In the nineteenth century, hallux valgus was thought to be due to an enlargement of the metatarsophalangeal joint of the great toe. It was not until Carl Huerter (1838-1882), a German-born surgeon, coined the term *hallux abducto valgus* that the deformity was more correctly described as a lateral deviation of the great toe at the metatarsophalangeal joint. A century of debate has failed to settle the importance of intrinsic versus extrinsic causes in the etiology of hallux valgus. In the 1950s, Sim-Fook and Hodgson compared shoe-wearing and non-shoe-wearing groups and showed a dramatic increase in the prevalence of hallux valgus among the shoe-wearing group. Unfortunately, it did not explain the prevalence of hallux valgus in the community of people who had never worn shoes, nor did it account for the many individuals who wear high-fashion footwear and never become affected. Clearly, the issue is more complex than simply a problem of footwear. Although much research has been done to define the multifactorial origin of hallux valgus and the effect of those factors on surgical outcomes, the quality and strength of this evidence have been variable.

**Pathoanatomy of Hallux Valgus**

**Development of Hallux Valgus (Figs. 1 through 4)**

It is generally accepted that hallux valgus occurs in steps, frequently on a background of several predisposing factors (Table I). These steps do not necessarily occur in series but may transpire in parallel. These steps are as follows:

1. As the only medial supporting structures of the first metatarsophalangeal joint are the medial sesamoid and medial collateral ligaments, their failure is the “early and essential lesion.”

2. The metatarsal head can then drift medially, slipping off the sesamoid apparatus. An oblique or an unstable tarso-metatarsal joint may encourage this movement.

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3. The proximal phalanx moves into a valgus position as it is tethered at its base to the sesamoids, the deep transverse ligament (via the plantar plate), and the adductor hallucis tendon.

4. The metatarsal head sits on the medial sesamoid and can erode the cartilage and the crista. The lateral sesamoid can appear to sit in the intermetatarsal space although it does not actually move.

**Fig. 1** Illustration of the medial view of the hallux, showing the medial structures whose failure is essential for hallux valgus deformity to occur. **Fig. 2** Illustration of the metatarsal head of the hallux in the anteroposterior plane, showing the medial shift of the metatarsal head (step 2 in the development of hallux valgus), with the valgus displacement of the proximal phalanx due to its attachment to the sesamoids, the deep transverse ligament (via the plantar plate), and the adductor hallucis tendon (step 3). The extensor hallucis longus bowstrings laterally (step 6).

**Fig. 3** Illustration showing the medial shift of the metatarsal head in the axial plane (step 2 in the development of hallux valgus) and the pronation of the metatarsal head that results from the muscle forces acting on it (step 7). The figure also illustrates the position of the sesamoids, abductor hallucis (AbH), adductor hallucis (AdH), flexor hallucis longus (FHL), and extensor hallucis longus (EHL). **Fig. 4** Illustration of the deformity of hallux valgus in the axial plane. The metatarsal is pronated and shifted medially, resulting in the lateral shift of the abductor hallucis (AbH), adductor hallucis (AdH), flexor hallucis longus (FHL), and extensor hallucis longus (EHL) (steps 6 and 8 in the development of hallux valgus). The bursa overlying the medial eminence thickens because of the pressure effect of footwear on a prominent medial eminence (step 5). Because of the pressure of the medial sesamoid on the crista, the cartilage is eroded and the crista flattened (step 4).
of the first ray. The sesamoids increase the moment arm of the flexor hallucis brevis, which powers plantar flexion of the hallux, and, finally, they function to elevate the first metatarsal head, which dissipates the forces on the metatarsal head\textsuperscript{12-16}. The first metatarsal head is elevated on the sesamoids during stance, but the sesamoids move during hallux dorsiflexion, coming to lie anterior to the metatarsal head rather than inferior. The sesamoid sling thus facilitates the first metatarsal plantar flexion that is essential for hallux dorsiflexion.

The sesamoids can appear to subluxate with first metatarsal pronation alone\textsuperscript{17,18}, but true subluxation requires a number of events to occur first. The joint reaction force of the metatarsosesamoid joint is normally sufficient to prevent subluxation\textsuperscript{19}. Thus, the metatarsosesamoid joint must become unloaded either by elevation of the first metatarsal head or by the transfer of plantar pressure laterally. Finally, the soft-tissue restraints and the cristae need to fail.

**First Ray Motion**

Morton believed that dorsal hypermobility of the first metatarsal segment was responsible for the widest array of foot deformity\textsuperscript{20}. However, several studies have questioned whether motion at the tarsometatarsal joint even exists\textsuperscript{21-24}. The studies that described motion of the first tarsometatarsal joint had no consensus with regard to either the axis of movement or the magnitude. In so-called normal feet, the small amount of movement permitted at the first tarsometatarsal joint is amplified by the long metatarsal shaft, resulting in an average dorsoplantar motion of 6 mm\textsuperscript{25}. However, the mean range of motion of the entire first ray in the foot with hallux valgus is significantly greater in both the sagittal and frontal planes.

**First Metatarsophalangeal Joint Motion**

The first metatarsophalangeal joint is a partial ball-and-socket joint rather than a simple hinge. When the hallux is held stable (as in push-off), the kinematic coupling of the first ray and the ankle joint motion results in a frontal plane rotation, pronating the great toe and causing a medial transverse plane motion. These motions both increase the loading on the medial aspect of the toe\textsuperscript{26}, creating a valgus moment at the metatarsophalangeal joint.

With the foot flat on the ground and loaded evenly (i.e., midstance), the dorsiflexion of the metatarsophalangeal joint is limited to approximately 20° as further motion requires plantar flexion of the first metatarsal\textsuperscript{27}. The phalanx and metatarsal are coupled such that 1° of phalangeal dorsiflexion requires 3° of metatarsal plantar flexion\textsuperscript{28}. The spiral-shaped nature of the metatarsal head\textsuperscript{29} forces a translational sliding motion as the proximal phalanx rotates\textsuperscript{30,31}. Thus, the locus of the axis of rotation has to move in an arc\textsuperscript{32} that necessitates metatarsal motion proximally and plantarward in order to avoid compression at the metatarsophalangeal joint. Prevention of this plantar flexion hinders dorsiflexion of the first metatarsophalangeal joint even when non-weight-bearing\textsuperscript{33}. Plantar flexion of the first ray also maintains ground contact during heel rise when the obliquity of the metatarsophalangeal break, which is

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### TABLE I Potential Intrinsic and Extrinsic Factors

<table>
<thead>
<tr>
<th>Extrinsic</th>
<th>Intrinsic</th>
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<tbody>
<tr>
<td>High-heeled narrow shoes</td>
<td>Genetics</td>
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<tr>
<td>Excessive weight-bearing</td>
<td>Ligamentous laxity</td>
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<td>Metatarsus primus varus</td>
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<td>Pes planus</td>
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<td>Age</td>
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<tr>
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<td>Metatarsal morphology</td>
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<td></td>
<td>First-ray hypermobility</td>
</tr>
<tr>
<td></td>
<td>Tight Achilles tendon</td>
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</tbody>
</table>

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5. The bursa overlying the medial eminence can thicken because of the pressure effect of footwear on a prominent medial eminence.

6. The extensor and flexor hallucis longus tendons appear to bowstring laterally\textsuperscript{7}, increasing the valgus displacement and occasionally acting as dorsiflexors of the proximal phalanx.

7. As the metatarsal head drops off the sesamoid apparatus, it pronates because of the muscle forces acting across it.

8. Normally, the abductor hallucis strongly resists valgus of the proximal phalanx, but it becomes dysfunctional as its medial and plantar attachment rotates inferiorly\textsuperscript{8}. The adductor hallucis is attached on the plantar surface laterally so it tends to pull the phalanx into pronation as well as tethering its base.

9. The weaker dorsal metatarsophalangeal joint capsule is not reinforced by any tendons and rotates medially with pronation and provides poor stability\textsuperscript{9}.

10. The metatarsal head elevation with medial motion can transfer plantar pressure laterally. The relatively mobile fifth metatarsal may also splay.

**First Ray Biomechanics**

The first ray plays a key role in maintaining the structure of the medial arch\textsuperscript{1}, and as the main load-bearing structure\textsuperscript{10}, it is subject to substantial forces during gait. Failure anywhere along the first ray, from the distal phalanx to the talonavicular joint, can result in hallux valgus. It is therefore worth considering the first ray biomechanics as a common factor to many of the key theories. There are no tendon attachments on the metatarsal head, and maintenance of this inherently unstable axial array requires (1) a congruent and stable metatarsophalangeal joint during push-off, (2) a distal metatarsal articulation angle that encourages stability, (3) balanced static and dynamic restraints, and (4) a stable tarsometatarsal joint\textsuperscript{11}.

**Sesamoids**

The functions of the sesamoid bones are, first, to absorb weight-bearing forces and enhance the load-bearing capacity...
the axis of the four lateral metatarsophalangeal joints, is enhanced during late stance, causing lower-extremity external rotation and inversion of the subtal joint.

Normal gait uses up to 65° of first metatarsophalangeal dorsiflexion, and first ray elevation substantially compromises this range of motion. Furthermore, the normal hallux has a tendency toward valgus (and any pronation further encourages this tendency). This combination means that, when dorsiflexion is restricted, the toe is forced to “escape” laterally in the direction of least resistance. As the transverse sphericity of the first metatarsal head permits multiplanar motion, the collaterals, sesamoids, and the so-called rein effect of the first metatarsophalangeal joint rotator cuff are all required for stability.

**Etiology of Hallux Valgus**

The different factors can be divided into extrinsic and intrinsic risks (Table I).

### Extrinsic Factors

#### Footwear

Even prior to the understanding of hallux valgus pathology, the use of footwear has been implicated as an etiology. In 1909, Porter advised against performing corrective surgery on patients unwilling to wear appropriate footwear because of a greater risk of recurrence of the deformity. There is a low prevalence of hallux valgus in unshod populations, and the prevalence increases with changes in shoe fashion. However, the association is not complete, and footwear is not at all important in juvenile hallux valgus.

High heels are commonly blamed for hallux valgus, and there is a direct association between increased first metatarsal loading and a valgus moment. This forefoot loading is exacerbated by the forefoot sliding forward into the toe-box, pronating as it does so. A third of the population naturally favors a tendency toward valgus (and any pronation further encourages this tendency). This combination means that, when dorsiflexion is restricted, the toe is forced to “escape” laterally in the direction of least resistance. As the transverse sphericity of the first metatarsal head permits multiplanar motion, the collaterals, sesamoids, and the so-called rein effect of the first metatarsophalangeal joint rotator cuff are all required for stability.

#### Intrinsic Factors

Genetic Factors

A genetic predisposition has long been suspected. Among the inheritable factors that may be relevant are metatarsal formula, arch height, and hypermobility. The best evidence showed that 90% of 350 white patients had at least one affected relative, with the most common pattern of inheritance being autosomal dominant with incomplete penetrance. The role of genetics in juvenile and young adult hallux valgus is much more established, with maternal transmission found in 94% (twenty-nine) of thirty-one patients with a family history.

Sexual Dimorphism

The true sex ratio is unknown, although the male-to-female ratio of 1:1.5 among those who have corrective surgery is well established. The higher prevalence among women may be due to footwear that is either poor (up to 90% of shoes in a survey of 365 women were too small) or less forgiving, resulting in earlier and more frequent presentation. Nevertheless, the prevalence is still greater in women, but there is no quality evidence to support the finding. Even less is known of the prevalence between the sexes with regard to juvenile hallux valgus.

<table>
<thead>
<tr>
<th>Deformity</th>
<th>Shod Feet (%)</th>
<th>Unshod Feet (%)</th>
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</thead>
<tbody>
<tr>
<td>Hallux valgus</td>
<td>33</td>
<td>2</td>
</tr>
<tr>
<td>Flatfoot</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Atavistic forefoot</td>
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<td>Metatarsus elevatus</td>
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<tr>
<td>Metatarsus primus varus</td>
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<td>25</td>
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<tr>
<td>Hypermobility of the metatarsus</td>
<td>1</td>
<td>13</td>
</tr>
</tbody>
</table>

*The data are from the study by Sim-Fook and Hodgson. There were 318 subjects in the group that wore shoes and 107 subjects in the group that did not wear shoes.
juvenile hallux valgus

Metatarsus Primus Varus

A biomechanical study in elderly patients

Mild ligamentous laxity is common in women with hallux valgus and has been reported in 70% of seventy patients with juvenile hallux valgus. Therefore, in conditions with generalized ligamentous laxity, such as Marfan syndrome, Ehlers-Danlos syndrome, and rheumatoid arthritis, hallux valgus is more common and more difficult to treat. It is interesting, although counterintuitive, that the only study assessing laxity with use of the Brighton scoring system failed to find any association between generalized ligamentous laxity and hallux valgus. Despite the fact that patients with laxity have a major risk for recurrence, little work has been done on this condition.

Age

A biomechanical study in elderly patients showed that changes in posture, joint kinematics, and plantar pressure are associated with a greater risk of hallux valgus. However, age is a poor predictor of hallux valgus angle. Although the peak onset is from thirty to sixty years of age, it is more likely that the initial changes occur during adolescence or even earlier for juvenile hallux valgus.

Metatarsus Primus Varus

The association between metatarsus primus varus and hallux valgus is well known, but it is not clear whether it is a cause or an effect. Argued that metatarsus primus varus comes first, stating that, as the abductor hallucis tendon subluxates inferiorly, it becomes dysfunctional, resulting in hallux valgus. Metatarsus primus varus is important in juvenile hallux valgus and has been reported to be found in up to 75% of such patients (forty-nine of sixty-five). This rate is greater than the prevalence in patients with adult hallux valgus (57% of 122 subjects) and in the general population (1% of 635 subjects), but the appearance of metatarsus primus varus lags behind the development of the hallux valgus.

A weak association has been found between the magnitude of metatarsus primus varus and hallux valgus in women, but the evidence shows that it is related to the choice of footwear. No direct association is found until the deformity becomes severe and self-propagating by that stage, muscle compression forces push the metatarsal head medially with a force equal to the posterior shear force of the hallux on the ground times the hallux valgus angle.

Snijders et al. concluded that the metatarsus primus varus was secondary to the toe deformity, on the basis of biomechanical investigations. This finding supports the observation that when hallux valgus is corrected, the metatarsus primus varus can improve without an attempted correction of the first metatarsal itself. This has been shown for basal osteotomy, first metatarsal phalangeal joint fusion, and even Keller osteotomy, suggesting that metatarsus primus varus is a secondary phenomenon. Cronin et al. believed that the adductor hallucis was a deforming force that could be used after fusion to adduct the entire ray without a basal first metatarsal osteotomy.

It appears that some people have an innate propensity toward metatarsus primus varus and are at risk of juvenile hallux valgus. If they wear high-heeled or small toe-box footwear, they have an increased risk of developing adult hallux valgus. In severe hallux valgus, a self-propagating cycle of worsening hallux valgus and metatarsus primus varus can develop.

Metatarsal Anatomy

Metatarsal dimension: Metatarsal formula refers to the relative lengths of the metatarsals. The normal order in terms of decreasing length is second, third, fourth, and then fifth, but the first and third are commonly equal in length. Morton described the short first metatarsal of Morton foot that he believed led to pronation and hypermobility of the first ray and therefore hallux valgus. There is no clinical evidence for this relationship, and more reliable measurement techniques have found the true association to be as low as 4%.

Mancuso et al. found that 80% of 110 patients with hallux valgus had a so-called zero-plus first metatarsal (i.e., it was equal to or greater in length than the second metatarsal), whereas 80% of 100 control subjects had shorter first metatarsals. According to Root et al., the long first metatarsal acts as a “functional metatarsus primus elevatus” as it cannot plantar flex below the transverse plane. This additional length inhibits metatarsophalangeal joint dorsiflexion and can cause subluxation.

A long first metatarsal creates a so-called buckle point, resulting in a hallux valgus with a high intermetatarsal angle, and there is a strong association between protrusion distance and intermetatarsal angle. On this basis, Mancuso et al. advocated that the definition of so-called normal metatarsal protrusion should be reduced to –2 to 0 mm from the accepted standard of –2 to +2 mm. It is important to remember that pronation of the foot causes metatarsal dorsiflexion, making it appear longer than it actually is. However, the new definition does not necessarily refute the theories regarding the long first metatarsal, as the function of the foot when weight-bearing is the important factor.

Metatarsal articular morphology: Heden and Sorto observed that a round first metatarsal head is common in hallux valgus (occurring in 90% of 100 affected subjects compared with 20% of 210 control subjects). A round first metatarsal head creates a more unstable articulation than other shapes and is associated with a higher rate of recurrence of hallux valgus. The round-shaped head is unlikely to be due to remodeling as it is not associated with any degenerative change. The flattened,
so-called square or chevron-shaped head is more stable^49,115. Phillips^16 noted that, as the vector of the extensor and flexor tendons runs through the vertical axis of motion, the articulation behaves somewhat like a hinge. However, the more rounded it is, the closer the vertical axis lies to the surface. Thus, even small displacements medially or laterally can produce greater angular changes than in a flattened head^66,115.

The biggest objection to this theory is that it is not clear whether the described head shapes are truly discrete anatomical entities, and magnetic resonance imaging studies support this observation^115. These appearances may be spurious, as apparent shape varies with metatarsal pronation and inclination^67-114. Unfortunately, there is still no consistent or accurate method of describing metatarsal head shape or of taking into account the concept of traveling distance of the head^119.

Measurement of the distal metatarsal articular angle is notoriously unreliable^120, and there is a very wide variation (–14° to +30°) of normal. However, a congruent metatarsophalangeal joint in hallux valgus requires an altered distal metatarsal articular angle, and the two are directly related^14. This relationship is strongest for juvenile hallux valgus^41, suggesting a congenital origin especially as degeneration of the joint is rare^122. But there is evidence of a 1° to 3° increase in the distal metatarsal articular angle with every decade of life, suggesting that it may be acquired^122. It is interesting that the congruent metatarsophalangeal joint appears to be more stable and less likely to progress^92. There is no association with metatarsal length, adduction, mobility, range of motion, or inheritance^98.

The proximal metatarsal articulation shows individual variation and an association between obliquity and hallux valgus^123,124. This association appears well established; however, these studies are all based on radiographic appearances, and apparent angulation varies considerably with foot posture^121. Intermetatarsal facets occur in approximately one-third of humans^126 and are associated with metatarsus primus varus and increased obliquity of the first tarsometatarsal joint^127 but not with hallux valgus^9,122.

Recent unpublished work presented at a British Orthopaedic Foot & Ankle Society meeting, held in Nottingham in 2010, indicated that the proximal articular morphology varies. The authors found that an articular surface with a single facet was associated with hallux valgus, and an articular surface with three facets only occurred in subjects with normal feet. They hypothesized that the increasing number of articular facets evoked stability^28.

Metatarsal bunion: The bunion is not an osteophyte^7, new bone formation^129, or ossification of inflamed tissues. There is actually no increase in the size of the medial eminence^49,130. Instead, the metatarsal head is increasingly exposed by cartilage loss because of the lack of contact from the phalanx^115. The sagittal groove, which is a thinning of the articular cartilage that develops laterally on the metatarsal head, is thought to be caused by pressure from the phalangeal margin^130. It is an area of minimal pressure (or fossa nudata)^132, and robust histological data have shown that it is due to a lack of stimulation rather than erosion^16. As the sagittal groove moves laterally with increasing hallux valgus deformity, it is not considered an indication for bunionectomy in severe hallux valgus^3.

Metatarsal Biomechanics

Static stabilizers around the first metatarsophalangeal joint: No musculotendinous structures attach to the metatarsal head. The only structures on the medial side are the capsule, collateral ligament, and medial sesamoid ligament. These structures are the most important joint stabilizers, and their insufficiency is essential for the development of deformity. Sectioning them alone results in a valgus angulation of >20°^122. These structures are mechanically abnormal in hallux valgus, with altered organization of the type-I and type-III collagen, leaving the first metatarsophalangeal joint vulnerable to continuous and cyclical distraction during gait^133. The insufficiency of these structures is more likely effect than cause unless it is part of a generalized ligamentous laxity.

McBride^9 advocated transverse metatarsal ligament transaction for correction, but there is no radiographic evidence to support the use of this procedure^46. This finding is not surprising as the deep transverse ligament joins the five plantar pads together and not the metatarsal heads^124. Sectioning the transverse ligament hardly changes the valgus deformity and does not alter the relationship between the first and second metatarsals^157. The lateral sesamoid is held by the transverse ligament and the adductor hallucis via the conjoined tendon and does not move. It is the medial sesamoid ligament that fails^9.

Dynamic stabilizers around the first metatarsophalangeal joint: The abductor hallucis abducts, plantar flexes, and inverts the great toe, while the adductor hallucis adducts, plantar flexes, and everts the toe, providing a balanced so-called plantar rotator cuff. When these moment arms are altered, the imbalance plays an important role in deformity progression. Suggestions of a primary muscle imbalance based on histological and electromyographic studies^106,137 probably reflect changes secondary to the deformity^138.

Normal variations in the attachment of the abductor hallucis have been described, but no association with hallux valgus has been found^139. The abductor hallucis also has a secondary role as a medial arch support and, when the tendon becomes dysfunctional in hallux valgus, it may be responsible for some of the tibialis posterior dysfunction^140. There is no evidence of shortening or overactivity of the adductor tendon, although botulinum toxin injection into the muscle has successfully treated hallux valgus^141.

Snijders et al. ^38 and Sanders et al. ^142,143 studied the role of flexion forces in the etiology of hallux valgus. Downward pull of the hallux onto the ground creates a force couple with a valgus moment on the hallux and a varus moment on the first metatarsal head, producing medial deviation and widening of the foot. In the normal subjects studied, the foot narrowed. In addition, the further the flexor hallucis longus is from the first metatarsal head, the weaker the moment arm of the flexor and the greater all three deformities become^144. The moment arm of the flexors moves from an inferior to a lateral direction as the great toe pronates or moves into valgus^145.
Migration of the sesamoids over the crista is important in deformity progression\textsuperscript{146,147}. When the medial sesamoid ligament is attenuated\textsuperscript{26} and the loss of the restraint provided by the crista\textsuperscript{148} occurs, deterioration can be rapid. The twofold increase in the prevalence of bipartite tibial sesamoids in feet with hallux valgus\textsuperscript{149} is unexplained\textsuperscript{150}.

**Metatarsal Kinematics**

The first-ray hypermobility theory states that the plane of motion of the first ray described by Hicks\textsuperscript{151} is exaggerated\textsuperscript{26} because of tarsometatarsal joint instability. There are no ligamentous structures binding the distal first and second metatarsals so the first tarsometatarsal joint can be affected by a number of factors, including pes planus, a long hallux, or a functional equinus of the foot\textsuperscript{152}. The elevation causes the pressures under the first metatarsal head to reduce. However, the pronation and varus moments cause a relative increase in the load on the medial side of the great toe, resulting in a valgus moment on the hallux\textsuperscript{153}.

The reported increased recurrence of hallux valgus after surgical correction when the first tarsometatarsal joint is not fused\textsuperscript{154} is disputed\textsuperscript{155}. Furthermore, it has been shown that ray realignment alone can stabilize sagittal motion without tarsometatarsal joint fusion\textsuperscript{156,157}, probably because of a realignment of the plantar fascia improving the windlass mechanism\textsuperscript{156,157}. This raises the question of whether the corollary is correct, i.e., is the instability due to a reduction in soft-tissue stability resulting from the malalignment\textsuperscript{158} or is the malalignment a result of reduction in soft-tissue stability?

Hypermobility is still not well understood\textsuperscript{159}, and data on the effect of first tarsometatarsal joint fusion are lacking. Interestingly, hypermobility usually refers to sagittal plane motion, but transverse plane motion (i.e., metatarsus primus varus) may be in fact more important\textsuperscript{160,161}.

**Pes Planus**

Much has been written\textsuperscript{148,162} about the role of pes planus in the etiology of hallux valgus\textsuperscript{163}. The mechanism appears obvious, i.e., pronation increases loading on the plantar medial border of the hallux during heel rise, but there are several other changes\textsuperscript{164}.

1. Pes planus produces an elevation and thus a functional lengthening of the first metatarsal\textsuperscript{164}, which can limit first metatarsal phalangeal joint movement.

2. The peroneus longus is less able to stabilize the first ray\textsuperscript{165}. If this insufficiency is prolonged, hypermobility of the first ray can result\textsuperscript{166}.

3. In the planovalgus foot, hindfoot and midfoot eversion reduce the load on the first metatarsophalangeal joint, although weight-bearing through the medial arch increases. This change is due to the relative mobility of the first tarsometatarsal joint compared with the second tarsometatarsal joint and the loss of the pull of the peroneus longus\textsuperscript{166}.

4. As the hindfoot everts, the foot becomes abducted to the line of progression, increasing the abduction force in dorsiflexion on heel rise.

5. There is early and excessive firing of the abductor and adductor hallucis in the pronated foot\textsuperscript{167,168}. Their line of pull alters as the sesamoids rotate, resulting in an overall valgus moment\textsuperscript{169}.

Coughlin et al.\textsuperscript{17} showed that, as the foot pronates, the first ray also rotates on its longitudinal axis. The first metatarsophalangeal joint collaterals are somewhat loose, allowing up to 2 mm of translation in the transverse plane on dorsiflexion\textsuperscript{170}, which can result in a repetitive injury to the medial restraints. With pronation comes axial rotation of the so-called plantar rotator cuff\textsuperscript{79} that further exacerbates the deformity\textsuperscript{171}.

Despite the commonly held belief that pes planus plays an important role in hallux valgus, there is cogent pedobarographic and radiographic evidence to the contrary\textsuperscript{14,53,73,172,173}, especially in juvenile hallux valgus\textsuperscript{13,172}. Coughlin and Jones\textsuperscript{73} assessed several different measures of pes planus in hallux valgus and found none to be significant. A link was detected between the prevalence of plantar gapping of the first tarsometatarsal joint and severity of hallux valgus, but this may be effect rather than cause. No study has looked at the prevalence of hallux valgus in pes planus. The association is likely to be far from 100%, given the difference between the relative prevalence of the two (i.e., a 20% rate of pes planus\textsuperscript{172} versus a 2% to 4% rate of hallux valgus\textsuperscript{173}). It is important to note that even studies implicating pes planus found rates close to this background rate\textsuperscript{174}. Mann and Coughlin\textsuperscript{73} believed pes planus to be only clinically relevant in patients with a background of neuromuscular deficit.

Given the proposed mechanism by which pes planus causes hallux valgus, correction of the hallux valgus in isolation should be associated with a higher recurrence rate. However, this has not been the case\textsuperscript{165,166,172,173}, although only one study\textsuperscript{170} looked at older patients in whom the biomechanical abnormalities had a longer time to produce an acquired deformity.

Eustace et al. showed that first metatarsal pronation is associated with hallux valgus and increases as the intermetatarsal angle increases, such that pronation and varus are intimately related\textsuperscript{176}. Furthermore, they showed that medial longitudinal arch collapse is also associated with first metatarsal pronation\textsuperscript{176} (a medial arch of <20° is associated with a first metatarsal pronation of >10°). They were unable to demonstrate which comes first, but it is logical when one considers the forces involved that arch collapse drives the pronation rather than vice versa\textsuperscript{177}.

At present, the most that can be said is that any individual with pes planus and hallux valgus is at risk for a more rapid progression because of the forces that encourage further deformity\textsuperscript{177}.

**Functional Hallux Limitus**

Structural hallux limitus is a limitation of dorsiflexion on both weight-bearing (<12°) and non-weight-bearing (<50°). It can predispose to hallux rigidus, which is not relevant to this review. Functional hallux limitus, on the other hand, describes limitation of motion on weight-bearing only. This poorly understood condition was first described, as far as we know, in 1972\textsuperscript{178}, but there continues to be little information
on this subject in the orthopaedic literature to either confirm or refute it. In essence, functional hallux limitus refers to the restriction of hallux dorsiflexion that occurs when the first ray is dorsiflexed. It can be observed to an extent even in normal feet and is due to the axis of rotation of the joint shifting plantarward as the first ray elevates\(^{179}\). Functional hallux limitus is purported to predispose to either hallux rigidus or hallux valgus\(^{180}\), depending on the coexisting biomechanics of the foot.

In hallux valgus, structural hallux limitus appears to be exaggerated and the passive range of motion at the metatarsophalangeal joint commonly reduces on weight-bearing\(^{49}\). The proposed link is that certain foot types (i.e., an everted hindfoot, a flexible forefoot valgus, or a plantar-flexed first ray)\(^{181}\) increase ground reaction force under the first metatarsal head (Fig. 5). The predisposed foot types also increase the ground reaction force for longer in the gait cycle\(^{182}\). Feet with good midtarsal movement can accommodate this first ray elevation. As the first ray dorsiflexes, the axis of the first metatarsophalangeal joint inverts, so the greater the elevation the greater the inversion. As the metatarsophalangeal joint dorsiflexion is limited at heel rise, the hallux is forced in the direction of least resistance. So feet with a great deal of mobility in the first ray are at risk of hallux valgus. This theory seems to fit in well with some of the other theories of the pathogenesis of hallux valgus, and there is evidence that a dorsiflexed first metatarsal is important\(^{180}\). This biomechanical theory still is not proven. The actual prevalence of functional hallux limitus and subsequent hallux valgus is low.

Windlass Model
The windlass model explains these findings more simply\(^{183}\). An increase in hallux valgus deformity on weight-bearing\(^{184}\) is due to tightening of the plantar fascia and the pronation effect of weight-bearing\(^{185}\). When this motion is excessive, the plantar aponeurosis is further tightened\(^{186}\). On heel rise, the first metatarsophalangeal joint has to dorsiflex to the same extent, activating the windlass mechanism. This tension can prevent the hallux from dorsiflexing. When the heel is lifted off the ground, the metatarsophalangeal joint should dorsiflex to an equal degree, but a tight plantar fascia causes a plantar flexion moment on the hallux. This plantar flexion moment opposes the dorsiflexion moment of the ground reaction forces on the hallux, causing it to veer along the path of least resistance. If the dorsiflexion forces are transmitted by a relatively rigid first metatarsophalangeal joint through to the first metatarsal, then this could explain the hypermobility often seen in the first ray\(^{156}\).

Tight Achilles Tendon
Mann and Coughlin\(^{53}\) and Hansen\(^{185}\) postulated that a tight Achilles tendon can predispose to hallux valgus. This is because of early and increased forefoot loading\(^{186}\). The natural tendency is to externally rotate the foot, rolling over the medial border rather than going forward through the third rocker (i.e., toe off, which is dorsiflexion at the metatarsophalangeal joint with concentric contraction of the gastrocnemius), increasing the valgus force. The evidence comes mainly from work done with diabetic ulcers\(^{187}\), but there is evidence of an association with hallux valgus if there is <5° of dorsiflexion at the ankle\(^{188}\). Clinical studies of hallux valgus have echoed this finding, but only if Achilles tendon tightness is defined as being <10° of dorsiflexion at the ankle\(^{189}\). Others have found no association\(^{35,189}\), and there is no evidence that failure to address Achilles tendon tightness results in a higher recurrence of hallux valgus\(^{107}\).

Overview
Hallux valgus is a complex condition with a range of deformities varying in severity, suggesting that several factors are responsible. Inheritance and sex are important, but other
anatomical and biomechanical factors, such as anatomical metatarsal variants, including a long first metatarsal (probably most important in men\textsuperscript{16}), a rounded articulation, and metatarsus primus varus, play an important role. These variants increase the vulnerability to first-ray hypermobility, pes planus, and ligamentous laxity.

The toe is at risk if loading is increased on the medial side. If the forefoot is in a narrow toe-box or pronated because of a hypermobile first ray or pes planus, the altered muscle pull can combine with the ground reaction forces and be sufficient to result in repetitive injury to the medial tissues. There is a lack of evidence of a sufficient scientific level to support or disprove the role of pes planus, first-ray instability\textsuperscript{17}, or functional hallux limitus, although all have some intellectual appeal and possibly some basis in terms of treatment response.

In the normal foot, there is a tendency for the great toe to be pulled into valgus, but the static restraints (the ligaments and the sesamoid apparatus) act like reins, preventing this tendency\textsuperscript{18}. The muscles attached to the base of the phalanx help to control the metatarsal head. Once the metatarsal head starts to escape, this control diminishes and the muscles may become deforming forces instead\textsuperscript{19}. The deep transverse ligament (and to an extent the adductor) holds the phalanx in place, while the incompetent medial sesamoid ligament and medial collateral ligament allow the metatarsal head to drift into varus.

We know that poor footwear is a risk, and yet few people who wear high-fashion ladies’ shoes develop hallux valgus. The same can be said of the other potential causes. The true answer lies in the interplay of the various intrinsic and extrinsic factors that come together in any one particular foot. Without large-scale population studies or longitudinal studies, there will always be some unanswered questions on the true pathogenesis and optimal treatment of hallux valgus.

References