-22]. A multimodal approach incorporating patient education, activity modification, analgesics and nonsteroidal anti-inflammatory drugs, rigid- or rocker-soled footwear, rigid orthoses or a Morton's extension, physical therapy, and selective intra-articular injections appears to be the most rational conservative strategy. In advanced stages, however, treatment response is generally limited, and conservative management should be regarded primarily as a temporizing measure before definitive surgical intervention[14,21,22,26].

Surgical treatment

Surgical treatment is indicated for patients who continue to experience pain and functional limitation despite at least six months of appropriate conservative management. Once surgery has been selected, the choice of procedure depends on multiple factors, including symptom severity, patient age, occupational and athletic demands, foot morphology, severity of the deformity, degree of joint mobility, and imaging findings, such as the metatarsal formula, extent of cartilage degeneration, presence of osteophytes, and subchondral cysts. The Coughlin and Shurnas[14] classification incorporates symptoms, range of motion, and radiographic findings into a five-grade staging system and is useful for surgical decision-making. However, discrepancies among these components are common; for example, a patient may present with Grade 1 symptoms, Grade 2 radiographic changes, and Grade 3 limitation of motion. Nevertheless, it remains the most comprehensive and widely adopted classification for guiding surgical treatment[16].

Patients with less severe disease (Grades 1 and 2) are candidates for joint-preserving procedures, including cheilectomy and decompression osteotomies, such as metatarsal shortening osteotomies and the Moberg osteotomy.

Coughlin and Shurnas[14] reported long-term outcomes of cheilectomy in 93 feet (80 patients), with a mean follow-up of 9.6 years. Significant improvements were observed in dorsiflexion, pain, and American Orthopaedic Foot & Ankle Society (AOFAS) scores, and clinical outcomes were not associated with radiographic findings at follow-up. Pain relief and functional improvement were achieved in 68 feet (92%), and the authors concluded that cheilectomy provides the most predictable results in Grades 1 and 2 disease and in selected Grade 3 cases with more than 50% preservation of the articular cartilage.

In 2015, Nicolosi et al.[32] published a retrospective study evaluating the long-term outcomes of cheilectomy in 58 patients with hallux rigidus (mean age, 55 years) followed for more than seven years. The overall success rate was 87.9%, with 51 patients (87.9%) reporting no limitations in ADL, and only two patients (3.3%) requiring conversion to first MTP arthrodesis during follow-up.

Sidon et al.[33] subsequently reported a retrospective questionnaire-based study evaluating the long-term outcomes of cheilectomy in 165 patients (169 feet), with a mean follow-up of 6.6 years (range, 5-11 years). The questionnaire assessed post-surgery pain recurrence, current functional status, and patient satisfaction. Overall survivorship, defined as absence of pain at the latest follow-up, was 70.4% (119 feet), with no significant differences among preoperative radiographic grades. Most recurrences (75%) occurred within the first two postoperative years. Overall, 69.3% of patients reported being satisfied or very satisfied with the procedure, and 75.1% stated that they would undergo the operation again under similar circumstances[33].

O'Malley et al.[34] demonstrated that combining the Moberg osteotomy with cheilectomy yields favorable clinical outcomes. The Moberg osteotomy shifts the center of contact plantarly on the proximal phalanx without altering either peak contact pressure or the overall contact area of the joint[35]. Additional studies with shorter follow-up have also demonstrated favorable outcomes with minimally invasive cheilectomy[36,37].

Montagna et al.[38] compared open cheilectomy combined with a Moberg osteotomy with the equivalent minimally invasive procedure and found no differences in functional outcomes. However, the open approach was associated with a higher rate of wound-related complications and greater postoperative opioid consumption.

A systematic review published in 2024 including 296 patients who underwent percutaneous cheilectomy with or without adjunctive arthroscopic shaver-assisted debridement showed an improvement in mean dorsiflexion from 32.4° preoperatively to 61.2° postoperatively, and all included studies reported improvements in clinical outcomes. The pooled complication rate was 6.1% (18 of 296 patients), with injury to the dorsomedial cutaneous nerve as the most common complication (2.0%)[39].

Another systematic review published in 2024 included 348 patients (370 feet) treated with percutaneous cheilectomy and a weighted mean follow-up of 37.9 months. The weighted mean AOFAS score improved from 68.9 preoperatively to 87.1 postoperatively. The overall complication rate was 8.4%, with persistent joint pain and stiffness representing the most common adverse events. Residual intra-articular bone fragments were identified in 100% of patients in one of the included studies. Overall, 32 failures (8.7%) and 33 secondary procedures (8.9%) were reported, with a weighted mean interval of 8.6 months between the index procedure and reoperation[40]. An important advantage of cheilectomy is that, if the procedure fails, first MTP arthrodesis remains a reliable salvage option, with outcomes comparable to those achieved in patients undergoing primary arthrodesis without previous surgery[41].

Another joint-preserving option for patients with early-stage hallux rigidus (Grades 1 and 2) is decompression metatarsal osteotomy. The rationale for these procedures is to achieve longitudinal decompression of the first MTP joint by shortening the first metatarsal while simultaneously translating the metatarsal head plantarly, thereby reducing tension in the surrounding soft tissues (including the plantar fascia, long flexor and extensor tendons, and joint capsule) and facilitating MTP dorsiflexion (Figures 2 and 3). These osteotomies were originally designed to correct either a relatively long first metatarsal (index plus or plus-minus) or metatarsus primus elevatus, based on the assumption that these anatomical characteristics increase loading across the

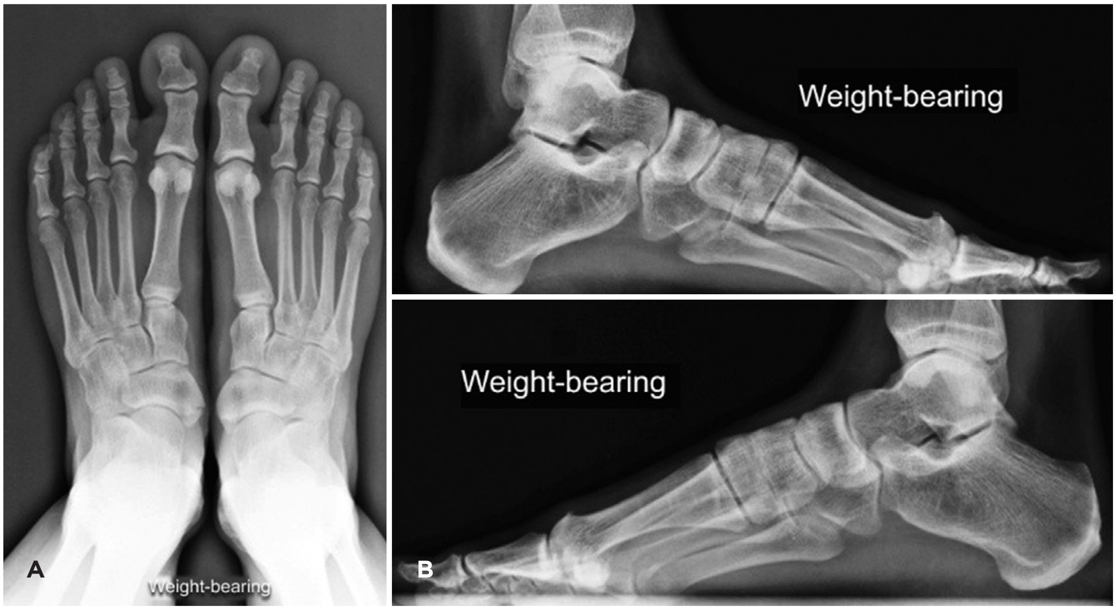

Figure 2. (A) Weight-bearing anteroposterior radiograph of both feet in a patient with Grade 2 hallux rigidus. (B) Weight-bearing lateral radiographs of the right and left feet, respectively.
Please note the relatively long first metatarsal (index plus) and the prominent dorsal osteophytes in both feet.

Figure 3. Postoperative radiographs following bilateral Youngswick osteotomy. (A) Weight-bearing anteroposterior view demonstrating shortening of the first metatarsal. (B) Weight-bearing lateral view demonstrating plantar displacement (depression) of the first metatarsal head achieved with the procedure.

first MTP joint. Although the role of these deformities in the pathogenesis of hallux rigidus remains controversial, the biomechanical rationale for these procedures is compelling.

The Youngswick-Austin osteotomy was developed to plantarflex a mildly elevated first metatarsal head and/or shorten a relatively long first metatarsal. Cöster et al.[42]

compared the outcomes of 115 patients treated with a Youngswick decompression osteotomy and 181 patients treated with cheilectomy for moderate hallux rigidus. After one year, the mean improvement in Self-Reported Foot and Ankle Score was 12 points in the osteotomy group and 10 points in the cheilectomy group. Patients treated with osteotomy also reported greater satisfaction than those undergoing cheilectomy (84% vs. 70%)[42].

Slullitel et al.[43] retrospectively evaluated 61 patients with Grade 1 or 2 hallux rigidus who underwent a Youngswick osteotomy, with a mean follow-up of 54 months. Functional improvement, as measured by the Foot and Ankle Outcome Score (FAOS), was observed in all patients. Although radiographic progression occurred in 49% of cases, none required conversion to arthrodesis[43].

The modified Youngswick osteotomy is another effective joint-preserving procedure for physically active adults with moderate hallux rigidus, providing excellent pain relief, functional improvement, increased range of motion, and high rates of return to sports. Ceccarini et al.[44] retrospectively evaluated 52 physically active patients younger than 60 years with Grade 2 hallux rigidus who underwent a modified Youngswick osteotomy and were followed for at least 24 months. A total of 49 patients (94.2%) returned to sports participation. Significant improvements were observed in pain (Visual Analog Scale [VAS]), functional outcomes (European Foot and Ankle Society General and Sports-Specific scores), and first MTP dorsiflexion, which increased from a mean of 24.5° preoperatively to 52.5° postoperatively after a mean follow-up of 79 months. Two patients developed transfer metatarsalgia, and one required reoperation because of implant intolerance[44].

Viladot et al.[45] compared the Youngswick osteotomy with a distal oblique osteotomy (first-ray Weil osteotomy) for the treatment of moderate hallux rigidus. A total of 46 patients (50 feet) were included with a mean follow-up of 42 months. Both techniques produced significant improvements in range of motion and AOFAS scores, with no evidence that either procedure was superior[45].

Gerbert et al.[46] demonstrated, through a mathematical model, that the angle of the plantar limb of the osteotomy relative to the plantar surface determines the degree of plantar translation of the metatarsal head. In practical terms, a more horizontal plantar limb produces greater shortening of a relatively long first metatarsal, whereas a more vertical plantar limb results in greater plantar displacement of the metatarsal head, making it more suitable for correcting metatarsus primus elevatus[46].

Minimally invasive decompression osteotomy of the first ray has also been described for the treatment of early-stage hallux rigidus. However, cadaveric studies have highlighted the proximity of the burr portals to the extensor tendons and the dorsomedial cutaneous nerve of the hallux, emphasizing the potential risk of iatrogenic injury associated with this technique[47].

More advanced stages of hallux rigidus (Grades 3 and 4) are generally treated with non-joint-preserving procedures, including arthrodesis and arthroplasty. When successful, first MTP arthrodesis eliminates the arthritic joint, improves hallux weight-bearing by functionally "lengthening" the first ray, and, as an added benefit, alleviates concomitant transfer metatarsalgia when present. Although the procedure carries a risk of complications, particularly nonunion and malunion, anatomically contoured implants and strict adherence to surgical principles have substantially reduced these risks[48-50].

One limitation of arthrodesis is the permanent loss of first MTP joint motion, which may affect return to certain athletic activities and the ability to wear high-heeled shoes. A recent systematic review of 153 patients (mean age, 58.6 years; mean follow-up, 18.9 months) demonstrated that return to sports following first MTP arthrodesis is highly variable and depends largely on both the patient and the specific sport. High rates of return to athletic activity were reported across several sports, with most patients describing postoperative athletic performance as equivalent to or better than their preoperative level. Approximately 10%-28% of patients reported improved athletic performance after surgery, 67.2%-87.5% reported no change, and only 1.8%-8.5% experienced greater difficulty participating in sports following hallux arthrodesis[51].

Maor et al.[52] evaluated return to sports after first MTP arthrodesis in 16 elite athletes with a mean age of 27 years (range, 19-32 years) and a mean follow-up of 81 months (range, 60-121 months). A total of 12 athletes (75%) returned to their pre-injury level of competition within one year of surgery. Among the four athletes who did not, two soccer players were relegated to lower divisions, one Association of Tennis Professionals tennis player never regained his previous ranking, and one badminton player could not return to his pre-injury competitive level. Mean VAS pain scores improved significantly from 5.6 preoperatively to 0.4 at final follow-up ($p < 0.001$). Likewise, all FAOS subscales improved significantly, and every athlete reported being either satisfied or very satisfied with the surgical outcome. These findings indicate that most elite athletes can successfully return to high-level competition following first MTP arthrodesis and that even those who fail to regain their previous competitive level experience substantial improvements in pain and functional outcomes[52].

Among female patients, another common concern is the ability to wear high-heeled shoes after arthrodesis. A retrospective study evaluated 50 women who underwent isolated first MTP arthrodesis using a structured telephone interview that assessed the ability to wear high-heeled shoes before and after surgery, including heel height and duration of wear. The study included 50 patients (62 feet) with a mean age of 63 years (range, 43-78 years) at surgery and a mean follow-up of eight years (range, 5-16 years). Of the 42 patients who wore high heels preoperatively, 26 (62%) continued to do so after surgery, and 88% of these were able to wear heels of the same height as before the procedure. Overall, the results suggest that many women can continue wearing high-heeled footwear after hallux arthrodesis with minimal or no symptoms in adjacent joints[53].

Scheurer et al.[54] evaluated 61 first MTP arthrodeses and compared outcomes among 28 patients younger than 50 years and 33 patients older than 60 years. After a mean follow-up of 14 years, no significant differences in functional outcomes were observed between the two groups. Pain relief, however, was more pronounced in younger patients, demonstrating that first MTP arthrodesis is an excellent treatment option across age groups[54].

From a technical standpoint, fixation with a dorsal plate combined with an interfragmentary compression screw provides greater stability than other fixation methods for first MTP arthrodesis[48-50,55,56]. In a retrospective study of 417 patients (450 feet), nonunion occurred in 25 cases (5.5%) and was associated with bilateral surgery and peripheral neuropathy[57]. Other factors associated with nonunion include obesity, concomitant hallux valgus deformity, and use of convex-concave reamers for joint preparation[58].

Pinter et al.[59] compared outcomes in 36 patients who underwent first MTP arthrodesis using a dorsal plate combined with a compression screw and 63 patients treated with dorsal plate fixation alone. Union rates were 89% and 84%, respectively. More importantly, the mean change in dorsiflexion angle between the immediate postoperative period and final follow-up was substantially smaller in the combined fixation group (0.57° vs. 6.73°), indicating significantly greater sagittal-plane stability and a lower risk of malunion with combined fixation[59]. Biomechanical studies have similarly shown that both dorsal plate fixation combined with an interfragmentary screw and crossed interfragmentary screws alone provide sufficient construct stiffness and strength to permit protected weight-bearing, provided forefoot loading is avoided during the early postoperative period[55,59].

Osteoarthritis in adjacent joints is a recognized concern following arthrodesis of any joint. However, after first MTP arthrodesis, this phenomenon appears to have limited clinical relevance. In a study of 77 patients with a mean follow-up of nine years, radiographic osteoarthritic changes developed in adjacent joints, predominantly the interphalangeal joint, in 66 patients. Nonetheless, 90.9% of patients were satisfied with the surgical outcome and reported minimal or no symptoms related to the adjacent joints[60].

As an alternative to arthrodesis for advanced hallux rigidus, arthroplasty may be performed with or without an implant. Interpositional arthroplasty is a joint-preserving resection arthroplasty that does not require prosthetic implantation and consists of cheilectomy, a Keller osteotomy, and interposition of autologous or allogeneic tissue.

In 1997, Hamilton et al.[61] described an interpositional arthroplasty technique using the dorsal capsule and extensor hallucis brevis tendon in 37 feet from 30 patients. Pain and function improved significantly without transfer metatarsalgia. All patients achieved at least grade 4/5 plantarflexion strength and a mean dorsiflexion of 50°[61].

Sanhudo et al.[62] reported outcomes for 25 feet with advanced hallux rigidus (Grades 3 and 4) treated with a modified dorsal capsular interpositional arthroplasty and followed for a minimum of 15 months (Figure 4). The mean AOFAS score at final follow-up was 93.6 points; 75% of patients were completely satisfied; no patient demonstrated less than 30° of first MTP joint motion at final follow-up; and only one patient developed mild transfer metatarsalgia[62]. In the author's experience, this procedure is particularly well suited for patients with an index plus or plus-minus metatarsal formula, lower functional demands, and female patients who wish to preserve first MTP joint motion for wearing high-heeled shoes.

In 2017, Aynardi et al.[63] published a retrospective review of patients who underwent interpositional arthroplasty between 2001 and 2014. Procedure survivorship, functional outcomes,

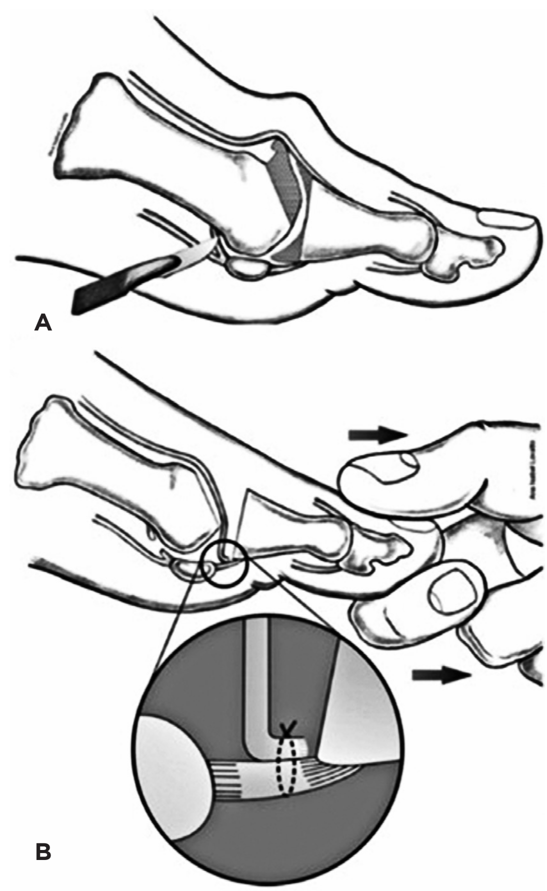

Figure 4. Schematic representation of the modified interpositional arthroplasty. (A) Release of the contracted proximal metatarsosesamoid ligament, generous cheilectomy, and limited resection of the base of the proximal phalanx to minimize shortening of the first ray. (B) Interposition of the dorsal capsule with fixation to the plantar plate.

and patient satisfaction were assessed by telephone interview. The study included 133 patients with a mean follow-up of 62.2 months (range, 24.3-151.2 months). The overall failure rate was 3.8% (5 of 133 patients). Patient-reported outcomes were rated as excellent in 65.4% of cases, good in 24.1%, and fair or poor in only 10.5%. Transfer metatarsalgia was reported by 23 (17.3%) patients at final follow-up[(63)].

Vulcano et al.[(64)] subsequently published a retrospective study of 42 patients who underwent interpositional arthroplasty between 1998 and 2011. After a mean follow-up of 11.3 years (range, 4-16 years), mean VAS pain scores improved from 7.9 preoperatively to 1.8 postoperatively, and significant improvements were observed in both Foot Function Index and Short Form-12 scores. Overall satisfaction was high, with 92.9% of patients reporting that they would choose the same procedure again under similar circumstances. Four patients (9.5%) required conversion to first MTP arthrodesis at a mean of 6.1 years after the index procedure[(64)].

Mroczek et al.[(65)] subsequently described a modification of interpositional arthroplasty consisting of an oblique osteotomy of the proximal phalanx while preserving the insertion of the flexor hallucis brevis. This modification increases joint stability and minimizes the risk of postoperative hallux extension deformity (cock-up deformity)[(65-67)].

More recently, Johnson et al.[(67)] compared the long-term outcomes of 15 patients treated with modified oblique Keller capsular interposition arthroplasty (MOKCIA), with a mean follow-up of 15 years, and 20 patients treated with first MTP arthrodesis, with a mean follow-up of 13 years. Patients treated with MOKCIA reported higher satisfaction scores and lower pain scores at final follow-up, suggesting this procedure is a durable, motion-preserving alternative to arthrodesis[(67)]. Similarly, Thome et al.[(68)] compared 58 feet treated with MOKCIA and 112 feet treated with arthrodesis after a mean follow-up of 13 years. Compared with their preoperative status, patients in the arthroplasty group reported less difficulty participating in sports than those treated with arthrodesis. Patient-Reported Outcomes Measurement Information System (PROMIS), VAS, and FAAM-Sports subscale scores were similar between groups, whereas satisfaction with postoperative activity level was higher in the arthroplasty group than in the arthrodesis group (100% vs. 87%)[(68)].

In 2022, Butler et al.[(69)] published a systematic review including 498 patients from 16 studies (one Level III and 15 Level IV studies). The mean AOFAS Hallux Metatarsophalangeal-Interphalangeal score improved from 51.6 preoperatively to 86.0 postoperatively after a weighted mean follow-up of 58 months. The weighted mean total range of motion increased from 39.3° preoperatively to 61.5° postoperatively. The overall complication rate was 21.5%, with transfer metatarsalgia as the most frequently reported complication[(69)].

In 2016, an industry-sponsored RCT comparing first MTP arthrodesis with hemiarthroplasty using a polyvinyl alcohol hydrogel implant reported equivalent pain relief and functional outcomes after two years of follow-up[(70)]; however, subsequent studies have not reproduced these initial findings.

El Masry et al.[(71)] compared 82 patients treated with polyvinyl alcohol hydrogel hemiarthroplasty and 101 patients treated with first MTP arthrodesis. Patients in the arthrodesis group experienced greater pain relief at both one and two years, and functional scores at two years were also significantly superior to those of the hemiarthroplasty group[(71)]. Likewise, Chrea et al.[(72)] compared 73 patients treated with cheilectomy plus Moberg osteotomy with 60 patients treated with the same procedure combined with a hydrogel implant. Pain relief was equivalent after one to two years of follow-up, suggesting that omitting the implant reduces both cost and implant-related risks without compromising clinical outcomes[(72)].

Another study involving 21 patients treated with hydrogel hemiarthroplasty demonstrated that 18.2% required reoperation and that 55% continued to experience pain and limited joint motion after a minimum follow-up of two years[(73)]. Similarly, Sanii et al.[(74)] evaluated 99 patients with at least 12 months of follow-up and found hydrogel arthroplasty to be inferior to both arthrodesis and implant-free interpositional arthroplasty with respect to pain relief and functional outcomes.

In contrast, Glazebrook et al.[(75)] demonstrated satisfactory medium- and long-term implant survivorship following hydrogel arthroplasty. However, conversion to arthrodesis after implant failure resulted in higher nonunion rates and inferior functional outcomes compared with primary arthrodesis[(75)]. Furthermore, a systematic review by Butler et al.[(76)] including 1,367 feet treated with hydrogel arthroplasty reported an overall complication rate of 27.9%, a failure rate of 14.8%, and a reoperation rate of 9.5% after a mean follow-up of only 24 months.

A systematic review published in 2024 compared arthrodesis with metallic, hydrogel, and double-stem silicone arthroplasties across 26 studies involving 1,348 feet[(77)]. In the arthrodesis group, the AOFAS Hallux Metatarsophalangeal-Interphalangeal score improved from 36-45 preoperatively to 79-89 postoperatively, with an overall union rate of 98.6%. Implant-related hardware discomfort was the most common complication. Among metallic implants, the ROTOglide® system achieved a mean AOFAS score of 95 with low complication rates. However, the ToeFit Plus™ and BioMed-Merck systems demonstrated revision rates of 37% and 15%, respectively, primarily because of aseptic loosening in studies with longer follow-up. Patients treated with hydrogel implants experienced marked improvements in FAAM-ADL and FAAM-Sports scores, increasing from 59.4 to 90.4 and from 60.9 to 89.7, respectively. Nevertheless, implant removal and conversion to arthrodesis were required in 20.5% of cases. Finally, among patients treated with double-stem silicone arthroplasty, the study with the longest follow-up reported improvement in the Manchester-Oxford Foot Questionnaire score from 78.1 to 11.0 and a mean postoperative range of motion of 22.3°, although periprosthetic osteolysis was observed in 10% of cases[(77)].

Overall, implant arthroplasty has produced inconsistent results in the literature. Given its high cost and the risks associated with prosthetic implantation, it should not be considered the first-line surgical treatment for hallux rigidus.

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References

1. Gould N, Schneider W, Ashikaga T. Epidemiological survey of foot problems in the continental United States: 1978-1979. Foot Ankle. 1980;1(1):8-10.
2. Williams BT, Hunt KJ. Hallux rigidus: anatomy and pathology. Foot Ankle Clin. 2024;29(3):371-87.
3. Lucas DE, Hunt KJ. Hallux rigidus: relevant anatomy and pathophysiology. Foot Ankle Clin. 2015;20(3):381-9.
4. Coughlin MJ, Shurnas PS. Hallux rigidus: demographics, etiology, and radiographic assessment. Foot Ankle Int. 2003;24(10):731-43.
5. Kihara T, Kimura T, Suzuki N, Hattori A, Saito M, Kubota M. Dysfunction of the windlass mechanism is associated with hallux rigidus: a case-control study. J Bone Joint Surg Am. 2025;107(6):558-64.
6. Migues A, Slullitel G. Joint-preserving procedure for moderate hallux rigidus. Foot Ankle Clin. 2012;17(3):459-71.
7. Jacob HA. Forces acting in the forefoot during normal gait: an estimate. Clin Biomech (Bristol, Avon). 2001;16(9):783-92.
8. Maceira E, Monteagudo M. Functional hallux rigidus and the Achilles-calcaneus-plantar system. Foot Ankle Clin. 2014; 19(4):669-99.
9. Jones MT, Sanders AE, DaCunha RJ, Cody EA, Sofka CM, Nguyen J, et al. Assessment of various measurement methods to assess first metatarsal elevation in hallux rigidus. Foot Ankle Orthop. 2019;4(3):2473011419875686.
10. Horton GA, Park YW, Myerson MS. Role of metatarsus primus elevatus in the pathogenesis of hallux rigidus. Foot Ankle Int. 1999;20(12):777-80.
11. Fukushima H, Kubota M, Kimura T, Kihara T, Saito M. Investigating the relationship between metatarsal primus elevatus and hallux rigidus using weight-bearing computed tomography: a retrospective comparison study. Cureus. 2025;17(8):e91139.
12. Lee HY, Mansur NS, Lalevee M, Maly C, Iehl CJ, Hembree WC, et al. Does metatarsus primus elevatus really exist in hallux rigidus? A weight-bearing CT case-control study. Arch Orthop Trauma Surg. 2023;143(2):755-61.
13. Sanchez PJ, Grady JF, Lenz RC, Park SJ, Ruff JG. Metatarsus primus elevatus resolution after first metatarsophalangeal joint arthroplasty. J Am Podiatr Med Assoc. 2018;108(3):200-4.
14. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am. 2003;85(11):2072-88.
15. Calvo A, Viladot R, Giné J, Alvarez F. The importance of the length of the first metatarsal and the proximal phalanx of hallux in the etiopathogeny of hallux rigidus. Foot Ankle Surg. 2009;15(2):69-74.
16. Nixon DC, Lorbeer KF, McCormick JJ, Klein SE, Johnson JE. Hallux rigidus grade does not correlate with Foot and Ankle Ability Measure score. J Am Acad Orthop Surg. 2017;25(9):648-53.
17. Munteanu SE, Buldt A, Lithgow MJ, Cotchett M, Landorf KB, Menz HB. Non-surgical interventions for treating osteoarthritis of the big toe joint. Cochrane Database Syst Rev. 2024;6(6):CD007809.
18. Kon Kam King C, Loh Sy J, Zheng Q, Mehta KV. Comprehensive review of non-operative management of hallux rigidus. Cureus. 2017;9(1):e987.
19. Colò G, Fusini F, Samaila EM, Rava A, Felli L, Alessio-Mazzola M, et al. The efficacy of shoe modifications and foot orthoses in treating patients with hallux rigidus: a comprehensive review of literature. Acta Biomed. 2020;91(14-S):e2020016.
20. Kunnasegaran R, Thevendran G. Hallux rigidus: nonoperative treatment and orthotics. Foot Ankle Clin. 2015;20(3):401-12.
21. Lam A, Chan JJ, Surace MF, Vulcano E. Hallux rigidus: how do I approach it? World J Orthop. 2017;8(5):364-71.
22. Ho B, Baumhauer J. Hallux rigidus. EFORT Open Rev. 2017;2(1):13-20.
23. Grady JF, Axe TM, Zager EJ, Sheldon LA. A retrospective analysis of 772 patients with hallux limitus. J Am Podiatr Med Assoc. 2002;92(2):102-8.
24. Smith RW, Katchis SD, Ayson LC. Outcomes in hallux rigidus patients treated nonoperatively: a long-term follow-up study. Foot Ankle Int. 2000;21(11):906-13.
25. Shamus J, Shamus E, Gugel RN, Brucker BS, Skaruppa C. The effect of sesamoid mobilization, flexor hallucis strengthening, and gait training on reducing pain and restoring function in individuals with hallux limitus: a clinical trial. J Orthop Sports Phys Ther. 2004;34(7):368-76.
26. Solan MC, Calder JD, Bendall SP. Manipulation and injection for hallux rigidus. Is it worthwhile? J Bone Joint Surg Br. 2001; 83(5):706-8.
27. Munteanu SE, Zammit GV, Menz HB, Landorf KB, Handley CJ, Elzarka A, et al. Effectiveness of intra-articular hyaluronan (Synvisc, hylan G-F 20) for the treatment of first metatarsophalangeal joint osteoarthritis: a randomised placebo-controlled trial. Ann Rheum Dis. 2011;70(10):1838-41.
28. Pons M, Alvarez F, Solana J, Viladot R, Varela L. Sodium hyaluronate in the treatment of hallux rigidus. A single-blind, randomized study. Foot Ankle Int. 2007;28(1):38-42.
29. Grice J, Marsland D, Smith G, Calder J. Efficacy of foot and ankle corticosteroid injections. Foot Ankle Int. 2017;38(1):8-13.
30. Galois L, Coillard JY, Porterie J, Melac-Ducamp S, Conrozier T.

Open-label pilot study of a single intra-articular injection of mannitol-modified cross-linked hyaluronic acid (HANOX-M-XL) for the treatment of the first metatarsophalangeal osteoarthritis (hallux rigidus): the REPAR trial. Clin Med Insights Arthritis Musculoskelet Disord. 2022;15:11795441211055882.

31. Butler JJ, Hartman H, Mener A, Mercer NP, Randall GW, Petropoulos S, et al. Limited evidence to support the use of intra-articular injection of hyaluronic acid for the management of hallux rigidus: a systematic review. Foot Ankle Orthop. 2024;9(3):24730114241265109.
32. Nicolosi N, Hehemann C, Connors J, Boike A. Long-term follow-up of the cheilectomy for degenerative joint disease of the first metatarsophalangeal joint. J Foot Ankle Surg. 2015;54(6):1010-20.
33. Sidon E, Rogero R, Bell T, McDonald E, Shakked RJ, Fuchs D, et al. Long-term follow-up of cheilectomy for treatment of hallux rigidus. Foot Ankle Int. 2019;40(10):1114-21.
34. O'Malley MJ, Basran HS, Gu Y, Sayres S, Deland JT. Treatment of advanced stages of hallux rigidus with cheilectomy and phalangeal osteotomy. J Bone Joint Surg Am. 2013;95(7):606-10.
35. Kim PH, Chen X, Hillstrom H, Ellis SJ, Baxter JR, Deland JT. Moberg osteotomy shifts contact pressure plantarly in the first metatarsophalangeal joint in a biomechanical model. Foot Ankle Int. 2016;37(1):96-101.
36. Gauthier C, Lewis T, O'Keefe J, Bakaes Y, Vignaraja V, Jackson JB 3rd, et al. Minimally invasive dorsal cheilectomy and hallux metatarsophalangeal joint arthroscopy for the treatment of hallux rigidus. Foot Ankle Surg. 2024;30(5):400-5.
37. Fletcher AN, Patel V, Cerrato R. Minimally invasive cheilectomy for hallux rigidus. Foot Ankle Clin. 2024;29(3):471-84.
38. Montagna A, Fiore PI, Pozzessere E, Vulcano E. Open vs percutaneous Moberg osteotomy with dorsal cheilectomy for hallux rigidus: a retrospective comparative study of surgical approaches with minimum 2 years' follow-up. Foot Ankle Orthop. 2025;10(4):24730114251388095.
39. Semelsberger SD, Lee MS, Dobson CB, Miller CP, Gianakos AL. Modern treatment of hallux rigidus by cheilectomy: a systematic review of patient-reported outcomes in minimally invasive techniques. Foot Ankle Orthop. 2024;9(4):24730114241303169.
40. Esser K, Butler JJ, Roof M, Mercer NP, Harrington MC, Samsonov AP, et al. Outcomes following minimally invasive dorsal cheilectomy for hallux rigidus: a systematic review. World J Orthop. 2024;15(6): 585-92.
41. Rajan L, Kim J, An T, Mizher R, Srikumar S, Fuller R, et al. Effect of prior cheilectomy on outcomes of first metatarsophalangeal joint fusion for treatment of hallux rigidus. Foot Ankle Orthop. 2022;7(3):24730114221119740.
42. Cöster ME, Montgomery F, Cöster MC. Patient-reported outcomes of joint-preserving surgery for moderate hallux rigidus: a 1-year follow-up of 296 patients from Swefoot. Acta Orthop. 2021;92(1):109-13.
43. Slullitel G, López V, Calvi JP, D'Ambrosi R, Usuelli FG. Youngswick osteotomy for treatment of moderate hallux rigidus: thirteen years without arthrodesis. Foot Ankle Surg. 2020;26(8):890-4.
44. Ceccarini P, Donantoni M, Nuzzo G, Carriero B, Ancillai G, Rinonapoli G, et al. Return to sport after osteotomy in patients with hallux rigidus. Foot Ankle Surg. 2026;32(2):145-51.
45. Viladot A, Sodano L, Marcellini L, Zamperetti M, Hernandez ES, Perice RV. Youngswick-Austin versus distal oblique osteotomy for the treatment of hallux rigidus. Foot (Edinb). 2017;32:53-8.
46. Gerbert J, Moadab A, Rupley KF. Youngswick-Austin procedure: the effect of plantar arm orientation on metatarsal head displacement. J Foot Ankle Surg. 2001;40(1):8-14.
47. Dealbera ED, Ferreira GF, Toepfer A, Dalmau-Pastor M, Del Vecchio JJ. Shortening, percutaneous, intra-articular, Chevron osteotomy for the treatment of hallux rigidus: an anatomical feasibility and risk assessment in cadavers. Foot Ankle Orthop. 2026;11(1):24730114251412837.
48. Kang YS, Bridgen A. First metatarsophalangeal joint arthrodesis/ fusion: a systematic review of modern fixation techniques. J Foot Ankle Res. 2022;15(1):30.
49. Politi J, John H, Njus G, Bennett GL, Kay DB. First metatarsal-phalangeal joint arthrodesis: a biomechanical assessment of stability. Foot Ankle Int. 2003;24(4):332-7.
50. Sanhudo JAV, Pereira TAP. Current trends in fixation techniques. Foot Ankle Clin. 2020;25(1):97-108.
51. Baumann AN, Walley KC, Kermanshahi N, Anastasio AT, Holmes JR, Walton DM, et al. Return to sport after first metatarsophalangeal arthrodesis: a systematic review. Foot Ankle Int. 2023;44(12):1319-27.
52. Maor D, Meyerkort D, Sobhi S, Calder J. Return to sport after first metatarsophalangeal arthrodesis in elite athletes. J ISAKOS. 2025;11:100390.
53. D'sa P, Vaidhyanathaswamy S, Teoh KH, Hariharan K. The ability to wear heeled footwear following first metatarsophalangeal joint fusion. Foot Ankle Surg. 2022;28(4):510-3.
54. Scheurer F, Zimmermann SM, Fischer P, Wirth SH, Beeler S, Viehöfer AF. Ten-year minimum follow-up study of first metatarsophalangeal joint fusion in young vs old patients. Foot Ankle Int. 2024;45(3):217-22.
55. Campbell B, Schimoler P, Belagaje S, Miller MC, Conti SF. Weight-bearing recommendations after first metatarsophalangeal joint arthrodesis fixation: a biomechanical comparison. J Orthop Surg Res. 2017;12(1):23.
56. Harris E, Moroney P, Tourné Y. Arthrodesis of the first metatarsophalangeal joint: a biomechanical comparison of four fixation techniques. Foot Ankle Surg. 2017;23(4):268-74.
57. Dingler CM, Hower CC, Kane KT, Edwards AG, Kadakia RJ, Bariteau JT. Metatarsophalangeal arthrodesis: risk factors for nonunion in a 10-year retrospective cohort. Foot Ankle Orthop. 2026;11(1):24730114251413590.
58. Füssenich W, Seeber GH, van Raaij TM, van Lingen CP, Zuurmond RG, Stevens M, et al. Factors associated with nonunion in arthrodesis of the first metatarsophalangeal joint: a multicenter retrospective cohort study. Foot Ankle Int. 2023;44(6):508-15.
59. Pinter Z, Hudson P, Cone B, Motwani G, Prasad K, Shah A. Radiographic evaluation of first MTP joint arthrodesis for severe hallux valgus: does the introduction of a lag screw improve union rates and correction of the intermetatarsal angle? Foot (Edinb). 2017;33:20-4.
60. Recheis S, Mattausch D, Kuehn N, Kindermann H, Ortmaier R, Bischofreiter M, et al. Long-term outcomes after first metatarsophalangeal joint arthrodesis: with focus on degenerative changes on adjacent joints. Foot Ankle Int. 2026. [Epub ahead of print].
61. Hamilton WG, O'Malley MJ, Thompson FM, Kovatis PE. Capsular interposition arthroplasty for severe hallux rigidus. Foot Ankle Int. 1997;18(2):68-70.
62. Sanhudo JA, Gomes JE, Rodrigo MK. Surgical treatment of advanced hallux rigidus by interpositional arthroplasty. Foot Ankle Int. 2011;32(4):400-6.
63. Aynardi MC, Atwater L, Dein EJ, Zahoor T, Schon LC, Miller SD. Outcomes after interpositional arthroplasty of the first metatarsophalangeal joint. Foot Ankle Int. 2017;38(5):514-8.

64. Vulcano E, Chang AL, Solomon D, Myerson M. Long-term follow-up of capsular interposition arthroplasty for hallux rigidus. Foot Ankle Int. 2018;39(1):1-5.
65. Mroczek KJ, Miller SD. The modified oblique Keller procedure: a technique for dorsal approach interposition arthroplasty sparing the flexor tendons. Foot Ankle Int. 2003;24(7):521-2.
66. Di Caprio F, Mosca M, Ceccarelli F, Caravelli S, Vocale E, Zaffagnini S, et al. Hallux rigidus: current concepts review and treatment algorithm with special focus on interposition arthroplasty. Acta Biomed. 2022;93(5):e2022218.
67. Johnson JE, Phinney AR, Hastings MK, Jeong HJ, Chen L, Thome AP, et al. Fifteen-year follow-up of the modified oblique Keller capsular interposition arthroplasty compared to arthrodesis for treatment of advanced first metatarsophalangeal joint arthritis. Foot Ankle Orthop. 2025;10(1):24730114251322766.
68. Thome AP Jr, Backus JD, Jeong HJ, McCormick JJ, Johnson JE. Long-term return to sports after modified oblique Keller capsular interposition arthroplasty vs arthrodesis for advanced hallux rigidus: a retrospective cohort. Foot Ankle Orthop. 2025;10(4):24730114251386022.
69. Butler JJ, Shimozono Y, Gianakos AL, Kennedy JG. Interpositional arthroplasty in the treatment of hallux rigidus: a systematic review. J Foot Ankle Surg. 2022;61(3):657-62.
70. Baumhauer JF, Singh D, Glazebrook M, Blundell C, De Vries G, Le IL, et al. Prospective, randomized, multi-centered clinical trial assessing safety and efficacy of a synthetic cartilage implant versus first metatarsophalangeal arthrodesis in advanced hallux rigidus. Foot Ankle Int. 2016;37(5):457-69.
71. El Masry S, Boden AL, DiGiovanni GM, Cororaton AD, Ellis SJ. A comparison of PROMIS scores of metatarsophalangeal joint arthrodesis and polyvinyl alcohol hydrogel implant hemiarthroplasty for hallux rigidus. JB JS Open Access. 2024;9(3):e23.00158.
72. Chrea B, Eble SK, Day J, Ellis SJ, Drakos MC, et al. Comparison between polyvinyl alcohol implant and cheilectomy with Moberg osteotomy for hallux rigidus. Foot Ankle Int. 2020;41(9):1031-40.
73. Schapira B, Johnson O, Faroug R. Surgical outcomes of synthetic cartilage implant hemiarthroplasty for metatarsophalangeal arthropathy. Cureus. 2023;15(11):e49036.
74. Sanii R, Phan K, Krumm D, Patton DJ, Madden T, Anderson JG, et al. Treatment of hallux rigidus: comparison of hemiarthroplasty with Cartiva implant, allograft interpositional arthroplasty, and arthrodesis. Foot Ankle Orthop. 2025;10(1):24730114251324184.
75. Glazebrook H, Bambarawana S, Morash J, MacDonald J, Walls A, Burgesson B, et al. Failures of polyvinyl alcohol hydrogel implant for hallux rigidus and outcomes of revision to arthrodesis: mid-term to long-term results. Foot Ankle Spec. 2025. [Epub ahead of print].
76. Butler JJ, Dhillon R, Wingo T, Lin CC, Samsonov AP, Azam MT, et al. Polyvinyl alcohol hydrogel implant for the treatment of hallux rigidus is associated with a high complication rate and moderate failure rate at short-term follow-up: a systematic review. Eur J Orthop Surg Traumatol. 2024;34(4):1765-78.
77. Sánchez Guzmán J, Gallo Oropeza R, Reyes Donado M, Martin Oliva X, Díaz Sánchez T. Arthrodesis vs arthroplasty for moderate and severe hallux rigidus: systematic review. Foot Ankle Surg. 2024;30(3):174-80.