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FOOT & ANKLE

# The first tarsometatarsal joint and its association with hallux valgus

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## Introduction

**The aetiology of hallux valgus is almost certainly multifactoral. The biomechanics of the first ray is a common factor to most. There is very little literature examining the anatomy of the proximal metatarsal articular surface and its relationship to hallux valgus deformity.**

## Methods

**We examined 42 feet from 23 specimens in this anatomical dissection study.**

## Results

**This analysis revealed three distinct articular subtypes. Type 1 had one single facet, type 2 had two distinct articular facets, and type 3 had three articular facets one of which was a lateral inferior facet elevated from the first. Type 1 joints occurred exclusively in the hallux valgus specimens, while type 3 joints occurred exclusively in normal specimens. Type 2 joints occurred in both hallux valgus and normal specimens. Another consistent finding in regards to the proximal articular surface of the first metatarsal was the lateral plantar prominence. This prominence possessed its own articular surface in type 3 joints and was significantly flatter in specimens with hallux valgus ($p < 0.001$) and the angle with the joint was significantly more obtuse ($p < 0.001$).**

## Conclusions

**We believe the size and acute angle of this prominence gives structural mechanical impedance to movement at the tarsometatarsal joint and thus improves the stability.**

**Keywords:** First metatarsal biomechanics, Hallux valgus, Tarsometatarsal joint, Aetiology, 1st metatarsal joint morphology, Medial cuneiform, 1st metatarsal joint, Tarsometatarsal joint instability

### Article focus

- Is there a relationship between the proximal articular anatomy of the first metatarsal and the development of hallux valgus?

### Key messages

- Three distinct articular subtypes were found. Type 1 had one single facet, type 2 had two distinct articular facets, and type 3 had three articular facets, one of which was a lateral inferior facet elevated from the first
- Type 1 joints occurred exclusively in the hallux valgus specimens, whilst type 3 joints occurred exclusively in normal specimens. Type 2 joints occurred in both hallux valgus and normal specimens
- A lateral plantar prominence was significantly flatter in specimens with hallux valgus

### Strengths and limitations

- Hardening of soft tissues prevented simulated weight bearing radiographs being obtained and we had to rely on anatomical changes of the metatarsal head for delineation of disease presence. This may exclude mild and physiological hallux valgus deformities that may not have developed anatomical changes

## Introduction

The term hallux (abducto) valgus was first coined by German surgeon, Carl Hueter, in 1877.[1] Prior to this, the 'bunion' was thought to be due to an enlargement of the metatarsophalangeal joint of the great toe.[2] Haines and McDougall[3] described the anatomy of hallux valgus in greater detail, with the digit being displaced laterally and pronating on the head of the metatarsal, the plantar pad

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and sesamoids displacing with the digit, and the ligaments on the medial side of the joint being stretched. The aetiology of hallux valgus is almost certainly multifactorial.[4] Stephens[5] described the deformity occurring in stages in the presence of multiple predisposing factors.[4,5] The biomechanics of the first ray is a common factor to most theories regarding the pathoanatomy of hallux valgus. The osseous anatomy of the first ray comprises the first metatarsal medial cuneiform and associated articulations.[6] As far back as Morton in 1935,[7] hypermobility of the first ray was hailed as the main factor behind many deformities of the foot. Lake[8] and Lapidus[9] went further, implicating the hypermobility in hallux valgus.

The first metatarsal head is inherently unstable, as it has no tendon attachments. Nevertheless, and despite being a small joint, it undergoes enormous forces during normal gait. McBride et al[10] calculated that on barefoot walking, 0.8 × body weight passes through the metatarsophalangeal joint on toe-off. The soft-tissue structures preventing varus displacement of the metatarsal head, such as the adductor hallucis tendon, the intermetatarsal ligament and the lateral capsule of the metatarsophalangeal joint, act indirectly through the sesamoid sling complex (i.e. plantar plate and flexor hallucis brevis) and appear insufficient in the development of hallux valgus.[4] Proximally, peroneus longus and tibialis anterior insert variably on to the first ray. These tendon insertions act as deforming forces on the first ray, although there is no proven link between the variations in their insertion and hallux valgus.[11,12]

It is generally accepted that the medial supporting structures of the first metatarsophalangeal joint, the metatarso-sesamoid, phalangeal-sesamoid and medial collateral ligaments, fail early in the development of deformity.[3,4,13] As the deformity develops, and the first metatarsal progresses into varus, the proximal phalynx that is anchored at its base to the sesamoids by the plantar plate is pulled into valgus and pronation. It is important to note that the adductor hallucis muscle has two heads, the oblique head that inserts onto the lateral sesamoid and the lateral capsule of the metatarsophalangeal joint and the transverse head that additionally inserts onto the lateral plantar side of the proximal phalynx.[14] Thus, the escape of the metatarsal head causes the extensor and flexor hallucis longus to act laterally to the axis of the metatarsal head, aggravating the metatarsal varus deformity and valgus deformity of the hallux.[3]

The varus movement of the first metatarsal in the deformity of hallux valgus has to occur at a proximal articulation as illustrated by the increase in the intermetatarsal angle. This movement may occur at any or all of the proximal articulations. Several studies have debated whether motion at the tarsometatarsal joint exist.[15-19] Nevertheless, any movement permitted at the first tarsometatarsal joint is amplified by the long metatarsal shaft.[19] There is very little literature examining the anatomy of the proximal metatarsal articular surface and its relation to hallux valgus deformity. The aim of this study is to investigate the proximal articular surface of the first metatarsal and investigate any association with hallux valgus. Our null hypothesis was that there was no difference between the first metatarsal proximal articular surface of a normal specimen compared with a specimen with hallux valgus.

## Materials and Methods

**Anatomical dissections.** We examined 46 feet from 23 cadavers. A total of four feet (three left, one right) proved unusable due to poor preservation. Each body had been preserved for dissection at the cadaveric lab in Cardiff University in a solution of formaldehyde. The median age at death was 86 years (66 to 104). In each dissection, it was noted by both authors whether the foot displayed evidence of hallux valgus as described by Haines and McDougall[3]; i.e. a spectrum of deformity with the mildest form having a small medial eminence with erosion occupying most of the groove and encroaching on the crista ridge. In the most severe form the ridge is eventually smoothed out so that there is no further bony resistance to the displacement of the sesamoids. The tarsometatarsal joint was examined in detail looking for any morphological differences, such as articular projection and surface irregularities. The photographs were taken of the specimens by one author (LWM) and were then analysed by the second author (HT) to confirm or refute previous findings. Any disagreement was resolved through discussion.

Due to the formaldehyde preservation of the feet used, any inferences made to the appearance of the dissected feet would be misleading as tendons and ligaments are affected by hardening. This may give a false pes planus or cavus deformity appearance, and thus this appearance was not included in any analysis. Similarly, this hardening of soft tissues prevented simulated weight-bearing radiographs being obtained and we had to rely on anatomical changes of the metatarsal head for delineation of disease presence. We acknowledge that this excludes mild and physiological hallux valgus deformities that may not have developed anatomical changes.

Exposure of the first metatarsal required the removal of all skin and subcutaneous tissue. The joints were incised and dislocated, followed by the soft tissue being gently removed. The first tarsometatarsal joint was often difficult to dislocate due to strong ligamentous attachments from the lateral aspect of the proximal first metatarsal and the middle cuneiform, and attachment of peroneus longus. On two occasions the lateral plantar prominence had fused and fractured on attempted dislocation, and were therefore excluded from assessment. The first metatarsophalangeal joint was approached through a mid-medial incision in order to view the sesamoid metatarsal joint prior to dislocation. Both the first metatarsal and the medial cuneiform were removed for closer analysis and photographic documentation.

**Table I.** Summary of the findings in each specimen examined

| **Specimens** | |
|---|---|
| Total | 23 cadavers (42 feet) |
| Excluded due to poor preservation | 4 cadavers (4 feet) |
| Excluded due to fusion of first tarsometatarsal joint | 1 foot |
| Total examined | 19 cadavers (37 feet) |
| Bilateral hallux valgus | 8 cadavers (15 feet) |
| Bilateral type 1 | 2 (4) |
| Bilateral type 2 | 4 (8) |
| Type 1 (right) + type 2 (left) | 1 (2) |
| Type 1 (right) + fused joint (left; excluded) | 1 (1) |
| Bilateral normal feet | 9 cadavers (18 feet) |
| Bilateral type 3 | 6 (12) |
| Bilateral type 2 | 2 (4) |
| Type 3 (right) + type 2 (left) | 1 (2) |
| Unilateral hallux valgus | 2 cadavers (4 feet) |
| Bilateral type 2 joints, hallux valgus (right) | 1 (2) |
| Hallux valgus (right, type 1) + normal (left, type 3) | 1 (2) |

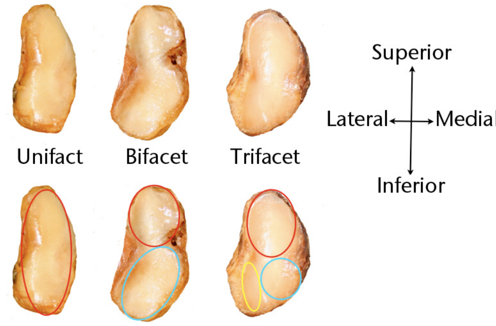


Fig. 1

Diagram of types 1, 2 and 3 joints showing their increasing number of facets.

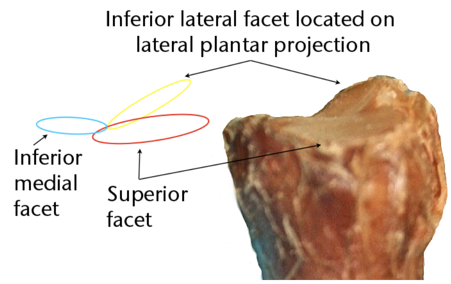


Fig. 2

Representation of a type 3 joint being pictured from the dorsal surface, showing the differing projections of the joint facets.

**Measurements.** Three measurements were taken of all dimensions of the proximal articular surface of the first metatarsal (height, width, articular slope, dimensions of articular facets) using a digital caliper accurate to 0.1 mm. The same investigator (LWM) performed all joint measurements to limit interobserver variability. The mean of these measurements are presented.

**Statistical analysis.** This was performed using Predictive Analytic Software 18 (PASW 18; SPSS Inc., Chicago, Illinois). Descriptive statistics was used to confirm the data was normally distributed and independent Student's *t*-tests were used to test significance between groups. The null hypothesis was that there would be no difference between normal and hallux valgus specimens.

## Results

Of the 23 cadavers examined, eight had bilateral hallux valgus, nine had bilateral normal feet and two had one affected and one unaffected foot. The remaining four cadavers had to be excluded from the study as their preservation was too poor to examine, and one foot was excluded as the first tarsometatarsal joint had fused. This is summarised in Table I. Of the 37 feet examined, 19 feet were identified as displaying hallux valgus. One specimen had a fused first tarsometatarsal joint and was thus excluded from the study.

**Joint type.** It was observed that the morphology of the first metatarsal articular surface was variable. Three distinct articular subtypes were identified. The first subtype was a unifacet articular surface with a smooth transition across the entire joint (type 1). There were seven feet with hallux valgus possessing type 1 joints, but no normal feet possessed this joint type. The second subtype was a bifacet articular surface with two distinct articular surfaces, one superior and one inferior (type 2). The planes of these articular surfaces were variable to one another. This joint type occurred in 12 feet with hallux valgus and six normal specimens. The third subtype was a trifacet articular surface, a large superior facet, a smaller medial inferior articular facet in the same plane as the first, and a lateral inferior facet elevated from the first two (type 3). This joint type occurred exclusively in normal feet, 16 of which possessed this joint type. These joint types are illustrated in Figure 1. Type 1 and type 3 joints were more common in males (71% and 69% males respectively) and type 2 joints were more common in females (88%).

**Lateral plantar prominence.** Another consistent finding with regards to the proximal articular surface of the first metatarsal is the lateral plantar prominence. This prominence is located proximal to, and invariably including, the peroneus longus tubercle extending to the articular surface. The articular surface located on this prominence was at a different angle compared with the rest of the articular surface, irrespective of the number of facets. An example of this differing orientation is illustrated in Figure 2. The size of this prominence differed greatly between specimens. In the type 3 joints, this prominence possessed its own articular surface. However, on the type 1 and 2 joints there was no articular surface. On two occasions the lateral plantar prominence had fused to the medial cuneiform and fractured on attempted dislocation of the joint. The height

**Table II.** Comparison of lateral planter prominence height and angles in hallux valgus and normal specimens

| | Hallux valgus (n = 18) | Normal (n = 21) | p-value |
|---|---|---|---|
| Mean (SD) lateral planter prominence height (mm) | 2.44 (0.67) | 3.75 (0.80) | < 0.001 |
| Mean (SD) lateral planter prominence angle (°) | 29.72 (8.48) | 50.71 (7.29) | < 0.001 |

of the lateral plantar prominence (measurements were taken from the lowest part of the joint surface to the highest bony prominence) was significantly flatter in specimens with hallux valgus ($p < 0.001$) (Table II). When measuring the angle made by the lateral plantar prominence to the joint surface it was found that this angle was significantly more obtuse in hallux valgus specimens ($p < 0.001$) (Table II). A *post-hoc* power calculation was undertaken using Lehr formulae.[20] To show significance with 80% probability for lateral plantar prominence height, which we set as 1 mm difference, then ten feet are needed in each group. Similarly, for lateral plantar prominence angle, which we set as 10° with a standard deviation of 8°, we again needed ten feet in each group. We had 19 in the hallux valgus group and 21 in the normal group.

## Discussion

The investigation of the pathological anatomy of hallux valgus deformity has historically concentrated mainly on the metatarsophalangeal joint.[21-25] However, the deformity at this joint is a direct consequence of proximal failure. Young,[26] after dissection of seven feet with hallux valgus, described an increase in the height and width of the proximal first metatarsal articular surface, along with an exostosis or os intermetatarsum. He also described the tuberosity to which the peroneus longus inserts to be markedly hypertrophied with an associated articular surface.[26] This associated articular surface was later termed an intermetatarsal facet, reportedly present in between 21% and 53% of all specimens.[27,28] Coughlin and Jones[22] identified both the os intermetatarsum and intermetatarsal facet in 7% of hallux valgus patients, although theirs was primarily a radiological study with an unknown level of sensitivity. In our study neither an os intermetatarsum or intermetatarsal facet could be identified in either normal or hallux valgus specimens. However, relatively rare occurrences such as this may not occur in a small sample size such as ours. The lateral plantar prominence identified in our study originated proximal and invariably included the peroneus longus tuberosity. The variation of this prominence has not previously been described. We hypothesised that the size and acute angle of this prominence gives structural mechanical impedance to movement at the tarsometatarsal joint and thus improves the stability.

Sagittal plane motion of the medial column of the foot is essential for normal gait. A significant proportion of this motion has been reported to occur at the tarsometatarsal joint (41% to 57%), with less occurring at the talar-navicular and medial cuneiform-navicular joints.[29,30] Root, Orien and Weed[31] described 'hypermobility' of the first ray when there is abnormal dorsiflexion (extension) motion of the first metatarsal head because of instability at the first metatarsal. A detailed review of the literature on hypermobility at the tarsometatarsal joint found no consensus on either the direction or amount of movement of the metatarsal in normal or hallux valgus subjects.[18] Nevertheless, Coughlin and Jones[32] found plantar gapping of the first tarsometatarsal joint on weight bearing lateral radiographs in 23% of hallux valgus specimens. This was associated with a significant increase in hallux valgus angle. In addition, Mizel[17] found that there was very little movement at the tarsometatarsal joint until the plantar tarsometatarsal ligament was sectioned. This suggests that progression of deformity in hallux valgus specimens requires plantar ligament failure of the tarsometatarsal joint. With dorsiflexion of the tarsometatarsal joint the peroneus longus is further defunctioned and the deformity is able to progress.[33] Dorsiflexion is not the only direction of movement of the metatarsal at the tarsometatarsal joint. Hicks[6] in 1953 described the axis of rotation of the first metatarsal as pronation (eversion) on flexion and supination (inversion) on extension. This axis of rotation however, varies with some studies agreeing with supination on extension[31,34-39] and others proposing pronation.[40-42] All studies on hallux valgus only suggest pronation of the first metatarsal.[43-46] In our study, wear patterns were only seen in four of the hallux valgus specimens, suggesting dorsiflexion, varus and supination of the first metatarsal, or pronation of the hind foot on a fixed metatarsal. However, as we cannot comment on the morphology of the foot in general, we can only hypothesize on the cause of the wear patterns we described in four of our type 2 specimens as compensatory forefoot supination is also seen in acquired pes planus.

The obliquity of the proximal metatarsal articulation has been associated with hallux valgus,[46] however to our knowledge there is no prior literature associating the first metatarsal proximal articulation with hallux valgus. There is very little literature on the anatomy of the proximal articular surface of the first metatarsal in normal subjects. Latimer and Lovejoy[47] examined the morphological characteristics of the first tarsometatarsal joint in both humans and quadrupedal pongids. They described an invagination of the articular margin in human subjects similar to the type 2 joints we describe. However, the Pan and Gorilla specimens that require greater motion at the tarsometatarsal joint for grasping activities had no such invagination, similar to the type 1 joints illustrated in our study.[47] We believe that having more joint facets present at the proximal articular surface promotes stability. Alternatively, another explanation for joint morphological differences is that the position of the first metatarsal – as a consequence of hallux valgus – causes articular metaplasia of the proximal articular joint. It is impossible to confirm or deny such a hypothesis as this would require knowledge of cartilage morphology over time. However, this is an unlikely scenario as we would expect joint wear, and not articular metaplasia, in this age group.

The fact that type 3 joints were only present in normal subjects and type 1 joints in hallux valgus subjects is significant. Type 2 joints are present in both normal and hallux valgus subjects, which suggests that this provides a degree of stability. With the addition of other factors such as shoe wear or generalized ligamentous laxity, type 2 joints may not provide enough stability to prevent hallux valgus formation. A spectrum of stability where at one end there are type 1 joints with a single facet that encourages mobility and on the other end, type 3 joints with a large lateral planter prominence and three facets that promote stability. This remains a hypothesis and needs further kinematic study.

We have identified three distinct articular types of the first metatarsal proximal articular surface. Of these types, the increasing amount of articular facets present at this joint protects against hallux valgus formation. We have also identified a lateral plantar prominence that is smaller and more obtuse in hallux valgus subjects.

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