Literature Review of Hypermobile First Ray

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Abstract: Hypermobile first ray is typically suggested to contribute to hallux valgus, and the only true treatment for this abnormality is an arthrodesis of the first metatarsocuneiform joint. Recent literature challenges these theories and endorses new ideas to the topic. This review article endeavors to summarize journals referring to hypermobility at the first ray.

Key words: first ray, hypermobile, hypermobility

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Hypermobility of the first ray has been fairly well documented throughout the literature. Assessment of first ray hypermobility is an intrinsic part of the orthopedic physical exam of the foot. However, the controversy regarding the evaluation of hypermobile first ray as well as its pathological consequences lends the subject to debate.[1]

The purpose of this article review is to describe the anatomic components of first ray, explore the normal biomechanics of this joint, distinguish these motions from the abnormal biomechanics that lead to hypermobility of this osseous segment, survey the variety of methods to enumerate the mobility, review the classic for correction of this deformity, and finally, compare the traditional literature to the newer concepts of hypermobility of the first ray.

Introduction

Duchenne was the first to describe first ray motion in the 1800s stating, “The joints of the medial border of the forefoot have a certain amount of vertical motion.”[2,3] Morton further advanced the understanding of first ray motion in 1928. He [4] proposed that hypermobility of the first ray is pathologic to normal foot mechanics. He believed that excessive dorsal excursion of a short first metatarsal causes the foot to roll inward and prevents the first ray from contacting the ground during gait. As a result, the second metatarsal bearing an abnormal load due to lateral shifting from the unstable first ray. Described as “first ray insufficiency,”[5] this pathologic condition has been associated with and proposed to lead to other compensatory pathologies.

Lapidus [6] proposed an association between first ray hypermobility and hallux valgus. The first ray elevates, diverges medially, and rotates with the valgus deformity of the hallux, considered compensatory to the malaligned position of the first ray.[7] He advocated arthrodesis in treating the deformity in the 1930s. Klaue et al. suggested a direct relationship

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between painful hallux valgus deformity and hypermobility of the first metatarsocuneiform joint.[8,9] They selected patients with clinical hallux valgus and evaluated first ray mobility during gait. They noted motion in the sagittal plane with a center of rotation just distal to the naviculocuneiform joint, using a custom-modified ankle-foot orthosis. Carl et al.[9,10] showed a correlation between symptomatic hallux valgus and a generalized hypermobility, when compared to control groups.

Theoretically, hypermobility of the first ray contributes to second metatarsophalangeal synovitis and instability, lesser metatarsal fractures, and posterior tibial tendon dysfunction.[11] The vertical ground reaction force elevates the hypermobile first ray, transferring the load to the lesser metatarsals. Myerson et al.[12] identified the medial cortex of the second metatarsal to be hypertrophied, indicating overload, in patients classified as having a hypermobile first ray. This concept is widely accepted with little objective data supporting it. Grebing et al.[13] studied the reliability of this radiographic sign and found no association between first ray mobility and cortical hypertrophy. Although compared to normal feet, Wong et al.[1] determined that the hypermobile foot has higher resultant metatarsocuneiform and metatarsophalangeal joint forces, after investigating joint forces during walking, using a 3D foot model.

**Anatomy & Biomechanics**

The medial longitudinal arch functions as the paramount load-bearing structure in the foot[14] which is dependent on the first ray for optimal support during gait.[4] The first ray is a single foot segment consisting of the first metatarsal and first cuneiform bone. During ambulation, the first ray exhibits dichotomous action in shock dissipation during heel impact and stabilization during propulsion.[14,15] About two-third of the body weight is transferred through the first ray during gait.[1,16] The first ray’s capability to load-bear and improve flexor hallucis longus’ mechanical advantage is accomplished by the two sesamoids bones underneath the first metatarsal head.[14]

A curved beam and a truss (Fig. 1) symbolizes the medial arch.[17,18] Beams are designed to withstand bending under an applied force. A truss is a triangular framework with two rigid supports connected together at its base. Truss-and beam mechanics of the foot rely on the first ray to function as the pillar for the medial arch. The first ray, therefore, is a critical element in controlling the structural integrity of the foot.[4]

**Fig. 1: Truss-and beam representation of the medial arch [14]**

Hicks[18] estimated that the axis of rotation for the first ray runs nearly horizontal from the posteromedial foot in an anterolateral direction (Fig.2). This positioning indicates that the first ray exhibits triplanar movement, which means that the first ray simultaneously undergoes dorsiflexion and inversion or plantarflexion and eversion. [19]

In the sagittal plane, the most important stabilizing factor is the plantar first metatarsocuneiform ligament. Mizel [9, 20] demonstrated in a cadaveric study that when cutting the plantar ligament to the first metatarsocuneiform joint, there is as much as 5 mm of dorsal displacement of the metatarsal relative to the cuneiform. This suggests that the plantar soft-tissue structures are very important in preventing dorsal translation at the metatarsocuneiform joint level. Grebing and Coughlin [21] evaluated the plantar fascia as it relates to first ray mobility with ankle position. They concluded that the plantar fascia is a key stabilizer of the first ray, as well. Also, other studies suggest that the plantar fascia attenuates intermetatarsal angle which leads to an increased first ray stability, without use of a joint sacrificing procedure.[9, 17]

**Fig. 2: Axis of rotation for the first ray [22]**

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When emphasizing the first ray’s functional importance, consideration should be taken to highlight the three different extrinsic muscles of the foot which insert at the base of the first ray.[23] The anterior tibialis, posterior tibialis, and peroneus longus muscles all act on the first ray to help maintain stability of the medial column of the foot, during the push-off phase of walking. Faber et al [24] suggested that the flexor hallucis longus and peroneus longus have stabilizing effects against the displacement force of the first tarsometatarsal joint to the dorsal position. In the transverse plane, the flexor hallucis longus tendon seems to be a destabilizing role by increasing the medial displacement of the hallux.

**Pathomechanics of the Hypermobile First Ray**

The biomechanics that make the foot rigid during terminal stance are disrupted by the hypermobile first ray.[4,14] When weight-bearing, the medial arch lowers and the foot widens, increasing tension on the plantar ligaments and plantar aponeurosis.[17] During propulsion, there is plantarflexion of the ankle and then dorsiflexion at the first metatarsophalangeal joint. This dorsiflexion activates the “windlass” mechanics of the medial arch, resulting in tightening of the plantar aponeurosis, elevating the arch, and promotes stabilization of the foot.[9,18] Conversely, a hypermobile first ray collapses the truss framework of the medial arch[4], decreasing the effectiveness of the foot-lever system needed for forward progression into propulsion.[5] The increasing joint force is due to the impaired shock absorption of the arch.[1] Rush et al [9] performed a cadaveric study that suggests that the windlass mechanism is more efficient, when the first metatarsal, sesamoid apparatus, and hallux position are properly aligned with the orientation of the plantar aponeurosis.

Failure of the first ray to plantar flex relative to the hallux during the propulsive sequence decreases the range of available dorsiflexion motion of the first metatarsophalangeal joint. Approximately 65 degrees of hallux dorsiflexion is required in gait. Root et al [21] measured hallux dorsiflexion to be 20 degrees from the ground in a standing position, hence the first metatarsal must plantarflex away from the hallux during normal gait. The unstable first ray elevates, decreasing the amount of dorsiflexion allowed at the first metatarsophalangeal joint at terminal stance. Furthermore, medial divergence and rotation of the first ray accompany this excessive dorsiflexion. Valgus deformity is theorized to be compensation for this malalignment.[14] This hypermobility in the transverse plane increases the intermetatarsal angle and analyzed radiographically by the use of the radiographic squeeze test (Fig. 3a-c), as described by Romash et al [25] A plantar gap on the weight-bearing lateral films (Fig. 4) is indicative of instability and hypermobility at the first tarsometatarsal joint.[26]
Pronation of the midtarsal joint lasting into the late support phase diminishes the ability of the peroneus longus muscle to stabilize the first ray. Lowering of the medial arch is the result of prolonged period of pronation by the diminished ability of the peroneus longus muscle to help stabilize the first metatarsal.\[27\] As a consequence, ligamentous tissues that limit end-range dorsiflexion movement of the first metatarsal are overly stressed, resulting in joint laxity.\[14\]

**Quantifying Hypermobility**

The first ray clinical mobility test described by Root et al.\[21\] involves placing the ankle and the subtalar joint (STJ) in neutral positions while one hand stabilizes the second, through fifth metatarsal heads, and the other hand stabilizes the first metatarsal head. In this position, the first metatarsal head is passed into full dorsiflexion and full plantarflexion, until a “soft endpoint” is reached. The range of motion in both directions is determined by comparing the position of the examiners fingernails dorsally and thumb nails plantarly (Fig. 5ab).

Since the introduction to this objective exam, the magnitude of sagittal plane dorsal movement of the first ray in a non-weight bearing position has been shown to average approximately 6mm±3mm in young adults without disease.\[8, 11,28\] However, most of these methods of measurement have proven to be impractical for routine clinical application due to poor intrarater reliability, the devices’ bulky size, intricate operation requirements, and/or the need for accompanying procedures such as radiology.\[23,29,30\] This suggests that a new more reliable clinical test is required as hypermobility has prove to be pathologic.

*Dynamic Hick’s Test [31]*

Similar to the Root’s technique, the ankle and STJ is in neutral positions, while one hand stabilizes the second through fifth metatarsal heads, and the other hand stabilizes the first metatarsal head. The hallux is fully dorsiflexed at the first metatarsophalangeal joint (MTPJ) while a dorsal and plantar directed force are applied to the first metatarsal head to evaluate motion \[32\] (Fig. 6). The dynamic Hicks technique was developed in an attempt to identify those hallux valgus deformities that would not be adequately corrected on a long-term basis, through the use of basal and/or head-neck-shaft osteotomies of the first metatarsal with distal soft-tissue release and realignment.\[9\]

![Fig. 5ab: Root’s Technique [22]](image)

![Fig. 6: Dynamic Hick’s Test [31]](image)
**Klaue Device[8]**

This device is a modified AFO with accommodated forefoot plate and micrometer (Fig. 7a). The foot is immobilized with a stock and straps to the AFO. A rail is fixed at the heel part of the AFO and holds a plexiglass plate that can be used in two ways for both left and right feet. This supports an aluminum plate through three threaded bars that in turn fits snugly to the lesser metatarsals with the foot in plantigrade position. A vertical bar is rigidly fixed onto the plate (external fixator) and a micrometer is positioned prone to the critical point on the first ray (head or basis of the first metatarsal). The first ray is held in neutral position (flexion-extension), by a smaller movable plate. In relation to this position, the first ray is passively extended and the excursion measured on the metatarsal head and bases. The validity and reliability of this device has been exhibited in several studies, as well as compared with other methods.[11,24]

Classically, hypermobility of the first ray has only been measured in a dorsal (vertical) direction, whereas a hallux valgus angle and an intermetatarsal angle are only measured in a transverse plane. Singh et al [33] examined 600 feet using the Klaue device and concluded that the weight bearing foot pronates during gait and the first metatarsal is displaced in a dorsomedial direction, rather than a pure dorsal direction. It is suggested that measuring hypermobility of the first ray at a 45° dorsomedial direction is more appropriate (Fig 7b).

**Glasoe Device[11]**

The freestanding device uses a customized immobilizer boot for rearfoot stabilization. A screw tightened clamp (Fig. 8a) prevents second through fifth metatarsal movement during testing. The first ray platform (Fig. 8b) cradles the head of the first metatarsal, independent from the remainder of the forefoot. A dorsiflexing force is applied by tightening a screw mechanism that elevates the first ray. The force applied is measured by a load cell (Fig. 8c) with output recorded from a signal conditioner-indicator (Fig. 8d) in newton of force.

Glasoe et al [11] tested this device on twelve fresh frozen cadavers with a maximum force of 85N. This study demonstrated the device is reliable and valid, when measuring vertical displacement of the first ray at load forces of 55 N or less. A majority of secondary movement error occurred at the second metatarsal. The device was unable to prevent movement of the second metatarsal, when testing at 85N of force. Elevation of the first ray drags the second metatarsal in a vertical direction, causing the device to overestimate the actual amount of displacement that occurred specific to the first ray.

![Fig. 7: (a) Klaue Device. (b) Device with first ray at a 45° dorsomedial direction. [33]](image1)

![Fig. 8: Glacose Device [11]](image2)
**EMC Device**

The EMC Instrument is used to determine mobility of the first ray of the foot. Two small plastic devices are used for measuring the mobility of the first ray, one as a scale and the other as an indicator (Fig. 9). This device is placed on the dorsal aspect of the metatarsal heads; therefore, reducing the error of compression of the fat pad from differences in thickness between the plantar fat pads of the first and second metatarsal heads, as previously discussed by Glasoe et al.[28] Kim et al [29] analyzed the validity of the EMC device in comparison to the modified Coleman block test developed by Fritz et al and the Klaue device. The results showed that this device has low interpersonal variation within measured values, low variation in multiple measurements by a single investigator, compact size, and simplicity of operation and construction of the device.

![Fig. 9: EMC Device][29]

Greisberg et al [34] built a device similar to EMC. The device was constructed by bending a metal engineering ruler to a right angle with reinforcing epoxy at the bend. They measured metatarsal translation with two different techniques. First, by holding the measuring devices dorsal to the metatarsal heads (Fig. 10a), similar to Kim et al. Then they placed the measuring devices plantar to the metatarsal heads (Fig. 10b). The examiner applied a dorsal/plantar force to the first metatarsal while stabilizing the lesser rays and the value of total metatarsal translation is read directly off the ruler. A positive value indicated elevation of the first metatarsal relative to the second, while a negative

![Fig. 10: Greisberg Device][34]

**Treatment**

In response to the theory that hypermobility causes HAV deformity, Lapidus established his classic first metatarsocuneiform fusion procedure for the operative correction of the bunion deformity.[6] The indications for arthrodesis at the metatarsocuneiform level are still an area of debate. Clark et al [35] distinguished that after first metatarsocuneiform arthrodesis, the first ray hypermobility was completely eliminated but they offered no objective measurement of preoperative and postoperative motion. Faber et al [36] compared the Lapidus to the Hohmann procedure, a closing-wedge-type osteotomy in the first metatarsal neck. They found the theory that
patients with hallux valgus and a hypermobile first tarsometatarsal joint should be managed with a Lapidus procedure was not supported.

Rush et al [9] suggest that perhaps with realignment of the ray through a metatarsal osteotomy and distal soft tissue rebalancing at the MTPJ, the hypermobility in the first ray can be reduced. Conversely, when the secondary constraints of the first ray begin to fail and the structural integrity of the first ray is compromised, an arthrodesis is an option with predictable results. Coughlin et al [37] noted that after proximal crescentic osteotomy and distal soft tissue reconstruction that the first ray mobility was significantly reduced. This suggested that extrinsic anatomic features play a role in stability, when the first metatarsocuneiform joint is undisturbed.

New Thoughts of Hypermobile First Ray

The association between first ray hypermobility and hallux valgus deformity has been a subject of controversy, especially when considering the etiology of the hallux valgus. This relationship is endorsed by evidence from only a few studies. Doty et al [22] suggest that isolated sagittal plane hypermobility is not the cause, but rather the result of a hallux valgus deformity. This comes after observing that mobility was consistently diminished to a normal level, following realignment procedures, sparing the first metatarsocuneiform joint.[37,38] The authors acknowledged that coronal mobility of the first metatarsocuneiform joint is necessary for the development of a hallux valgus deformity, yet re-establishment of the first ray alignment dramatically diminished the increased sagittal mobility.

Smith et al [39] showed that a hallux valgus deformity causes further exacerbation of a pre-existing hypermobility of the first ray. This is due to the hallux valgus deformity causing the dynamic restraints, including the plantar aponeurosis, sesamoids, and intrinsic musculature becoming compromised and malaligned.[9,17] Even though a painful hallux valgus deformity is more predominant in the existence of a hypermobile first ray, Roukis et al [31] assessed the incidence of true sagittal plane instability or hypermobility on the basis of their empiric observation of patients with symptomatic hallux valgus deformity to be only approximately 10 percent.

**Conclusion**

While the argument may never be settled, hypermobility is reasonably documented in the literature. It appears that the collapses of the medial arch sequentially weaken the surrounding soft tissues, causing a dorsal excursion of the first metatarsal.

There are several methods to identify individuals with this condition. Nonetheless, with several conflicting articles on the correlation between hallux valgus and hypermobility, as well as the treatment for hypermobile first ray, there is a need for supporting data to advocate the new theories on this topic.

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