Ilkka Pentikäinen

DISTAL CHEVRON OSTEOTOMY FOR HALLUX VALGUS SURGERY

ROLE OF FIXATION AND POSTOPERATIVE REGIMENS IN THE LONG-TERM OUTCOMES OF DISTAL CHEVRON OSTEOTOMY – A RANDOMISED, CONTROLLED, TWO-BY-TWO FACTORIAL TRIAL OF 100 PATIENTS
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DISTAL CHEVRON OSTEOTOMY FOR HALLUX VALGUS SURGERY
Role of fixation and postoperative regimens in the long-term outcomes of distal chevron osteotomy – a randomised, controlled, two-by-two factorial trial of 100 patients

Academic Dissertation to be presented with the assent of the Doctoral Training Committee of Health and Biosciences of the University of Oulu for public defence in Auditorium 1 of Oulu University Hospital, on 20 November 2015, at 12 noon
Abstract

Hallux valgus is a very common foot deformation and it is also very common reason for orthopaedic surgery in Western industrialised countries, including Finland. In Finland, about 90% of the patients are women.

Several early studies support the opinion that distal chevron osteotomy is a predictably successful treatment for mild-to-moderate hallux valgus deformities. Nevertheless, the necessity of chevron osteotomy fixation is controversial and only limited evidence supports the effectiveness of postoperative regimens. In this prospective randomised study, we compared the long-term results of 2 operative techniques (osteotomy fixation versus no fixation) and 2 postoperative regimens (a soft cast versus an elastic bandage) in 100 patients who underwent surgery for hallux valgus. Clinical evaluations based on the American Orthopedic Foot and Ankle Society (AOFAS) scale scoring were performed at baseline and again at 6 weeks, 6 months, 1 year, and a mean of 7.9 years postoperatively. Radiographic measurements were also made of the hallux valgus angle (HVA), first intermetatarsal angle (I/II IMA), distal metatarsal articular angle (DMAA), sesamoid position (LaPorta), congruence of the first metatarsophalangeal joint and the shift of the metatarsal head. Intraobserver repeatability and interobserver reliability of radiographic measurements were evaluated by an experienced orthopaedic surgeon and an experienced radiologist.

The mean AOFAS function scores were better in the group treated without osteotomy fixation and with an elastic bandage at 6 weeks postoperatively, but the difference disappeared at later dates. AOFAS scores were significantly worse when the preoperative hallux valgus angle exceeded 30 degrees. The AOFAS scores did not differ statistically among the groups in our population.

Radiological recurrence of hallux valgus deformity of 15 degrees or more was very common at long-term follow-up after distal chevron osteotomy. Preoperative congruence, DMAA, sesamoid position (LaPorta), HVA and I/II IMA affected recurrence. All recurrences were painless; thus, no revision surgery was required.

A statistically higher metatarsal head shift was observed in the fixation group, but the clinical significance of 0.8 mm was very small.

The experienced orthopaedic surgeon and experienced radiologist each exhibited good repeatability and reliability.

Based on this study, the fixation of the distal chevron osteotomy is not necessary, nor is a rigid soft cast bandage required. The risk of recurrence of hallux valgus is higher when the preoperative HVA is 30 degrees or over.

Keywords: chevron osteotomy, hallux valgus, radiology, reliability
Pentikäinen, Ilkka, Ensimmäisen jalkapöydänluun etäisen osan V-muotoinen luunkorjausleikkaus (chevron osteotomia) vaivaisenluun kirurgiassa. Luun kiinnityksen ja leikkauskseen jälkeisen hoidon merkitys pitkäaikaistulosten valossa - 100 potilaan satunnaiset ja kontrolloitu seurantatutkimus

Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta; Oulun yliopistollinen sairaala

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Tiivistelmä

Vaivaisenluu on hyvin yleinen jalan epämääräisyys ja se on myös hyvin yleinen syy jalkakirurgiaan läntisissä teollisissa maissa ja myös Suomessa. Noin 90 % suomalaisista potilaita on naisia.

Useat aiemmat tutkimukset tukevat mielipidettä, jonka mukaan ensimmäisen jalkapöydänluun alaosan V-muotoinen luunkorjausleikkaus näyttäisi olevan suositeltava hoito lievän ja kohdalaisen vaivaisenluun hoidossa.

Luunkorjauksen kiinnityksen tarpeellisuus on kiistanalainen ja todisteet leikkauskseen jälkeisen hoidon tehosta ovat rajalliset. Tässä eteenpäin suuntautuvassa, satunnaitetussa tutkimuksessa vertasimme kahden leikkaustekniikan (luunkorjauksen kiinnitys/ei kiinnitystä) ja kahden leikkauskseen jälkeisen hoidon (kevyt kipsisidos/elasmin tuoksidos) pitkäaikaistuloksia 100 potilaalta, jotka hoidettiin vaivaisenluun vuoksi. Kliinin arvioointi suoritettiin Amerikan ortopedisen jalka- ja nilkkayhdistyksen pisteyttäksen mukaan (AOFAS) ennen leikkausta ja 6 viikkoa, 6 kuukautta, 1 vuosi sekä keskimäärin 7.9 vuotta leikkauskseen jälkeen. Samoin röntgenkuvista mitattiin vaivaisenluukulma (HVA), ensimmäisen ja toisen jalkapöydänluun välinen kulma (I/II IMA), ensimmäisen jalkapöydänluun alapään nivelin kulma (DMAA), sisemmän jänne- luun asema (LaPorta), ensimmäisen jalkapöydänluun ja varpaan välisen nivelin asento sekä leikkauskseen tapahtunut jalkapöydänluun pään siirto. Röntgenkuvista tehtyjen mittausten toistettavuus ja luotettavuus arvioitiin kokeen ortopedin ja kokeen röntgenlääkärin välillä.

Keskimääräiset AOFAS toimintapisteet olivat parempia siinä leikkausryhmässä, jossa luunkorjasta ei kiinnitetty ja leikkauskseen jälkeen käytettiin joustavaa tukisidosta 6 viikon kontrollissa, mutta seurannassa ero hävisi. AOFAS-pisteet olivat merkittävästi luonnomat, jos vaivaisenluukulma oli ennen leikkausta yli 30 astetta. Aineistossamme AOFAS-pisteet eivät eronneet tilastollisesti merkittävästi eri ryhmien välillä.

Röntgenkuvissa vaivaisenluukulman uusiutuminen 15 asteeseen tai sen yli oli hyvin tavallinen jalkapöydänluun alaosan chevron osteotomian jälkeisessä pitkäaikaistulossassa. Ennen leikkausta arvioidut nivelin asema, DMAA, LaPorta, HVA ja I/II IMA vaikutivat uusiutumiseen. Kaikki uusiutumiset olivat kivuttomia ja uusintaleikkauskia ei tarvittu.

Röntgenkuvissa vaivaisenluukulma uusiutui 15 asteeseen tai sen yli. Ennen leikkausta arvioidut nivelin asema, DMAA, LaPorta, HVA ja I/II IMA vaikutivat uusiutumiseen. Kaikki uusiutumiset olivat kivuttomia ja uusintaleikkauskia ei tarvittu.

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Asiasanat: luotettavuus, luukirurgia, röntgentutkimus, vaivaisenluu
To Marjatta
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Oulu, September 2015

Ilkka Pentikäinen
## Abbreviations

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<th>Definition</th>
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<tr>
<td>AOFAS</td>
<td>American Orthopedic Foot and Ankle Society</td>
</tr>
<tr>
<td>AP</td>
<td>antero-posterior</td>
</tr>
<tr>
<td>BMI</td>
<td>body mass index</td>
</tr>
<tr>
<td>DMAA</td>
<td>distal metatarsal articular angle</td>
</tr>
<tr>
<td>HV</td>
<td>hallux valgus</td>
</tr>
<tr>
<td>HVA</td>
<td>hallux valgus angle</td>
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<tr>
<td>IMA</td>
<td>intermetatarsal angle</td>
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<tr>
<td>MTP</td>
<td>metatarsophalangeal</td>
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<tr>
<td>RCT</td>
<td>randomised controlled trial</td>
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List of original publications

This thesis is based on the following original articles, which are referred to in the text by their Roman numerals.


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1 Introduction

Hallux valgus is a very common foot deformation, with a reported prevalence in adult female shoe-wearing populations as high as 44% (Elton & Sanderson 1987). It is also a very common reason for orthopaedic surgery in Western industrialised countries so that more than 200 000 patients are estimated to undergo hallux valgus surgery in the USA every year (Coughlin & Thompson 1995), while in Finland the annual incidence is 78 operations/100 000 inhabitants (Finnish Hospital Discharge Register 1998).

The deformity of hallux valgus is progressive, and involves several stages, but it begins with lateral deviation of the great toe (hallux) and medial deviation of the first metatarsal (metatarsus primus varus) (Hardy & Clapham 1951). In its later stages, hallux involves progressive subluxation of the first metatarsophalangeal (MTP) joint (Mann & Coughlin 1981).

Angular measurements on radiographs made with patient standing are helpful to define magnitude of the hallux valgus deformity (Coughlin 1997). The hallux valgus angle (HVA) is formed by the intersection of the longitudinal axes of the proximal and the first metatarsal. HVA of less than 15 degrees is considered normal (Hardy & Clapham 1951). The first-second intermetatarsal angle (IMA) is formed by the intersection of the longitudinal axes of the first and second metatarsals, and an angle less than 9 degrees is considered normal (Mann & Coughlin 1993). With the use of these two measurements, a general classification scheme for hallux valgus was developed. It is helpful to define mild, moderate and severe deformities, both to standardize their description and to assist in preoperative planning (Mann & Coughlin 1993).

Although there are an enormous number of publications of hallux valgus, there is insufficient evidence based on randomised controlled trials to determine, which methods of treatment are the most appropriate. One systematic review found only 21 randomised trials concerned with the treatment of adult hallux valgus, three involving conservative treatment, fourteen operative treatment and four postoperative treatment (Ferrari et al. 2004). There is evidence that surgical treatment for the hallux valgus deformity is superior to conservative treatment, which appears to be of little use for either the control of deformity, the alleviation of pain or the improvement of function in the long term (Ferrari et al. 2004). One trial comparing chevron osteotomy with conservative treatment and no treatment found surgical treatment effective (Torkki et al. 2001).
Although chevron osteotomy is a very widely used procedure, long-term reports are only few in number and results are variable (Schneider et al. 2004, Torkki et al. 2001). Variability exists in the surgical technique. While internal fixation was not originally advocated by Austin and Leventen in 1981, miscellaneous fixations have been used by some authors (Hirvensalo et al. 1991, Johnson et al. 1991, Pochatko et al. 1994). No randomised controlled trial comparing fixation and no fixation following chevron osteotomy has been introduced. Variability exists also in the postoperative treatment, and the evidence available from the few known trials is limited to determining which methods of treatment are most appropriate (Connor et al. 1995, Ferrari et al. 2004, Lampe et al. 1991, Meek & Anderson 1999). In general, a trend is apparent towards more rapid full mobilisation with less rigid elastic bandaging of the foot postoperatively, but it is unclear how postoperative control of alignment will influence the long-term postoperative outcome.

The indications for standard distal chevron osteotomy are currently limited to mild and moderate cases of hallux valgus (Park et al. 2013).

The present prospective randomised controlled trial compared two operative techniques (no osteotomy fixation vs. bioabsorbable rod fixation) and two postoperative regimens (soft cast vs. elastic bandage) in order to test the null hypothesis that the functional results after an average of 7.9 years of follow-up do not differ between these four study groups.

No prospective, randomised controlled trial has yet assessed the shift of the first metatarsal head with two operative techniques (no osteotomy fixation versus bioabsorbable rod fixation) and two postoperative regimens (soft cast versus elastic bandage). One purpose of this study was also to determine if the head fragment displaces to a greater or lesser extent with either of the operative and postoperative bandaging techniques.

One common complication of hallux valgus surgery is recurrence, which can be associated with the deterioration of operative results (Sammarco & Idusuyi 2001).

The present study also aimed to analyse the radiological long-term results after distal chevron osteotomy for hallux valgus, and to determine the preoperative radiological factors that contribute to radiological recurrence of deformity. The factors evaluated included HVA, I/II IMA, the distal metatarsal articular angle (DMAA), sesamoid position (LaPorta), and first metatarsophalangeal joint congruence.
A further goal was to analyse the interrater and intrarater reliability between one experienced orthopaedic surgeon and one experienced radiologist. We estimated LaPorta, HVA, IMA, DMAA, metatarsus adductus angle, congruence, and calcaneal pitch angle from weightbearing radiographs.
2 Review of the literature

2.1 The pathogenesis of hallux valgus

In the nineteenth century, hallux valgus was thought to arise due to an enlargement of the metatarsophalangeal joint of the great toe. The first published reference to hallux valgus was by Carl Hueter (1870), who described that hallux abductovalgus was more correctly 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 aetiology of hallux valgus. In the 1950s, Sim-Fook and Hodgson (1958) compared shoe-wearing and non-shoe-wearing groups and showed a very great increase in the prevalence of hallux valgus among the shoe-wearing group. However, this did not explain the prevalence of hallux valgus in the community of people who had never worn shoes, nor did it account for many individuals who wore high-fashion footwear and never became affected. Clearly, the issue is more complex than simply a problem of footwear. Although much research has been conducted 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 (Perera et al. 2011).

2.1.1 Pathoanatomy of hallux valgus

Development of hallux valgus

Hallux valgus is generally accepted to occur in steps (Eustace et al. 1996, Stephens 1994), frequently against a background of several predisposing factors. These steps do not necessarily occur in series but may transpire in parallel. These steps are as follows (Perera et al. 2011):

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 tarsometatarsal joint may encourage this movement.
3. The proximal phalanx moves into the 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, where it can erode the cartilage and the crista. The lateral sesamoid can appear to sit in the intermetatarsal space, although it does not actually move.

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, 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 attachments rotate inferiorly. The adductor hallucis is attached laterally to the plantar surface, 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, providing poor stability.

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 begins from the distal phalanx of the hallux and extends to the talonavicular joint. It plays a key role in maintaining the structure of the medial arch (McBride 1928). As the main load-bearing structure (Morton 1930), it is subject to substantial forces during gait.

Failure anywhere along the first ray can result in hallux valgus. The first ray biomechanics are therefore worth considering as a common factor in many of the key theories. The metatarsal head has no tendon attachments, so 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 (Easley & Trnka 2007).
The functions of the \textit{sesamoid} bones are, first, to absorb weightbearing forces and enhance the load-bearing capacity of the first ray. The sesamoids also increase the moment arm of the flexor hallucis brevis, which powers plantar flexion of the hallux. The first metatarsal head is elevated on the sesamoids during stance, but the sesamoids move during hallux dorsiflexion. The sesamoid sling facilitates the first metatarsal plantar flexion, which is essential for hallux dorsiflexion.

The sesamoids can appear to subluxate with first metatarsal pronation alone, but the joint reaction force of the metatarsosesamoid joint is normally sufficient to prevent subluxation. Thus, the metatarsosesamoid joint must become unloaded either by elevation of the first metatarsal head or by the lateral transfer of plantar pressure (Perera \textit{et al.} 2011).

\textit{First ray motion} is important. Morton (1935) believed that dorsal hypermobility of the first metatarsal segment was responsible for the widest array of foot deformity. However, some studies have questioned whether motion at the tarsometatarsal joint even exists (Philips \textit{et al.} 1996, Roukis & Landsman 2003). The studies that described the motion of the first tarsometatarsal joint had no consensus with regard to either the axis of movement or its magnitude. In so-called normal feet, the normal average dorsoplantar motion is 6 mm. 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 (Glasoe \textit{et al.} 1998).

\textit{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 motion. These motions increase the loading on the medial aspect of the toe (Perera \textit{et al.} 2011).

Plantar flexion of the first ray also maintains ground contact during heel rise, when the obliquity of the metatarsophalangeal break (the axis of the four lateral metatarsophalangeal joints) is enhanced during late stance, causing lower-extremity external rotation and inversion of the subtalar joint (Perera \textit{et al.} 2011). A normal gait uses up to 65 degrees of first metatarsophalangeal dorsiflexion, and first ray elevation substantially compromises this range of motion (Dananberg 1986). Furthermore, the normal hallux has a tendency toward valgus and any pronation further encourages this tendency. The transverse sphericity of the first metatarsal head (Yoshika \textit{et al.} 1998) permits multiplanar motion, so the collaterals, sesamoids and so-called rein effect of the first metatarsophalangeal joint rotator cuff are all required for stability.
2.1.2 Etiology of hallux valgus

Extrinsic factors

The use of footwear has been implicated as an etiology (Coughlin & Thompson 1995), even prior to the understanding of hallux valgus pathology. The prevalence of hallux valgus is low in unshod populations (MacLennan 1966), and the prevalence increases with changes in shoe fashion (Kato & Watanabe 1981). However, the association is not complete and footwear is not at all important in juvenile hallux valgus (Coughlin et al. 1995). High heels are commonly blamed for hallux valgus; however, this forefoot loading is probably more important in deformity progression than in initiation (Hughes et al. 1991).

The prevalence of hallux valgus in women who wear shoes with a narrow toe-box or a high heel is certainly not 100%. Therefore, even in women, footwear is probably more important in progression than in causation. Intuitively, this risk is greater in those with a wider foot (Perera et al. 2011).

Excessive loading effects on the development of hallux valgus, and that develops slowly. However, despite the importance of occupation or excessive walking and weightbearing, there is no proven link between these and the occurrence of hallux valgus (Coughlin & Jones 2007). The only exception is a weak association with ballet dancing (Einarsdottir et al. 1995). Mann and Coughlin (1981) reviewed the literature on cumulative industrial trauma and dismissed any occupational link.

No clear link has been established between hallux valgus and obesity (Frey & Samora 2007).

Intrinsic factors

A genetic predisposition has long been suspected (Johnston 1956). The best evidence showed that 90% of 350 white patients had at least one affected relative (Pique-Vidal et al. 2007), with the most common pattern of inheritance being autosomal dominant with incomplete penetrance. The role of genetics in juvenile (Coughlin et al. 1995) and young adult (Coughlin & Jones 2007) hallux valgus is much more established, with maternal transmission found in 94% (29) of 31 patients with a family history. There is weak evidence of a racial difference. The prevalence of hallux valgus has been reported to be two times greater in white than that in black Africans (Barnicot & Hardy 1955).
The true sex ratio is unknown, although a male-to-female ratio of 1:15 is well established among those who have corrective surgery (Pique-Vidal et al. 2007, Saro et al. 2007, Thordarson et al. 2005). The higher prevalence among women may be due to footwear that is either poor or less forgiving, resulting in earlier and more frequent presentation.

Fundamental differences are evident in osseous anatomy; for instance, the articular surface of the metatarsal head is more rounded and smaller in female patients, which provides a less stable joint (Ferrari & Malone-Lee 2002). Women also tend to have a more adducted first metatarsal, which in turn may be due to differences in the tarsometatarsal articulation (Ferrari et al. 2004).

Ligamentous laxity (Wilkerson & Mason 2000) and first ray hypermobility (Coughlin & Shurnas 2003) are more common in women than in men. No link has been made with pregnancy.

Systemic conditions

Mild ligamentous laxity is common in women with hallux valgus and has been reported in 70% of twenty patients with juvenile hallux valgus. Therefore, in conditions with generalised ligamentous laxity, such as Marfan syndrome, Ehlers-Danlos syndrome and rheumatoid arthritis, hallux valgus is more common and more difficult to treat (Perera et al. 2011). Despite the fact that patients with laxity have a major risk for recurrence, little work has been done on this condition (Coughlin 1996).

When the age of patient becomes higher, the risk of hallux valgus grows. 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 (Scott et al. 2007). Although the peak onset is from thirty to sixty years of age, the initial changes more likely occur during adolescence, or even earlier for juvenile hallux valgus (Coughlin et al. 1995).

The association between metatarsus primus varus and hallux valgus is well known, but whether this is a cause or an effect is unclear (Coughlin et al. 1995, Hardy & Clapham 1952). Metatarsus primus varus is important in juvenile hallux valgus and has been reported in up to 75% of such patients (Pontious et al. 1994).

A weak association was found between the magnitude of metatarsus primus varus and hallux valgus in women (Coughlin & Jones 2007), but the evidence shows that it is related to the choice of footwear.
Snijders et al. (1986) concluded, based on biomechanical investigations, that metatarsus primus varus was secondary to the toe deformity. This finding supports the observation that when hallux valgus is corrected, the metatarsus primus varus can improve without any attempted correction of the first metatarsal itself. This has been shown for basal osteotomy (Coughlin & Jones 1995), first metatarsophalangeal joint fusion (Cronin et al. 2006), and even the Keller procedure, suggesting that metatarsus primus varus is a secondary phenomenon.

Some people appear to 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 (Perera et al. 2011).

**Metatarsal anatomy**

Metatarsal formula refers to the *relative lengths of the metatarsals*. The normal order, in terms of decreasing length, is second, first, third, fourth and then fifth, but the first and third are commonly equal in length. Morton (1935) described the short first metatarsal of Morton foot that he believed led to pronation and hypermobility of the first ray and therefore hallux valgus. No clinical evidence exists for this relationship and more reliable measurement techniques have found the true association to be as low as 4% (Coughlin & Jones 2007).

Mancuso et al. (2003) found that 80% of 110 patients with hallux valgus had 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. A long first metatarsal creates a so-called buckle point, resulting in a hallux valgus with a high intermetatarsal angle and a strong association exists between protrusion distance and intermetatarsal angle. It is important to remember that pronation of the foot causes metatarsal dorsiflexion, making it appear longer than it actually is (Perera et al. 2011).

Heden and Sorto (1981) 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 (Okuda et al. 2007). The flattened, so-called square or chevron-shaped head is more stable (Coughlin & Jones 2007).
Measurement of the distal metatarsal articular angle is notoriously unreliable (Robinson et al. 2006), and shows a very wide variation (-14 to 30 degrees) of normal, which was defined as 6 degrees or less (Richardson et al. 1993). Although these authors suggested that the distal metatarsal articular angle (DMAA) can be determined reliably by radiography, others have reported poor interobserver reliability (Chi et al. 2002, Coughlin & Freund 2001, Vittetoe et al. 1994). However, a congruent metatarsophalangeal joint in hallux valgus requires an altered DMAA and the two are directly related. Interestingly, the congruent metatarsophalangeal joint appears to be more stable and less likely to progress (Turan 1990). No association is found with metatarsal length, adduction, mobility, range of motion or inheritance (Coughlin & Jones 2007).

The proximal metatarsal articulation shows individual variation and an association between obliquity and hallux valgus (Ferrari & Malone-Lee 2002). This association appears well established; however, these studies are all based on radiographic appearances and apparent angulation varies considerably with foot posture (Perera et al. 2011).

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, while an articular surface with three facets only occurred in subjects with normal feet. They hypothesised that increasing number of articular facets evoked stability (Mason et al. 2010).

The metatarsal bunion is not an osteophyte, new bone formation or ossification of inflamed tissues. No actual increase occurs in the size of the medial eminence (Coughlin & Jones 2007). Instead, the metatarsal head is increasingly exposed by cartilage loss because of the lack of contact from the phalanx. 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. As the sagittal groove moves laterally with increasing hallux valgus deformity, this is not considered an indication for bunionectomy in severe hallux valgus (Perera et al. 2011).

**Metatarsal biomechanics**

The role of the static stabilisers around the first metatarsophalangeal joint is important. 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 stabilisers and their insufficiency is essential for the development of deformity. Sectioning them alone results in a valgus angulation of > 20 degrees. These structures are mechanically abnormal in hallux valgus, with altered organisation of the type-I and type-II collagen, which leaves the first metatarsophalangeal joint vulnerable to continuous and cyclical distraction during gait (Uchiyama et al. 2005).

McBride (1928) advocated transverse metatarsal ligament transection for correction, but no radiographic evidence yet supports the use of this procedure (Scott et al. 2007). This finding is not surprising, since the deep transverse ligament joins the five plantar pads together and not the metatarsal heads. Sectioning the transverse ligament barely changes the valgus deformity and does not alter the relationship between the first and second metatarsals. 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 (Perera et al. 2011).

Dynamic stabilisers around the first metatarsophalangeal joint are different. The abductor hallucis abducts, the plantar flexes and inverts the great toe, while the adductor hallucis adducts, the 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 the progression of deformity (Perera et al. 2011).

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 (Wong 2007).

Sanders et al. (2005) studied the role of flexion forces in the etiology of hallux valgus. The downward pull of the hallux onto the ground creates a force coupled 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.

Migration of the sesamoids over the crista is important in deformity progression (Suzuki et al. 2004). When the medial sesamoid ligament is attenuated and the loss of the restraint provided by the crista occurs, deterioration can be rapid.

Metatarsal kinematics is little more complicated. The first-ray hypermobility theory states that the plane of motion of the first ray is exaggerated because of tarsometatarsal joint instability (David et al. 1989). No ligamentous structures bind 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. The elevation causes a reduction in the pressure under the first metatarsal head. 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 (Dananberg 1986).

The reported increase in the recurrence of hallux valgus after surgical correction, when the first tarsometatarsal joint is not fused, is disputed (Coughlin & Jones 2007). Furthermore, ray realignment alone has been shown to stabilise sagittal motion without tarsometatarsal joint fusion (Coughlin & Jones 2007, Coughlin & Shumas 2003), probably because of a realignment of the plantar fascia, which improves the windlass mechanism (Sarrafian 1987).

Hypermobility is still not well understood 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, in fact, be more important (Faber et al. 1999).

Much has been written about the role of pes planus in the etiology of hallux valgus. The mechanism appears obvious, i.e. pronation increases loading on the plantar medial border of the hallux during heel rise, but several other changes occur (Perera et al. 2011):

1. Pes planus produces an elevation and thus a functional lengthening of the first metatarsal, which can limit first metatarsophalangeal joint movement.
2. The peroneus longus is less able to stabilise the first ray. If this insufficiency is prolonged, hypermobility of the first ray can result.
3. In the planovalgus foot, eversions of the hindfoot and midfoot reduce the load on the first metatarsophalangeal joint, although weightbearing through the medial arch increases. This change is due to the relative mobility of the first tarsometatarsal joint compared with second tarsometatarsal joint and the loss of the pull of the peroneus longus.
4. As the hindfoot everts, the foot becomes abducted to the line of progression, increasing the abduction force in dorsiflexion on heel rise.
5. Early and excessive firing of the abductor and adductor hallucis occur in the pronated foot. Their line of pull alters as the sesamoids rotate, resulting in an overall valgus moment.

Coughlin et al. (2007) 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, which can result in a repetitive injury to the medial restraints. With pronation comes axial rotation of the so-called plantar rotator cuff, which further exacerbates the deformity (Shereff et al. 1986).

Despite the commonly held belief that pes planus plays an important role in hallux valgus, strong pedobarographic and radiographic evidence exists to the contrary (Coughlin & Jones 2007), especially in juvenile hallux valgus.

No study has looked at the prevalence of the 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 versus a 2 to 4% rate of hallux valgus (Myerson & Badekas 2000). It is important to note that even studies implicating pes planus found rates close to this background rate.

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 case (Coughlin et al. 1995, Mann & Coughlin 1981), although only one study looked at older patients in whom the biomechanical abnormalities had a longer time to produce an acquired deformity.

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 (Coughlin et al. 2007).

**Structural hallux limitus** is a limitation of dorsiflexion on both weightbearing (< 12 degrees) and non-weightbearing (< 50 degrees). 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 weightbearing only.

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 some extent even in normal feet and is due to the axis of rotation of the joint shifting plantarward as the first ray elevates (Roukis et al. 2006). Functional hallux limitus is purported to predispose to either hallux rigidus or hallux valgus, depending on the coexisting biomechanics of the foot (Scherer et al. 2006).

In hallux valgus, structural hallux limitus appears to be exaggerated and passive range of motion at the metatarsophalangeal joint commonly reduces on weightbearing (Coughlin & Jones 2007). The proposed link is that certain foot types (i.e. an everted hindfoot, a flexible forefoot valgus or a plantar-flexed first ray) increase the ground reaction force under the first metatarsal head. These foot types also increase the ground reaction force earlier and for longer in the gait cycle.
As the metatarsophalangeal joint dorsiflexion is limited at heel rise, the hallux is forced in the direction of least resistance. Consequently, feet with a great deal of mobility in the first ray are at risk of hallux valgus. The actual prevalence of functional hallux limitus and subsequent hallux valgus is low (Perera et al. 2011).

The windlass model explains these findings simply. An increase in hallux valgus deformity on weightbearing (Tanaka et al. 1995) is due to tightening of the plantar fascia and the pronation effect of weightbearing. When this motion is excessive, the plantar aponeurosis is further tightened. 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. 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 (Perera et al. 2011, Rush et al. 2000).

A tight Achilles tendon can predispose to hallux valgus (Mann & Coughlin 1981). This is because of early and increased forefoot loading. The natural tendency is to externally rotate the foot, rolling over the medial border rather than going forward through the third rocker, thereby increasing the valgus force. Clinical studies of hallux valgus have showed that the Achilles tendon tightness must be defined as being < 10 degrees of ankle dorsiflexion (Coughlin & Jones 2007). Others have found no association (Dananberg 1986), and no evidence exists that failure to address Achilles tendon tightness results in a higher recurrence of hallux valgus (Grebing & Coughlin 2004).

Peroneus longus dysfunction plays an important role. In hallux valgus the first metatarsal rotates to an inverted position relative to the hallux and the peroneus longus tendon is the only ector of it. Thus, malfunction of the peroneus longus tendon might play a crucial role in the development of hallux valgus (Johnson & Christensen 1999, Rush et al. 2000).

2.1.3 Overview of the pathogenesis of hallux valgus

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, a rounded articulation and the metatarsus primus varus, play an important role. These variants increase the vulnerability to first-ray hypermobility, pes planus and ligamentous laxity (Perera et al. 2011).

The toe is at risk if loading is increased on the medial side. If the forefoot is in a narrow toe-box or if it is 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.

In the normal foot, the great toe has a tendency to be pulled into valgus, but the static restraints act like reins, preventing this tendency. 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. The deep transverse ligament holds the phalanx in place, while the incompetent medial sesamoid ligament and medial collateral ligament allow the metatarsal head to drift into the varus (Perera et al. 2011).

We know that poor footwear is a risk, and yet few people who wear high-fashion ladies’ shoes develop hallux valgus. The true answer lies in the interplay of the various intrinsic and extrinsic factors that come together in any one particular foot. In the absence of large-scale population studies or longitudinal studies, some unanswered questions will always persist regarding the true pathogenesis and optimal treatment of hallux valgus (Perera et al. 2011).

2.2 Diagnosis of hallux valgus

2.2.1 History, physical examination and clinical assessment

The evaluation of hallux valgus begins with a careful history of the patient’s condition. This should include the chief complaint, which in our series of bunions is pain over the medial eminence in about 70% of patients. A symptomatic, intractable plantar keratosis beneath the second metatarsal head was present in about 40% of patients. Other associated problems include neuromas, lesser toe deformities, corn and calluses. Information should be obtained regarding the patient’s level of activity, occupation, athletic inclinations, preference in shoe wear and reasons for choosing surgery. The patient’s medical history should be obtained (Mann & Coughlin 1999).
The physical examination is carried out by observing the patient’s gait, then carefully observing the foot while the patient stands. At this time, the degree of deformity of the hallux and lesser toes is noted and the longitudinal arch and hindfoot position observed.

The physical examination begins with the patient standing, as this often increases the hallux valgus and associated deformities. Assessment of the hindfoot as well as the forefoot is important. Planovalgus deformities and tightness of the gastrocnemius and soleus can often exacerbate loading and pain under the forefoot (Robinson & Limbers 2005). The Achilles or gastrosoleus tightness should be assessed with the knee extended and flexed, with care taken to ensure that the foot is maintained in a neutral position (with the talonavicular joint reduced to eliminate transverse tarsal or subtalar motion) (Coughlin & Jones 2007).

The severity of the hallux valgus deformity and whether it is correctable is documented. Any pronation of the great toe is noted. The first metatarsophalangeal joint is examined to assess the range of movement. The lesser toes should be examined for associated deformities and callosities. The intermetatarsal spaces should be palpated for interdigital neuromas. The plantar surface of the foot should be checked for tender callosities under the lesser metatarsal heads (transfer lesions). Assessment of instability of the first tarsometatarsal is conducted by having the examiner immobilise the lesser metatarsals with the thumb and fingers of one hand. The thumb and index finger of the other hand then grasp the first metatarsal and move it from a plantar to a dorsomedial direction. Movement of more than 9 mm indicates hypermobility (Klaue et al. 1994). The patient should also be examined for signs of generalised ligamentous laxity.

The vascular evaluation includes palpation of the dorsalis pedis and posterior tibial pulses, capillary filling of the toes and evaluation of the skin and hair. If any question exists regarding the circulatory status of the foot, a Doppler evaluation should be performed (Mann & Coughlin 1999).

The neurologic examination focuses on sensation, vibratory sense and the strength of the intrinsic and extrinsic muscles (Mann & Coughlin 1999).

### 2.2.2 Radiological assessment

Weightbearing anteroposterior and lateral radiographs of the foot are taken to help assess the deformity and assist in preoperative planning. All first and second ray
angular measurements should be made according to the guidelines set forth by the American Orthopedic Foot and Ankle Society ad hoc Committee on Angular Measurements (Coughlin et al. 2002).

Hallux valgus angle (HVA, Figure 1) is created by a line that bisects the proximal phalanx and the first metatarsal shaft (normal is 15 degrees or less, mild is less than 20 degrees, moderate is 20 to 40 degrees and severe 40 degrees or more) (Mann & Coughlin 1999).

![Fig. 1. Hallux valgus angle A. Intermetatarsal I/II angle B.](image)

The I/II intermetatarsal angle (IMA, Figure 1) is created by a line that bisects the first and second metatarsal shafts. Normal is less than 9 degrees.

The hallux interphalangeal angle is created by a line that bisects the proximal phalanx shaft and the distal phalanx shaft. Normal is 10 degrees or less (Barnett 1962).

The DMAA (Figure 2) is the angle between the articular surface of the head and shaft of the first metatarsal. Normal is less than 10 degrees (Mann & Coughlin 1999). A normal value has also been defined as 6 degrees or less (Richardson et al. 1993).
Fig. 2. Distal metatarsal articular angle

The tibial sesamoid position (Figure 3) is determined by the location of the tibial sesamoid relative to the bisection of the first metatarsal shaft. Number 1 is normal, number 4 is at the centre of metatarsal shaft and number 7 is most laterally luxated (LaPorta et al. 1974).

Fig. 3. Tibial sesamoid position according to LaPorta.
The congruence (Figure 4) of the first metatarsophalangeal joint is determined by lines drawn at the base of the proximal phalanx and along the articular surface of the first metatarsal (Mann & Donatto 1997). If these lines are parallel, the joint is congruent. If these lines intersect outside the joint, the joint is deviated, and if the lines intersect within the joint, the joint is subluxated (Piggott 1960).

Fig. 4. Congruence of the first metatarsophalangeal joint.

The metatarsus adductus should be measured on the anteroposterior radiograph. The technique for measurement relates the position of the metatarsals relative to the midfoot; a normal value is 15 degrees or less, mild adductus is 16 to 19 degrees, moderate is 20 to 25 degrees and severe is more than 25 degrees (Coughlin 1999).

The shape of the distal first metatarsal articular surface has been recorded as oval, flat or chevron shaped (Mann & Coughlin 1981).

The size of the medial eminence should be measured by drawing a line along the medial diaphyseal border of the first metatarsal. A perpendicular line should then be drawn at the widest extent of the medial eminence and measured in millimetres (Thordarson & Krewer 2002).

The first metatarsal length should be measured in comparison to the second metatarsal length (metatarsal protrusion distance) on the preoperative anteroposterior radiograph (Hardy & Clapham 1951). Values should be measured and recorded in millimetres; measurements within the range of +1 to -1 mm should be considered to be equal length.

The anteroposterior and lateral radiographs should also be inspected for evidence of pes planus. On the anteroposterior radiograph, the talonavicular coverage angle can be measured. This means the angle between the distal talar and proximal navicular articular surface (pes planus more than 14 degrees (Sangeorzan et al. 1993).
The lateral radiograph should be used for measurement of the calcaneal pitch angle, Meary’s line and the lateral talocalcaneal angle. The calcaneal pitch angle is the angle between the inferior surface of calcaneus and the line using the plantar-most surface of sesamoids and the inferior calcaneus (pes planus less than 20 degrees) (Tanaka et al. 1995). Meary’s line is the lateral talometatarsal angle. It is the angle between the lateral axis of the talus and the longitudinal axis of the first metatarsal (pes planus less than -4 degrees) (King & Toolan 2004). The lateral talocalcaneal angle is the angle between the lateral axis of the talus and the lateral axis of the calcaneus (pes planus more than 50 degrees) (Tanaka et al. 1995).

2.3 Treatment of hallux valgus

Treatment options for hallux abductovalgus deformities can be roughly broken down into one of three types: observation, conservative care and surgical management. Factors that may help to guide the physician in this decision process include the presence or absence of symptoms, the severity and duration of symptoms, the presence of secondary deformities (i.e. hammer toe of the second digit), joint adaptation, the presence or absence of degenerative joint changes, the anticipated progression of the deformity, the expectations of the patient, the general health of the patient and the likelihood of response to conservative care (Martin & Pontious 2001).

2.3.1 Observation

Observation may be employed for those patients with few if any symptoms and without secondary deformities, joint degeneration or joint adaptation. Surgical intervention in patients who present for cosmetic reasons remains a controversial issue and must be negotiated individually by each surgeon. Yearly or biyearly follow-up examinations may allow the physician to monitor the progression of the deformity and to note the development of symptoms. Employing orthotics may be useful at this stage (Martin & Pontious 2001).

2.3.2 Conservative treatment

Non-operative care is always the first option for a patient who has a hallux valgus deformity. Pain, blistering and bursal inflammation can often be relieved by
elimination of friction over the medial eminence. Evaluation of the patient’s footwear may prove helpful for making recommendations for modifications or a change in the size or style of the shoes. A wider toe box may reduce symptoms substantially. Stretching of areas of the shoe that cause increased pressure can result in complete relief of the symptoms overlying a painful bunion (Coughlin 1996).

Conservative care typically falls into one of two categories, palliative or biomechanical. Palliative forms of conservative management include the variety of pads, shields, spacers and splints that are commercially available. Shoes may be purchased with greater width or space or made of softer materials. These modalities occasionally supply a degree of symptomatic relief, but they offer no real ability to correct the deformity (Martin & Pontious 2001). Biomechanical modalities such as orthosis or supportive shoes can assist in controlling the pronatory forces within the foot. Specific devices are available that are designed to address first ray instability and to improve function at the hallux.

In the Cochrane Library, Volume (3), 2005 Ferrari et al. found three trials considering conservative therapies. Night splint versus no treatment was compared in a randomised study involving 28 people with hallux valgus aged from 10 to 77 years (Juriansz 1996). No difference was found regarding the hallux valgus angle between the groups. No significant difference was noted between the numbers of patients with pain after night splints compared with no treatment.

Functional orthoses were used in a randomised study involving 122 children aged 9 to 10 years (Kilmartin et al. 1994). The children were randomly assigned to no treatment or to the use of foot orthosis; 93 subjects were followed up for 3 years. The study showed evidence of a significant in hallux valgus angle, in favour of the control group. The hallux valgus angle in both the treatment and control group increased; this adverse development was more marked in the group treated with orthoses.

Torkki et al. (2001) compared 69 adult patients (mean age 49 years) who were prescribed functional orthoses and 69 adult participants who received no treatment. No evidence was obtained for any difference in functional AOFAS score between those receiving orthoses and those receiving no treatment. No difference was noted in the pain scores reported on a visual analogue scale by patients receiving orthoses and by those receiving no treatment.

A patient who has pes planus can be managed with an orthosis. A contracture of the Achilles tendon may be treated with stretching exercises or, occasionally,
by lengthening of the Achilles tendon. Severe pes planus may not only be a factor in etiology of hallux valgus but it may also lead to recurrent deformity (Coughlin 1996).

2.3.3 Operative treatment

Even following non-operative measures, some patients eventually may need operative management. The patient should be counselled regarding the risks, complications and expectations of the operation. Various magnitudes of deformity, different pathological elements and anatomical abnormalities emphasise the importance that the surgeon have several techniques of hallux valgus repair available. The selection of the specific procedure is often based on the severity of the hallux valgus deformity and the magnitude of the first-second intermetatarsal angle, but it may vary from surgeon to surgeon. Angular measurements provide only some of the indications for a particular procedure. The chosen operative technique must correct all elements of the problem: prominence of the medial eminence, increased valgus angulation of the proximal phalanx, an increased first-second intermetatarsal angle, congruency of the metatarsophalangeal joint, subluxation of the sesamoids and pronation of the great toe. When operation is planned, the association of the main symptoms with the physical findings as well as with the radiographic information helps the surgeon to select the best procedure for correction of a hallux valgus deformity (Coughlin 1996).

Over 100 different operative treatments have bee proposed for hallux valgus. As a general principle, the severity of the deformity dictates treatment options. While mild-to-moderate deformities often can be corrected with a more distal procedure, such as a chevron osteotomy, more severe deformities typically are managed with a more proximal procedure, such as a proximal metatarsal osteotomy or Lapidus procedure. A first metatarsophalangeal (MTP) joint arthrodesis generally is reserved for hallux valgus associated with first MTP joint arthrosis, severe deformities or salvage of failed previous hallux valgus procedures (Easley & Trnka 2007).

The indication for surgery is pain which is not adequately controlled by non-operative means. The pain may be over the bunion itself or in the second metatarsophalangeal joint as a result of insufficiency of the first ray. The management of patient expectation is important. The outcomes from hallux valgus surgery are not always ideal and extensive preoperative counselling is required. Only 60% of patients can expect to wear unlimited shoes following
surgery. If transfer lesions are present before operation, it may be necessary to wear cushioned shoes or even insoles following operation (Robinson & Limbers 2005).

The surgical procedures available are numerous and the most important operations are discussed in detail as follows.

Osteotomies of the first metatarsal are numerous. Osteotomy may be undertaken proximally or distally. Proximal osteotomies allow a greater correction of the increased intermetatarsal angle than distal osteotomies which are usually used for mild or moderate deformities. Distal osteotomies usually require a less extensive exposure, which allows a shorter recovery time. In recent years, intermediate diaphyseal osteotomies, such as the scarf and Ludloff procedures, have become popular.

A number of important principles should be remembered when selecting a first metatarsal osteotomy:

1. The technique should be technically easy to undertake and reproducible.
2. The technique should be stable so that re-displacement does not occur.
3. The length of the first metatarsal should be maintained to prevent the development of transfer lesions and metatarsalgia. Similarly, dorsiflexion, with the resultant elevation of the metatarsal head, should be avoided.
4. The technique should be versatile so that the HVA, the IMA and the DMAA can be corrected.
5. The metatarsal blood supply should be preserved in order to avoid avascular necrosis of the metatarsal head.
6. The long-term outcome should show a low recurrence rate of the deformity. (Robinson & Limbers 2005).

Distal metatarsal osteotomies

The Wilson procedure is an oblique metaphyseal osteotomy from distal medial to proximal lateral that allows displacement of the metatarsal head both laterally and proximally. This technique allows correction of the IMA and HVA (Robinson & Limbers 2005). Satisfactory results have been described in approximately 90% of patients (Keogh et al. 1990). Pouliart et al. (1996) found an average shortening of 8.5 mm in the first metatarsal and a 24% incidence of dorsal angulation with this operation. Metatarsalgia occurred postoperatively in 35% of their patients. Callosities were present under the second metatarsal head in 78% of their patients.
More than 5 mm of shortening has been shown to correlate strongly with the onset of transfer metatarsalgia (Nery et al. 2002). Due to these results, this operation is not recommended.

The Mitchell osteotomy involves a double cut through the first metatarsal neck, leaving a step in the lateral cortex. This step is used to ‘hitch’ on to the metatarsal head. The capital fragment is displaced laterally and plantarward and held with a suture through drill holes (Robinson & Limbers 2005). Good clinical results have been reported with this procedure, with a 91% rate of patient satisfaction (Blum 1994). It is recommended for an IMA up to 15 degrees and HVA up to 35 degrees. Good correction of the deformity has been reported (Kuo et al. 1998). Nevertheless, shortening of the first metatarsal occurs due to removal of bone to create the step cut. This, combined with a lack of inherent stability resulting in dorsal malunion, has led to reports of transfer metatarsalgia in 10 to 30% of patients (Kuo et al. 1998). Loss of correction can also occur. Some authors have reported a decrease in these complications by the use of internal fixation in order to increase stability (Blum 1994).

Bucioto (2014) compared Mitchell’s osteotomy and chevron osteotomy. The author concluded that both procedures offer an equivalent level of correction for mild-to-moderate hallux valgus. However, Mitchell’s osteotomy was associated with a significantly higher rate of postoperative transfer metatarsalgia and symptomatic hammertoe, as a result of relative shortening of the first metatarsal in relation to the second metatarsal.

The distal chevron osteotomy is a V-shaped osteotomy of the first metatarsal neck, described by Johnson et al. (1979) and Austin & Leventen (1981). The forefoot is narrowed by a lateral shifting of the capital fragment. An anatomical study suggested that the capital fragment can be safely shifted laterally 6.0 mm in men and 5.0 mm in women and still maintain greater than 50% bony apposition of the fragments. The procedure has been performed with or without fixation of the shifted capital fragment (Mann & Donatto 1997, Schneider et al. 2004, Torkki et al. 2003, Trnka et al. 2000, Trnka et al. 1997). The symmetric orientation of the distal chevron osteotomy (Austin & Leventen 1981) has undergone several modifications to accommodate fixation (Johnson et al. 1979, Mann & Donatto 1997). Austin and Leventen did not use any fixation of osteotomy, but some surgeons used temporary Kirschner wire fixation. Bioabsorbable pins and screws have also been used (Gill et al. 1997, Morandi et al. 2013, Murphy et al. 2014). The combination of a medial closing wedge osteotomy of the first proximal phalanx (Akin) and distal chevron osteotomy have been described when hallux
valgus with metatarsus primus varus is associated with hallux valgus interphalangeus (Tollison & Baxter 1997). The distal chevron osteotomy also has been combined with a lateral capsular or adductor tendon release, or both (Kuhn et al. 2005, Resch et al. 1994, Schneider et al. 2004, Trnka et al. 2000).


The average preoperative IMA was less than 15 degrees in all studies. Deorio and Ware (2001) reported satisfactory outcomes and patient satisfaction with low complication rate with bioabsorbable fixation. Crosby and Bozarth (1998) noted no significant differences in favourable outcomes or patient satisfaction and minimal complications when comparing screws and Kirschner wires with no fixation and comparing Kirschner wires with bioabsorbable fixation.

The addition of a lateral release to a distal chevron osteotomy may improve the correction of the hallux alignment; however, patient satisfaction is similar to that of patients who have distal chevron osteotomies with or without lateral release (Easley & Trnka 2007). One prospective randomised clinical investigation by Resch et al. (1994) compared distal chevron osteotomy with and without adductor tenotomy. Although the clinical appearance and radiographic alignment were significantly better in the group with adductor release, patient satisfaction was not. Mann and Donatto (1997), in a small case series, noted satisfactory outcomes for distal chevron osteotomy without lateral release, similar to results of case series of distal chevron osteotomies with lateral release (Pochatko et al. 1994, Trnka et al. 1994).

Two recently published case series of distal chevron osteotomies with lateral release (Schneider et al. 2004, Trnka et al. 2000) noted that the results were maintained with longer follow-up: Trnka et al, follow-up of 2 to 5 years and Schneider et al, follow-up of 5.6 to 12.7 years. Furthermore, both studies suggested that results were equal for patients under and over the arbitrarily chosen age of 50 years.

Complications with distal osteotomies can be very difficult. A concern with the chevron and other distal osteotomies is the development of avascular necrosis of the first metatarsal head, which has a reported incidence between 0 and 20% (Donnelly et al. 1994, Green et al. 1993, Horne et al. 1984). Some authors have
noted a higher incidence when a concomitant lateral release is performed (Hattrup & Johnson 1985) and have cautioned against such a combined procedure. Others have not found this to be the case (Trnka et al. 1997).

A number of studies (Jones et al. 1995, Peterson et al. 1994, Shereff et al. 1987) have described the blood supply of the head of the first metatarsal. Laterally, it is derived from the first dorsal and first plantar metatarsal artery and medially from the superficial branch of the medial plantar artery. Dissection through the first dorsal web space and release the tendon of adductor hallucis and the intermetatarsal ligament is possible by performing a longitudinal incision in the capsule of the first metatarsophalangeal joint, without damaging the dorsolateral blood supply to the head (Peterson et al. 1994). If the sawblade passes too far beyond the lateral cortex of the metatarsal, it may damage the first dorsal metatarsal artery. The blood supply to the metatarsal head will also be seriously damaged if the dorsal, lateral or inferior capsular attachment are disrupted. Therefore, when performing a distal osteotomy, the surgeon must ensure that dorsal and plantar cuts exit the bone proximal to to the capsular attachments, that the plantar soft tissues to the metatarsal head are left intact and that the sawblade passed through, but not beyond, the lateral cortex. Following these guidelines is crucial in order to avoid avascular necrosis following a chevron osteotomy (Robinson & Limbers 2005).

Given the numerous positive Level IV evidence investigations and one Level I evidence study in the orthopaedic literature, a Grade B treatment recommendation can be made to support the use of a distal chevron osteotomy for correction of mild-to-moderate hallux valgus deformity. The Level I evidence study and multiple Level IV evidence investigations provide Grade B evidence that hallux alignment and functional outcome may be better after a distal chevron osteotomy with a lateral soft-tissue procedure than without it, and indicate that patient satisfaction is no different in these two groups. Moreover, consistently positive Level IV evidence and the one Level I evidence investigation allow a Grade B recommendation that a lateral capsular or adductor hallucis tendon release can be done with a distal chevron osteotomy without increased risk of the first metatarsal head osteonecrosis (Easley & Trnka 2007). Two relatively recent Level IV evidence studies confirm the use of distal chevron osteotomy to correct mild-to-moderate hallux valgus associated with an increased DMAA (Nery et al. 2002, Tollison & Baxter 1997). While functional outcomes and patient satisfaction for these case series are favourable, only Grade C evidence supports
their use in the management of mild-to-moderate hallux valgus with an increased DMAA.

**Diaphyseal metatarsal osteotomies**

These operations have been recommended if the IMA is between 14 degrees and 20 degrees (Kristen *et al.* 2002). They allow longitudinal division of the diaphysis and either translation (scarf) or rotation (Ludloff) of the metatarsal to correct the IMA. Plication of the medial capsule and lateral release are usually performed simultaneously (Robinson & Limbers 2005). Diaphyseal osteotomies are technically demanding and require extensive surgical exposure, which necessitates postoperative physiotherapy to prevent stiffness.

The modified Ludloff osteotomy consists of a bone cut extending distally and inferiorly from the dorsal cortex, 2 mm distal to the metatarsocuneiform joint, to the plantar cortex (Chiodo *et al.* 2004). The osteotomy forms an angle of 30 degrees to the long axis of the metatarsal. The distal fragment is rotated laterally on the proximal fragment and held with two screws. The metatarsal head can also be displaced plantarwards by angling the osteotomy. This ensures that elevation of the metatarsal head does not occur and can help relieve pressure on the second metatarsal head. Excellent clinical results have been reported with the Ludloff osteotomy, with good correction of the deformity and without subsequent transfer metatarsalgia (Chiodo *et al.* 2004). Minimal shortening of the metatarsal occurs and it is biomechanically more stable than proximal chevron and proximal crescentic osteotomies (Nyska *et al.* 2003).

The scarf osteotomy is a Z-shaped step-cut osteotomy named after its woodworking equivalent. A longitudinal cut is made along the length of the diaphysis, sloping plantarward as it passes laterally, allowing plantar displacement and off-loading of lesser rays. Chevrons are made at each end of the osteotomy to connect it to the dorsal cortex distally and to the plantar cortex proximally. The head and plantar cortical fragment are then translated laterally and the osteotomy held with two compression screws (Robinson & Limbers 2005). This technique relies on translation of the metatarsal head rather than rotation; therefore, it avoids shortening and increases in the DMAA (Nyska *et al.* 2003, Smith *et al.* 2003). Altering the geometry of the cuts allows shortening of the metatarsal or reducing an abnormally-elevated DMAA. The procedure can be modified so that an abnormally increased DMAA can be corrected (Kristen *et al.* 2002, Nyska 2001). This osteotomy has a high degree of inherent biomechanical
stability and is more stable than the basal osteotomies (Newman et al. 2000, Popoff et al. 2003).

The clinical outcomes of the scarf osteotomy are better than those of basal osteotomies, but the procedure has an incidence of significant complications of between 4% and 11% (Crevoisier et al. 2001, Kristen et al. 2002). Other studies have reported less favourable results with a much higher incidence of complications (Coetzee 2003), indicating that it is a technically-demanding procedure with a learning curve. However, once mastered, it is a highly effective and versatile procedure. It has been traditionally been recommended for an IMA of up to 18 to 20 degrees (Crevoisier et al. 2001, Kristen et al. 2002), but with experience it can be used for more severe deformities (Barouk 2000, Smith et al. 2003). The corrective power can be increased by adding a varus osteotomy of the proximal phalanx (Akin procedure). Robinson & Limbers (2005) prefer the scarf osteotomy for deformities with an IMA > 14 degrees, as they believe that it best fulfils the previously mentioned guidelines for osteotomies.

Deenik et al. (2007) reported a randomised controlled trial of 96 patients that compared scarf versus distal chevron osteotomy for hallux valgus deformity. They found no statistically significant differences between the two groups with respect to the AOFAS score, HVA and IMA. Although both groups showed good to excellent results, they favoured chevron osteotomy because the procedure is technically less demanding. Stephanie et al. (2011) reported a case series of 29 patients who underwent scarf osteotomy. Their results suggest that scarf osteotomy produces improved AOFAS scores, a high percentage of patient satisfaction, and effective correction of hallux valgus deformities. Their use of a scarf technique of rotation combined with translation minimises the need for an Akin osteotomy while still obtaining good correction and avoids associated complications described in the literature. Vopat et al. (2013) presented a retrospective comparative study of scarf and extended distal chevron osteotomy. Both methods adequately reduced the HVA and IMA in patients with moderate to severe hallux valgus and yielded similar patient outcomes in terms of stiffness, pain and satisfaction. Based on their results, they recommend both the scarf and extended chevron osteotomy as acceptable forms of correction for moderate to severe hallux valgus.
Arthrodesis

First metatarsophalangeal joint arthrodesis is indicated for hallux valgus in the rheumatoid patient and when significant degenerative changes are evident in the metatarsophalangeal (MTP) joint. It is also an option for severe or recurrent deformity, particularly in the older patient. Other indications include hallux valgus secondary to neuromuscular diseases and as a salvage procedure following failed surgery. Various techniques have been described, with an overall success rate of 90% and high levels of patient satisfaction in appropriately-selected patients (Robinson & Limbers 2005). Many different investigations favour a Grade B recommendation for use of MTP arthrodesis in the management of a wide spectrum of hallux valgus deformities (Easley & Trnka 2007).

Lapidus (1934) originally described an arthrodesis between the bases of the first and second metatarsals and the first intercuneiform joint to correct metatarsus primus varus in patients with hallux valgus. Currently, the modified Lapidus procedure incorporates an isolated arthrodesis of the first tarsometatarsal joint with a lateral and plantar based closing wedge osteotomy of the medial cuneiform. This procedure has been indicated for the correction of metatarsus primus varus in patients with moderate to severe hallux valgus and hypermobility of the first ray. First ray hyper-mobility has been controversial and often questioned (Coughlin & Shurnas 2003, Glasoe & Coughlin 2006).

This procedure is indicated in combination with a distal soft-tissue procedure in the patient with hypermobility of the first tarsometatarsal joint, especially if associated with generalised ligamentous laxity (Robinson & Limbers 2005). Mann and Coughlin (1999) estimate this to occur in approximately 3% to 5% of patients. Hypermobility can be determined clinically, as outlined previously, but it is difficult to estimate accurately and reproducibly. The procedure is also indicated in the presence of degenerative changes in the first or second tarsometatarsal joint and is an option in severe deformity with an IMA of > 20.

The procedure is technically demanding and associated with a prolonged period of recovery and increased morbidity when compared to metatarsal osteotomies (Myerson 1990, Sangeorzan & Hansen 1989). It also leads to shortening and care must be taken to resect as little bone as possible to avoid this. As the varus of the first metatarsal is corrected, the first ray should be plantar flexed slightly to avoid elevation and transfer metatarsalgia. The rate of patient satisfaction varies between 75% and 90%, with fusion rates of approximately 90% (Coetzee & Wickum 2004, Myerson 1990, Sangeorzan & Hansen 1989).
Klemola et al. (2014) reported a new first metatarsotarsal joint derotation and arthrodesis in which they mimic the function of the peroneus longus tendon without involving the first metatarsophalangeal joint, allowing function of the windlass mechanism without interference. In their study, the mean HVA correction was 20 degrees and IMA correction was 9 degrees.

Dayton et al. (2015) described a modified Lapidus procedure with transverse plane correction and rotational correction performed at the centre of rotational angulation. With this kind of first tarsometatarsal arthrodesis, all components of the deformity can be reduced, giving the surgeon complete control of positioning, including the transverse, sagittal and frontal planes. Frontal plane rotation aligns both the sesamoids and the sesamoidal grooves and the potential deforming force vectors are aligned. This represents true triplane anatomic correction.

Several retrospective case series (Level IV evidence) have collectively reported excellent radiographic correction, high rates of satisfaction and significant improvement in the functional outcomes with the modified Lapidus procedure (Coetzee & Wickum 2004, Kopp et al. 2005, Sangeorzan & Hansen 1989, Thompson et al. 2005). Faber et al. (2004), in a prospective randomised study comparing the Hohmann procedure (distal first metatarsal osteotomy) to the Lapidus procedure in 101 feet (Level I evidence), found no significant differences in clinical outcomes, radiographic correction or patient satisfaction. Feet with preoperatively identified hypermobility had equally favourable outcomes with either procedure when compared to feet without hypermobility.

Early reports identified nonunion rates of 10 to 12% with the modified Lapidus procedure (Myerson 1990, Myerson 1992, Sangeorzan & Hansen 1989). However, a more recent large clinical series reported a 4% nonunion rate and a 2% revision rate in feet treated with the Lapidus procedure. One study reported no nonunions with the use of the modified Lapidus procedure for the primary correction of hallux valgus. The uniformly successful results from numerous case series, supported by one Level I evidence study, justify a Grade B recommendation for the use of modified Lapidus procedure in the treatment of primary hallux valgus. Although the results of Coetzee et al. (2003) suggest that the modified Lapidus procedure is also an effective salvage procedure for recurrent hallux valgus, this evidence from a single Level II study is insufficient (Grade I) to make a recommendation (Easley & Trnka 2007).
Summary points of the operative treatment of hallux valgus:

1. A distal chevron osteotomy appears to be a predictable treatment for mild and some moderate hallux valgus deformities.

2. The addition of a limited lateral capsule release or adductor hallucis tenotomy or both to a distal chevron osteotomy does not seem to increase the risk of first metatarsal osteonecrosis.

3. Multiple proximal first metatarsal procedures, when combined with a distal soft-tissue procedure, appear to provide satisfactory treatment for moderate-to-severe hallux valgus deformity (hallux valgus associated with metatarsus primus varus). These include proximal oblique (Ludloff), scarf osteotomies and the Lapidus procedure.

4. First metatarsophalangeal joint arthrodesis appears to offer satisfactory outcome in patients with severe hallux valgus. (Easley & Trnka 2007).
3 Aims of the study

The aims of the present study were:

1. to compare, in a prospective randomised controlled trial, the role of fixation and postoperative regimens in the long-term outcomes of distal chevron osteotomy for hallux valgus (I).
2. to determine, in a prospective randomised controlled trial, if the head fragment displaces more or less with one of the techniques (no fixation versus no fixation) and postoperative regimens (soft cast versus elastic band) (II).
3. to analyse the long-term radiologic results after distal chevron osteotomy for hallux valgus, and to determine the preoperative radiological factors correlating with radiological recurrence of the deformity (III).
4. to analyse intraobserver repeatability and interobserver reliability between an orthopaedic surgeon and a radiologist based on preoperative and postoperative radiographs (IV).
4 Materials and methods

The research was performed at the Department of Surgery, Oulu University Hospital, Oulu, Finland, in cooperation with the Department of Diagnostic Radiology (II–IV).

4.1 Patients (I–IV)

The study was conducted at the Oulu University Hospital and was approved by the local research ethics committee. The subjects were adult patients who had been referred by general practitioners for orthopaedic evaluation on account of symptomatic hallux valgus. The inclusion criteria were age between 20 and 50 years and the presence of a painful bunion with a hallux valgus angle of 40 degrees or less and an intermetatarsal angle of 20 degrees or less. Only one foot was operated at a time, if the patient had bilateral hallux valgus. The exclusion criteria were any foot that had previously undergone bunion surgery and the presence of hallux rigidus, hallux limitus, rheumatoid disease or pregnancy. One hundred consecutive patients (100 affected feet) fulfilling the inclusion criteria received oral and written information on the aims and content of the study, and a written statement of freely given informed consent was obtained. All the patients were examined by one author (I.P.). The mean age was 39 (21–50) years, and 92 of the patients were females. The patients underwent operations at Oulu University Hospital during years 1998–2002.

The baseline clinical data were gathered from the patients by the same author (I.P.). The feet were scored on the hallux-metatarsophalangeal scale of the American Orthopedic Foot and Ankle Society (AOFAS) (Kitaoka et al. 1994). The clinical rating system combined objective and subjective data as follows: pain 40 points, function 45 points and alignment 15 points, for a total of 100 points. A total of 100 points indicated best functional ability.

Radiographs were taken of both feet in anteroposterior and lateral projections during weightbearing, and the hallux valgus angle and intermetatarsal angle between the first and second metatarsal bones were measured by the centre-of-head method (Mann & Donatto 1997). All the radiographic measurements were performed by same investigator (I.P.).

The reliability analysis included 20 randomly selected patients from the total 100-patient population. Their preoperative anteroposterior and lateral weightbearing radiographs and postoperative (six months) control radiographs
were evaluated. One author (I.P.), an experienced orthopaedic surgeon, evaluated the radiographs twice, and the interval between measurements was about one year. One author (R.O.), an experienced radiologist, also evaluated the same radiographs twice and the interval was about six months. Evaluators were instructed to use a goniometer and a pen for all measurement and to follow guidelines according to Coughlin & Jones (2007). The hallux valgus angle, 1–2 inter-metatarsal angle, metatarsus adductus angle, distal metatarsal articular angle, the tibial sesamoid position (LaPorta), calcaneal pitch angle and the congruence of the metatarsophalangeal joint were evaluated.

4.2 Randomisation and treatment (I–IV)

The randomisation process was based on 100 randomly shuffled numbered and sealed opaque envelopes opened by one author (I.P.). Allocation of surgery and postoperative treatment was concealed until immediately prior to the operative incision. Each group consisted of exactly 25 randomly assigned patients. Randomisation was performed at the level of the individual patient and the data were also analysed at this level (Figure 5). The groups did not differ significantly with respect to age, gender, BMI or affected foot (Table 1). All the chevron procedures were performed by one author (I.P.), using a spinal nerve block in 52 cases and general anaesthesia in 48 cases, always with a tourniquet. A medial, slightly curved longitudinal incision was made, and the medial exostosis was removed after medial capsulotomy. A 60-degree metal guide was fixed on the medial side of the first metatarsal with two K-wires, and the apex of the guide was inserted 10 mm proximal to the joint surface. A V-shaped osteotomy was then performed on the metatarsal head using an oscillating saw with a thin, sharp blade. The distal fragment was shifted laterally by approximately 4–5 mm and the medial overlap was excised with the saw. In the fixation group, a 1.2 mm hole was drilled from the medial upper part of the joint surface through the proximal and medial cortex of the first metatarsus, and a 40 mm long L-lactide absorbable rod was inserted and shortened adequately. The medial capsule was tightened in a good position with an absorbable Biosyn® 3-0 gauge shoestring stitch. In the other group, no bone fixation was used and the medial capsule was tightened directly with an absorbable Biosyn® 3-0 gauge shoestring stitch.
Half of the patients in each group were randomised to use a soft cast (Figure 6) for six weeks postoperatively, while the other half had a traditional elastic bandage for the same length of time. Weightbearing was allowed on the heel immediately after the operation in all four groups and plantigrade walking was allowed after three weeks. Active exercising of the great toe was begun at three
weeks for the patients in the traditional elastic bandage group. The care programs were identical from six weeks onwards.

![Unique soft cast](image)

**Fig. 6. Unique soft cast.**

### 4.3 Corrections

The number of patients in figure 5 are incorrect for six months and for 12 months follow-up. The correct numbers at six months are: 24 patients (no fixation and elastic bandage), 24 patients (no fixation and soft cast), 24 patients (fixation and elastic bandage) and 23 patients (fixation and soft cast). At 12 months control the correct numbers are: 23 patients (no fixation and elastic bandage), 25 patients (no
fixation and soft cast), 24 patients (fixation and elastic bandage) and 25 patients (fixation and soft cast).

The analysis was however made regarding to the right numbers.

4.4 Follow-up and assessment of results (I–IV)

All the patients were examined at the outpatient clinic baseline, and again at six weeks, six months, one year and a mean of 7.9 (range 5.8–9.4) years after the operation. The outcome measures were the AOFAS score (pain, limited walking, footwear requirements, range of motion), complications, satisfaction, global assessment, hallux valgus angle and intermetatarsal angle. The grading for the AOFAS scoring was in 4 steps for pain (none; mild occasional; moderate daily; and almost constantly severe) and for limited walking (no limitations; limited recreational activities but not daily activities; limited daily and recreational activities; and severe limitation of daily and recreational activities), and in 3 steps for footwear requirements (fashionable, conventional shoes, no insert required; comfort footwear, insert required; and modified shoes or brace required) and for range of motion (≥ 75 degrees; 30–74 degrees; and < 30 degrees). The global assessment was in 3 steps (better; the same; and worse than before surgery), based on radiographs of the foot in anteroposterior and lateral projections during weightbearing. The hallux valgus angle and intermetatarsal angle between the first and second metatarsal bones were measured by the centre-of-head method (Mann & Donatto 1997).

An experienced orthopaedic surgeon (I.P.) read all the radiographs. The distance (mm) of the medial corner of medial articular surface from the median axis of the first metatarsal proximal diaphysis was measured. The DMAA was calculated by measuring the angle between the first metatarsal distal joint surface and the metatarsal longitudinal axis. A value of 9 degrees or less was accepted as normal (Coughlin & Caroll 2007). By drawing two straight lines representing effective articulating surface of the first metatarsal head and effective articular cartilage at the base of the first proximal phalanx (Karasic & Wapner 1990), the congruence of the metatarsophalangeal joint was estimated to one of three classes: congruent joint, parallel lines; deviated joint, lines converge outside joint; and subluxated joint, lines intersect within joint. The tibial sesamoid position was assigned a LaPorta value from number one (normal) to number seven (most laterally luxated) (La Porta et al. 1974). Sesamoid osteoarthritis development was also followed and evaluated according to the Kellgren and Lawrence graduation
(I–IV), as used for knee osteoarthritis (Schiphot et al. 2008). All 100 patients attended follow-up examinations at six weeks, 94 at six months, 95 at 12 months and 77 at a mean of 7.9 years (range, 5.8–9.4).

The reliability analysis included 20 randomly selected preoperative anteroposterior and lateral weightbearing radiographs and 20 postoperative (6 months) control radiographs. One author (I.P.), an experienced orthopaedic surgeon, evaluated the radiographs on two separate occasions, with an interval of approximately 1 year between measurements. One author (R.O.), an experienced radiologist, also evaluated the same radiographs on two separate occasions, with an interval of approximately 6 months. Evaluators were instructed to use a goniometer and a pen for all measurements and to follow guidelines according to Coughlin & Jones (2007). The hallux valgus angle, 1–2 inter-metatarsal angle, metatarsus adductus angle, distal metatarsal articular angle, tibial sesamoid position (LaPorta), calcaneal pitch angle and congruence of the metatarsophalangeal joint were evaluated. Most parameters were estimated from the anteroposterior weightbearing radiographs.

All first and second ray angular measurements were made according to the guidelines set forth by the American Orthopedic Foot and Ankle Society ad hoc Committee on Angular Measurements (Smith et al. 1984). First and second ray angular measurements were drawn using mid-diaphyseal reference points. Because some radiographs were postoperative, the HVA was measured according to the method described by Miller (1974): a line was drawn from the centre of the head of the first metatarsal through the centre of the base of the first metatarsal.

The magnitude of the metatarsus adductus angle was assessed by first drawing an axis of the lesser tarsus. A line was drawn along the medial border of the lesser tarsus connecting the most medial extent of the metatarsocuneiform joint to the most medial extent of the talonavicular joint. Next, a line was drawn on the lateral aspect of the foot, along the lateral border of the lesser tarsus. A line was drawn from the most lateral extent of the calcaneocuboid joint to the most lateral extent of the fifth metatarsocuboid joint. A mark was then made at the midpoints of each of these lines; then, a line was drawn connecting these points and bisecting the lesser tarsus. A line perpendicular to the lesser tarsus bisection line was drawn. The metatarsus adductus angle was defined as the angle that this perpendicular line formed with the longitudinal axis of the second metatarsal (Coughlin 1995).

The DMAA was calculated by placing two reference points on the most medial and the most lateral extents of the metatarsal articular surface. A line was
drawn to connect these points, and then a line was drawn perpendicular to that line. The angle between this line and the longitudinal axis of the first metatarsal was defined as the DMAA (Coughlin 1995).

The tibial sesamoid position (LaPorta) was evaluated on a 7-point scale, with 1 representing normal and 7 representing the greatest lateral luxation (LaPorta et al. 1974).

First metatarsophalangeal joint congruence was estimated by drawing two straight lines representing the effective articulating surface of the first metatarsal head and the effective articular cartilage at the base of the first proximal phalanx. Metatarsophalangeal joint congruence was categorised as belonging to one of three classes: congruent joint (lines were parallel); deviated joint (lines converged outside the joint); or subluxated joint (lines intersected within the joint) (Mann & Donatto 1997).

The calcaneal pitch angle was defined as the angle between the inferior surface of the calcaneus and the line using the plantar-most surface of the sesamoids and the inferior calcaneus (Coughlin 1995). The calcaneal pitch angle was estimated from lateral weightbearing radiographs.

4.5 Statistical analyses (I–IV)

*Paper I:* The summary measurements for continuous variables were expressed as means with standard deviation (SD), unless otherwise stated. All analyses were performed assuming four parallel groups. Fisher’s exact test was used for categorical data and analysis of variance for continuous data in the comparisons of demographic data. The generalised linear mixed model approach with binary link-function was used in the comparisons of AOFAS pain (none vs. mild to severe) and AOFAS alignment (good vs. fair to poor), and the linear mixed model approach was used when comparing continuous variables (total AOFAS score, AOFAS function, MTP and IP angles). The *P*-values are reported as follows:

- *P* <sub>group</sub> indicates a significant difference between the groups,
- *P* <sub>time*group</sub> indicates time-group interaction and
- *P* <sub>time</sub> indicates change over time.

Both mixed-model approaches take into account that the measurements were taken repeatedly from the same subjects, so they are not independent. Furthermore, both methods use all the data available, i.e. subjects with missing information are not excluded from the analyses. The paired samples t-test was
used to compare the preoperative and long-term follow-up values. Spearman’s correlation coefficient ($\tau$) was calculated to describe simple correlation between continuous variables. The statistical analyses were performed using SPSS (SPSS, version 14.0, SPSS Inc., Chicago, IL) and SAS (version 9.1.3, SAS Institute Inc., Cary, NC) statistical software.

Two-tailed significance levels are reported. Readers should treat the $P$-values with caution, since several comparisons are made and no $P$-value correction coefficient method is used.

**Paper II:** The summary measurements for continuous and ordinal variables were expressed as means with standard deviations (SD) or medians with 25th–75th percentiles. Fisher’s exact test was used for categorical data and analysis of variance for continuous data in the simple comparisons. The statistical analyses were performed using SPSS (version 14.0, SPSS Inc., Chicago, IL) statistical software.

**Paper III:** The summary measurements for continuous variables are expressed as means with standard deviation (SD), unless otherwise stated. The analyses between randomised groups were performed assuming four parallel groups. Between-group comparisons were performed using Fisher’s exact test for categorical data, and analysis of variance or Student’s $t$-test for continuous data. A generalised linear mixed model approach and linear mixed model approach were used for repeatedly measured data. Two-tailed significance levels are reported. The $P$ values are reported as follows:

- $P_{\text{group}}$ indicates the significance of the difference between groups,
- $P_{\text{time*group}}$ describes the time–group interaction, and
- $P_{\text{time}}$ describes change over time.

Readers should interpret the $P$-values cautiously, since several comparisons are made and no $P$-value correction coefficient method was used. The statistical analyses were performed using SPSS (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and SAS (version 9.3, SAS Institute Inc., Cary, NC) statistical software.

**Paper IV:** The summary measurements are presented as mean and standard deviation (SD). Intraclass correlation coefficient (ICC) or Kappa coefficient with 95% confidence interval (95% CI) were calculated to assess interrater reliability and intrarater repeatability, the latter separately for both evaluators. The Kappa coefficient was classified as follows (Landis & Koch 1977):
– a kappa value not exceeding 0.2 was classified as slight reliability;
 – 0.21 to 0.40, fair
 – 0.41 to 0.60, moderate
 – 0.61 to 0.80, substantial
 – and 0.81 to 1.00, nearly perfect.
ICC values were classified as follows (Cicchetti 1994):
– greater than 0.75, excellent
– 0.60 to 0.74, good
– 0.40 to 0.59, fair and
– less than 0.40, poor.
Analyses were performed using SPSS for Windows (IBM Corp., released 2012; IBM SPSS Statistics for Windows, version 21.0, Armonk, NY, IBM Corp.).

4.6 Ethics

The study (I–IV) was approved by the local research ethics committee.
5 Results

5.1 Role of fixation and postoperative regimens in the long-term outcomes of chevron osteotomy: a randomised controlled two-by-two factorial trial of 100 patients (I)

The groups did not differ significantly with respect to age, gender, body mass index or affected side (Table 1). Three patients withdrew from the study, so analysis was not possible in these cases. The outcome assessors were not blinded to treatment status. The care programmes were identical other than with respect to the trial options.

The AOFAS function score (max. 45 points) improved from a preoperative mean value of 38 to 43 at 6 months and 44 at 12 months, but deteriorated to a mean of 38 by the final analysis (Figure 7). The function results were best in the group treated without absorbable rod fixation and with an elastic bandage at 6 weeks postoperatively, but the difference disappeared thereafter ($P_{time} < 0.001$, $P_{group} = 0.011$, $P_{time\times group} < 0.001$).

![Fig. 7. AOFAS function scores preoperatively, at 6 weeks, 6 months and 12 months postoperatively and after long-term follow-up. Values are medians with 25th to 75th percentiles.](image)
The pain score was calculated as per cents and no or mild pain was 100% and severe pain was 0%. Pain score (mild to severe, %) diminished from a mean preoperative value of 99 to 37 at 12 months, but had returned to 62 by the final analysis ($P_{\text{time}} < 0.001$, $P_{\text{group}} = 0.17$). (Figure 8).

The malalignment score was also calculated as per cents and fair alignment was 100% and poor was 0%. The malalignment score (fair to poor, %) diminished from a mean preoperative value of 86 to 23 at 12 months, but had returned to 69 by the final analysis ($P_{\text{time}} < 0.001$, $P_{\text{group}} = 0.052$). (Figure 9).

The total AOFAS score (max. 100 points) improved from a preoperative mean value of 69 points to 74 points at 6 weeks, 91 at 6 months and 93 at 12 months, but had deteriorated to 81 by the final analysis ($P_{\text{time}} < 0.001$, $P_{\text{group}} = 0.77$, $P_{\text{time} \times \text{group}} = 0.049$). (Figure 10).
Fig. 9. AOFAS alignment scores preoperatively, at 6 weeks, 6 months and 12 months postoperatively and after long-term follow-up. Values are medians with 25th to 75th percentiles.

Fig. 10. AOFAS total scores preoperatively, at 6 weeks, 6 months and 12 months postoperatively and after long-term follow-up. Values are medians with 25th to 75th percentiles.
The mean hallux valgus angle improved from 26.3 degrees (SD 7.1) preoperatively to 20.2 degrees (SD 7.5) at the final analysis ($P_{time} < 0.001$, $P_{group} = 0.41$, $P_{time*group} = 0.10$), (Figure 11), while the mean IM angle improved from 12.7 degrees (SD 3.0) preoperatively to 7.6 (SD 2.9) degrees at the final analysis ($P_{time} < 0.001$, $P_{group} = 0.10$, $P_{time*group} = 0.011$). (Figure 12).

Fig. 11. Hallux valgus angles (HVA)s preoperatively, at 6 weeks, 6 months and 1 year postoperatively, and after long-term follow-up. Data presented as median and 25th to 75th percentiles; MT1, first metatarsal; Prox1, proximal phalanx of the hallux.

The data were stratified to the two groups according to a hallux valgus angle above and below 30 degrees. Preoperatively, the hallux valgus angle was above 30 degrees in 27 patients and below 30 degrees in 73. In groups with absorbable fixation with and without the soft cast, the hallux valgus angle was > 30 degrees in 4 (16%) and 8 (32%) patients, and in groups without absorbable fixation plus with and without the soft cast hallux valgus angle was > 30 degrees in 7 (28%) and 8 (32%) patients ($P = 0.57$), respectively.

In AOFAS scores, the average function ($P_{time} < 0.001$, $P_{group} = 0.002$, $P_{time*group} = 0.18$), alignment (function ($P_{time} < 0.001$, $P_{group} < 0.001$, $P_{time*group} = 0.10$) and total points ($P_{time} < 0.001$, $P_{group} < 0.001$, $P_{time*group} = 0.13$) were significantly worse when preoperative HV angles exceeded 30 degrees (Table 2). No avascular necrosis, tilt or deep wound infection occurred and no revision was required by the time of the long-term follow-up.
The correlation coefficient between follow-up time and total AOFAS score was ($\tau = -0.02, P = 0.87$), and that between follow-up time and the hallux valgus angle was ($\tau = 0.06, P = 0.50$). The 21 patients who did not take part in the final check-up were younger than the other participants ($P = 0.051$). No gender difference was noted in participation.

The hospitalisation time was 1 day in 86 cases and 2 days in 14 cases. The main cause of an overnight stay was pain and/or living alone. The average sick leave was somewhat longer in group IV (Biofix®+, soft cast+), at 51 days (SD 7, range 39–61) when compared to group III at 47 days (SD 6, range 38–69), group II, also at 47 days (SD 7, range 41–68) or group I at 49 days (range 38–69) ($P = 0.066$).
Table 2. AOFAS\(^1\) scores stratified by hallux valgus angle.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Preoperative</th>
<th>Baseline</th>
<th>Postoperatively</th>
<th>Last Follow-Up</th>
<th>(P_{\text{time}})</th>
<th>(P_{\text{group}})</th>
<th>(P_{\text{time*group}})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HVA(^2)</td>
<td>n(_1) = 73,(n_2) = 27</td>
<td>6 wk</td>
<td>6 mo</td>
<td>1 y</td>
<td>.(n_1 = 57,)</td>
<td>(n_2 = 22)</td>
</tr>
<tr>
<td>((\ast)</td>
<td>(n_1 = 73,)</td>
<td>(n_1 = 69,)</td>
<td>(n_1 = 70,)</td>
<td>(n_2 = 27)</td>
<td>(n_2 = 26)</td>
<td>(n_2 = 27)</td>
<td>(n_2 = 27)</td>
</tr>
<tr>
<td>Total</td>
<td>(\leq 30)</td>
<td>68 (65–75)</td>
<td>74 (69–82)</td>
<td>90 (85–100)</td>
<td>100 (90–100)</td>
<td>85 (75–88)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td>65 (58–73)</td>
<td>74 (68–79)</td>
<td>88 (85–93)</td>
<td>90 (83–93)</td>
<td>76 (73–83)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Function</td>
<td>(\leq 30)</td>
<td>37 (37–40)</td>
<td>32 (29–34)</td>
<td>45 (40–45)</td>
<td>45 (45–45)</td>
<td>40 (35–40)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td>37 (37–40)</td>
<td>32 (29–34)</td>
<td>41 (40–45)</td>
<td>41 (40–45)</td>
<td>35 (35–35)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pain, mild to severe</td>
<td>(\leq 30)</td>
<td>72 (99)</td>
<td>65 (89)</td>
<td>39 (57)</td>
<td>21 (30)</td>
<td>36 (63)</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td>27 (100)</td>
<td>22 (82)</td>
<td>11 (42)</td>
<td>15 (56)</td>
<td>13 (59)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Alignment, fair to poor</td>
<td>(\leq 30)</td>
<td>59 (81)</td>
<td>8 (11)</td>
<td>10 (15)</td>
<td>7 (10)</td>
<td>33 (58)</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>&gt; 30</td>
<td>27 (100)</td>
<td>11 (41)</td>
<td>15 (58)</td>
<td>15 (23)</td>
<td>22 (100)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

\(^1\) American Orthopaedic and Ankle Society, \(^2\) hallux valgus angle, \(^3\) number of patients in HVA ≤ 30° group in visits 1 to 5, \(^4\) number of patients in HVA > 30° group in visits 1 to 5. Data presented as median (25th to 75th percentiles) or n (%).
5.2 Radiographic analysis of the impact of internal fixation and dressing choice of distal chevron osteotomy: randomised control trial (II)

All 100 patients came for control examinations at six weeks, 94 at six months, 95 at 12 months and 77 at a mean of 7.9 years (range, 5.8–9.4).

The shift of the first metatarsal head is presented in figure 13 for all four study groups. A higher shift is detected for patient with fixation, with the average shift in the fixation group being 3.9 (SD 0.8) mm at six weeks, while that in the no fixation group was 3.1 (SD 0.9) mm (difference between mean change 0.7 mm, \( P < 0.001 \)). At 6 months, at 1 year, and at the mean 7.9 year follow-up both the shift and the difference remained same in both groups, the latter being 0.8 mm, 0.7 mm and 0.5, respectively (Table 3). The two bandage types had no significant effect on the mean shift in either surgical group at six weeks, one year and long-term follow-up.

Fig. 13. The distance (mm) of the medial corner of medial articular surface from the median axis of the first metatarsal proximal diaphysis.
Table 3. Mean shift compared to preoperative measurement in fixation and no-fixation groups.

<table>
<thead>
<tr>
<th>Control time</th>
<th>Fixation</th>
<th>No-fixation</th>
<th>Difference between means</th>
<th>P (difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (mm)</td>
<td>Mean (mm)</td>
<td>Difference (mm)</td>
<td>95% CI (mm)</td>
</tr>
<tr>
<td>6 week</td>
<td>3.9</td>
<td>3.2</td>
<td>0.7</td>
<td>0.4 to 1.1</td>
</tr>
<tr>
<td>6 month</td>
<td>3.9</td>
<td>3.2</td>
<td>0.7</td>
<td>0.4 to 1.1</td>
</tr>
<tr>
<td>1 year</td>
<td>3.9</td>
<td>3.2</td>
<td>0.7</td>
<td>0.4 to 1.0</td>
</tr>
<tr>
<td>7.9 year follow-up</td>
<td>3.7</td>
<td>3.2</td>
<td>0.5</td>
<td>0.2 to 0.9</td>
</tr>
</tbody>
</table>

The mean hallux valgus angle improved from 26.3 degrees (SD 7.1) preoperatively to 20.2 degrees (SD 7.5) at the long-term follow-up, while the mean IM angle improved from 12.7 degrees (SD 3.0) preoperatively to 7.6 (SD 2.9) degrees at the long-term follow-up.

The data were stratified to the two groups according to hallux valgus angle above and below 30 degrees. Preoperatively, the hallux valgus angle was above 30 degrees in 27 patients and below 30 degrees in 73. At six weeks postoperatively, the mean hallux valgus angle was significantly greater in the group with the preoperative value above 30 degrees (21.8 (SD 6.3) vs. 14.0 (SD) degrees, \( P < 0.001 \)). After six weeks, the difference between the groups did not change significantly.

No cases of slippage, tilt, avascular necrosis or deep wound infection were found and no reoperation was needed.

5.3 Distal chevron osteotomy: Preoperative radiological factors contributing to long-term radiological recurrence of hallux valgus (III)

Radiologic evaluation revealed recurrence of hallux valgus deformity—defined as an HVA of greater than 15 degrees—in 56 feet (73%) at a mean of 7.9 (range, 5.8–9.4) years postoperatively (Table 4). Eleven feet (14%) exhibited mild recurrence (less than 20 degrees), 44 (57%) moderate recurrence (20 degrees or more but less than 40 degrees), and 1 (1%) severe recurrence (40 degrees or more). Among patients with hallux valgus recurrence, the mean preoperative HVA was 28 (SD, 5.7) degrees, which was a mean of 9 degrees greater than that in patients without recurrence (\( P < 0.001 \)). All the patients (22/22) with a preoperative HVA of greater than 30 degrees experienced a recurrence, whereas
recurrence occurred in 62% (34/55) of those with a preoperative angle of less than 30 degrees ($P < 0.001$). Among the patients with hallux valgus recurrence, the preoperative I/II IMA was significantly greater than that in patients without recurrence ($P = 0.0018$; Table 4). For evaluation of first metatarsophalangeal joint congruence, radiographs were available for 93 patients. Preoperatively, the first MTP joint was congruent in only 8.6% of cases, 73.1% were deviated, and 18.3% were subluxated. At the six-week postoperative follow-up, 83.9% were congruent, 16.1% deviated and none of the first MTP joints was subluxated. At long-term follow-up, the radiographs of 68 patients were evaluated and 39.7% were congruent, 54.4% were deviated, and 5.9% subluxated. Patients with a preoperative HVA 30 degrees or more had more frequently preoperatively deviated/subluxated MTP I joints ($P < 0.001$), but the change over the follow-up period did not significantly differ between these two groups (Table 5). Compared to those who did not experience recurrence, patients with hallux valgus recurrence exhibited significantly greater preoperative incongruency ($P = 0.004$; Table 4).

Table 4. Impact of preoperative measurements on HVA recurrence (HVA > 15 degrees) at long-term follow-up.

<table>
<thead>
<tr>
<th>Variables</th>
<th>HVA ≤ 15</th>
<th>HVA &gt; 15</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 21</td>
<td>n = 56</td>
<td></td>
</tr>
<tr>
<td>Preoperative angles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVA, mean (SD)</td>
<td>19.1 (4.5)</td>
<td>28.4 (5.7)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>DMAA, mean (SD)</td>
<td>9.1 (2.8)</td>
<td>12.6 (4.3)</td>
<td>0.001</td>
</tr>
<tr>
<td>IMA, mean (SD)</td>
<td>11.4 (2.5)</td>
<td>13.1 (2.9)</td>
<td>0.018</td>
</tr>
<tr>
<td>LaPorta, median (25th–75th percentile)</td>
<td>4 (3–4)</td>
<td>5 (4–5)</td>
<td>0.001</td>
</tr>
<tr>
<td>Preoperative congruency$^1$</td>
<td></td>
<td></td>
<td>0.004</td>
</tr>
<tr>
<td>Congruent, n (%)</td>
<td>5 (24)</td>
<td>2 (4)</td>
<td></td>
</tr>
<tr>
<td>Deviated, n (%)</td>
<td>16 (76)</td>
<td>39 (75)</td>
<td></td>
</tr>
<tr>
<td>Subluxated, n (%)</td>
<td>0 (0)</td>
<td>11 (21)</td>
<td></td>
</tr>
</tbody>
</table>

$^1$ Fisher’s exact test
Table 5. The Impact of Preoperatively Large Hallux Valgus Angle (HVA Greater Than 30 Degrees) on DMAA, Congruence, LaPorta (Sesamoid Position) and Sesamoid Osteoarthritis.

<table>
<thead>
<tr>
<th>Variables</th>
<th>preop</th>
<th>preop</th>
<th>6 w postop</th>
<th>6 m postop</th>
<th>1-y postop</th>
<th>last follow-up</th>
<th>P-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVA&lt;sup&gt;6&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 30</td>
<td>11 (8–13)</td>
<td>7 (6–9)</td>
<td>7 (6–9)</td>
<td>8 (6–9)</td>
<td>8 (6–11)</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>Congruence, congr.2/dev.3/sublux4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 30</td>
<td>8/5/8/4</td>
<td>64/6/0</td>
<td>57/9/0</td>
<td>52/16/0</td>
<td>25/25/1</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>&gt; 30</td>
<td>0/10/13</td>
<td>14/9/0</td>
<td>8/15/0</td>
<td>6/15/2</td>
<td>2/12/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sesamoid osteoarthritis, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>≤ 30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22 (43)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5 (29)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LaPorta&lt;sup&gt;5&lt;/sup&gt;, med (25&lt;sup&gt;th&lt;/sup&gt;–75&lt;sup&gt;th&lt;/sup&gt; pct)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>≤ 30</td>
<td>4 (3–5)</td>
<td>2 (2–3)</td>
<td>2 (2–3)</td>
<td>3 (2–3)</td>
<td>3 (3–4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 30</td>
<td>5 (5–5)</td>
<td>3 (2–3)</td>
<td>3 (3–4)</td>
<td>4 (3–4)</td>
<td>4 (4–4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> distal metatarsal articular angle, <sup>2</sup>n congruent, <sup>3</sup>n deviated, <sup>4</sup>n subluxated, <sup>5</sup>sesamoid position (LaPorta) (1–7), <sup>6</sup>hallux valgus angle, <sup>7</sup>number of patients with HVA ≤ 30 degrees during visits 1 to 5, <sup>8</sup>number of patients with HVA > 30 degrees during visits 1 to 5.
Figure 14 presents the changes in DMAA in the four study groups. DMAA correction was not sufficient, but improved from a preoperative mean value of 11.9 degrees to a mean of 9.8 degrees at the long-term follow-up. DMAA was larger than normal (greater than 6 degrees) in 90% of patients preoperatively, and in 74% of patients at long-term follow-up. Patients with a preoperative HVA of 30 degrees or more also had a greater median preoperative DMAA when compared with patients with an HVA of less than 30 degrees (16 vs. 11 degrees), but the change over the course of follow-up did not differ significantly between these two groups (Table 5). The mean preoperative DMAA of 12.6 degrees in patients with hallux valgus recurrence was significantly greater than that in patients without recurrence ($P < 0.001$; Table 4)).

Figure 14 presents the changes of the median LaPorta classification in the four study groups. No significant differences were observed between the study groups. The median LaPorta value improved from a preoperative mean of 4 to an early postoperative mean of 2, but deteriorated to a mean of 3 by the long-term follow-up. In patients with hallux valgus recurrence, the median preoperative LaPorta value was 5 (25th to 75th percentile 4 to 5), which was 1 U greater than that in
patients without recurrence ($P = 0.001$). Postoperatively, no patients were in LaPorta group 6 or 7. Patients with a preoperative HVA of greater than 30 degrees had greater median LaPorta values preoperatively ($P < 0.001$), but the change over the follow-up period did not differ significantly between these two groups (Table 5).

None of the patients had metatarsosesamoid arthritis preoperatively or at six weeks, six months, or one year postoperatively. At long-term follow-up, 39.7% of the patients exhibited first grade metatarsosesamoid arthritis. No significant differences were observed between the different groups.

5.4 Intraobserver repeatability and interobserver reliability of preoperative and postoperative radiographic measurements in hallux valgus (IV)

The study population consisted of 20 patients (three males and 17 females), with a mean age of 39 (SD 8) years.

Preoperative results

The mean preoperative interobserver reliability and intraobserver repeatability values are shown in Table 6. I/II IMA reliability and repeatability were excellent (ICC > 0.90). HVA had excellent reliability (ICC 0.89) and repeatability (ICC 0.87, 0.84). Sesamoid position (LaPorta) also featured excellent reliability (ICC 0.86) and excellent/high repeatability (0.78, 0.73).

DMAA had excellent reliability (ICC 0.78), excellent repeatability (ICC 0.80) for the radiologist and good repeatability (ICC 0.68) for the orthopaedic surgeon. First metatarsophalangeal joint congruence was shared in 2 groups: a group with congruent joints, and another group with deviated and subluxated joints. Congruence had low reliability (kappa 0.46), low repeatability for the orthopaedic surgeon (kappa 0.46), and moderate repeatability for the radiologist (kappa 0.64). The calcaneal pitch angle had excellent reliability and repeatability (ICC > 0.90 for all). The reliability of MAA was fair and repeatability varied from fair to excellent.
Table 6. Intraclass correlation coefficients (ICC) between two authors (IP and RO, intrarater) and preoperatively within orthopaedic surgeon and within radiologist.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Interrater</th>
<th>Intrarater, Orthopaedic Surgeon1</th>
<th>Intrarater, Radiologist2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
</tr>
<tr>
<td>Hallux valgus angle</td>
<td>0.89 0.73 to 0.96</td>
<td>0.87 0.69 to 0.95</td>
<td>0.84 0.63 to 0.94</td>
</tr>
<tr>
<td>1-2 Intermetatarsal angle</td>
<td>0.99 0.98 to 1.00</td>
<td>0.97 0.91 to 0.99</td>
<td>0.93 0.82 to 0.97</td>
</tr>
<tr>
<td>LaPorta</td>
<td>0.86 0.63 to 0.95</td>
<td>0.78 0.51 to 0.91</td>
<td>0.73 0.42 to 0.89</td>
</tr>
<tr>
<td>Distal metatarsal articular angle</td>
<td>0.78 0.51 to 0.91</td>
<td>0.68 0.34 to 0.87</td>
<td>0.80 0.54 to 0.92</td>
</tr>
<tr>
<td>Congruency3</td>
<td>0.464 -0.26 to 1.17</td>
<td>0.464 -0.26 to 1.17</td>
<td>0.644 -0.05 to 1.33</td>
</tr>
<tr>
<td>Metatarsus adductus angle</td>
<td>0.44 0.01 to 0.74</td>
<td>0.53 0.12 to 0.79</td>
<td>0.89 0.74 to 0.96</td>
</tr>
<tr>
<td>Calcaneal pitch</td>
<td>0.98 0.95 to 0.99</td>
<td>0.93 0.89 to 0.97</td>
<td>0.96 0.91 to 0.99</td>
</tr>
</tbody>
</table>

1 IP, intrarater, 2 RO, intrarater, 3 Congruent vs deviated/subluxated, 4 Kappa coefficient

Results at six postoperative months

The mean postoperative interrater reliability and intrarater repeatability values are shown in Table 7. HVA had excellent repeatability (ICC 0.90) and reliability (ICC 0.84). I/II IMA reliability (ICC 0.79) and repeatability were excellent (ICC 0.97) for the orthopaedic surgeon and fair (ICC 0.51) for the radiologist.

Table 7. Intraclass correlation coefficients (ICC) between two authors (IP and RO, intrarater) and at 6 postoperative months within orthopaedic surgeon and within radiologist.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Interrater</th>
<th>Intrarater, Orthopaedic Surgeon1</th>
<th>Intrarater, Radiologist2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
</tr>
<tr>
<td>Hallux valgus angle</td>
<td>0.84 0.65 to 0.93</td>
<td>0.90 0.77 to 0.96</td>
<td>0.90 0.75 to 0.96</td>
</tr>
<tr>
<td>1-2 Intermetatarsal angle</td>
<td>0.79 0.55 to 0.91</td>
<td>0.97 0.93 to 0.99</td>
<td>0.51 0.06 to 0.79</td>
</tr>
<tr>
<td>LaPorta</td>
<td>0.82 0.46 to 0.93</td>
<td>1.00 1.00 to 1.00</td>
<td>0.60 0.21 to 0.83</td>
</tr>
<tr>
<td>Distal metatarsal articular angle</td>
<td>0.58 0.20 to 0.82</td>
<td>0.49 0.02 to 0.77</td>
<td>0.98 0.91 to 1.00</td>
</tr>
<tr>
<td>Congruency3</td>
<td>0.624 0.23 to 1.00</td>
<td>0.534 0.12 to 0.94</td>
<td>0.514 0.08 to 0.93</td>
</tr>
<tr>
<td>Metatarsus adductus angle</td>
<td>0.69 0.14 to 0.89</td>
<td>0.93 0.74 to 0.98</td>
<td>0.91 0.77 to 0.96</td>
</tr>
<tr>
<td>Calcaneal pitch</td>
<td>0.90 0.72 to 0.96</td>
<td>0.98 0.97 to 1.00</td>
<td>0.73 0.36 to 0.90</td>
</tr>
</tbody>
</table>

1 IP, intrarater, 2 RO, intrarater, 3 Congruent vs deviated/subluxated, 4 Kappa coefficient

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Sesamoid position (La Porta) had excellent reliability (ICC 0.82), repeatability (ICC 1.0) for the orthopaedic surgeon and good repeatability (0.60) for the radiologist. DMAA featured fair reliability (ICC 0.58), excellent repeatability for the radiologist (ICC 0.98), and fair repeatability (0.49) for the orthopaedic surgeon. First metatarsophalangeal joint congruence exhibited moderate reliability (kappa 0.62) and moderate repeatability (kappa 0.53, 0.51). The calcaneal pitch angle exhibited excellent reliability (ICC 0.90) and repeatability (ICC 0.98) for the orthopaedic surgeon, and good (ICC 0.73) repeatability for the radiologist. The reliability of MAA was good (ICC 0.69), while repeatability was excellent for both the orthopaedic surgeon and the radiologist (ICC 0.93 and 0.91, respectively).
6 Discussion

6.1 Role of fixation and postoperative regimens in the long-term outcome of chevron osteotomy (I)

The mean AOFAS function score was better in the group treated without osteotomy fixation and with an elastic bandage postoperatively at six weeks postoperatively, but the differences disappeared thereafter. The total AOFAS scores improved significantly in all subgroups over the first 12 months, but some deterioration occurred in the final analysis. In the secondary analysis, the data were stratified to HV angles above and below 30 degrees, where the long-term AOFAS scores (function, pain, alignment and total) were worse and postoperative HV angle greater in the group with preoperative HV angle 30 degrees or more. These results may have changed if chevron osteotomy was used in smaller bunions by excluding the large ones.

In our previous paper, the authors determined whether the head fragment displaces more or less with either technique (fixation vs. no fixation). A larger shift was found when fixation was used: 3.9 (SD, 0.8) mm at six weeks versus 3.1 (SD, 0.9) mm in the no fixation group ($P < 0.001$), but the clinical significance of this 0.8 mm difference is small and questionable (Pentikäinen et al. 2012). The two bandage types had no significant effect on the mean shift (Pentikäinen et al. 2012). Because no significant long-term difference was seen in the AOFAS scores between the 4 subgroups, our interpretation is that osteotomy fixation and postoperative cast immobilisation are not necessary in chevron osteotomy. However, the power calculations were not done, and consequently the results must be taken up critically. The risk of HV recurrence is also higher if the preoperative HV angle is 30 degrees or more (Pentikäinen et al. 2012).

In uncontrolled case series, good clinical results at short-term follow-up have been reported in 80–90% of the cases that undergo operations, although recurrences or undercorrections have been reported in 10–14% of cases (Austin & Leventen 1981, Hirvensalo et al. 1991, Lewis & Feffer 1981). Theoretically, a recurrence may occur if the correction of metatarsal malrotation is limited and the position of sesamoids is not optimal, if the incongruent first MTP joint remains incongruent and no distal soft tissue procedure is performed, and if the congruent first MTP joint becomes incongruent during the procedure. Long-term reports on chevron osteotomy are only few in number (Schneider et al. 2004, Torkki et al. 2007).
Torkki et al. (2001) reported the recurrence rate of an HV angle of over 25 degrees as high as 20% at a 6-year follow-up; 17% of the feet had undergone re-operation and 6% of the patients were waiting for a re-operation. The main reason for the high recurrence rate was an unselected patient population. In our series, no revision had been required by the time of the long-term check-up.

Schneider et al. (2004) reported good 10-year clinical and radiographic results, but they had early complications in 13 of 112 cases (wound infections, hypoaesthesia and delayed union of osteotomy) and two late complications (avascular necrosis of the metatarsal head). Our results differed from those of Schneider et al. (2004) in the matter of early and late complications and long-term outcome. In our series, no cases of slippage, tilt, avascular necrosis or deep wound infection were found. The differences in the surgical technique may explain these differences. In addition to the standard osteotomy technique without internal fixation, Schneider et al. (2004) used a lateral capsulotomy and an adductor tenotomy. Jones et al. (1995) studied the effects of chevron osteotomy plus lateral capsular release on the blood supply to the metatarsal head in cadaveric specimens and showed that technical errors with extensive capsular stripping can result in damage to the vessels that supply the metatarsal head. The work of Kuhn et al. (2005) showed that medial capsulotomy and chevron osteotomy together caused a 58% decrease in the blood flow to the metatarsal head. Lateral release and adductor tenotomy caused a 13% decrease, totalling 71% decrease from the baseline. In one randomised study, chevron osteotomy for hallux valgus was not improved by additional adductor tenotomy at 3-year follow-up (Resch et al. 1994). We did not use adductor tenotomy or lateral capsulotomy.

The strengths of this study lie in its prospective randomised design, the homogeneous groups of patients and the long duration of the follow-up. All the patients were operated on by the same surgeon (I.P.) and the final check-up was performed by an independent investigator (J.P.). Seventy-nine per cent of the patients took part in the final check-up at a mean 7.9 years postoperatively.

One potential limitation of this study is the generalisability of the study outcome and conclusions. This study population was a relatively young, white, female and normal BMI group of patients. Another potential limitation for bias is that nearly the entire study was carried out by only one individual (I.P.). This author was the only one who performed the preoperative clinical evaluations and the preoperative radiographic evaluations, was the only surgeon who operated on all the study participants and carried out the vast majority of the postoperative
analysis during 6 weeks, 6 months and 12 months. The final check-up was performed another author (J.P.). Although a potential for bias exists with only one person as the evaluator and surgeon in this study, this problem may be countered and eliminated with the quality of the AOFAS survey. This subjective survey was given to each study participant preoperatively and postoperatively; therefore, the results and measures of this survey can balance out the bias of the study investigator.

6.2 Radiographic analysis of the impact of internal fixation and dressing choice to head fragment displacement in chevron osteotomy (II)

This study showed a mean 0.8 mm difference in the shift of the metatarsal head between the fixation and no fixation groups. The difference was statistically significant but clinically small. The two bandage types had no significant effect on the shift in either surgical group. This study also demonstrated that chevron osteotomy involves a risk of recurrence when the hallux valgus angle is 30 degrees or more. The surgeons need to be aware of this risk when using this surgical technique.

Distal chevron osteotomy is known for its good intrinsic stability. In one study on dried human first metatarsal bones, the chevron showed greater inherent stability when compared to the step-cut Mitchell osteotomy, a distal transverse osteotomy, a distal biplanar osteotomy and a basilar osteotomy (Shereff et al. 1991). While internal fixation was not originally advocated by Austin and Leventen (1981), miscellaneous fixations have been used by some authors (Gill et al. 1997, Hirvensalo et al. 1991, Pochatko et al. 1994). Gill et al. (1997) compared bioabsorbable pins and Kirschner wires in distal chevron osteotomies and found no difference between the treatment groups with regards to complications or stability of the fixation. To our knowledge, no previous randomised controlled trial has assessed the shift in the first metatarsal head with two operative techniques (no osteotomy fixation versus bioabsorbable rod fixation). Our study showed only a small difference in the shift of the metatarsal head between the study groups, and our interpretation is that either of the two surgical techniques is justified.

Variability also exists in the postoperative treatment, and the evidence available from the few known trials is limited to determining which methods of treatment are most appropriate (Connor et al. 1995, Ferrari et al. 2004, Johnson et
In general, a trend is apparent towards more rapid and full mobilisation, with less rigid elastic bandaging of the foot postoperatively. After modified Wilson's osteotomy, patients treated with a crepe bandage were back to full activity as quickly as their plaster slipper counterparts and the patient's overall assessment of the operation was no different (Meek et al. 1999). The way that early postoperative control of alignment will influence the shift of the metatarsal head is not yet clear, and no previous randomised controlled trials have examined this. In the present study, the two bandage types had no significant effect on the shift in either surgical group. Our interpretation is that there does not appear to be a need for rigid postoperative soft cast immobilisation: an elastic bandage is sufficient.

The strengths of this study lie in its prospective randomised design, the homogeneous groups of patients and the long duration of the follow-up. All the patients were operated on by the same surgeon (I.P.), who also performed all the radiographic measurements. Most patients came to the control examination at one year (95) and as many as 77 patients returned for the long-term control examination at a mean of 7.9 years.

6.3 Distal chevron osteotomy: preoperative radiological factors contributing to long-term radiological recurrence of hallux valgus (III)

The most significant finding of the present study was that, following standard distal chevron osteotomy without lateral release for mild-to-moderate hallux valgus, the radiological recurrence of hallux valgus deformity of greater than 15 degrees was observed in 56 feet (73%) at a mean of 7.9 years long-term follow-up. However, no revision surgery was needed, since each situation of recurrence was painless. The recurrence of hallux valgus deformity was significantly affected by preoperative DMAA, HVA, IMA I/II, sesamoid position (LaPorta) and congruency.

Previous reports have shown that the threshold for radiological recurrence varies between 15 and 25 degrees (Deenik et al. 2007, Hirvensalo et al. 1991, Hyong-Nyun et al. 2013, Torkki et al. 2001). Torkki et al. (2001) reported a recurrence rate of up to 20% at a 6-year follow-up. Hirvensalo et al. (1991) reported a recurrence rate of 10% at a mean follow-up of 14 months. Okuda et al. (2011) reported the recurrence of a hallux valgus angle of greater than 20 degrees in 14% after a mean follow-up of 33 months following proximal metatarsal...
osteotomy. Deenik et al. (2007) performed a randomised controlled study of distal chevron osteotomy and scarf osteotomy for moderate-to-severe hallux valgus, and reported recurrence of an HVA of more than 15 degrees in 54% of all patients, with no significant between-group differences after a 2-year follow-up. Several other authors have reported recurrence or undercorrections in 10% to 14% of the cases after distal chevron osteotomy (Austin & Leventen 1981, Fuhrmann et al. 2010, Lewis & Feffer 1981). Some reports have examined clinical recurrence rather than radiological recurrence (Austin & Leventen 1981).

In our present investigation, all study groups exhibited improved postoperative congruence of the first MTP joint and no congruent joints were made incongruent. Patients with preoperative HVA of 30 degrees or more had more deviated/subluxated MTP I joints preoperatively ($P < 0.001$), but the change over the follow-up did not differ significantly between these two groups. We found that congruence was a predictor of hallux valgus recurrence. The preoperative incongruency in patients with hallux valgus recurrence was significantly greater than that in patients without recurrence ($P = 0.004$). Distal soft-tissue reconstruction cannot be used to correct a hallux valgus deformity with a congruous MTP joint, as an intra-articular realignment may lead to a non-congruous joint, thereby creating a risk of recurrence or of degenerative osteoarthrosis development (Coughlin 1996, Coughlin & Mann 1987). Fuhrmann et al. (2010) reported a correlation between HVA and joint congruity, and found that the clinical and radiologic results were not affected by the HVA and IMA. However, a high preoperative HVA does not require joint incongruity.

In our series, the mean preoperative HVA in patients with hallux valgus recurrence was a mean of 9 degrees greater than that in patients without recurrence. This is in accordance with the findings of Deenik et al. (2008), who reported preoperative HVA as the main radiological predictor for hallux valgus correction. The correction rate declined in patients with HVA exceeding 37 degrees.

Our results also showed that the preoperative DMAA was a predictor in hallux valgus correction. Preoperative DMAA was not very large (8 to 17 degrees), but was above normal in 90% of the patients preoperatively and in 74% at the long-term follow-up. There were no significant differences between the study groups. Preoperative HVA did not affect the magnitude of DMAA change. If the preoperative DMAA is very large, it is better to make multiple first ray osteotomies that maintain congruity of the first metatarsophalangeal joint (Coughlin & Carlson 1999). Deveci et al. (2013) were unable to postoperatively
measure DMAA because the rotational osteotomy disrupted the long axis of the first metatarsal. We also found a correlation between preoperative DMAA and sesamoid deviation (LaPorta). Okuda et al. (2011) reported that incomplete sesamoid (LaPorta) reduction was a reason for recurrence in the postoperative follow-up period, and therefore that sesamoid reduction requires loosening the medial capsule and flexor components. In the present study, distal chevron osteotomy was performed without medial liberation; however, the LaPorta values improved significantly.

The strengths of the study include the randomised patient population, the fact that all surgeries were performed by the same orthopaedic surgeon who also read all radiographs, and the long duration of follow-up (mean, 7.9 years). The weakness of the study is the dropout of 23 of the initial 100 patients by the long-term follow-up.

6.4 Intraobserver repeatability and interobserver reliability of preoperative and postoperative radiographic measurements in hallux valgus (IV)

In patients with hallux valgus, the HVA, I/II IMA, DMAA, first metatarsophalangeal joint congruence and sesamoid position are the most important parameters with which to estimate the severity of the deformity and recommend an indicated surgical technique. In this study, these parameters appear to feature relatively good reliability. The experienced orthopaedic surgeon and the experienced radiologist each exhibited good repeatability and reliability.

Hallux valgus angular measurements are the most common parameters used to establish severity of deformity and to determine the correction yielded by the surgical treatment. Although some studies do confirm its use, several reports have demonstrated that hallux valgus angular measurement has little reproducibility and is unreliable (Lee et al. 2012, Schneider et al. 2002). Coughlin & Freund (2001) assessed the reliability of the hallux valgus angle, the 1-2 intermetatarsal angle and the distal metatarsal articular angle between 24 orthopaedic surgeons. Twenty-five anteroposterior standing feet radiographs were measured on three occasions with a minimum interval of six weeks. The authors reached the conclusion that the distal metatarsal articular angle reliability is questionable, but the hallux valgus angle and the 1-2 intermetatarsal measurements are reliable.

Srivastava et al. (2010) compared manual and computer-assisted measurements of HVA, IMA, DMAA and the interphalangeal angle (IPA). They
have three different observers and they compared measurements done by marker pen and goniometer to those that were done computer-assisting. Technical error of measurement as lower with the computer-assisted method, suggesting that this method is more reliable. Furthermore, the time taken was also reduced with this method.

Shima et al. (2009) measured the hallux valgus angle and the second intermetatarsal angle as well preoperatively as postoperatively before and after proximal crescentic osteotomy. According to their data, the method, in which the longitudinal axis of the first metatarsal corresponds with a line connecting the centres of the first metatarsal head and the proximal articular surface of the first metatarsal, had the best intraobserver and interobserver reliability and agreement for the radiographic measurement of the preoperative and postoperative hallux valgus patients who were managed with a proximal crescentic metatarsal osteotomy.

In our study, the reliability of HVA and IMA was also good, but also the reliability of DMAA was at least moderate and the intraobserver reliability for radiologist even good or excellent. Schneider et al. (2002) investigated the reproducibility of the radiographic metatarsophalangeal angle in hallux surgery. Observers were two experienced foot surgeons and they measured HVA by drawing the axis of the first metatarsal according to the five different methods. Methods with reference points distal and proximal to any possible osteotomy had much better measurement reproducibility. They recommend the method described by Miller (1974), in which a line is drawn from the centre of the first metatarsal head through the centre of the base of the first metatarsal, as it was most precise method and was at least biased by postoperative effects. In our series, the postoperative measurements of the hallux valgus angle were also done by this method and the reliability was at least good in all categories.

Coughlin & Freund (2001) examined also the reliability of the MTP joint congruency. Whether a first MTP joint is congruent or not is a subjective evaluation and not a quantitative computation as are other angular measurements. They had 24 orthopaedic surgeons assess the radiographs. The interobserver reliability was very variable, but they also had good reliability. In our study, the reliability of the first metatarsophalangeal joint congruity was relatively poor, which was a concern for intraobserver as well as interobserver groups.

Saro et al. (2005) reported a series from 100 patients undergoing hallux valgus surgery. Two independent observers evaluated radiographs preoperatively as well as postoperatively. They used the same method described by Miller (1974),
where a line is drawn from the centre of first metatarsal head through the centre of the base of the first metatarsal. The ICC measures within and between agreements were 0.97 for hallux valgus angle and were better than in our study.

The observers also compared two different systems for measuring the position of the sesamoid bones. They used the method of Smith et al. (1984) and of Mann & Donatto (1977). Both methods used three degrees for recording the severity of the luxation of the sesamoids. In our series, we used the classification according to LaPorta (1974). The place of the tibial sesamoid was assigned from number one (normal) to number seven (most laterally luxated). The results in the series of Saro et al. (2005) concerning the reliability of sesamoid evaluation were nearly the same classes as in our series. In both studies, the reliability of the evaluation of sesamoid position was lower for the postoperative measurements. This could indicate a more difficult assessment of the position of the sesamoid bones when the osteotomy has healed, because of callus formation.

In the published literature, we were unable to find any examination of the reliability of the evaluation of the metatarsus adductus angle. Our study produced varied results. On the other hand, the metatarsus adductus angle is of very little importance in distal osteotomies; it is more important in metatarsus adductus surgery. Engel et al. (1983) described a method for evaluating a simplified metatarsus adductus angle. This method requires only the intersection of the middle cuneiform and second metatarsal bisectors. They showed statistically that the simplified method yields angular values consistently three degrees greater than the traditional method used in our study.

Only one parameter was evaluated from lateral weightbearing radiographs. Our evaluation of the calcaneal pitch angle revealed very good reliability in every group. We found no published investigations concerning the reliability of the evaluation of the calcaneal pitch angle. On the other hand, the significance of that angle is generally very slight in hallux valgus surgery. Evaluation of calcaneal pitch angle is more important in the surgery of the pes planus (Coughlin 1995).

The strengths of the present study are that it is a retrospective subanalysis of a prospective, randomized material and included homogenous groups of patients. All radiographs were evaluated by an experienced orthopaedic surgeon (I.P.) and an experienced radiologist (R.O.). All measurements (preoperative and at 6 postoperative months) were made at two different times. Both authors used the methods of Coughlin & Jones (2007) to conduct the evaluations.
The greatest weakness of the present study is its small sample size. We have one hundred patients, all of whom had radiographs taken five times. However, only twenty patients had a control evaluation at six postoperative months.

6.5 Further studies

Many studies have examined distal chevron osteotomy since its first publication by Austin & Leventen (1981). The most recent examination was published by Buciato (2014), who compared chevron osteotomy and Mitchell’s osteotomy with a follow-up time of three years. He recommends chevron osteotomy as the first-line procedure for treatment of mild and moderate HV deformity in female adult patients.

In our study, we compared two operative techniques and two postoperative regimens in distal chevron osteotomy for hallux valgus. The follow-up time was a mean of 7.9 years. We found that the results were good for mild to moderate hallux valgus, that the fixation of the osteotomy was not necessary and that an elastic bandage postoperatively is adequate.

Further studies should focus to more severe hallux valgus deformities and their operative techniques. Studies should be randomised controlled trials (RCTs) and the follow-up time must be as long as possible.

Nowadays, the scarf osteotomy of the first metatarsal shaft is generally the usual procedure for more severe hallux valgus deformities, as is the Lapidus operation with its variations. Further RCTs should focus on these operative techniques and their long-term results.
7 Conclusions

The main conclusions reached in this research are as follows:

*Paper I:* We found that it is unnecessary to fix the distal chevron osteotomy for hallux valgus deformity. An elastic bandage is recommended for postoperative treatment. The AOFAS scores did not differ statistically between the groups in our population. The functional result is worse and the risk of HV recurrence is higher if the preoperative HV angle is 30 degrees or more.

*Paper II:* As a conclusion, the observed difference in shift of about 0.8 mm between operative groups was statistically significant, but clinically so small, that our interpretation is that either of the surgical techniques is justified. The dressing choice does not make a difference, so there does not appear to be a need for a rigid soft cast bandage.

*Paper III:* Our results showed that radiological recurrence of hallux valgus deformity (defined as a hallux valgus angle of 15 degrees or greater) was found in 73% of the patients at long-term follow-up after distal chevron osteotomy. Furthermore, the radiological recurrence of hallux valgus was significantly affected by the preoperative HVA, I/II IMA, DMAA, sesamoid position (LaPorta) and congruence.

*Paper IV:* In conclusion, the 1-2 intermetatarsal angle, the distal metatarsal articular angle and the sesamoid position evaluations appear to exhibit relatively good reliability. Evaluations by the orthopaedic surgeon and the radiologist featured similar reliability.
References


Sarrafian SK (1987) Functional characteristics of the foot and plantar aponeurosis under tibiotaral loading. Foot Ankle 8: 4–18.


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