(i) Disorders of the first ray

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Abstract
Musculoskeletal conditions are a common presentation in primary care, and almost one third of these are related to the foot and ankle. Of these, the most common pathologies are disorders of the first ray, which includes hallux valgus and hallux rigidus. Pain in the first ray, which forms the weight-bearing medial column of the foot, can significantly impact on a patient’s quality of life. Diagnosis is often not difficult, but it is important to examine for pathologies in the lesser rays that coexist with the presenting disorder. Initial treatment is with physiotherapy and orthotics, but surgical treatment of degenerative change and valgus deformity yields good outcomes and patient satisfaction. This article reviews the common conditions affecting the first ray, their assessment and their management.

Keywords first metatarsophalangeal joint; great toe; hallux; hallux rigidus; hallux valgus

Introduction
Patient complaints of foot and ankle symptoms are frequently seen in primary care and are referred for further treatment to a podiatry service in the community or to a surgeon if conservative treatment fails. Of these, the most common pathologies are disorders of the first ray, which forms the weight-bearing medial column of the foot, and these pathologies include hallux valgus and hallux rigidus. The origin of pain in the forefoot needs to be specifically isolated and may not necessarily be related to the obvious deformity. For example, a severe hallux valgus may not be the site of pain, and the symptoms may all be related to the 2nd metatarsophalangeal joint where there is a subtle plantar plate insufficiency, a secondary effect of a relatively asymptomatic hallux valgus. Therefore, an orthopaedic surgeon has to have a good understanding of the pathophysiology and biomechanics of the first ray in order to be able to treat these conditions appropriately. This article offers an overview of the common conditions affecting the first ray.

Hallux valgus
Hallux valgus (HV) is a common deformity of the first ray, in which the great toe is deviated towards the second toe, and it affects a reported 28.4% of adults over the age of 40 years. Patients complain of restricted shoe choice, pain over the bunion, cosmetic concerns, lesser toe crowding and pain around the second metatarsal head due to transfer metatarsalgia.

Aetiology
The aetiology of hallux valgus is multifactorial, but generally has extrinsic and intrinsic causes, including the following.

Footwear: the common extrinsic cause of hallux valgus is inappropriate footwear, the condition having a low prevalence in unshod populations and a prevalence linked to changes in shoe fashion. It is felt that high heels with a narrow toebox cause increased forefoot loading and great toe pronation. However, there is not a complete association, it is not important in the juvenile hallux valgus population, and shoe wear is probably more important in hallux valgus progression rather than initiation.

Genetics: the most commonly implicated intrinsic cause is a genetic predisposition, with contributing factors being loss of arch height and hypermobility. One paper found that 90% of patients had one affected relative, with the most common pattern of inheritance being autosomal dominance with incomplete penetrance. This rises to up to 94% in those with juvenile hallux valgus. The predominance in females is another intrinsic factor, with women having an increased incidence of requiring corrective surgery in a ratio of 15:1, although the true sex ratio in the untreated population is less well known. The desire to seek treatment to enable use of socially conforming shoe wear could account for some of this difference, as well as women having an increased incidence of ligamentous laxity, first ray hypermobility and a more rounded metatarsal head articular surface providing a less stable joint.

Structural malalignment: metatarsus primus varus also has an association with HV, particularly in the juvenile group, but again it remains unclear whether this is causative. Biomechanical studies suggest that metatarsus varus is secondary to the toe deformity, this being supported by its correction following first MTPJ fusions. In the adolescent population, a subgroup of juvenile HV is associated with an abnormal distal metatarsal articular angle (DMAA) of the metatarsal head. In these cases true subluxation is minimal as the metatarsophalangeal joint (MTPJ) as a whole unit is tilted into valgus.

Hypermobility: hypermobility of the first ray at the level of the tarsometatarsal joint (TMTJ) could be a causative factor for hallux valgus, although recent evidence suggests that the HV deformity could be the causative factor for TMTJ instability and that correction of the deformity improves this hypermobility. Current evidence is unclear about the cause and effect relationship of TMTJ hypermobility in the general population, although it might be a major factor in conditions with generalized connective tissue disorders such as Ehlers–Danlos syndrome.
Flatfeet: pes planus is unlikely to be a primary causative factor for hallux valgus, but when present can have the secondary effect of making the deformity progress more rapidly. There is no evidence in clinical studies that pes planus reduces the success rate following corrective surgery. A tight gastrocsoleus promotes hyperpronation and can potentially accelerate the progression of hallux valgus.

Pathogenesis
The pathogenesis of hallux valgus has been described as a staged process driven by various of extrinsic and intrinsic causes.5-8

Progression of HV: the first stage is weakening of the medial capsular ligaments, with failure of the medial collateral and medial sesamoid ligaments. This results in the metatarsal head drifting into varus, with the proximal phalanx drifting into valgus. The cartilage over the uncovered medial metatarsal head atrophies in response to an absence of the normal pressure and gives rise to the medial bony prominence, whilst the gutter next to it is due to the edge of the proximal phalanx base eroding the head whilst mal-tracking. A medial bursa develops in response to the extra pressure from shoes rubbing over this prominence. Further attenuation of the medial soft tissues causes the metatarsal head to drift further medially, causing relative displacement of the sesamoids laterally (as they are still attached to the second MTPJ by the deep transverse metatarsal ligament) and erosion of the ridge or ‘crista’ between the medial and lateral sesamoids. The medial sesamoid now lies in the flattened groove between the two sesamoids, and the lateral sesamoid now lies in the first intermetatarsal space, so pulling the proximal phalanx into pronation (Figure 1). The deformity is worsened as the extensor hallucis longus (EHL) and flexor hallucis longus (FHL) insertions have drifted laterally with the phalanx, becoming two tight laterally placed bowstrings that have now become adductors of the toe. Adductor hallucis and the lateral head of flexor hallucis brevis between the sesamoid and the proximal phalanx and the lateral capsule all contract, contributing further to the deformity.

Transfer metatarsalgia: this is typically demonstrated by the observation of smooth plantar skin directly under the 1st MT head, with calllosities over the medial bunion and under the 2nd MT head. Preferential loading of the first metatarsal head normally occurs through the windlass mechanism during gait, with tightening of the plantar fascia during the toe off phase. When the big toe dorsiflexes and the first metatarsal head is plantarflexed by the tightened fascia, the first metatarsal head is loaded.9 In HV, as the hallux goes into valgus and pronation rather than true dorsiflexion during toe off, this windlass mechanism at the first MTPJ is altered and it appears to cause a medial moment and less of a plantar moment on the metatarsal head. As a result the first ray remains relatively dorsiflexed during gait, causing overload of the lesser rays.

Lesser toe deformities: as the hallux increasingly tilts, it pushes on the second toe sitting plantar to it within the shoe and causes the latter to gradually curl up, extending at the MTPJ and flexing at the PIPJ. Walking and weight-bearing within a shoe with hyperextension and overloading of the 2nd MTPJ eventually leads to plantar plate insufficiency, causing clawing and eventual joint dislocation of the MTPJ. In some cases the 2nd toe remains straight, but tilts into valgus along with other toes in a ‘domino effect’, secondary to the hallux leaning on it.

Clinical examination
The whole foot should be examined in the standing position, to assess for planovalgus deformities, tibialis posterior tendon dysfunction (tip toe test) and the extent of hallux and lesser toe deformities. One should look for associated gastrocsoleus tightness. The first TMTJ should be examined for instability, with dorso-plantar movement of more than 9 mm suggesting hypermobility.10 The severity of the hallux valgus, the degree of pronation, and whether the deformity is rigid or flexible should all be determined. The first MTPJ should be assessed for movement and pain in the corrected position. Identify the location of the plantar calllosities (transfer lesions) and also assess for generalized hyperlaxity, diabetic neuropathy and neurovascular disease. It is also important to look at the appropriateness of shoes and orthoses being used.

Investigations
Weight-bearing AP and lateral view radiographs aid pre-operative planning. The severity of the deformity can be

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Figure 1

**Progressive relative sesamoid subluxation secondary to medial 1st metatarsal drift**

- **Normal/mild**: Normally aligned sesamoids without erosion of crista.
- **Mild/moderate**: Medially migrated 1st metatarsal with eroded crista and more central location of medial sesamoid.
- **Severe**: Lateral sesamoid lies vertically, dorsal to medial sesamoid. Lateral soft tissues contracted. Crista completely eroded.

Reproduced from ‘hallux valgus’, current orthopaedics 2003
classified according to radiographic criteria (Table 1). The angles to look for (Figure 2) include:

- **Hallux valgus angle (HVA)**: Normal < 15°
- **Intermetatarsal angle (IMA)**: Normal < 9°
- **Distal metatarsal articular angle (DMAA)**: Normal < 10°
- **Interphalangeal angle (IPA)**: Normal < 10°

If the joint is subluxed it is termed an ‘incongruent’ hallux valgus deformity. Generally, in the adult form, the DMAA is normal and the joint is subluxed (incongruent), whereas in the juvenile form the DMAA is often increased without subluxation (congruent). Although DMAA measurements on X-rays are not totally reliable due to pronation, a final true assessment can be made at surgery. This is relevant, as a congruent joint appears to be more stable and less prone to progression, and when an osteotomy is performed the cut must be modified to achieve correction of the DMAA. The position of the sesamoids should also be noted, along with the size of the medial prominence and the presence of any degenerative change.

**Treatment**

**Conservative:** accommodative footwear with extra width and depth can alleviate symptoms, and with bunion pads may be the treatment of choice in the elderly or those with compromised skin or vascularity. Physiotherapy and insoles are prescribed to treat tibialis posterior tendon dysfunction. There is no evidence supporting the use of orthoses to prevent progression of hallux valgus.

**Surgical:** the main indication for surgery is pain that is not controlled by conservative measures, and recent BOFAS and BOA guidelines suggest that surgery should not be undertaken for cosmetic or prophylactic reasons. A Cochrane review in 2004 concluded, with limited evidence and short follow-up, that surgery (a chevron osteotomy) was beneficial compared to orthoses or no treatment. No osteotomy technique was shown to be superior to others.

It is important to inform patients that not all patients will have unlimited shoe wear choice post-operatively, transfer lesions may require insoles following surgery, and a number of patients remain dissatisfied after surgery (up to 25–33%), even when the deformity has been corrected and pain has improved.

A guide to the commonly used surgical options for hallux valgus deformities is given in Table 2, and the surgical techniques are detailed below.

**Simple bunionectomy** — a medial incision is used to excise the medial eminence followed by capsular plication. There is a high rate of dissatisfaction and this technique is only recommended for patients with a medial prominence and no hallux valgus.

**Distal soft tissue procedure** — this involves a release of the tight lateral structures with medial capsular plication. The McBride procedure involves detaching the adductor tendon from the proximal phalanx and reattaching this onto the first metatarsal neck. In the original article the lateral sesamoid was also excised, but due to the risk of hallux varus this is now not done. Current evidence suggests that the adductor does not pull the sesamoids laterally, but it is the metatarsal head that is shifted off the sesamoids. Consequently, the sesamoids migrate onto the lateral aspect of the head causing the ligaments attaching the lateral sesamoid to the metatarsal head and the proximal phalanx to contract.

Barouk popularized a more limited lateral release, which involves incising the tight lateral structures consisting of the metatarsal sesamoidal suspensory ligament and the ligament between the lateral sesamoid and the proximal phalanx. Division of these two sesamoid ligaments aids relocation of the sesamoids under the metatarsal head (Figures 3 and 4), although in severe cases the adductor insertion and transverse metatarsal ligament can also be released. The lateral collateral ligament of the MTPJ is preserved to avoid instability and hallux varus. The senior author checks the adequacy of the lateral release by reducing the intermetatarsal angle by side-to-side compression of the foot, which then realigns the hallux if a sufficient lateral release has been performed.

Severe subluxation is associated with a significant shortening of the long flexors and extensors, which can continue to be deforming forces unless neutralized by slight shortening of the bones. Barouk popularized the concept of proportionate shortening based on the extent of subluxation. He hypothesized that transfer metatarsalgia would not be a problem in such cases if there is a proportionate plantar translation with the Scarf osteotomy.

**Excision arthroplasty (Keller’s procedure)** — this is a procedure for historical note, and should only be considered in an elderly patient with low functional demands who is unable to tolerate a larger procedure. The proximal one third of the proximal phalanx is resected, decompressing the joint and relaxing the tight lateral structures. There is a high rate of recurrence, the IMA is little improved, metatarsalgia from overload of the lesser rays is common, and the procedure can result in a ‘cock-up’ deformity of the great toe, with reduced range of motion at the MTPJ. Salvage involves fusion of the MTPJ with an interpositional graft if needed to restore length.

**Proximal phalanx osteotomy (Akin)** — this medial based closing wedge osteotomy at the base of the proximal phalanx is often used if there is residual hallux valgus interphalangeus or pronation of the hallux after metatarsal correction. It can be used in isolation if the deformity is purely due to an increase of the interphalangeal angle. Fixation is with a screw, K-wires or staple.

**First metatarsal osteotomies** — the addition of a first metatarsal osteotomy realigns the metatarsal head over the sesamoids and can also correct the DMAA. Proximal osteotomies have greater corrective power of the IMA due to the longer lever arm,

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**Hallux valgus classification — the severity of the deformity classified according to radiographic criteria**

<table>
<thead>
<tr>
<th>Deformity severity</th>
<th>HVA</th>
<th>IMA</th>
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<tbody>
<tr>
<td>Mild</td>
<td>&lt;19°</td>
<td>&lt;13°</td>
</tr>
<tr>
<td>Moderate</td>
<td>20–40°</td>
<td>14–20°</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;40°</td>
<td>&gt;20°</td>
</tr>
</tbody>
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Table 1
although more distal osteotomies have less extensive exposure and a shorter recovery time.

A) Distal osteotomies: the distal metatarsal osteotomies aim to translate the metatarsal head laterally, so replacing it over the sesamoids. The main advantages are that they are a simpler procedure, but they can only be used for mild to moderate deformities as excessive lateral translation more than 50% causes the osteotomy to become unstable, especially if the metatarsal width is small. There is also the risk of damage to the blood supply to the metatarsal head, with the risk of avascular necrosis (AVN). The blood supply of the first metatarsal is supplied laterally from the first dorsal and plantar metatarsal arteries, and medially from the superficial branch of the medial plantar artery. A leash of capillaries then enters the head just proximal to the inferior surface. It is therefore important that the plantar soft tissues to the head remain intact, that the dorsal and plantar saw cuts exit proximal to the capsular attachments, and that laterally the saw blade should not plunge past the cortex.

The distal chevron osteotomy: this is a V-shaped osteotomy in the first metatarsal head (Figure 5), and has been modified with the inferior limb running from the centre of the metatarsal head to the undersurface of the metatarsal neck, avoiding the blood supply to the head, with the superior limb at 70° to this. The distal fragment is slid laterally up to 50% of the metatarsal shaft diameter, and the direction of the cut can be altered to achieve shortening and plantar translation if required. The DMAA can also be corrected by the addition of a medial based closing wedge to reduce the angle, and this is then called a biplanar chevron osteotomy. A single superoinferior screw secures the osteotomy. The osteotomy is vertically stable, so patients can start walking immediately in a heel weight-bearing shoe. The largest cohort series followed up over 10 years showed excellent correction that did not deteriorate with time, and an AVN rate of less than 2%. Although only recommended for mild to moderate deformity, some studies have shown good results with severe deformity.

B) Diaphyseal osteotomies: moderate deformities can be managed with a diaphyseal osteotomy, allowing translation (Scarf) or rotation (Ludloff) of the metatarsal to correct the IMA.

Modified Ludloff osteotomy: this is a long oblique osteotomy at an angle of approximately 30°. The osteotomy starts dorsally, just distal to the TMT joint, and ends just proximal to the

<table>
<thead>
<tr>
<th>Severity</th>
<th>Findings</th>
<th>Procedures</th>
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</thead>
<tbody>
<tr>
<td>Mild hallux valgus</td>
<td>Normal</td>
<td>Chevron &amp; DSTP</td>
</tr>
<tr>
<td></td>
<td>DMAA</td>
<td>+/- Akin</td>
</tr>
<tr>
<td></td>
<td>Increased</td>
<td>Biplanar chevron</td>
</tr>
<tr>
<td></td>
<td>DMAA</td>
<td>+/- Akin</td>
</tr>
<tr>
<td>Moderate hallux valgus</td>
<td>Normal</td>
<td>Scarf &amp; DSTP</td>
</tr>
<tr>
<td></td>
<td>DMAA</td>
<td>+/- Akin</td>
</tr>
<tr>
<td></td>
<td>Increased</td>
<td>Rotated Scarf</td>
</tr>
<tr>
<td></td>
<td>DMAA</td>
<td>+/- Akin</td>
</tr>
<tr>
<td>Severe hallux valgus</td>
<td>Scarf / proximal osteotomy / fusion at MTPJ or TMTJ</td>
<td>+/- DTSP</td>
</tr>
<tr>
<td>Hallux valgus with 1st TMTJ</td>
<td>Lapidus</td>
<td>procedure</td>
</tr>
<tr>
<td>Instability</td>
<td></td>
<td>&amp; DSTP</td>
</tr>
<tr>
<td>Hallux valgus with 1st MTPJ</td>
<td></td>
<td>1st MTPJ</td>
</tr>
<tr>
<td>Degeneration</td>
<td></td>
<td>arthrodesis</td>
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</table>

DSTP — distal soft tissue procedure for incongruent Hallux Valgus

Table 2
sesamoids on the plantar surface. The distal fragment is rotated laterally on the proximal fragment and held with two screws. The MT head can be displaced plantarwards by angling the osteotomy. The long osteotomy plane and two screw fixation makes this very stable.

**Scarf osteotomy**: this osteotomy has a high degree of stability and represents the workhorse for most bunion corrections. It is a Z-shaped osteotomy, with the longitudinal cut along the length of the diaphysis, with a plantar slope from medial to lateral allowing plantar displacement, so offloading the lesser toes (Figure 6). Chevrons are made at either end, and the head and plantar fragment are translated laterally and secured with two screws. The osteotomy can be modified as a ‘rotated Scarf osteotomy’ to correct an abnormal DMAA. The Scarf does well in reported series, with satisfaction rates of 85%—90% and a complication rate as low as 5%—10%. In a comparative study between the Ludloff and the Scarf osteotomies, the Scarf performed slightly better, with improved maintenance of the correction, reduced transfer lesions and fewer non-unions. A systematic review comparing Scarf and chevron osteotomies suggested the Scarf only improved radiographic correction of the IMA by less than 1°, but the evidence was low quality. Whilst traditionally recommended for an IMA to 20, more severe deformities can be treated with the addition of an akin osteotomy (Figure 7).

**C) Basal**: proximal osteotomies have a high corrective power due their proximal location providing a long lever arm.

**Proximal opening and closing wedge osteotomies**: proximal opening or closing wedge osteotomies can be used. Open wedge osteotomies traditionally used bone grafts to fill the gap, but currently most surgeons now use a low profile plate with a metal wedge that fits into the osteotomy gap. Opening wedge osteotomies lengthen and tighten the deforming soft tissues, such as the long and short extensors and flexors. Closing wedges shorten the ray, potentially leading to painful transfer metatarsalgia. An abnormal DMAA that is likely to be exacerbated may need to be addressed by another distal osteotomy, and an incongruent joint may require the addition of a distal soft tissue procedure. Although the osteotomy is powerful, dorsal malunion and non-
union has been reported, but the use of modern plates may reduce these complications.

_Crescentic osteotomy_: the crescent is cut 1 cm distal to the TMTJ with a crescentic saw blade, and the concavity is directed proximally. The shaft can then be rotated laterally, which leads to minimal shortening of the first metatarsal. Good correction has been reported, but its instability can lead to dorsal tilt and malunion.

_Proximal chevron_: this is technically easier and more stable to the deforming forces of dorsiflexion than the crescentic osteotomy and has good reported results. It involves a medial V-shaped cut like the distal chevron, with lateral translation. It can be a proximal or distal based Chevron. The excised medial eminence can be inserted into the superior limb for stability and plantar tilt, to restore first ray loading.

_Arthrodesis for hallux valgus_

_First MTPJ arthrodesis_: this is indicated for rheumatoid patients, neurological disease, significant degeneration or in elderly patients with severe or recurrent disease.

_First TMTJ arthrodesis (Lapidus procedure)_: this is used for patients with 1st TMTJ hyperlaxity, patients with degenerative change at this joint or those with severe deformity. The procedure is often combined with a distal soft tissue procedure. Varus correction should be combined with a small amount of plantarflexion. The procedure can be technically demanding and there is a prolonged period of recovery when compared to osteotomies. Recent introduction of compression locking plates is likely to make fixation easier.

_Minimally invasive surgical correction_ — minimally invasive techniques for hallux valgus correction include arthroscopy, percutaneous techniques and minimum incision surgery. NICE guidelines state that the current evidence is limited and is related to a wide range of surgical techniques, so the evidence on safety is inadequate. They recommended that minimal access techniques should only be undertaken as part of a research project or where special arrangements for audit are in place. Currently the technique used in the UK utilizes small burrs that have a low speed but high torque combination, performing a Chevron and Akin osteotomy under image intensifier guidance. Guided screws are applied percutaneously for fixation.

_Management of recurrent deformity_

Recurrence of the deformity requires a comprehensive clinical and radiographic assessment. Recurrence has been categorized as being due to surgical factors (incomplete correction, malunion, non-union), deformity factors that have not been addressed (increased DMAA, 1st TMTJ hypermobility, hallux valgus interphalangeus) or patient factors (hallux rigidus, sesamoid pain, inflammatory arthropathy, neurological spasticity, ligament laxity). Management should consider all these factors prior to proceeding with correction for a persistently painful foot. For a degenerative MTP joint, muscle imbalance or inflammatory arthropathy, the best option is fusion. Instability at the 1st TMTJ
can be managed with a Lapidus procedure. If the above factors are not present then careful assessment of the deformity and correction with single, double or triple level osteotomies can be considered.\textsuperscript{10}

**Complications of surgery**

Potential complications of surgery include thromboembolic disease, wound infection, nerve injury (dorsomedial cutaneous nerve), recurrent deformity (8%–15%), transfer metatarsalgia (5%–40%), hallux varus (0–5%), MTPJ stiffness and AVN of the metatarsal head (1–2%).

**Hallux rigidus**

Arthritis of the first MTPJ is the most common form of osteoarthritis in the foot. The patient presents with MTPJ pain during the extremes of motion, usually just before toe off, from dorsal impingement. Prominent dorsal osteophytes can restrict dorsiflexion, lead to shoe wear problems and cause numbness as they press against the dorsomedial cutaneous nerve. Lateral foot weight-bearing to offload medial pain may lead to altered gait patterns. Shoes with heels increase 1st MTPJ loading and so increase symptoms.

**Aetiology**

The aetiology of hallux rigidus is not well understood. It often presents in the patients 50’s, more frequently in women, with 2/3 having a family history, and a reported 90% of cases are bilateral. Unilateral cases may be post-traumatic. Correlation has been found with a flat metatarsal head shape, metatarsus adductus and hallux valgus interphalangeus.\textsuperscript{19}

The majority of cases are idiopathic. Various theories exist regarding the triggering anatomical variation, though it may be a combination of factors. Metatarsus elevatus, aspherical shape of the head and a tight plantar fascia causing functional hallux rigidus when young have all been implicated. Known causes include trauma, gout, infection, and inflammatory arthropathy. Degeneration begins dorsally with limitation of dorsiflexion and impingement pain. As the normal windlass mechanism is absent, the first metatarsal head does not shift plantarwards during toe off phase and it is therefore off loaded, with increased loading of the lesser metatarsals.

**Clinical examination**

The whole ankle and foot should be assessed. When examining the great toe, the site of tenderness should be evaluated, differentiating whether pain is at the extremes of motion or throughout the whole range. One should check if there is dorsal osteophyte pain (on maximum dorsiflexion and plantarflexion), and whether there is pain related to the sesamoids. The range of motion will be below the normal 70\(^\circ\) dorsiflexion and 30\(^\circ\) plantarflexion. Alignment of the great toe should be observed, looking for valgus and interphalangeal joint (IPJ) hyperextension, and one should check for any lesser ray problems. Extension at the IPJ is important to compensate for lack of extension at the first MTPJ after fusion, and lack of it can cause pain post-operatively.

**Investigations**

Weight-bearing AP, oblique and lateral view radiographs are routinely taken. Further imaging with MRI and CT is only required if radiographs are normal and one is suspecting pathology such as an osteochondral defect. On the AP view signs of osteoarthritis are seen, although dorsal osteophytes potentially obstructing the view of the joint could lead to the false impression of more severe arthritis. The lateral view highlights that the disease tends to start dorsally, and as the disease progresses it then affects the lower half of the joint. Arthritis of the sesamoids can be a co-existent or independent pathology.

**Classification**

The Hattrup and Johnson radiographic classification was modified by Coughlin\textsuperscript{20} into a more comprehensive but inevitably more complex system. The new grading has five grades (Table 3). This classification is useful as a cholecystectomy gives reproducible results for grades 1 and 2 and grade 3 if <50% of the metatarsal head articular surface is involved. Arthrodesis or arthroplasty is recommended for the remaining grade 3 and grade 4 cases.

### Coughlin and Shurnas classification for hallux rigidus\textsuperscript{19}

<table>
<thead>
<tr>
<th>Grading</th>
<th>Dorsiflexion</th>
<th>Radiographs</th>
<th>Clinical findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>40–60° and/or 10–20% loss vs opposite side</td>
<td>Normal</td>
<td>Stiffness, no pain</td>
</tr>
<tr>
<td>Grade 1</td>
<td>30–40° and/or 20–50% loss vs opposite side</td>
<td>Dorsal osteophyte Otherwise minimal degenerative change</td>
<td>Mild pain and stiffness, pain at extremes of motion</td>
</tr>
<tr>
<td>Grade 2</td>
<td>10–30° and/or 50–75% loss vs opposite side</td>
<td>Dorsal, lateral +/- medial osteophyte. &lt;25% joint involvement on lateral view, mild-moderate joint space narrowing and sclerosis</td>
<td>Moderate to severe pain and stiffness that may be constant, pain at extremes of motion</td>
</tr>
<tr>
<td>Grade 3</td>
<td>&lt;10° and/or 75–100% loss vs opposite side</td>
<td>As grade 2 with &gt;25% joint involved on lateral view and substantial joint space narrowing. Sesamoids enlarged +/- cystic</td>
<td>Almost constant pain with significant stiffness at the extremes of motion</td>
</tr>
<tr>
<td>Grade 4</td>
<td>As grade 3</td>
<td>As grade 3</td>
<td>As grade 3 with pain in the midrange of passive motion</td>
</tr>
</tbody>
</table>

Table 3
**Treatment**

**Conservative:** analgesics, weight loss, activity modification and improved shoewear all have their place in the early management of the disease. Inserts include orthotics such as the Morton’s extension, which is a firm material supporting the great toe, so reducing MTPJ dorsiflexion, but they are often not well tolerated. Rocker bottom shoes and wide toe box shoes can also reduce pressure from the osteophytes and painful movement. Corticosteroid injections can be therapeutic as well as diagnostic, but are unlikely to achieve long lasting results, with around 50% requiring surgery 1 year after injection. One other study that followed up patients for a minimum of 12 years found that 25% required surgery in that time period, suggesting that the disease is slowly progressive.

**Surgical:** options are based on the degree of arthritis, patient symptoms, and the patient’s goals and how much time off work they might be able to take.

**Cheilectomy** — a cheilectomy preserves joint motion and stability. In this procedure, no more than one third of the dorsal metatarsal head articular surface is removed; any more and there is the risk of dorsal subluxation or overload on the remaining articular surface. Satisfaction rates of 92% have been reported, with improvement in dorsiflexion from 20° to 40°. The paper with the largest series to-date suggested that if less than 50% of the articular surface is involved and if there is no pain in the midrange of motion, then cheilectomy produces good results. The Roukis systematic review, which was limited by the different classifications used, supported this with a revision rate of 9%–20% for grades 1–3 and a 50% revision rate for grade 4 cases.

**Cheilectomy with proximal phalanx osteotomy** — a cheilectomy can be combined with a proximal phalanx dorsal closing wedge osteotomy (Moberg procedure) to decompress the joint and increase dorsiflexion of the MTPJ. Only low number case series have been reported for phalangeal osteotomy combined with cheilectomy, and most produce comparable results to cheilectomy alone (Figure 8).

**Arthrodesis** — this is the current gold standard for the management of severe hallux rigidus. Satisfaction rates are consistently high, in the range of 81 to 100%, with high functional scorings. The arthrodesis bone cuts can be with flat or conical and fixation can be with wires, staples, plates or screws (Figure 9). The main technical consideration is fixing the MTPJ in 10°–15° dorsiflexion and 10°–15° of valgus. The ideal outcome is a hallux pulp that is just off the ground when the foot is plantigrade. A toe fixed without dorsiflexion could promote interphalangeal arthritis, as this joint has to take the brunt of forced dorsiflexion. A toe excessively off the ground causes the dorsal aspect of the IPJ to impinge against the shoe.

A systematic review showed that non-union occurs in 5% of cases (of which one third were symptomatic), malunion occurs in 6%, and metalwork removal is required in 8%. Depending on the bone quality and the degree of shortening, non-unions can be managed with revision arthrodesis, with the potential addition of bone grafts if needed, and with internal or externally stabilization.

**Keller resection arthroplasty** — this is discussed under section on hallux valgus, with similar limited indications for hallux rigidus.

**Interpositional arthroplasty** — this procedure involves cheilectomy, resection of the phalangeal base, and interposition with a biological spacer such as tendon (autograft or allograft) or joint capsule. Comparison between methods is difficult as techniques have evolved over time, and case series have low numbers. It seems that for now it is a technique in evolution as it does not consistently reproduce excellent results.

**Implant arthroplasty** — first MTPJ arthroplasty aims to eliminate pain yet preserve motion (Figure 10). It was first performed over 50 years ago using silicone implants, initially used...
as a spacer to improve the stability following a Keller’s arthroplasty. Stemmed silicone implants were later introduced, but single stemmed implants had a high failure rate so the double-stemmed implants have superseded these. The Swanson double stem implant now comes with metal grommets to reduce fretting against the bone edges. Double stem silastic arthroplasty could be considered for older less active patients, but this group does well with arthrodesis. Silastic arthroplasty is associated with the risks of high wear, loosening, silastic synovitis and failure. Contraindications for joint replacement include hallux valgus and varus, as well as inflammatory arthropathy.

Several other designs have been used, including metal hemiarthroplasty, metal-on-plastic total joint replacement and ceramic total joint replacement. A systematic review of MTPJ replacements looking only at satisfaction rates found these to be 85%–95% following surgery.25 A systematic review comparing joint replacement to arthrodesis showed a similar AOFAS score between the two procedures but there was an increased revision rate in the arthroplasty group.26

NICE guidelines concluded that the available evidence supported the use of first MTPJ arthroplasty but that there was limited evidence as to its durability.27 They also recommended informed consent, with discussion of the potential adverse reactions; including persistent pain, infection, implant loosening, implant fracture, osteolysis, bone overproduction, cyst formation, silastic granulomas and transfer metatarsalgia.

The results for arthroplasty have some variability and are not as reproducible as arthrodesis at this stage.

Hallux varus
Hallux varus is often comprised of three components; medial deviation of the hallux at the first MTPJ, supination and IPJ flexion. It is most commonly due to an iatrogenic over-correction following bunion surgery but it can also be related to burns contractures, inflammatory arthropathy, Charcot-Marie-Tooth or AVN of the first metatarsal head, or it can be idiopathic.

Pathogenesis
Medial deviation of the great toe is due to a bony, tendon and capsuloligamentous imbalance at the first MTPJ. In the case of overcorrected bunion surgery, excessive lateral release combined with medial overtightening is often worsened with the unopposed pull of abductor hallucis brevis and the medial head of flexor hallucis brevis. Loss of medial osseous support due to excessive bone resection is another iatrogenic cause for hallux varus.

Clinical examination
The appearance of the toe varies from being too straight at the MTPJ to gross medial deviation. The toe is often supinated with an extended proximal phalanx. Other potential findings include a dorsal IPJ callus and a taut EHL. It is important to assess if the deformity is flexible or rigid, and if there is pain or crepitus on joint movement.

Investigations
Plain radiographs should include weight bearing AP, oblique and lateral views, and axial sesamoid views should also be considered. Radiographic findings include:
- excessive medial eminence resection
- medial subluxation of tibial sesamoid
- over-correction of the IM angle with a value approaching 0°
- phalangeal varus following an osteotomy
- degenerative changes at the MTPJ or IPJ

Treatment
Management depends on time to diagnosis, flexibility of the deformity and associated arthritis.

Conservative: straight or mild varus can be accommodated in a wide toe box shoe and can incorporate padding devices. More severe rigid deformities often require surgical intervention. Hallux varus diagnosed early after surgery should be taped with correction for 3 months to prevent worsening. Degenerative joints require analgesia in the first instance.

Surgical: the first element to consider is the flexibility of the first MTPJ. In the case of severe stiffness or painful arthritis, MTPJ arthrodesis is the most appropriate solution. If the MTPJ is pain free the treatment options depend on the state of the IPJ and the neighbouring rays.

Flexible joints leave more options open, all starting with a wide medial capsular release removing the pull of the abductor hallucis tendon. Subsequent tendon transfers can be dynamic or
static, aiming to substitute for the incompetent lateral collateral ligament. Dynamic transfers include lateral proximal phalangeal attachment of adductor hallucis, extensor hallucis longus or the first dorsal interosseous tendons.

Other options include a lateral collateral ligament reconstruction using a synthetic graft or an allograft. In the case of an over-resected medial metatarsal head, this can be reconstituted with a bone graft, buttressing the base of the proximal phalanx and restoring support for the tibial sesamoid.

Most surgical techniques are reported only in small case series and so comparison is difficult. Therefore, careful clinical and radiographic assessment is important and all elements that contribute to the deformity should be addressed.

**Sesamoid disorders**

The sesamoids in the great toe lie below the first MTPJ, contained within the tendons of flexor hallucis brevis (Figure 11). They function to absorb the weight of the first ray, protect the tendon of FHL from weight bearing forces and increase the lever arm at the fulcrum for the musculature of the first ray to provide a strong plantarflexion force at the first MTPJ. Pain related to the sesamoids is most commonly seen in athletes, and the tibial sesamoid is the commoner source of discomfort.

**Anatomy**

The medial sesamoid is slightly larger and more distal than the lateral. Both sesamoids lie entirely within the tendon of FHB apart from their surface where they articulate with the plantar facets of the metatarsal head. The ridge between the two facets is called the crista, and provides stability. The plantar plate connects the sesamoids to the plantar base of the proximal phalanx and is suspended by a sling mechanism formed by the collateral ligaments of the MTPJ. An intersesamoid ligament forms the floor of a tendinous tunnel on which the FHL runs. The blood supply arrives proximally from branches of the medial plantar artery and the plantar arch, leaving the distal third more vulnerable to non-union following a fracture.

**Clinical examination**

Patients often complain of pain under the 1st MTPJ, and it is important to establish any co-existant pathologies like clawing of the big toe or a cavus foot. There is often point tenderness over the affected sesamoid, pain and stiffness on movement of the first MTPJ and the pain is often exacerbated by compression against the metatarsal head. A plantar callosity below the sesamoids may be present. Hallux valgus or varus may develop secondary to trauma to the sesamoids.

**Investigations**

Plain AP, oblique and lateral view radiographs should be obtained, to check for other potential pathologies. The sesamoids are best seen on lateral oblique (lateral sesamoid), medial oblique (medial sesamoid) and axial sesamoid views (Figure 12). A bone scan or MRI scan can reveal bone inflammation, and CT can show any subtle fractures.

**Clinical conditions**

**Congenital conditions:** it can be difficult to differentiate between a bipartite sesamoid and an un-united sesamoid fracture. Multi-partite sesamoids are relatively rare, with the majority affecting the medial sesamoid. Congenital absence is often asymptomatic, but may lead to a progressive sagittal plane deformity of the hallux.

**Acquired conditions:** fractures, arthritis and bursitis can all follow a traumatic event. Sesamoiditis is associated with repetitive sporting microtrauma in young adults. Osteoarthritits follows local trauma and interrupted blood supply to the sesamoids, leading to fragmentation and flattening.

**Treatment**

**Conservative:** almost all sesamoid pathologies are managed in the first instance with orthotics, anti-inflammatories and activity modification. A metatarsal pad or custom-made orthotic device with cut outs below the sesamoids redistributes the weight to relieve symptoms. For an acute injury, a below knee walking cast is required for 6–8 weeks. Injections can be used to manage refractory inflammation.

**Surgical:** sesamoids can be shaved, drilled, excised or fixed. Shaving is used for hypertrophic or distorted bones resulting in plantar keratosis, with excision reserved for intractable cases of sesamoid pain. Removal of one sesamoid can cause the hallux to...
drift to the opposing side, so excision of the medial sesamoid can cause hallux valgus. Removal of both sesamoids risks a 'cock-up' deformity. Fractures can be treated with bone grafting, internal fixation or both.

**Hallux claw deformity**

A claw deformity of the hallux is associated with hyperextension at the MTPJ and flexion at the IPJ. Often all the toes are affected, although the great toe deformity can be the most severe.

**Aetiology**

A claw toe deformity occurs due to muscle imbalance. Aetiological factors include neuromuscular conditions (diabetes, compartment syndrome, stroke, Charcot-Marie-Tooth), congenital deformity, post-traumatic sequelae, inflammatory arthropathy, long metatarsals and overcrowding in the shoe toebox. Total sesamoidectomy can also cause this deformity. Some cases are idiopathic in origin.

Claw toes result from weak intrinsic muscles allowing simultaneous contracture of the long extensors and flexors, with imbalance and overpowering of these intrinsic muscles. Hyperextension of the MTPJ is caused by the excessive pull of the EHL and EDB, whilst PIPJ hyperflexion is caused by the pull of the long flexors. As the plantar plate attenuates the proximal phalanx subluxes dorsally and pulls the metatarsal fat pad distally, depressing the metatarsal head plantarwards, leading to painful metatarsalgia.

**Clinical examination**

The whole foot and ankle should be examined, looking for a cavovarus foot or other lesser toe deformities, and a neurological assessment should be performed. The degree of great toe deformity should be assessed, and the presence of callosities below the metatarsal head or over the IPJ observed. One should assess whether the deformity flexible or rigid; if the deformity disappears on ankle plantarflexion then it is deemed flexible. If toe hyperextension is worse in the swing phase then it is due to recruitment of the long toe extensors to accommodate for weak ankle dorsiflexors.

**Investigations**

Plain radiographs show apparent joint narrowing due to the proximal phalanx overlapping the metatarsal head. It is important to determine the degree of underlying 1st MTPJ arthritis. Nerve conduction studies and EMG can identify those with underlying neuromuscular disease.

**Treatment**

**Conservative:** non-surgical management is attempted in most cases and consists of avoiding high heeled shoes, padding painful callosities with felt or silicone pads, use of moulded insoles to distribute the load, and wearing shoes with a high and wide toe box.

**Surgical:** the Jones procedure is indicated for a flexible claw deformity of the first ray without degenerative change at the MTPJ. It was originally described as a transfer of the EHL to the neck of the first metatarsal with release of the plantar fascia, but it has been further modified with IPJ fusion, with high reported satisfaction and reliable correction. For cavus deformities this should be combined with a dorsiflexion osteotomy of the first metatarsal.

**Conclusion**

Patients frequently present with pain or deformity associated with the first ray. Careful history and examination differentiates more common pathologies, such as hallux valgus or rigidus, from more subtle disorders that may coexist. Whilst surgical treatment often results in a good outcome, conservative therapies should always be considered as first line management.