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The influence of first ray instability and hindfoot valgus in the development of hallux rigidus: state of art

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Abstract. Hallux rigidus (HR) is a painful condition associated with degenerative arthritis of the first metatarsophalangeal (MTP1) joint, leading to a progressive loss of dorsiflexion. The etiological factors leading to the development of the condition are not yet fully understood in the literature. When the hindfoot is aligned in excessive valgus, the medial border of the foot tends to roll over, which brings to increased stress on the medial side of the MTP1 joint, and consequently on the first ray (FR), thus potentially influencing the development of HR deformity. This state of art aims to analyze the influence of FR instability and hindfoot valgus in HR development. From the results of the analyzed studies, it appears that a FR instability may predispose the big toe to increased stress and to narrow the proximal phalanx motion on the first metatarsal, which brings to compression and ultimately degeneration of the MTP1 joint, mostly in advanced stages of disease, less in mild or moderate HR patients. A strong correlation between a pronated foot and MTP1 joint pain was found; forefoot hypermobility during the propulsion phase may promote MTP1 joint instability and increase pain. Thus, the increased moment of pronation of the foot with the overload of the medial column, when present, should be corrected conservatively or surgically; this, most likely, would be useful not only to eliminate or at least limit the painful symptoms but above all to prevent the worsening of the condition, also after the surgical treatment of HR. (www.actabiomedica.it)

Key words: First ray, hallux limitus, hallux rigidus, risk factor, valgus

Introduction

Hallux rigidus (HR) is a painful condition associated with degenerative arthritis of the first metatarsophalangeal (MTP1) joint, which usually leads to a progressive loss of dorsiflexion, and proliferative bony response, leading to increased bulk of the joint (Figure 1) (1).

The pathology affects about 2.5% of people older than 50 years and significantly impacts patients' quality of life, reducing daily-life activity (2).

Nonsurgical treatment, such as shoe modifications and orthotics planned to limit motion in the MTP1 joint, should always be the primary intervention of HR (3,4). When nonsurgical management fails, a variety of surgical procedures available may be proposed (5).

The MTP1 offers unique anatomy, and its configuration may play a significant role in HR development (6). MTP1 sustains about 119% of the body weight during the gait with each phase (2).

The etiological factors leading to the development of the condition are not yet fully understood

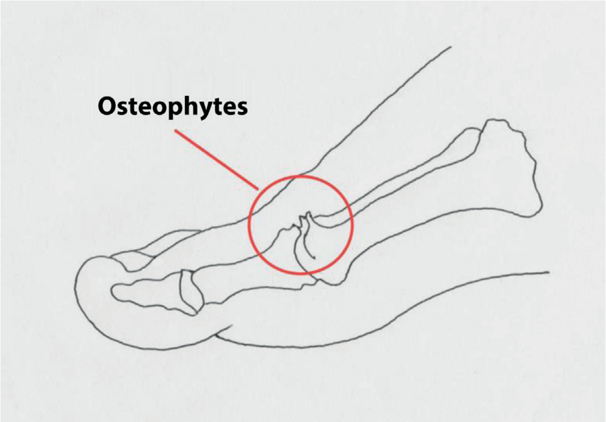

Figure 1. A schematic drawing of hallux rigidus in the advanced stage with a painful and deformed great toe and dorsomedial osteophytes.

in the literature (7, 8); Cotterill (9) in 1887 believed that rheumatoid diseases and infections were the leading causes. Since then, many causes have been associated with the condition. Trauma is still considered one of the most common causes of unilateral HR, but also repetitive microtraumas or inflammatory and metabolic causes such as gout, rheumatoid arthritis, and seronegative arthropathy may cause degeneration of the joint (10). Anyhow, most cases are likely idiopathic (2).

Predisposing factors include a long hallux and a long, slender, or pronated foot (11). A valgus hindfoot would also predispose to MTP1 joint osteoarthritis. When the hindfoot is aligned in too much valgus, the medial border of the foot tends to roll over. This position brings to increased stress on the medial side of the MTP1 joint and consequently on the first ray (FR) (12), thus potentially influencing the development of HR deformity (13). However, these risk factors have been poorly analyzed in the literature as a possible cause of HR development (14, 15). This state of art aims to analyze the influence of FR instability and hindfoot valgus in HR development.

Hallux rigidus or hallux limitus?

The terms HR and hallux limitus (HL) are often used as synonymous; nevertheless, an important distinction needs to be made. HR is defined as pain due to an arthritic and ankylotic joint with loss of movement, while HL is defined as functional pain due to soft tissue tension (i.e., gastrocnemius contracture) or an excessively long and elevated first metatarsal (16). Patients affected by HL typically have increased MTP1 dorsiflexion when the foot is examined in plantarflexion, as this releases the tightness of gastrocnemius and removes the restricting factor (2).

We must further distinguish between structural hallux limitus (SHL) and functional hallux limitus (FHL). FHL is characterized by a lack of motion of the MTP1 joint during gait only (17), while the MTP1 joint will demonstrate normal motion during an open kinetic chain examination. X-rays will sometimes show a small amount of dorsal spurring of the joint; however, the joint does not demonstrate significant degenerative joint disease (2).

On the other hand, SHL is characterized by structural adaptations of the MTP1 joint that prevent its normal movement. These changes may show different degrees of severity, with limited dorsiflexion mobility of the MTP1 joint. When MTP1 motion is impaired enough to prevent stabilization of the foot structure during maximal hallux dorsiflexion, through the effect of the windlass mechanism, then expected foot stabilization during propulsion is altered and becomes clinically significant. In SHL, the range of motion (ROM) will be impaired during open and closed kinetic chain activities (18).

However, it must be noted that HL can evolve to HR; we can therefore deduce that the condition of HR results in a more advanced stage of the HL. The distinction between the two conditions and their cause is essential for directing proper treatment, conservative or surgical (2).

Pathomechanics of hallux rigidus

The hindfoot constantly influences the forefoot, especially during walking. When a patient pronates the hindfoot, weight shifts to the medial forefoot and, consequently, on the FR (19). It is for this reason that an orthotic or surgical hindfoot correction may avoid painful symptoms and limit the development of the pathology (16) (Figure 2). The FR is the medial

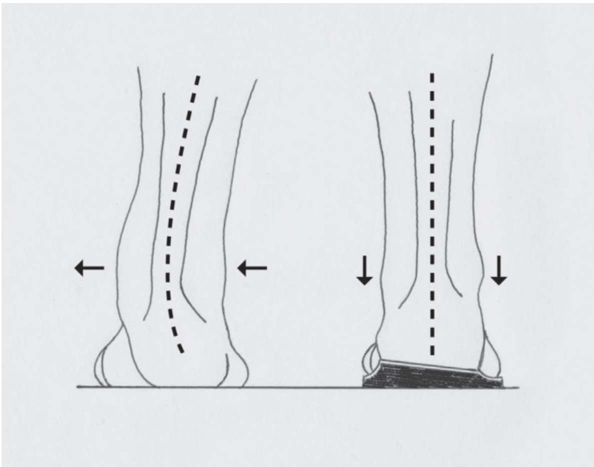

Figure 2. On the left: a valgus hindfoot of the right foot resulting from an overload of the medial column. On the right: the use of an insole allows the realignment of the hindfoot with a redistribution of loads.

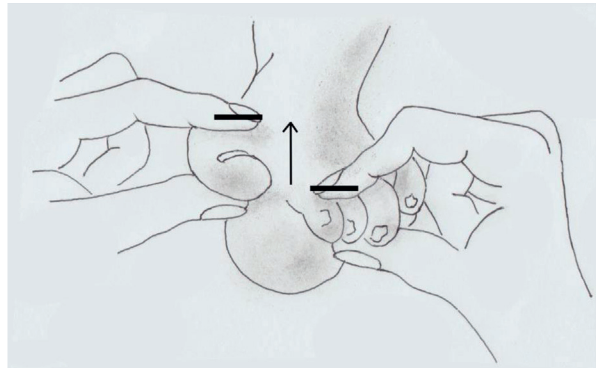

Figure 3. Root's Test: place left thumb and index finger on the head of the 1st metatarsal bone, then place the thumb and index finger on the 2nd, 3rd, and 4th metatarsal head with the right hand. Moving only the 3rd metatarsal head and take it through the dorsal and plantar excursion. A normal total excursion is 10 mm (5 mm dorsal, 5 mm plantar); if the excursion is more than 10 mm, it is considered as a hypermobile first ray.

stabilizer of the foot, and, through retrograde forces, it may support and balance the subtenaculum tali, which is eccentrically loaded by the talus. In a physiological foot, the FR can resupinate the foot in the propulsion moment with the correcting the subtalar joint axis, whose extension is usually placed between the first and second metatarsals (20, 21).

Kirby (22) described that reactive floor loads through the first metatarsal can generate a supinator moment of the hindfoot, whereas loads applied to any of the lesser metatarsals collectively generate a pronator moment. The plantar fascia is the structure that receives the combined load from Achilles tendon tension and bodyweight during the midstance phase of gait (23-25), also providing a significant arch-supporting function (26).

The concept of the "windlass effect" was first described by Hicks (27) as the passive tensioning of the plantar fascia that occurs during gait when the foot enters the propulsive phase. The windlass is most intense on the MTP1 joint for the leverage generated through the sesamoids and the larger arc of curvature of the first metatarsal head. During the gait, heel lift, hallux, and lesser toes adapted to the floor as the foot rotates and rises over the fixed digits. The resultant dorsiflexion enhances the tension of the plantar fascia and reduces its working distance, inducing several changes in the foot: increased arch height, metatarsal plantarflexion, arch joint compression/stabilization, and calcaneal inversion (23). As the windlass engages in propulsion, the first metatarsal will plantarflex and induce increased plantar pressures while simultaneously the second metatarsal pressures will decrease. The peroneus longus muscle participates in plantar flexion and its main function is to reversal of the foot at the ankle. Due to its insertion on the medial part of the foot and its descent along the lateral part of the leg, the muscle contraction lifts the foot upwards (plantar flexion) and outwards (eversion) (28).

FR hypermobility and instability can cause FR insufficiency resulting in increased foot pronation (29-32). A widely used clinical examination for this condition is the Root's test that evaluates the hypermobility of the FR in the sagittal plane (Figure 3), which may be helpful in the overall clinical evaluation of a patient affected by HR (33).

Apart from this, other methods have been suggested in the literature for the measurement of the hypermobility of the FR, even on sagittal and transversal plane, equally useful (34,35).

Conversely, in a pathologically pronated foot the hindfoot everts and the forefoot abducts on the rearfoot. The subtalar joint axis, in this setting, projects medially to the entire forefoot; thus, load on any metatarsal head generates a pronation moment on the rearfoot (22). The pronator moment of the forefoot overloads the medial column leading to a progressive collapse of the medial column, a possible gradual break down of the plantar ligaments, and causing a segmental malalignment in the sagittal and coronal planes (30).

Thus, there seems to be a relation between HR and increased foot pronation with a consequent medial column overload (31). Patients suffering from FHL usually have significant resistance to MTP1 dorsiflexion in early propulsion; nevertheless, in the open kinetic chain, they appear to have no such restriction of movement (30). While the reverse windlass forces the hallux to flex plantar and purchase the floor, if the windlass hires too rapidly, the proximal phalanx has reduced capacity to induce the plantarflexion of the FR. This has a blocking effect on the joint. As the pathology worsens, progressive joint degeneration starts along the dorsal half of the MTP1 with focal erosions at the metatarsal head and early dorsal metatarsal spurring. The succession of these movements, repeated over time, can develop the condition of HR (33).

With further progression, the metatarsal head flattens, and lateral and medial osteophytes develop as the dorsal osteophytes widen, narrowing joint space (20).

First ray hypermobility and metatarsus primus elevatus

First ray hypermobility has been repeatedly mentioned in the literature as a possible etiological factor (37, 38), Root and colleagues (28) cited it as a secondary cause in the onset of HR. As a consequence of increased subtalar joint pronation, the lateral column of the foot turns unstable in midstance and the propulsive stages of gait, thus depriving the peroneus longus of its plantar flexion on the FR. A functional limitation of hallux dorsiflexion can follow a first metatarsal that inverts and dorsiflexes, rather than having the mechanical advantage of plantar flexion (39).

The notion of metatarsus primus elevatus (MPE) was first described by Lambrinudi in 1938 (40) as associated with HR based on a single case report. It is defined as the elevation of the FR on the lateral standing X-rays compared with the second metatarsal position. Historically considered a primary pathology associated with HR, more recent opinions view medial column elevation due to limited dorsiflexion of the MTP1 joint (41). MPE can be seen in grades third and fourth X-rays more frequently than in control subjects, marking disease progression (42). However, one may question whether the MPE may result from a painful arthritic big toe causing an antalgic or compensatory gait or simply because of instability (43).

MPE is a deformity found more frequently in HR than in Civinini-Morton Syndrome, hallux valgus (HV), and plantar fasciitis (44, 45). Roukis stated the average first to second metatarsal elevation was 5.8 mm in a HR group compared to 4.2, 4.6, and 4.1 mm in HV, plantar fasciitis, and Civinini-Morton's Syndrome populations, respectively (45). McMaster has declared that FR instability predisposes the big toe to increased stress, and it may be responsible for the characteristic HR chondral lesion on the first metatarsal head (46). It has also been suggested that a dorsiflexed first metatarsal narrows the proximal phalanx motion on the first metatarsal, which brings to compression and ultimately degeneration of the MTP1 joint (47).

Bingold and Collins (48) affirmed that HR develops due to an abnormal gait, such as hypermobility of the first metatarsal and pain in the big toe, altering foot dynamics and leading to MTP1 osteoarthritis. Horton et al. (44) in their radiographic analysis of subjects with and without HR, reported that advanced HR patients had a slightly higher average value for MPE, but patients with mild or moderate HR had suchlike values as those without HR.

Anyhow, this was not confirmed by Van Beek et al. (49), highlighting that in not all analyzed studies, they have found an unstable or elevated first metatarsal in HR patients. Coughlin and Shurnas retrospectively reviewed HR subjects treated with cheilectomy and MTP1 joint fusion (42). Using the Klaue device, the FR elevation averaged 5.5 mm, within the acceptable limits of normal. Usually, the FR mobility was 5 mm in patients treated with arthrodesis and 5.8 mm in patients treated with cheilectomy.

If the MPE may be a causative factor in HR patients, then a plantarflexion surgery may be helpful. Different studies have validated the use of a first metatarsal plantarflexing-shortening osteotomy to treat HR pathology (50-52). In their retrospective analysis, Derner et al. (50) plantarflexed the first metatarsal by 1 to 4 mm, shortened it by 6.1 mm, and had 85% good to optimal results. However, shortening can contribute to pain relief as well as plantar flexion.

The MTP1 fusion in a plantarflexing position has also been proposed and indicated in HR patients with a MPE in mild to moderate degenerative changes of the MTP1 joint. Baravarian et al. reported promising results in nine patients with HR treated with a modified Lapidus arthrodesis (53).

Thus, FR instability should be always considered when planning the therapeutic strategy for HR patients. Young Lee et al. (54), in their single-center retrospective case-control study, analyzed 27 HV patients (30 feet; mean age 54.2 years), 26 HR patients (30 feet; mean age 56.6 years), and 30 controls (30 feet; mean age; 43 years). Multiplanar instability of the first tarsometatarsal (TMT) joint was confirmed using weight-bearing computed tomography (CT) in HV and HR groups compared with controls. HV group demonstrated instability mainly in sagittal and axial planes, while the HR group predominantly had sagittal instability. The authors concluded that a surgical correction of the instability at the first TMT joint might be an option to address both HV and HR.

Hindfoot valgus

Over the years, hindfoot valgus as a cause of HR has been involved by several authors (9, 48, 55-58) with the comprehension that excessive foot pronation results in increased plantar fascia tension and increased dorsiflexion force under the first metatarsal head, and thus a reduced ability of the hallux to dorsiflex. However, no demographics were reported in any of these studies to support the idea that hindfoot valgus may cause HR.

Jack (39) evaluated foot posture by noting the weight-bearing arch of the foot, but unfortunately no criteria were documented to quantify this. The author recked an association between hindfoot valgus and HR but was unclear which comes first or whether the two develop simultaneously.

Coughlin and Shurnas (42) assessed foot posture using a Harris Beath mat to estimate arch height or excess heel valgus. Among their patients, only 11% of them had pes planus. Similar outcomes were those of Harris and Beath (59) (15%), who examined 3619 healthy military recruits. However, Coughlin and Shurnas' results based on previous studies cannot be considered reliable or conclusive as the Harris and Beath mat has not been tested for reliability and validity.

Scherer (60) prompted that calcaneal eversion can theoretically limit MTP1 joint activity. Harradine and Bevan (61) seemed to validate this hypothesis by examining the effect of static hindfoot eversion (using 3°, 5°, and 8° valgus wedges in a standard shoe) on MTP1 joint ROM. A decreased joint motion with increasing calcaneal eversion was found.

Mahiquez et al. (14) examined the relationship between hindfoot valgus and MTP1 joint arthritis and found that 23% of patients were more likely to develop MTP1 joint arthritis with hindfoot valgus. Halstead et al. (62) found that subjects with MTP1 joint arthritis proved higher medial forefoot pressures and more pronated foot postures. Grady et al. (63) analyzed 772 HR patients and found 5.5% had a past medical history of both excessive pronation and trauma while 21.7% had excess pronation only. The measurement criteria enclosed excess pronation at mid-stance/toe-off and Kite's angle > 45°.

Payne and Dananberg (64) suggested that hindfoot valgus may be the consequence and not the cause. Authors supported that block of MTP1 joint sagittal plane motion (sagittal plane facilitation theory) brings compensation within other planes. Then, compensatory midtarsal and subtalar joint pronation (frontal plane) with forefoot abduction (transverse plane) can derive, producing flatfoot in some HR patients. Although all these studies provide interesting theories linking pes planus with HR, unluckily, none use a validated tool to quantify foot posture.

Beeson et al. (15) used the Foot Posture Index (FPI) (65) to quantify the degree of supination or pronation. This is a valid, reliable, and objective measure of foot function (65), quantifying foot posture in a relaxed stance position, requiring no measurement with instrumentation. In this study, 84 (47%) feet had hindfoot valgus (11% were in advanced grade). A strong correlation between a pronated foot and MTP1 joint pain was found (r = 0.84, p = 0.05).

It is theorized that in a hindfoot valgus, forefoot hypermobility at propulsion may promote MTP1 joint instability, increasing pain and ROM. Although not statistically significant, a correlation between increased MTP1 joint ROM and pronated foot (r = 0.72, p = 0.1) sustain this hypothesis (15).

Thus, the increased moment of pronation of the foot with an overload of the medial column, when present, should be corrected conservatively (16) or surgically (66-68); this, along with weight reduction and regular physical activity (69-71), would be useful not only to eliminate or at least limit the painful symptoms but above all to prevent the worsening of the condition (66-68).

Conclusion

From the literature analysis, first ray instability may predispose the big toe to increased stress and cause the characteristic hallux rigidus chondral lesion on the first metatarsal head. It has also been noted that a dorsiflexed first metatarsal narrows the proximal phalanx motion on the first metatarsal, which brings to compression and ultimately degeneration of the first metatarsophalangeal joint, above all in advanced hallux rigidus patients, less in patients with mild or moderate hallux rigidus.

A strong correlation between a pronated foot and first metatarsophalangeal joint pain was found. It is theorized that in a hindfoot valgus, forefoot hypermobility at propulsion may promote first metatarsophalangeal joint instability, increasing pain and range of motion.

Thus, the increased moment of pronation of the foot with the overload of the medial column, when present, should be corrected conservatively or surgically; this, most likely, would be useful not only to eliminate or at least limit the painful symptoms but above all to prevent the worsening of the condition, also after the surgical treatment of hallux rigidus.

Future epidemiological studies would be helpful to determine whether systemic aetiology is involved in hallux rigidus development and clarify the respective influences of mechanical and systemic factors in the condition's development.

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