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The pathology and management of lesser toe deformities

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- Deformities of the lesser toes are common and can be associated with significant morbidity. These deformities are often multiple, and numerous treatment strategies have been described in the literature.

- The goal of surgical treatment is to improve symptoms by restoring alignment and function, and avoiding recurrence. In order to achieve this, it is essential for the treating surgeon to understand the normal anatomy and pathology of the various deformities.

- There is a paucity of prospective studies and randomised-controlled trials assessing the efficacy of specific interventions.

- We describe the normal anatomy and biomechanics of the lesser toes, and the pathology of commonly adult deformities. The rationale behind various treatment strategies is discussed and the results of published literature presented. Algorithms for the management of lesser toe deformities based on current literature are proposed.

Keywords: lesser toes; toe deformities; claw toe; hammer toe; mallet toe

Introduction

Deformities of the lesser toes are a frequently-encountered condition associated with significant morbidity. Data from the Swedish registries suggests that almost a quarter of patients undergoing forefoot surgery had lesser toe procedures performed.[1] Despite the prevalence of lesser toe conditions there are few randomised controlled trials (RCTs) comparing the efficacy of various treatments, and current surgical practice is largely based on the results of retrospective case series. Each patient, and indeed each toe, is unique and in order to choose the most appropriate treatment strategy a thorough understanding of the anatomy and pathology of lesser toe deformities is required. We discuss the basic anatomy of the lesser toes and the pathology of some of the more common deformities. We then summarise the current treatment strategies for management of these deformities.

Anatomy and function

All primates have five toes. However, the first toe is divergent in all primates apart from humans. Humans, the only habitual bipeds in the primate order, have shorter, non-divergent toes, as prehensile function is less important.[2] Bipedal locomotion requires the foot to act both as a shock absorber after foot strike and a lever for push-off. To achieve this, the human foot is constructed with a lever arm and a load arm, bound via the plantar aponeurosis. This forms the 'windlass mechanism' first described by Hicks in 1954.[3]

The metatarsal (MT) heads take a significant proportion of the body weight during gait, particularly the first, second and third MTs. The lesser toes increase the surface area for weight-bearing and share the load with the MT heads. This can only occur if the toes remain in contact with the ground during gait.[4] In the normal foot, the toes are in contact with the ground for three-quarters of the stance phase and receive similar pressures to the MT heads.[2]

The lesser toes usually have a distal, middle and proximal phalanx. The proximal phalanx articulates with the corresponding MT at the metatarsophalangeal joint (MTPJ). The joints are supported medially and laterally by collateral ligaments and are surrounded by a joint capsule. Each toe is supplied by two flexors, the flexor digitorum longus (FDL), and the flexor digitorum brevis (FDB). The FDL attaches to the plantar aspect of the base of the distal phalanx. The FDB travels plantar to the FDL until the proximal phalanx, where it divides into two slips and attaches to the middle phalanx. The FDL flexes the distal interphalangeal joint (DIPJ) and the FDB flexes the proximal interphalangeal joint (PIPJ) (Fig. 1).

The lesser toes have a complex extensor apparatus. The extensor digitorum longus (EDL) passes dorsal and central to the MTPJ and is joined at this level by the extensor digitorum brevis (EBD) from the lateral side (apart

from in the fifth toe where EDB is absent). The tendons then trifurcate into a central slip, which attaches to the middle phalanx, and medial and lateral slips which join onto the base of the distal phalanx. On occasion the EBD does not join with EDL and forms the lateral slip independently.[5] The proximal phalanx does not receive a direct tendinous extensor attachment, but the extensor tendons form a sling-like aponeurotic structure which encircles the MTPJ. This apparatus merges with the plantar plate before inserting on the plantar base of the proximal phalanx. It is termed the extensor sling and extends the MTPJ. The interossei pass dorsal to the deep transverse metatarsal ligament on either side of the MTPJ and insert on the proximal phalanx and extensor sling. The lumbricals pass plantar to the transverse metatarsal ligament on the medial side and join with the extensor hood. Sarrafian performed cadaveric dissections of the toes and applied tension to the severed tendon ends. He found that most of the tension applied to the EDL was transmitted through the extensor sling to the MTPJ.[6] Once the MTPJ was extended, further excursion of the tendon was limited and the PIPJ and DIPJ were not extended. The interphalangeal joints (IPJs) could only extend when the MTPJ was neutral or flexed. The intrinsic muscles were found to travel plantar to the centre of rotation of the MTPJ and then insert on the extensor hood, such that their pull acts dorsal to the centre of rotation of the IPJs. Thus the intrinsics flex at the MTPJ but extend at the IPJs.[5-7]

Plantar fascia

The plantar fascia is an aponeurotic structure arising from the calcaneum, passing subcutaneously forwards and attaching to the proximal phalanx of each toe via a slip. In concert with the longitudinal arch of the foot the plantar fascia forms a truss. Because it attaches to the proximal phalanx, hyperextension of the MTPJ will tighten the plantar fascia, pulling the calcaneum and MT heads together and thereby increasing the height of the longitudinal arch (the 'windlass' mechanism). In contrast, during weight-bearing, the downward force exerted on the talus flattens out the longitudinal arch. The plantar fascia stretches, as the MT heads and calcaneum move apart, which in turn exerts a strong, passive, plantarflexion force at the MTPJ. This is termed the 'reverse windlass' mechanism and is essential for maintaining toe contact with the ground during gait.[3] Division of the plantar fascia or its attachments has been shown to disrupt push-off function and load distribution during gait.[8] The plantar fascia has deep (dorsal) and superficial (plantar) layers at the MTPJ. A plantar fat pad lies between these layers and has an important role in cushioning the MT head. Displacement of the plantar fat pad results in metatarsalgia.

   The plantar plates are attached to those of adjacent toes by the deep transverse metatarsal ligament. Together
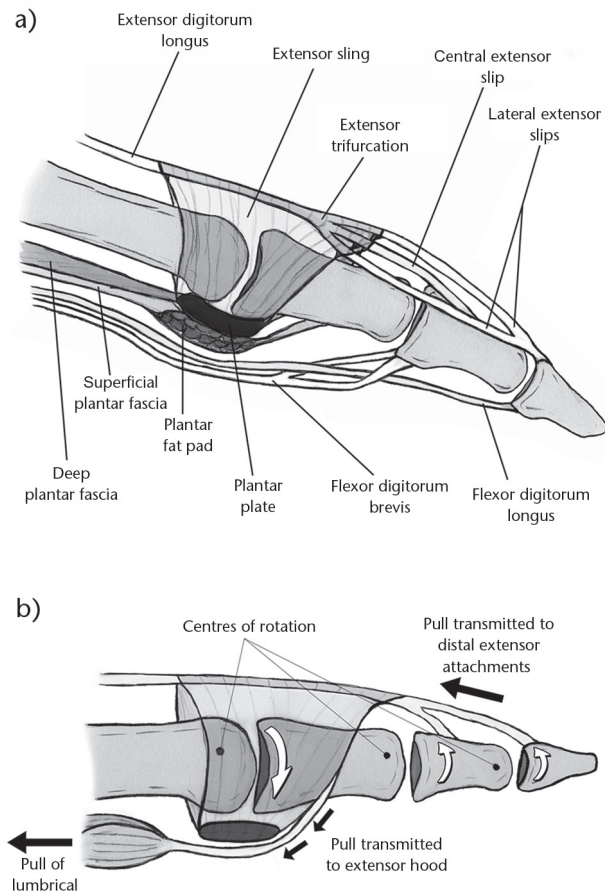

Fig. 1 a) Anatomy of the flexor and extensor tendons of the lesser toes and their relationships. The extensor digitorum brevis (not drawn) joins the extensor digitorum longus tendon from the lateral side proximal to the trifurcation. b) Function of the intrinsic muscles. The interosseus muscles are not depicted but act in a similar fashion to the lumbricals. The pull of the muscles is transmitted via the extensor hood to the extensor tendons. This produces a flexion force around the metatarsophalangeal joint (as attachments to the hood and proximal phalanx lie plantar to its centre of rotation) and an extension force at the proximal and distal interphalangeal joints (as the extensor attachments lie dorsal to their centre of rotation). The action of the intrinsics is depicted by the white arrows.

these form a 'tie-bar' mechanism which prevents the forefoot from splaying during weight-bearing.[9] The plantar plate also has a significant stabilising effect on the MTPJ and prevents dislocation in the sagittal and axial planes. Bhatia et al performed a cadaveric study to assess the force required to dislocate the second MTPJ. They found that division of the plantar plate reduced to 30% the force required to dislocate. Division of the collateral ligaments resulted in a 46% reduction in force required to dislocate, and division of both rendered the joint highly unstable. They further found that a flexor-to-extensor transfer restored the resistance to dislocation.[10]

Table 1. Net forces at the distal interphalangeal joints (DIPJ), proximal interphalangeal joints (PIPJ) and metatarsophalangeal joints (MTPJ). In the normal foot the extension and flexion forces are balanced around each joint. However, if this balance is disrupted deformity will occur: extension at the MTPJ and flexion at the interphalangeal joints (IPJs)

Joint	Extensors	Flexors
DIPJ	EDL / EDB + (via lateral and medial slips) Intrinsics + (via extensor hood)	FDL ++
PIPJ	EDL / EDB + (via central slip) Intrinsics + (via extensor hood)	FDB ++
MTPJ	EDL / EBD +++ (via extensor sling)	Plantar fascia ++ (passively, via reverse windlass) Intrinsics +

EDL, extensor digitorum longus; EDB, extensor digitorum brevis; FDL, flexor digitorum longus; FDB, flexor digitorum brevis

Net forces around the joints

As discussed above, although the EDL and EDB attach to the middle and distal phalanx, most of their power is diverted to the MTPJ. Extension at the IPJs is brought about by the intrinsic muscles through their attachment on the extensor hood (Fig. 1b). At the IPJs, the FDL and FDB exert a stronger flexion force than the extensors provide extension, and therefore the net force is one of flexion. By contrast, the main flexion force at the MTPJ is passive via the plantar fascia (reverse windlass mechanism). The intrinsics also contribute to flexion. The net overall force at the MTPJ is therefore one of extension.[5,9] Net forces at each joint are summarised in Table 1.

Pathology and deformity

Deformities of the lesser toes often occur gradually, though they can be brought on by trauma. Ill-fitting or high-heeled footwear is often implicated in the causation of deformity. Hallux valgus can contribute to the formation and propagation of lesser toe deformities as effective shortening of the first ray may slacken the plantar fascia and weaken the windlass effect on the first toe. This in turn leads to greater strain on the lesser toes, which makes their supporting structures more likely to fail.[9] Pathology can also be linked to inflammatory arthritis, synovitis, diabetes mellitus and neuromuscular disorders.

The main adult sagittal plane deformities consist of claw toes, hammer toes and mallet toes (Fig. 2). Axial plane deformities include crossover toes. These deformities have been variously defined in the literature, perhaps in part because the treatment for claw and hammer toes is not very different. However, in this review we use the same definitions as Coughlin and Stainsby.[9,11] They defined a mallet toe as an isolated flexion deformity of the DIPJ and described a hammer toe as a primary flexion deformity of the PIPJ, with or without hyperextension at the MTPJ, but with a neutral or hyperextended DIPJ. Most authors define a claw toe as a primary hyperextension
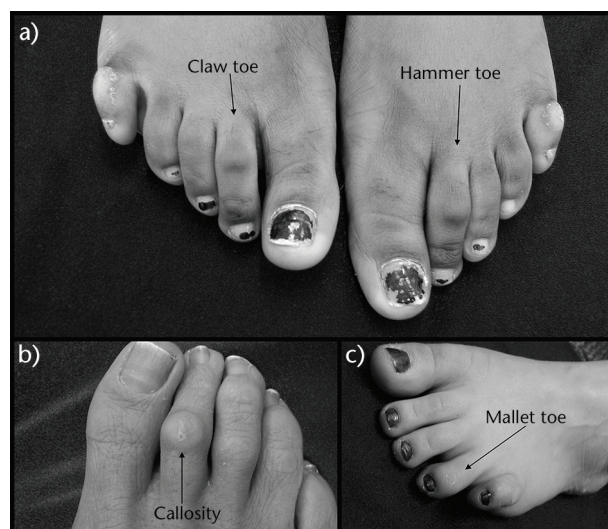

Fig. 2 Common deformities seen in the lesser toes, as described in Table 2. a) demonstrates a claw toe deformity of the right-hand second toe and a hammer toe deformity of the left second toe. b) Callosity over the proximal interphalangeal joint of a second hammer toe. c) Mallet deformity of the fourth toe.

Table 2. Location of deformities in common lesser toe deformities

Deformity	MTPJ	PIPJ	DIPJ
Mallet	Normal	Normal	Flexion
Hammer	Neutral / hyperextension	Flexion	Neutral / hyperextension
Claw	Hyperextension	Flexion	Flexion
Crossover	Hyperextension + Medial / lateral deviation	-	-

MTPJ, metatarsophalangeal joint; PIPJ, proximal interphalangeal joint; DIPJ, distal interphalangeal joint

deformity of the MTPJ with flexion at the PIPJ and DIPJ, and a crossover toe as a deviation of the toe in the axial plane associated with hyperextension at the MTPJ (Table 2).

These deformities may occur as a result of an imbalance between the forces of extension and flexion about the relevant joints and are illustrated in Figure 2.

The relative length of the metatarsals also plays a role in symptomatology. In the normal foot morphotype, the second metatarsal is the longest lesser metatarsal and the fifth is the shortest. The first metatarsal is often similar in length to the second[12] (square foot morphology), although it may be shorter (Greek type foot) or longer (Egyptian foot type).[13,14] The metatarsal heads form a normal distal cascade or parabola, which has been quantified by Maestro et al.[15] If one or more metatarsals are relatively elongated or plantar-flexed, abnormal pressure and metatarsalgia may result.

MTPJ subluxation

As discussed above, the plantar plate and collaterals have an important stabilising role at the MTPJ. With chronic hyperextension of the MTPJ, synovitis may develop in the capsule and the plantar plate may become

damaged or stretched. This process may occur due to footwear, but is also seen in athletes with overuse.[16] Inflammation or attenuation of the plantar structures of the MTPJ allows the proximal phalanx to translate dorsally, leading to eventual subluxation. As this occurs, the plantar fat pad displaces with the superficial layer of plantar fascia and the MT head becomes uncovered on its plantar aspect. The fibres of the plantar plate and plantar fascia slip dorsally around either side of the metatarsal head and encompass it. The displaced plantar plate, however, remains attached to the adjacent plantar plates by the deep transverse metatarsal ligaments. During gait, when the reverse windlass mechanism activates, the malpositioned, now dorsal plantar plate fibres exert a plantar force on the MT head. This has been termed the 'plunger effect' and causes metatarsalgia and plantar callosities.[9]

The degree of instability of the MTPJ was described and graded by Thompson and Hamilton. They defined a Grade 1 as minor instability, Grade 2 as 50% dorsal displacement, and Grade 3 as dislocatable.[17] They also described the MTPJ Lachman toe translation test which is considered pathognomic for MTPJ instability.[17,18]

Crossover toe

If there is a unilateral/partial plantar plate tear and a deficiency in one of the collaterals, the toe may deviate medially or laterally, becoming a crossover toe. Medial deviation is more common and the second toe is most commonly affected.[19] Crossover toe is most commonly seen in women over the age of 50 years, and in patients with hallux valgus.[20] Haddad et al defined the stages of subluxation for crossover toe as follows: Stage 1, mild deviation; Stage 2, moderate deviation; Stage 3, overlap of hallux; and Stage 4, total dislocation.[21]

In the early stages the deformity may remain flexible, however with time the capsule, extensors and other soft-tissues scar and shorten. The deformity becomes fixed and irreducible. Deland and Sung performed cadaveric dissections and found that in the medial crossover toe there was lateral attenuation of the plantar plate with significant soft-tissue changes.[22] They surmised that simply releasing the extensors and dorsal capsule would be inadequate to correct the deformity.

Mallet toe

The DIPJ deformity in the mallet toes is often attributed to tightness in shoes. Initially the DIPJ flexes due to direct pressure from the shoe but eventually the FDL tightens, causing a persistent deformity. This may be associated with callosities on the tip of the toe and pressure on the nail.[7] The mallet deformity is flexible in the early stages, but as the collaterals and capsule tighten the deformity becomes fixed.

Hammer toe

In a hammer toe, the first deformity is at the PIPJ. This occurs in a similar manner to the mallet toe. It is often seen in the fifth and sixth decades of life and is associated with hallux valgus and inflammatory arthritis. Although footwear plays a significant role in its development, trauma can result in an acute rupture of the central slip of the extensor tendon which may cause the deformity.[18,23]

As discussed above, the pull of the extensor tendons is mainly transmitted to the MTPJ via the extensor sling. The extensors are therefore unable to correct the PIPJ deformity, but hyperextension may occur at the MTPJ instead. This may progress to MTPJ instability as the plantar plate becomes attenuated.[24] The DIPJ remains largely unaffected, or may become hyperextended by the pull of the extensors via the lateral slips. The deformities are flexible initially, but become fixed with time.

Claw toe

In a claw toe - commonly seen in neuromuscular disorders - the first causative deformity is thought to be hyperextension at the MTPJ, but the exact mechanism is unclear. When the MTPJ becomes chronically hyperextended, the intrinsics shorten and the axis of pull shifts dorsal to the centre of rotation of the MTPJ.[25] The intrinsics can therefore no longer produce a flexion moment at the MTPJ and the extensors act unopposed.[26] The flexors are pulled taut and flex the IPJs.

Initially this clawing may be dynamic and only noticeable on walking. Over time the plantar plate tears, subluxation occurs at the MTPJ, and the deformity becomes permanent. In both claw and hammer toes the reverse windlass mechanism eventually fails and the toes cannot be brought into contact with the ground during gait. More force is then taken over the MT heads which results in metatarsalgia.[25]

Assessment

History

It is important to note past medical history, particularly of trauma, diabetes, inflammatory arthritis and neuromuscular disorders. Note should be made of neuropathy, peripheral vascular disease, smoking status and family history. Assessment should be made of pain and swelling about the plantar aspect of the MTPJ (suggestive of capsulitis) and enquiries made regarding footwear, occupation and previous procedures. Finally, it is important to ascertain the reason for presentation (i.e. pain and disability *versus* appearance) and the patient's expectations.

Examination

The deformities should be assessed and note made of any hallux and hindfoot and/or midfoot deformities.

The examiner should look for signs of callosities on the plantar aspect of the foot and pressure areas on the toes. Assessment for under-riding/over-riding toes, or crossover should be made. A Lachman test for MTPJ instability should be performed and flexibility of all deformities should be recorded. Note should also be made of the deformities during gait, type of footwear, orthotics or walking aids, and neurovascular status of the foot. In cases of claw toe it is important to check for other signs of a neuromuscular disorder. The ankle should be moved through its range of movement to see whether the deformities correct. The IPJs should be tested with the MTPJ in neutral. Dhukaram et al described hammer and claw toes according to three types: Type 1 had a reducible MTPJ and PIPJ; Type 2 had a reducible MTPJ but a fixed PIPJ and Type 3 had a fixed or subluxed MTPJ and a fixed PIPJ deformity.[27]

Investigations

Investigations may include routine blood tests for inflammatory markers and glucose levels. In cases where there is concern for neuromuscular disorders and/or neuropathy, nerve conduction studies or magnetic resonance imaging (MRI) of the spine may be indicated. Imaging includes plain weight-bearing radiographs to assess the deformities and MRI or ultrasound of the forefoot may also be useful to identify other pathology. An MRI arthrogram may help diagnose a plantar plate tear.

Non-operative treatment

A significant proportion of patients will respond to non-operative treatment measures which should be tried prior to surgical intervention. Treatment consists largely of footwear modification: using wider shoes with a larger toe box region may help alleviate symptoms and prevent progression of the deformities.[7] Pressure areas may be relieved by toe sleeves and padding over the dorsum of the PIPJ and under the MT heads.[23] Metatarsal off-loading insoles may also be used. Capsulitis may respond to a steroid injection[28] and reducible MTPJ subluxation associated with plantar plate tears may be managed with taping.[11] Figure 3 demonstrates an example of a conservative treatment option.

Operative treatment

Where non-operative measures have failed, surgery may be considered. Treatment aims to restore normal alignment of the joints and to restore the balance between the flexors, extensors and intrinsics. The MTPJ must be stabilised and any associated factors (such as hallux valgus) corrected to minimise the risk of recurrence. Most of the evidence for treatment is from retrospective case series. We discuss the various treatment strategies and suggest algorithms for management based on the latest evidence (Figs 4-7).

Fig. 3 Clinical photograph of toe sleeves with oil-impregnated silicone pads. These can be placed over toes and help prevent rubbing in shoes.

MTPJ instability

MTPJ instability may be seen in claw toe, hammer toe and crossover toe. In general, MTPJ instability should be treated prior to distal deformities. Myerson and Shereff describe a sequence of steps for the dorsal MTPJ release.[26] The first step is extensor release or lengthening. They found that the location of the tenotomy had no bearing on the result. If this fails to correct the deformity a dorsal capsulotomy is performed. On occasion it is necessary to divide the collaterals as well. If the deformity still does not correct, a flexor-to-extensor transfer may be considered.[9] Dhukaram et al found no difference in results between extensor lengthening and extensor tenotomy.[27] They also operated on 157 hammer toes requiring extended release of the MTPJ, and reported a 79% satisfaction rate.[27] Mild instability in the sagittal plane may be adequately addressed in this manner.

Toes which are severely subluxed or dislocated may not reduce adequately without osseous decompression.[26] Briggs and Stainsby described a proximal hemiphalangectomy (Stainsby procedure).[29] They found that in patients who had a single Stainsby procedure, (69 feet), 61% were symptom-free, but in patients who had multiple procedures (41 feet, mostly rheumatoid), 81% were symptom-free. They therefore suggest that this procedure is more useful for patients with significant MTPJ deformities in multiple toes.[29] Other authors have also found that this procedure results in persistent deformity and is better tolerated by patients with MTPJ synovitis or rheumatoid arthritis.[30]
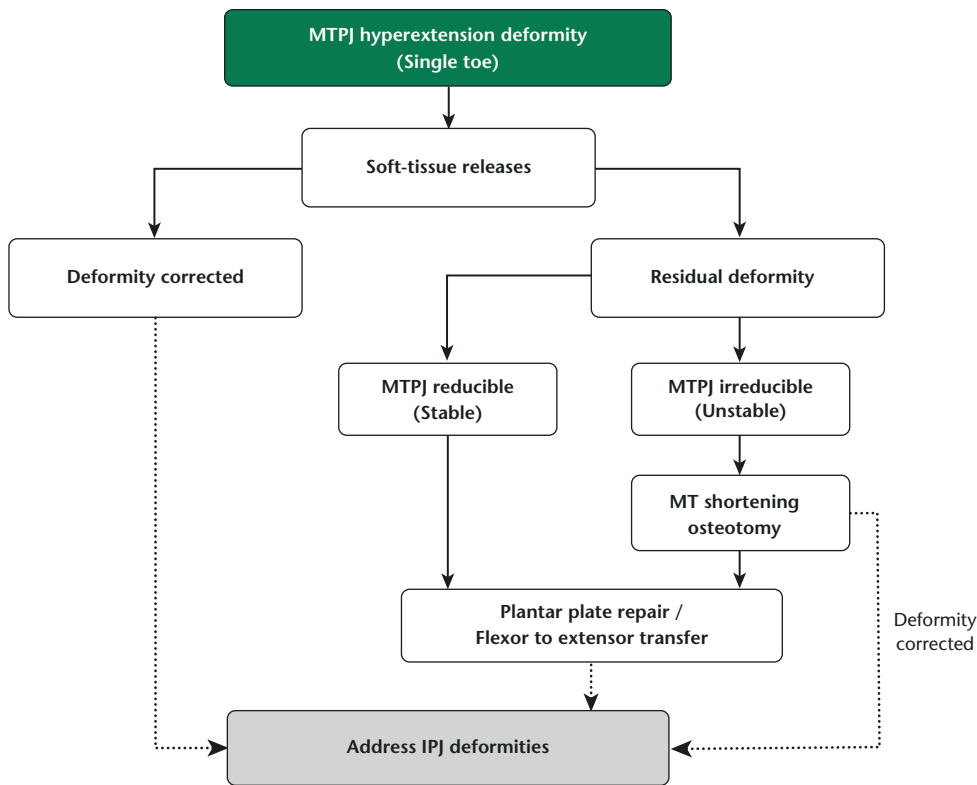
Fig. 4

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Fig. 4 Algorithm for the management of hyperextension deformities of the metatarsophalangeal joint (MTPJ) affecting a single toe. Once the deformity is corrected, more distal interphalangeal joint (IPJ) deformities should be addressed.
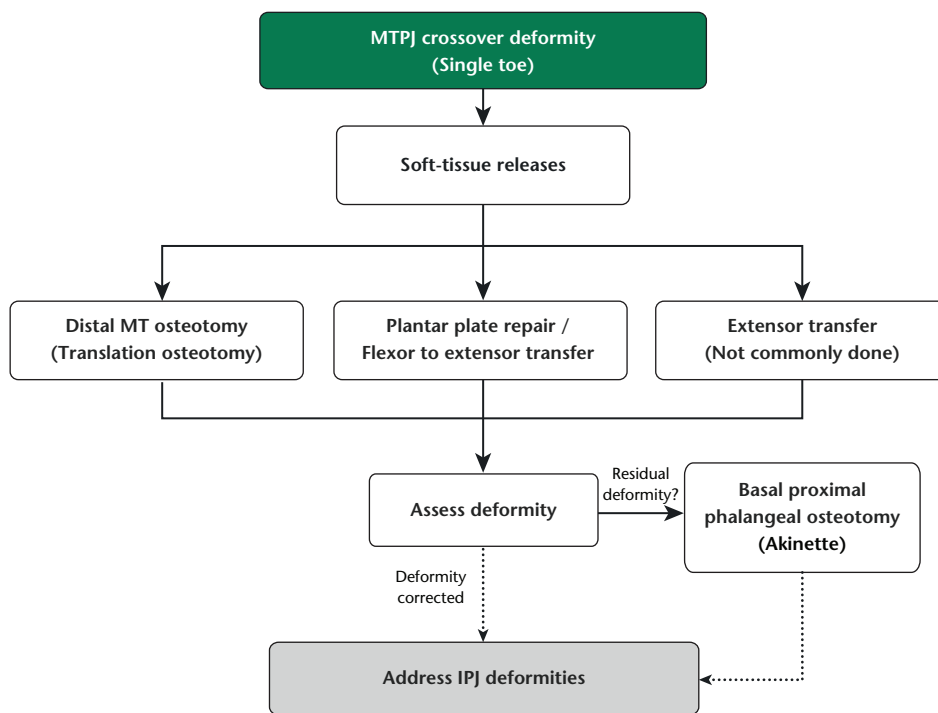
Fig. 5

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Fig. 5 Algorithm for the management of crossover deformities of the metatarsophalangeal joint (MTPJ) affecting a single toe. Once the deformity is corrected, more distal interphalangeal joint (IPJ) deformities should be addressed.
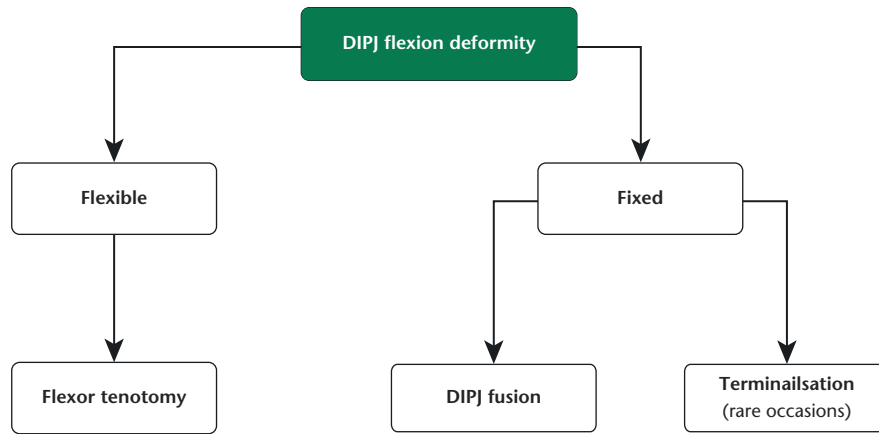
Fig. 6 Algorithm for the management of flexion deformities of the distal interphalangeal joint (DIPJ), as seen in mallet toe, or as part of a claw toe).
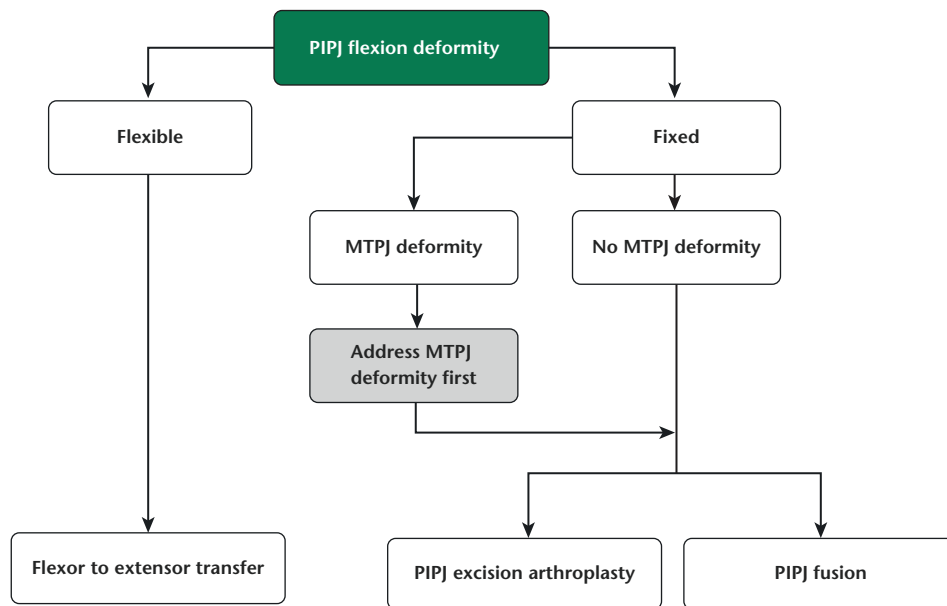

Fig. 7 Algorithm for the management of flexion deformities of the proximal interphalangeal joint (PIPJ), as seen in hammer toe or claw toe. In the presence of fixed deformity, any coexistent metatarsophalangeal joint (MTPJ) deformity should be addressed first.

A distal metatarsal shortening osteotomy, such as the Weil osteotomy, is a more commonly used form of osseous decompression. Trnka et al compared the Weil and Helal osteotomies and found that the Weil osteotomy gave a superior reduction of the MTPJ which the authors attributed to the plantar shortening which, they surmised, de-tensioned the dorsal capsule.[31] Hofstaetter et al followed up 25 Weil osteotomies for seven years, and found 76% excellent results. The main complication was of the fixation screw piercing the plantar cortex, and a 12% re-dislocation rate at seven years.[32] Garcia-Fernandez et al compared the results of 97 patients with Weil osteotomies either with or without

fixation (106 toes with, and 92 toes without) with a twist-off screw and reported no significant difference in results.[33]

Weil osteotomies have a low rate of avascular necrosis and help to offload the MT head. This may reduce pain from plantar callosities: Vandeputte et al demonstrated decreased load under the MT heads and a 95% reduction in callosities after Weil osteotomy (59 toes).[34] Weil osteotomies may be used in the treatment of metatarsalgia where it results from relative elongation or plantarflexion of the lesser metatarsals. In this setting shortening osteotomy of one or more lesser metatarsals may be used to restore the metatarsal parabola and biomechanics of the forefoot.[15]

It is important to note that lesser toe deformities may coexist with metatarsalgia and MTPJ deformity may be corrected following osseous decompression to address the metatarsalgia. Vandeputte et al[34] performed Weil osteotomies primarily for metatarsalgia. However, their cohort included 33 toes with subluxation of the MTPJ. They reported an 85% MTPJ reduction rate at final follow-up. Similarly, the metatarsal parabola should be borne in mind when performing a shortening osteotomy on a single metatarsal, and neighbouring metatarsals may also need to be shortened to prevent subsequent transfer metatarsalgia.[15]

Complications of a Weil osteotomy include malunion, excessive shortening, stiffness and a floating toe, which has been shown to be as high as 28% to 43%, and higher in the presence of PIPJ fusion.[33,35] A floating toe may occur due to the effective shortening of the plantar fascia with a Weil osteotomy, thereby disrupting the reverse windlass mechanism. In an attempt to reduce the incidence of floating toes, Herzog et al performed an osteotomy fixed with a T-plate (33 toes).[36] They had only a 3% rate of floating toes, but noted a longer healing time. Garg et al performed segmental resection MT osteotomy to prevent floating toes, preserve articular surface and prevent plantar migration (71 toes). They report a 27% rate of floating toes and no subluxation at the three-month follow-up.[37]

If the MTPJ does not reduce despite a Weil osteotomy, further stabilisation may be required in the form of a plantar plate repair or flexor-to-extensor transfer. Nery et al reported on 40 toes treated with a Weil osteotomy and plantar plate repair and found that 68% of the joints were stable post-operatively, with the rest having only mild instability.[38] However, they noted a 70% rate of floating toes in toes which were dislocated pre-operatively (27 toes). Bouché and Heit combined a plantar plate repair with a flexor-to-extensor transfer for hammer toe without a Weil osteotomy in 17 toes, and reported 60% of patients were pain-free, with stiffness in 40%, and 76% of patients 'completely' or 'very' satisfied. They reported no persistent instability and a good appearance of the toe in 88%; they did not, however, report the incidence of floating toes.[39]

In a dislocated toe, the plantar plate may be severely attenuated and repair may not be possible. In these circumstances a flexor-to-extensor transfer may be more appropriate. Isolated flexor-to-extensor transfers without a shortening osteotomy may not completely correct subluxation and patients may have residual stiffness.[40]

Once the MTPJ deformity has been corrected, any associated IPJ deformities may be addressed. Our suggested algorithm for management of MTPJ deformity in a single toe is illustrated in Figure 4.

Crossover toe

For the crossover toe, in addition to the soft-tissue release, capsular reefing may be sufficient to correct mild deformities.[11] For more severe deformities, however, a flexor-to-extensor transfer has traditionally been used. Myerson and Jung studied 64 feet and reported a good overall correction but only a 68% satisfaction rate.[41] For slightly less severe deformities an extensor transfer has also been used. This has the advantage of avoiding stiffness of the toe, but does apply a supination vector. Variations have been tried by various authors to overcome this.[42] Barca and Acciaro reported on 30 toes treated in this fashion, with 83% good to excellent results and a 3% recurrence rate.[43] Fuhrmann reported on 23 patients, with improvement in alignment in all cases. However, four patients with concomitant hallux valgus all had recurrence. Fuhrmann reported a congruent joint in 78%.[44] Haddad et al found that an extensor transfer worked well for mild to moderate crossover deformity, but flexor-to-extensor transfer was superior in more advanced deformity.[22]

More recently, Klinge et al reported on five patients who had a Weil osteotomy with medial translation to correct a crossover toe. All patients were satisfied, but one patient (20%) had a floating toe.[45] Devos Bevernage et al reported on 25 feet with medial translation Weil osteotomy, and described 68% of toes as stable and 30% as floating.[46] Basal proximal phalangeal osteotomy has also been described to realign the toe.[47,48] Kilmartin and O'Kane performed the procedure in 26 valgus second toes without additional soft-tissue procedures. Although they did not achieve full correction, 19 patients (73%) were satisfied. They reported floating toes in 19% and recurrence in 15% of patients.[48] This procedure does not in itself address the MTPJ and therefore has been advocated as an adjunct for persistent or recurrent deformity after adequate soft-tissue procedures have been performed.[47] In cases of a crossover toe with a unilateral plantar plate tear, repair of the plantar plate is increasingly popular, although there is little literature on the results of this technique.[18]

Crossover toes are often one of the most challenging lesser toe deformities to correct. In elderly patients with severe deformity, amputation may on occasion be preferable to significant bony and soft-tissue correction. In these cases the accompanying hallux deformity need not be corrected. Gallentine and DeOrio report on 17 toes amputated through the MTPJ with an 82% satisfaction rate.[49]

As with sagittal plane MTPJ deformities, once crossover toe is corrected, concurrent IPJ deformities may be addressed. Our suggested algorithm for management of crossover toe is illustrated in Figure 5.

Mallet toe

Evidence on the best treatment of an isolated adult mallet toe is sparse. In children, flexible curly toe deformities have been successfully treated with flexor tenotomy, but there have been few similar reports in

adults.[50,51] Nevertheless, as flexible mallet toes are caused by a tight FDL, percutaneous flexor tenotomy is advocated to correct the deformity.[18,52]

A fixed deformity requires excision of the DIPJ and fusion or stabilisation. This is most commonly performed using a percutaneous wire. Coughlin reported on 72 mallet toes treated in this fashion. Bony fusion occurred in 72% of cases and the remainder had a fibrous union. He found that 86% of patients were satisfied with the procedure and 97% had improvement in their symptoms.[53] Intramedullary devices can also be used instead of a wire.[54] For patients with significant ulceration, terminalisation is an alternative to fusion. Our proposed algorithm is illustrated in Figure 6.

Claw toe and hammer toe

Although distinct clinical entities, the treatment of claw toe and hammer toe is similar. Treatment must address the deformities at the PIPJ, DIPJ (if present), and MTPJ. If MTPJ instability exists, this should be addressed first. Myerson and Shereff suggested that for mild, flexible claw toe, the PIPJ deformity may be corrected by an FDB tenotomy.[26] However, the unopposed pull of the intrinsics and extensors may then cause hyperextension of the toe at the MTPJ and so a flexor-to-extensor transfer is recommended.

In 1951 Taylor first described the Girdlestone-Taylor flexor-extensor transfer in 68 patients.[25] The FDL and FDB were divided and attached to the extensor hood. Good results were achieved in 73%. This procedure is effective at removing the deforming force of the flexors and counteracting hyperextension of the toe, but results in loss of prehensile function in the toes.[55] Passive plantar flexion at the MTPJ via the plantar fascia is maintained. Initially described for claw toe, variations of this procedure are now also widely used in the treatment of hammer toes and MTPJ subluxation. Barbari and Brevig performed this procedure on 39 flexible claw toes and obtained an 84% satisfaction rate.[56] Boyer and DeOrio performed the procedure on 79 hammer toes with an 89% satisfaction rate and no floating toes.[57] Losa et al performed a meta-analysis of 515 flexor-to-extensor transfers for lesser toe deformities and found patient satisfaction to be 87%.[58] After a tendon transfer it is important to mobilise early, but the risk of stiffness must be balanced against the risk of recurrence.[24]

For fixed PIPJ deformities the PIPJ is excised or fused. In cases where the MTPJ is stable, this procedure is often sufficient.[55] Coughlin et al reported on 118 toes treated with PIPJ resection and stabilised with a percutaneous wire. They found that 81% fused, while the rest developed a fibrous union. Pain was improved in 92% of cases, and 84% of patients were satisfied.[23] However, PIPJ excision without fusion may result in malalignment and instability.[27] Some authors have advocated the use of intramedullary implants in IPJ fusion, in an attempt to improve alignment of the toe and obviate the requirement for a wire. The results are generally favourable, but the evidence consists largely of non-randomised, retrospective studies.[59-64] Our suggested algorithm for management of PIPJ deformities is illustrated in Figure 7.

Minimally invasive surgery

Minimally-invasive surgery (MIS) involves bony or soft-tissue procedures carried out through a small incision, without direct visualisation on the underlying structures. It has gained popularity with the perceived advantages of reduced soft-tissue damage and scarring, a shorter length of surgery and hospital stay, lower post-operative pain and reduced infection risk. Gilheany et al audited the results of 299 lesser toe MIS procedures including tenotomies, capsular releases, and osteotomies, and reported a 0.5% infection rate.[65] The main risk of MIS is damage to neurovascular and tendinous structures and therefore surgeons should be specifically trained in these techniques and have the appropriate instruments.

A commonly performed soft-tissue MIS procedure in the lesser toes is a percutaneous flexor tenotomy. Debarge et al performed a percutaneous flexor tenotomy on 50 patients with clawing of the lesser toes. They found a 10% recurrence rate and 4% of patients developed complex regional pain syndrome.[66]

Various authors have reported on the results of minimally invasive distal metatarsal metaphyseal osteotomies (DMMOs). This is seen as an alternative to the Weil osteotomy with the perceived advantages of being extra-articular and avoiding plantar translation. Dhukaram, Chapman and Upadhyay performed DMMOs on ten cadavers, from the second through to the fourth rays.[67] They then dissected the cadavers to examine the results. They found no incidence of nerve or tendon damage. They also observed that the soft-tissue sleeve was intact (a desired goal of MIS), and therefore the degree of shortening was restricted.[67] Henry et al retrospectively compared the results of 37 patients treated with DMMO, with 30 patients treated with Weil osteotomies. The indication was metatarsalgia with or without MTPJ subluxation. They found that the residual oedema and residual metatarsalgia was significantly higher in the DMMO group at three months, but after one year the pain, swelling and range of movement were similar for both groups.[68] Haque et al also reported prolonged swelling (for six months) after percutaneous DMMO in 30 patients, although they performed the procedure on multiple toes in all cases. They report a 3% nonunion rate and a 3% malunion rate.[69]

Conclusions

Lesser toe deformities are common and can have a significant impact on the function of the foot and quality of

life. A number of deformities may coexist. Conservative treatment with digital pads and footwear modification should be tried first. The goal of surgical treatment is to achieve a well-aligned and functional toe, but corrective surgery often results in loss of prehensile function or stiffness. To reduce the risk of recurrence it is important to understand, and adequately address, the underlying pathology. There is a paucity of randomised controlled trials to guide best management. Minimally invasive techniques are increasingly being used, but good quality, prospective studies will be required to determine their efficacy. We suggest the addressing of proximal deformities prior to distal deformities and present treatment algorithms based on the results of currently published literature.

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REFERENCES

1. **Saro C, Bengtsson AS, Lindgren U, et al.** Surgical treatment of hallux valgus and forefoot deformities in Sweden: a population-based study. *Foot Ankle Int* 2008;29:298-304.

2. **Klenerman LBW.** *The human foot: a companion to clinical studies.* New York: Springer; 2006.

3. **Hicks JH.** The mechanics of the foot. II. The plantar aponeurosis and the arch. *J Anat* 1954;88:25-30.

4. **Hughes J, Clark P, Klenerman L.** The importance of the toes in walking. *J Bone Joint Surg [Br]* 1990;72-B:245-251.

5. **Kelikian AS.** *Sarrafian's anatomy of the foot and ankle: descriptive, topographic, functional.* Third ed. Philadelphia: Lippincott Williams & Wilkins, 2011.

6. **Sarrafian SK, Topouzian LK.** Anatomy and physiology of the extensor apparatus of the toes. *J Bone Joint Surg [Am]* 1969;51-A:669-679.

7. **Shirzad K, Kiesau CD, DeOrio JK, Parekh SG.** Lesser toe deformities. *J Am Acad Orthop Surg* 2011;1:9505-9514.

8. **Erdemir A, Hamel AJ, Fauth AR, Piazza SJ, Sharkey NA.** Dynamic loading of the plantar aponeurosis in walking. *J Bone Joint Surg [Am]* 2004;86-A:546-552.

9. **Stainsby GD.** Pathological anatomy and dynamic effect of the displaced plantar plate and the importance of the integrity of the plantar plate-deep transverse metatarsal ligament tie-bar. *Ann R Coll Surg Engl* 1997;79:58-68.

10. **Bhatia D, Myerson MS, Curtis MJ, Cunningham BW, Jinnah RH.** Anatomical restraints to dislocation of the second metatarsophalangeal joint and assessment of a repair technique. *J Bone Joint Surg [Am]* 1994;76-A:1371-1375.

11. **Coughlin MJ.** Common causes of pain in the forefoot in adults. *J Bone Joint Surg [Br]* 2000;82-B:781-790.

12. **Dominguez-Maldonado G, Munuera-Martinez PV, Castillo-Lopez JM, Ramos-Ortega J, Albornoz-Cabello M.** Normal values of metatarsal parabola arch in male and female feet. *Scientific World Journal* 2014:505736.

13. **Morton DJ.** Metatarsus atavicus: The identification of a distinctive type of foot disorder. *J Bone Joint Surg [Am]* 1927;9-A:531-544.

14. **Harris RI, Beath T.** The short first metatarsal; its incidence and clinical significance. *J Bone Joint Surg [Am]* 1949;31-A:553-565.

15. **Maestro M, Besse JL, Ragusa M, Berthonnaud E.** Forefoot morphotype study and planning method for forefoot osteotomy. *Foot Ankle Clin* 2003;8:695-710.

16. **Coughlin MJ.** Second metatarsophalangeal joint instability in the athlete. *Foot Ankle* 1993;14:309-319.

17. **Thompson FM, Hamilton WG.** Problems of the second metatarsophalangeal joint. *Orthopedics* 1987;101:83-89.

18. **Coughlin MJ.** Lesser toe deformities. In: Coughlin MJSC, Anderson RB, eds. *Mann's surgery of the foot and ankle.* Ninth ed. Elsevier; 2014:322-424.

19. **Coughlin MJ.** Subluxation and dislocation of the second metatarsophalangeal joint. *Orthop Clin North Am* 1989;20:535-551.

20. **Kaz AJ, Coughlin MJ.** Crossover second toe: demographics, etiology, and radiographic assessment. *Foot Ankle Int* 2007;28:1223-1237.

21. **Deland JT, Sung IH.** The medial crossover toe: a cadaveric dissection. *Foot Ankle Int* 2000;21:375-378.

22. **Haddad SL, Sabbagh RC, Resch S, Myerson B, Myerson MS.** Results of flexor-to-extensor and extensor brevis tendon transfer for correction of the crossover second toe deformity. *Foot Ankle Int* 1999;20:781-788.

23. **Coughlin MJ, Dorris J, Polk E.** Operative repair of the fixed hammertoe deformity. *Foot Ankle Int* 2000;21:94-104.

24. **Veljkovic A, Lansang E, Lau J.** Forefoot tendon transfers. *Foot Ankle Clin* 2014;19:123-137.

25. **Taylor RG.** The treatment of claw toes by multiple transfers of flexor into extensor tendons. *J Bone Joint Surg [Br]* 1951;33-B:539-542.

26. **Myerson MS, Shereff MJ.** The pathological anatomy of claw and hammer toes. *J Bone Joint Surg [Am]* 1989;71-A:45-49.

27. **Dhukaram V, Hossain S, Sampath J, Barrie JL.** Correction of hammer toe with an extended release of the metatarsophalangeal joint. *J Bone Joint Surg [Br]* 2002;84-B:986-990.

28. **Mizel MS, Michelson JD.** Nonsurgical treatment of monarticular nontraumatic synovitis of the second metatarsophalangeal joint. *Foot Ankle Int* 1997;18:424-426.

29. **Briggs PJ, Stainsby GD.** Metatarsal head preservation in forefoot arthroplasty and the correction of severe claw toe deformity. *Foot Ankle Surg* 2001;7:93-101.

30. **Conklin MJ, Smith RW.** Treatment of the atypical lesser toe deformity with basal hemiphalangectomy. *Foot Ankle Int* 1994;15:585-594.

31. **Trnka HJ, Mühlbauer M, Zettl R, Myerson MS, Ritschl P.** Comparison of the results of the Weil and Helal osteotomies for the treatment of metatarsalgia secondary to dislocation of the lesser metatarsophalangeal joints. *Foot Ankle Int* 1999;20:72-79.

32. **Hofstaetter SG, Hofstaetter JG, Petroutsas JA, et al.** The Weil osteotomy: a seven-year follow-up. *J Bone Joint Surg [Br]* 2005;87-B:1507-1511.

33. **García-Fernández D, Gil-Garay E, Lora-Pablos D, et al.** Comparative study of the Weil osteotomy with and without fixation. *Foot Ankle Surg* 2011;17:103-107.

34. **Vandeputte G, Dereymaeker G, Steenwerckx A, Peeraer L.** The Weil osteotomy of the lesser metatarsals: a clinical and pedobarographic follow-up study. *Foot Ankle Int* 2000;21:370-374.

35. **Migues A, Slullitel G, Bilbao F, Carrasco M, Solari G.** Floating-toe deformity as a complication of the Weil osteotomy. *Foot Ankle Int* 2004;25:609-613.

36. **Herzog JL, Goforth WD, Stone PA, Paden MH.** A modified fixation technique for a decompressional shortening osteotomy: a retrospective analysis. *J Foot Ankle Surg* 2014;53:131-136.

37. **Garg R, Thordarson DB, Schrumpf M, Castaneda D.** Sliding oblique versus segmental resection osteotomies for lesser metatarsophalangeal joint pathology. *Foot Ankle Int* 2008;29:1009-1014.

38. **Nery C, Coughlin MJ, Baumfeld D, Mann TS.** Lesser metatarsophalangeal joint instability: prospective evaluation and repair of plantar plate and capsular insufficiency. *Foot Ankle Int* 2012;33:301-311.

39. **Bouché RT, Heit EJ.** Combined plantar plate and hammertoe repair with flexor digitorum longus tendon transfer for chronic, severe sagittal plane instability of the lesser metatarsophalangeal joints: preliminary observations. *J Foot Ankle Surg* 2008;47:125-137.

40. **Thompson FM, Deland JT.** Flexor tendon transfer for metatarsophalangeal instability of the second toe. *Foot Ankle* 1993;14:385-388.

41. **Myerson MS, Jung HG.** The role of toe flexor-to-extensor transfer in correcting metatarsophalangeal joint instability of the second toe. *Foot Ankle Int* 2005;26:675-679.

42. **Lui TH, Chan KB.** Technique tip: modified extensor digitorum brevis tendon transfer for crossover second toe correction. *Foot Ankle Int* 2007;28:521-523.

43. **Barca F, Acciaro AL.** Surgical correction of crossover deformity of the second toe: a technique for tenodesis. *Foot Ankle Int* 2004;25:620-624.

44. **Fuhrmann RA.** Subligamentous transfer of the extensor digitorum brevis tendon for medial malalignment of the lesser toes. *Oper Orthop Traumatol* 2009;21:88-96. [In German]

45. **Klinge SA, McClure P, Fellars T, DiGiovanni CW.** Modification of the Weil/Maceira metatarsal osteotomy for coronal plane malalignment during crossover toe correction: case series. *Foot Ankle Int* 2014;35:584-591.

46. **Devos Bevernage B, Deleu PA, Leemrijse T.** The translating Weil osteotomy in the treatment of an overriding second toe: a report of 25 cases. *Foot Ankle Surg* 2010;16:153-158.

47. **Davis WH, Anderson RB, Thompson FM, Hamilton WG.** Proximal phalanx basilar osteotomy for resistant angulation of the lesser toes. *Foot Ankle Int* 1997;18:103-104.

48. **Kilmartin TE, O'Kane C.** Correction of valgus second toe by closing wedge osteotomy of the proximal phalanx. *Foot Ankle Int* 2007;28:1260-1264.

49. **Gallentine JW, DeOrio JK.** Removal of the second toe for severe hammertoe deformity in elderly patients. *Foot Ankle Int* 2005;26:353-358.

50. **Hamer AJ, Stanley D, Smith TW.** Surgery for curly toe deformity: a double-blind, randomised, prospective trial. *J Bone Joint Surg [Br]* 1993;75-B:662-663.

51. **Ross ER, Menelaus MB.** Open flexor tenotomy for hammer toes and curly toes in childhood. *J Bone Joint Surg [Br]* 1984;66-B:770-771.

52. **Louwerens JWSJ.** Lesser toe deformities. In: Bentley G, ed. *European surgical orthopaedics and traumatology*. *The EFORT textbook*. Vol 6. Berlin Heidelberg: Springer-Verlag, 2014:3407-3973.

53. **Coughlin MJ.** Operative repair of the mallet toe deformity. *Foot Ankle Int* 1995;16:109-116.

54. **Khan F, Kimura S, Ahmad T, D'Souza D, D'Souza L.** Use of Smart Toe(©) implant for small toe arthrodesis: A smart concept? *Foot Ankle Surg* 2015;21:108-112.

55. **Myers SH, Schon LC.** Forefoot tendon transfers. *Foot Ankle Clin* 2011;16:471-488.

56. **Barbari SG, Brevig K.** Correction of clawtoes by the Girdlestone-Taylor flexor-extensor transfer procedure. *Foot Ankle* 1984;5:67-73.

57. **Boyer ML, DeOrio JK.** Transfer of the flexor digitorum longus for the correction of lesser-toe deformities. *Foot Ankle Int* 2007;28:422-430.

58. **Losa Iglesias ME, Becerro de Bengoa Vallejo R, Jules KT, Trepal MJ.** Meta-analysis of flexor tendon transfer for the correction of lesser toe deformities. *J Am Podiatr Med Assoc* 2012;102:359-368.

59. **Ellington JK, Anderson RB, Davis WH, Cohen BE, Jones CP.** Radiographic analysis of proximal interphalangeal joint arthrodesis with an intramedullary fusion device for lesser toe deformities. *Foot Ankle Int* 2010;31:372-376.

60. **Fazal MA, James L, Williams RL.** StayFuse for proximal interphalangeal joint fusion. *Foot Ankle Int* 2013;34:1274-1278.

61. **Konkel KF, Menger AG, Retzlaff SA.** Hammer toe correction using an absorbable intramedullary pin. *Foot Ankle Int* 2007;28:916-920.

62. **Roukis TS.** A 1-piece shape-metal nitinol intramedullary internal fixation device for arthrodesis of the proximal interphalangeal joint in neuropathic patients with diabetes. *Foot Ankle Spec* 2009;2:130-134.

63. **Coillard JY, Petri GJ, van Damme G, Deprez P, Laffenêtre O.** Stabilization of proximal interphalangeal joint in lesser toe deformities with an angulated intramedullary implant. *Foot Ankle Int* 2014;35:401-407.

64. **Sung W, Weil L Jr, Weil LS Sr.** Retrospective comparative study of operative repair of hammertoe deformity. *Foot Ankle Spec* 2014;7:185-192.

65. **Gilheany M, Baarini O, Samaras D.** Minimally invasive surgery for pedal digital deformity: an audit of complications using national benchmark indicators. *J Foot Ankle Res* 2015;8:17.

66. **Debarge R, Philippot R, Viola J, Besse JL.** Clinical outcome after percutaneous flexor tenotomy in forefoot surgery. *Int Orthop* 2009;33:1279-1282.

67. **Dhukaram V, Chapman AP, Upadhyay PK.** Minimally invasive forefoot surgery: a cadaveric study. *Foot Ankle Int* 2012;33:1139-1144.

68. **Henry J, Besse JL, Fessy MH; AFCP.** Distal osteotomy of the lateral metatarsals: a series of 72 cases comparing the Weil osteotomy and the DMMO percutaneous osteotomy. *Orthop Traumatol Surg Res* 2011;97(suppl):S57-S65.

69. **Haque S, Kakwani R, Chadwick C, Davies MB, Blundell CM.** Outcome of minimally invasive distal metatarsal metaphyseal osteotomy (DMMO) for lesser toe metatarsalgia. *Foot Ankle Int* 2016;37:58-63.