OrthoSolutions Group

The Subtalar Joint

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Consensus of the 6th Round Table

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Preface

The 1st Round Table meeting was held in Padua in June 2011, followed by annual meetings in Paris, Barcelona, Budapest and Edinburgh. The 6th Round Table in Munich has once again not followed the usual orthopaedic meeting format where faculty members lecture to delegates. As always, the meeting is unique in that all participants have an equal input to review the literature and present their individual experience on a topic - with ample time for an informal discussion of the subject in a relaxed setting.

This year, we have adopted a novel format by dealing in depth with a single topic. We have chosen the subtalar joint because of its important role in the mechanics of the foot and ankle, because its pathology is poorly understood and because of emerging techniques in treatment.

Alanna Pentlow and Shelain Patel were responsible for recording opinions and capturing the essence of the debates. This booklet collates the literature review and the views of all those who participated.

This booklet does not represent Level I evidence derived from prospective randomized controlled trials but represents the compilation of the combined experience of 25 British orthopaedic surgeons as well as a much valued input from Mark Myerson from USA.

We have not provided a detailed list of references in order to keep the booklet small and easily readable.

I hope that you will find something of use and relevant to your own practice.

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The subtalar joint

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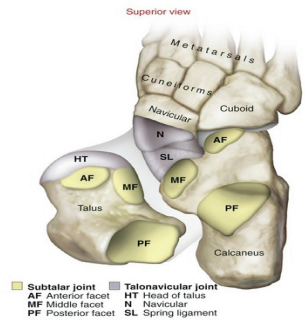
Anatomy and biomechanics of the subtalar joint

Overview

The subtalar joint can no more be viewed in isolation from the mechanics of the lower limb than a crankshaft can from the engine of a car. The anatomy of the subtalar joint directs its function as a couple between the leg and the foot and allows the foot structure to adapt depending on its functional needs.

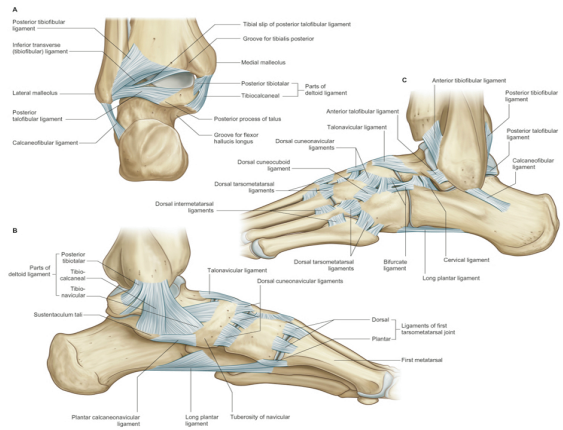
Osteology



The subtalar joint is divided into 2 distinct articulations; the posterior facet and anterior joints, containing the middle and anterior facets. These joints usually have their own separate synovial capsules, which is important to remember when performing injections into the subtalar joint.

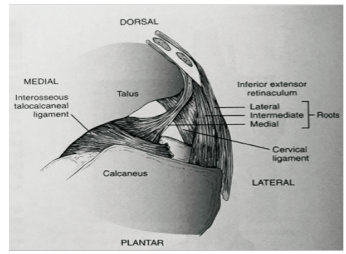
Ligaments

The ligaments can be divided into intrinsic and extrinsic. The extrinsic ligaments comprise medially of the deltoid complex, spring ligament and medial and posterior talocalcaneal ligament. Laterally the ligaments are the ATFL, CFL, AITFL, PITFL, and PTFL.



There are 3 main important intrinsic ligaments:

- **Cervical ligament –** runs from talar neck to calcaneum. It is tight in both supination and pronation and acts as a check rein to increase stability
- **Inferior extensor retinaculum** - comprises of 3 roots: lateral, intermediate and medial
- **Interosseous talo-calcaneal ligament –** this ligament lies between the posterior and middle facets. It is closely related to the ligament of the tarsal canal, and there is some debate between anatomists, as to whether the two ligaments are in-fact part of the same structure. Its role is to reduce excessive supination.



Attrition or rupture of the ligments can lead to excessive movements of the subtalar joint, which can give symptoms of instability and pain.

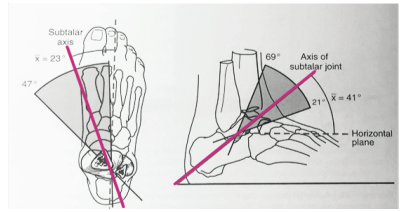
Myology

There are no direct muscle attachments on the subtalar joint, with all actions being indirect. The invertor include tibialis posterior, tibilais anterior and the long flexors. The evertors are the peroneals and extensor digitorum longus.

Extensor digitorum brevis is a large muscle which attaches onto the cervical ligaments, the ATFL and extensor retinaculum. It's function is not fully understood, It is possible it may have a role in subtalar stability, as well as extending the toes. When standing on tiptoes or on an unstable surface it is certainly active suggesting it is contributing to subtalar stability.

Biomechanics

The subtalar joint is a bicondylar joint, with rotation of the 2 bones occuring around an axis of the condyles. The hinge seems to be centred on the interosseous ligaments. Although the subtalar joint has 2 separate synovial articulations, the motion of the articulations is coupled, like hinges on a door; they are independent but work together. The axis of motion in the joint passes obliquely from poster laterally, through the sustentaculum talus, to anteromedially. Rotation is conical, with more movement posteriorly and less anteriorly, due to tethering from the intrinsic ligaments. There is significant variability in the ranges of movement between people, with $0\text{-}47^0$ in one direction and $21\text{-}69^0$ in the other, as shown below:



The movements of the subtalar joint are inversion and eversion, however movements of the hind foot are more complex as joints do not move in isolation. Instead the functional movements of the subtalar joint can be though of as:

- Flat foot (pronation) – a combination of eversion, abduction dorsiflexion and heel valgus. This position is good for shock absorbtion as the foot is unlocked
- High arch foot (supination) – inversion, adduction, plantar flexion and heel varus. This position is good for propulsion as the foot is locked

The role of the subtalar joint is to act as an mitre hinge, where rotation of the vertical limb causes an equal rotation of the horizontal limb, transferring load from the tibia, across the hind foot into the mid-foot.

Summary

- The subtalar joint is a complex joint consisting a 2 separate synovial capsules
- There are 3 intrinsic ligaments (cervical, extensor retinaculum and interosseous), which are very important for subtalar stability, in addition to the extrinsic ligaments
- Movements of the subtalar joint occur in conjunction with movements of the tibia and midfoot to produce either a flat foot or high arch position

Clinical Assessment

All clinical assessments start with history and examination. These invariably provide the diagnosis in many cases and also dictate treatment based upon the severity of the findings.

History

Symptoms to ask for include:

- Pain
- Swelling
- Stiffness
- Weakness
- Instability

Specifically for each relevant complaint, one should identify the nature, location, duration and progression. Subtalar pathology classically affects walking on uneven ground due to the plane of motion of the joint, and patients may describe being unable to walking on a particular camber due to stiffness not allowing for in the hindfoot any corrective motion. Specific footwear (e.g. high top shoes) may be needed to provide stability, and function can also be assessed by asking whether running, cutting or jumping manoeuvres can be performed.

Examination

General Approach

This begins the moment the patient walks in to the clinic with inspection of gait, walking aids, splints or signs of systemic disease such as rheumatoid arthritis. Shoes may be modified or show abnormal patterns of wear. Inside the shoe, corrective or accommodative insoles may be present. Look from the front and behind for standing alignment (normal: 5-10˚ valgus), deformities, medial arches, skin integrity, hyperkeratosis, scars, swelling and muscle wasting. The planovalgus or cavovarus foot should prompt a specific examination (see section below). Inspect the sole of foot when the patient is supine.

Observe the gait cycle, engagement of each rocker and whether the patient can walk on the medial and lateral borders of their feet.

Palpation of the subtalar joint is difficult due to its location but a suggested approach to the hindfoot is to start distally on the lateral side at the fifth metatarsal styloid and work proximally to the groove in cuboid for peroneus longus, sinus tarsi, talar dome, fibular tip, ATFL, CFL, peroneal tubercle, retro fibular groove and insertion of the Achilles tendon. The medial side can then be palpated proximally at medial malleolus, and work distally to the sustenataculum tali, talar head, tarsal tunnel, navicular tubercle and first TMT joint.

Subtalar motion is assessed with supination and pronation which are tri-planar movements; namely supination combines calcaneal inversion, adduction and plantarflexion and pronation combines calcaneal eversion, abduction and dorsiflexion. Neurovascular assessment completes the examination including testing all muscles that traverse the ankle and hindfoot.

Specific Conditions and Tests

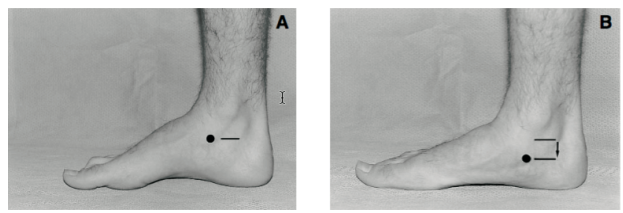
Hindfoot varus

From the front, a 'peek a boo heel' sign described by Beals and Manoli (1996) may be present. This is where one can easily view the heel pad with the patient standing and feet aligned straight ahead. A plantar flexed first ray of a cavus foot will cause a callosity under the 1st metatarsal head while the varus will generate them under the 5th metatarsal head. Gastrocnemius tightness which can contribute towards a deformity should be assessed with the Silfverskiöld's test. A Coleman block test evaluates hindfoot flexibility. Unexplained cavovarus feet are secondary to neurological disorders until proven otherwise so neurological examination is mandatory; Charcot Marie Tooth disease if classically associated with weakness of tibialis anterior and peroneus brevis.

Hindfoot valgus

From the back, a 'too many toes' sign may be observed. It is normal to see up to two toes and more than this is positive. Valgus can be associated with pes planus where there is loss of the normal medial arch and it is necessary to see if this is correctable or fixed. This can be done by passively dorsiflexing the hallux with the patient standing in a relaxed position (Jack's test) although it is more common to perform a standing single-leg heel raise which assesses both the integrity of the windlass mechanism and the power of the hindfoot inverters.

In the planovalgus foot, the foot may pronate or abduct at the navicular-cuneiform joint. The navicular drop and drift tests may demonstrate deformity is occurs in the sagittal or transverse planes. In the drop test, the most prominent part of the navicula is noted with the patient sitting and the foot placed in a subtalar neutral position. The distance from this point to the floor in noted and then repeated with the patient standing; more than 10mm difference is considered abnormal (Brody, 1982). The drift test is performed in a near identical manner but consists of measuring the lateral excursion of the most identified point. If the deformity occurs in the sagittal plane, then placing an arch support is likely to be of more value.



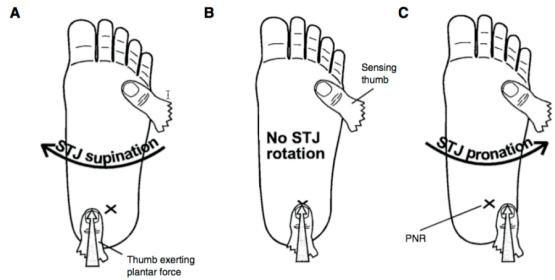
Navicular drop test

Subtalar Instability

Thermann's test is used to assess subtalar instability; the forefoot is stabilised while a varus and internal rotational force is applied to the calcaneus. The forefoot is then internally rotated and a positive result occurs with either excessive medial shift of the calcaneus or in reproducing instability symptoms.

Subtalar Axis

This can be approximated by plotting the points of no rotation. This involves marking a point on the heel which is unaffected by pronation and supination and then identifying distal points on the sole of the foot which are similarly unaffected (see below). The direction of this axis should aim from the heel towards the first metatarsal head and this axis can be used intra-operatively to guide deformity correction.



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Imaging

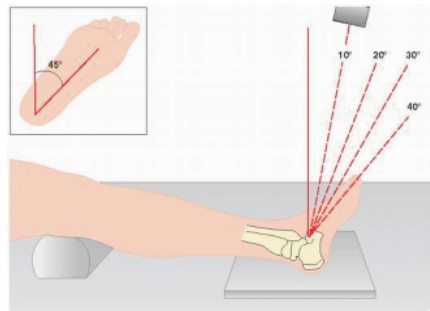
The three most widely used means of imaging the subtalar joint are:

- X-rays
- Computerised Tomography (CT)
- Magnetic Resonance Imaging (MRI).

X-rays

X-rays are the primary mode of imaging the subtalar joint. Their main advantages are low cost, high availability and reproducibility. They can identify much pathology and special views can be used in addition to standard antero-posterior and lateral views of the ankle to specifically view different parts of the joint. These are particularly useful intra-operatively when performing reconstructive surgery after trauma. They include:

Broden's view taken with the knee slightly flexed, foot in neutral dorsiflexion and internally rotated to 30-45 degrees. The beam is centred towards the lateral malleolus and images obtained at 10 (to show posterior facet), 20, 30 and 40 (to show anterior facet) degrees of cephalic tilt:



Lateral oblique view taken with the patient supine with the inner border of the foot placed on a wedge inclined at 45 degrees. The beam is centred 2.5 cm anterior and distal to the lateral malleolus to show the anterior process:

Medial oblique axial view taken with patient supine and the foot inverted and internally rotated to 60 degrees. The beam is centred 2.5 cm anterior and distal to the lateral malleolus at 10 degrees cephalad tilt to show the middle and posterior facets:

Lateral oblique axial view taken with patient supine and the foot everted and 60 degrees externally rotated. The beam is centred 2.5 cm below the medial malleolus to show the posterior facet:

Harris Beath view taken with the sole of the foot flat on the cassette. The beam is aimed towards the midline of the heel at either 45 degrees or ideally the angle of the posterior facet. This shows the body of the calcaneus and is also useful for identifying coalitions. The picture below shows normal middle and posterior facets on the left foot but the right has an irregular middle facet suggesting a coalition:

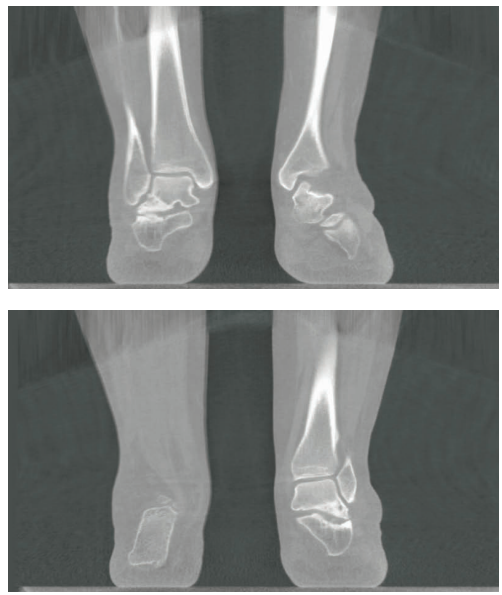
Computerised Tomography

Radiographs of the subtalar joint are limited by projectional superimposition caused by the 2-dimensional representation of a 3-dimensional structure and it is in this context where CT is extremely helpful. It is excellent for viewing osseous anatomy, fractures, coalitions and post-surgical changes including healing of

osteotomies and arthrodesis. Most CT machines do not allow the foot to be loaded which has been shown to alter joint orientation and may be helpful both before and after surgery.

Ferri et al. (2008) constructed a specialised device to simulate weight bearing in a CT scanner and imaged 18 normal feet and 30 painful severe and flexible flat feet in both the non-weightbearing and 50% weight-bearing states. They found the weight-bearing device significantly altered floor to skin distance and forefoot arch angle in both groups. Furthermore, four of the pes planus patients had subtalar joint subluxation which became more pronounced in the weight-bearing state supporting the concept of weight-bearing as an adjunct to imaging.

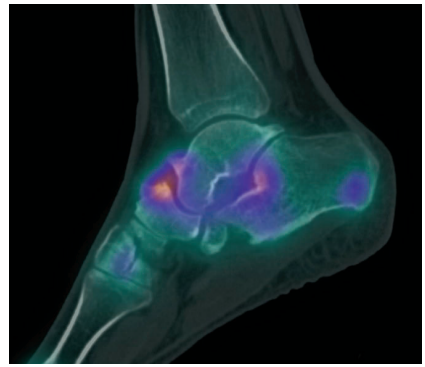
Since 2012, weight-bearing CT has become commercially available and offers a theoretical advantage over simulated weight-bearing which is otherwise aphysiologic, eliminates muscle pull and cannot apply enough load. To date, no study has compared unloaded, simulated and actual weight bearing CT. The weight-bearing CT below demonstrates subtalar arthropathy in both feet. Sequential slices demonstrate normal hindfoot alignment:



Richter et al. (2014, 2016) published two reports on the use of the PedCAT standing CT machine whose radiation dose is equivalent to only six digital radiographs. When comparing standard digital radiographs with the patient standing and fully weight bearing, CT scans without weight bearing, and pedCAT scans with full weight bearing in standing position, most radiographic indices except dorsal talo-metatarsal angle and calcaneal pitch were noted to differ on pedCAT. They suggested it was therefore the most accurate imaging modality for quantifying osseous anatomy. In a further study, they added a pedography sensor to the pedCAT but no correlation was found between the images and pressure readings from which they concluded that force and pressure distribution cannot be inferred from bone positions measured on pedCAT scans.

Krähenbühl et al. (2016) recently investigated the role of the orientation of the subtalar joint on ankle arthritis using weight-bearing CT scans. The subtalar vertical angle (SVA) which describes the posterior facet of the subtalar joint in the frontal plane was analysed in 40 patients with ankle arthritis and 20 controls. The scans were reliable and consistent and they found varus ankle osteoarthritis occurred with varus orientation of the subtalar joint and similarly valgus osteoarthritis occurred with valgus orientation of the subtalar joint. They suggested that the subtalar joint orientation may be a risk factor for the development of ankle joint osteoarthritis.

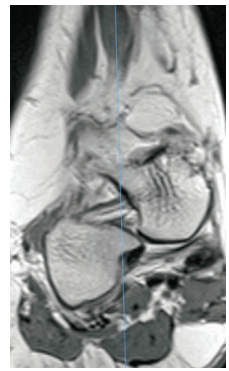
SPECT-CT has also come to the fore for its ability to help identify pain generators when the clinical assessment and other imaging is vague. Claassen et al. (2014) reported their experience in patients with inconclusive presentations and radiographs; SPECT-CT changed their treatment decision in 65% of patients with subtalar pathology and led to pain relief in 95% of patient after specific intervention based upon the SPECT-CT findings. The image below shows how SPECT-CT may highlight pain generators through superimposition of osteoblastic activity on three dimensional imaging.



Magnetic Resonance Imaging

MRI's principle advantages over x-rays and CT are it emits no radiation and offers better soft tissue visualisation. It is particularly useful in identifying bone oedema and synovitis although weight bearing cannot be replicated in an MRI scanner (Wolf et al. 2007).

A recent focus of subtalar pathology has been on the subtalar ligaments and their role in subtalar instability. Pastore et al. (2009) evaluated these ligaments using MRI and MR arthrography in cadavers. MR arthrography provided superior delineation of the articular, periarticular structures and ligaments than plain MRI. The axial plane was best for viewing the lateral talocalcaneal ligament, fibulotalocalcaneal ligament, anterior and posterior talofibular ligaments and the posterior tibiotalar ligament; the sagittal was best for posterior talocalcaneal ligament; and the coronal was best for medial talocalcaneal ligaments. Better recognition of these ligaments may change practice in future to enable clinicians to use MRI to identify features of subtalar instability. The coronal, T1 weighted MR image overleaf clearly demonstrates an intact ITCL between talus and calcaneum:



Summary

Advances in 3-dimensional imaging have aided diagnosis and management in foot and ankle surgery. The challenge faced by surgeons is to ensure that radiology colleagues are adept in understanding the patho-anatomy of disease so relevant diagnostic information is delivered to optimally manage patients.

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Subtalar Dislocations

Definition

It was first described by Judet and Dufaurest in 1811. It is an unusual injury and is not a dislocation of the subtalar joint! It is instead dislocation of the talus from the navicular and calcaneus with preservation of the calcaneocuboid and tibiotalar joints and without fracture of the talar neck. Common synonyms are talo-naviculo-calcaneal dislocation, peritalar dislocation, subastragalar dislocation and talo-tarsal dislocation.

Fig. 2. Antero-posterior radiograph showing no lateral or medi
foot and confirming the diagnosis of pure posterior subtalar dis

Classification

Broca (1853) classified dislocations into:

- Medial
- Lateral
- Posterior

Malgaigne & Beurger (1856) added anterior although Inokuchi (1997) questioned the existence of anterior dislocations.

Medial subtalar dislocations are believed to represent about 65-85% of cases, lateral 15-35% and posterior 0.8-2.5%. 22.5% are open dislocations, with 19.3% of medial dislocations and 31.7% of lateral dislocations being open.

Demographics

Subtalar dislocations, infrequent, making up 1% of all foot trauma. 76% involve males and 61% involved the right foot. The average age patients is 33.8 years.

Mechanism

Hoexum & Heetveld found in their meta-analysis that a road traffic accident was the most common cause of injury, occurring in 43.7% of cases. Falls from height (32.9%) and sporting activities (13.9%) accounted for the majority of the remaining cases.

Sporting Injuries usually low energy injuries, and is common in basket ball players. Inversion forces applied to a plantar- flexed foot produce closed medial dislocation.

The dislocations occur in stages as described below:

The stages of a lateral dislocation

1. Rupture of the dorsal talonavicular ligament with external rotation of the talus and talonavicular joint dislocation;
2. Widening of the sinus tarsi, with tensing and tearing of the external portion of the interosseous talocalcaneal ligament and consequent dislocation of the anterior talocalcaneal joint;
3. Rupture of the remaining portion of the interosseous ligament with dislocation of the posterior talocalcaneal joint.

The stages of a medial dislocation

1. Rupture of the dorsal talonavicular ligament with external rotation of the talus and talonavicular joint dislocation;
2. Widening of the sinus tarsi, with tensing and tearing of the external portion of the interosseous talocalcaneal ligament and consequent dislocation of the anterior talocalcaneal joint;
3. Rupture of the remaining portion of the interosseous ligament with dislocation of the posterior talocalcaneal joint.

Presentation

Clinical deformity is usually obvious in medial and lateral dislocations. In medial dislocations there is the appearance of an acquired club-foot. The heel is translated medially, the foot is inverted and plantar-flexed and skin is tented over lateral malleolus and talar head. In lateral dislocations there is the appearance of an acquired flat-foot. The heel is translated laterally, the foot everted and abducted and the talus is seen medially distorting the skin

In posterior & anterior dislocations, the lack of a coronal deformity makes them less obvious.

The foot should be examined for skin under threat, open wounds and neurovascular deficits.

Imaging

Plain films will show the deformity. CT should be performed post-reduction. Bibbo et al's (2001) series of 9 cases showed 100% had CT detected bony injuries not appreciated on plain films. The majority had intra-articular fractures of peri-talar joints (32% talar, 9.8% calcaneal & 9.1% navicular, 18.3% "avulsion fractures", 15.9% malleolar, 10.4% metatarsal).

With open fractures additional soft tissue injuries are prevalent. Goldner's series of grade III open injuries found 66% had injury to tibial nerve, 33% had laceration of posterior tibial artery, and 33% had rupture of tibialis posterior tendon.

Treatment

Aim for closed Reduction with prompt reduction under sedation or GA

- Exaggerate deformity, apply traction and reduce deformity
- Flex knee to 90 degrees
- Apply pressure on talus

- Immobilise in below knee cast. Literature suggests 4-5weeks is the optimum time for immobilization to reduce risks of instability or stiffness

Excessive force or repeated attempts should be avoided. Failure of closed reduction has been reported in 10-30% cases (60% medial and 30% lateral), mainly due to interposition of soft tissue. In these cases, open reduction will be necessary. Surgery is necessary in open cases, the approach depends on the direction of dislocation and usually involves incision over the dislocated talar head.

Outcomes

Outcomes are variable due to mixed series of case reports. Many cases report stiffness of the subtalar joint post-injury due to scarring of the interosseous ligaments, however the stiffness may offer some protection against developing arthritis as few patients with closed injuries develop pain. In open injuries 33% developed avascular necrosis of the talus at 2 years. Hoexum and Heetveld (2014) attempted to summarise the overall outcomes in their meta-analysis. To be able to compare studies that used different outcome measures, they developed a 3-stage grading system of good, fair & poor:

							Lateral: 1× interposition
Merianos et al. [18]	–	–	–	–	–	–	"The most common obst dislocation, was buttonh extensor retinaculum, w obstacle was the flexor between the talus and tl
Case reports [19–76]	19	10	6	1	2	0	8× displaced posterior til retinaculum or talar hea 3× not specified/2× Ins 1× interposition extens interposition talonavicul
Totals	51	31	15	1	2	2	

Ant anterior, *Lat* lateral, *Med* medial, *N*. number of patients, *Pos* posterior, *U* unknown

Using this system, they found that overall outcomes in the literature were good in 52.3%, fair in 25.2% and poor in 22.5%. Analysed by direction and soft-tissue injury, the breakdown of the results was:

	Closed Medial	Closed Lateral	Open Medial	Open Lateral
Good	76.8%	65%	11.5%	0%
Fair	18.3%	15%	19.2%	18.2%
Poor	7.2%	20%	69.2%	81.8%

Summary

Subtalar dislocations are an unusual injury so much of the literature is based upon limited case series. Whilst most can be reduced closed and managed non-operatively, more significant injuries can present.

The outcome for low-energy dislocations, which are usually closed, medial and without associated fractures, are often excellent. However, the results for higher energy injuries, often associated with bony injuries are poorer. Unfortunately, the fate of patients who sustain open dislocations is rather bleak.

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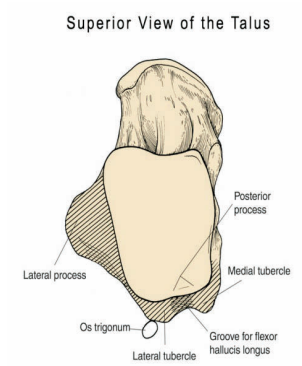
Talar Process Fractures

Talar process fractures can be divided into lateral and posterior process fractures, with lateral process fractures being more common.



Lateral process fractures

Incidence

Lateral process fractures make up 0.5-1% of all ankle injuries. They are particularly common in snow boarders where they account for 34% of ankle injuries.

Mechanism

The mechanism is unclear, they are often high energy injuries and 15-25% are associated with other foot and ankle injuries. They result from forced dorsiflexion plus either external rotation or eversion. The avulsion may be due to the pull of the lateral talocalcaneal ligament.

Presentation

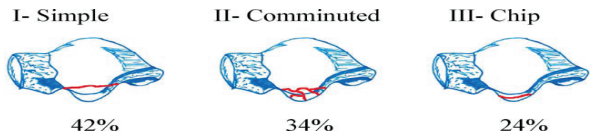
These injuries are often missed with 46-59% missed on initial presentation. Clinically they mimic ankle sprains, with tenderness 1cm distal to tip of fibula and the presence of a subtalar effusion. The Ottowa ankle rules were not designed for and may not pick up on these injuries and therefore if any index of suspicion is present, the patient should have imaging.

Imaging

These injuries may be visible on plain films on a Broden or lateral views, although they can be hard to see. A CT scan is the imaging modality of choice to define the injury. MRI may also be used to show the injury and surrounding oedema. Ultrasound is rarely used.

Classification

The most widely used is the Hawkin's classification, where there are 3 subtypes.



Management

In type 1 fractures, there is often significant chondral damage. Overall they do better with ORIF, 88% mild or no symptoms compared with 62% in non-operatively managed cases. Where there is significant displacement and an adequate sized fragment open reduction and internal fixation, with screw fixation, is the recognised preferred treatment. The management of undisplaced type 1 fractures is more controversial. There are no published randomised controlled trials for ORIF versus non-operative treatment for this subgroup. Early range of movement is an advantage of fixation.

Type 2 fractures, are by definition not reconstructable and can be managed non-operatively or with excision of the fragments. With excision most patients do well, with few needing salvage surgery. There have been reports of arthroscopic excision but this can be technically challenging. With non-operatively treated cases there is no evidence that immobilization in a cast or a boot is better than no treatment and 30-50% need salvage surgery at a later date. Patients do better with an early excision rather than delayed salvage surgery. One cadaveric study assessed the affect on stability of excising the lateral process fracture. Excision of 1cm fragment removes 97% LTCL footprint and 10-15% ATFL and PTFL however there are no published reports of symptomatic STJ instability following excision.

Type 3 fractures are generally managed non-operatively either with immobilization in a cast or boot. There is no difference in pain long term between those who have no immobilization and those who are immobilized however there is less need for salvage surgery in the long-term and the surgery required in less severe in those that had a period of post injury.

Outcomes

All types who have delayed presentation have a poorer outcome with 45% having ongoing pain. Although those who heal without problems will not present.

There is limited published data on the outcomes of lateral process fractures. The most significant paper is a meta-analysis by Perera et al., and that could only identify outcomes in 109 patients, combining all published series. Lateral process fractures are often not benign injuries, with 25-50% suffering from ongoing pain, stiffness and development of subtalar arthritis. Non-union is a problem in non-operatively treated cases.

Posterior Process Fractures

Anatomy

The posterior process is formed from medial and lateral tubercles divided by the FHL groove. The medial tubercle has the posterior deltoid attachment, the lateral has the posterior PTFL and TCL attachments. Both tubercles form part of roof of subtalar joint.

Incidence

Isolated whole posterior process fracture rare, they are more often part of more complex injury.

Mechanism

Caused by direct by forced plantar flexion of the foot. Can also occur Indirectly where the PTFL avulses the posterior process in hyper-dorsiflexion and inversion.

Imaging

Plain film lateral views may show. CT is imaging of choice to best show the injury.

Differential diagnosis

Os trigonum, can mimic posterior process fracture, particularly where trauma disrupts the pseudoarthrosis. MRI may help differentiate, with oedema being present in acute trauma, although this may also be present where the pseudoarthrosis has been disturbed.

Management

In true fractures if displaced then ORIF through a postero-medial approach, is the preferred treatment. If the fragment is too small, it can be excised. If undisplaced they can be managed conservatively. For a symptomatic os trigonum, it may settle with conservative management. If it continues to be symptomatic, excision(open or arthroscopic) can be performed.

Outcomes

Only 2 case series exist containing 2 patients each. All 4 did well after ORIF.

Summary

These injuries are often not benign with long-term pain not infrequent. Small and undisplaced fractures are managed conservatively. Large and fixable fractures should be fixed. Comminuted fractures should be primarily excised. Delayed treatment yields poor outcomes.

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Subtalar joint instability

Subtalar joint instability (STJI) is abnormal, excessive motion occurring between the talus and calcaneus. It is estimated that 20% of inversion ankle injuries result in chronic ankle instability (Freeman 1965) and up to a quarter of these have STJI (Brantigan et al. 1977). It is much rarer to occur in isolation.

Pathoanatomy

The ITCL, CFL, cervical ligament and ankle retinaculum are all important restraints to subtalar joint motion but it the first two which are primarily implicated in STJI. The majority of the literature supports the ITCL as the primary stabiliser of the STJ. Cadaveric studies show talocalcaneal joint motion increasing by 43% after ITCL sectioning (Kjaersgaard-Andersen et al. 1988), and if one sequentially divides the ATFL, CFL and ITCL, the greatest increase in subtalar joint motion occurs only after ITCL sectioning (Choisne et al. 2012). Tochigi et al. (2000) has highlighted that the additional role of the ITCL on ankle stability when they measured the joint motion of cadaveric specimens subjected to simulated load bearing conditions with an axial cyclic load before and after ligament sectioning. They found the ankle and the subtalar joints rotated consistently with increasing load before sectioning, did not significantly change after ATFL sectioning alone but the addition of ITCL sectioning significantly increased adduction and total rotation of the ankle joint.

However historically, injury to the CFL was believed to be the prime initiator of STJI after Leonard (1949) found sectioning of the CFL led to aphysiologic increases in subtalar motion. This has been corroborated by others (Weindel et al. 2010) and the most recent publication once again highlights the importance of the CFL over the ITCL. Pellegrini et al. (2016) found that regardless of the subsequent ligament-sectioning order, significant subtalar motion increases occurred only after transection of the CFL and that sectioning of this ligament produced increased inversion and external rotation, which was most evident with the foot dorsiflexed.

Clinical Assessment

Patients present with a feeling of unsteadiness while walking with persistent lateral ankle or hind foot pain. Symptoms will be worse on uneven ground and athletic activity levels may be compromised. Differentiating STJI from lateral ligament instability is difficult since they both can occur from an ankle inversion injury mechanism. Occasionally the history will instead include prior dislocation of the subtalar joint as the precipitating event although the symptoms will remain the same.

Clinical examination may identify tenderness in the sinus tarsi. A varus tilt test and anterior drawer test is warranted to assess for co-existing injury to the CFL and ATFL while Thermann's test (described in Clinical Assessment) is specific for identifying subtalar joint instability.

Investigation

Plain radiographs of the subtalar joint should be taken in the first instance with stress views to highlight pathology. The literature reports 3 means by which to obtain views:

- Stress applied: Hindfoot inversion
- View: AP radiographs of the ankle
- Positive: >3mm of opening of the lateral talocalcaneal joint

- Stress applied: Hindfoot inversion
- View: Broden's view
- Positive: >5mm separation or difference of 3 degrees (Heilman et al. 1990)

- Stress applied: Axial traction to foot
- View: AP radiograph centred on TNJ
- Positive: >4mm displacement of the perpendicular distance between two cross points on the axis of the foot from the heads of the talus and the calcaneus (Kato, 1995)

Ultrasound has been described by Waldecker and Blatter (2001) for assessment by calculating the fibulo-trochlear angle. This is measured between the longitudinal axis of the fibula and the short, peroneal side of the trochlea peronealis in both neutral and inverted positions to give a ratio. In controls and patients with STJI, a sonographic ratio of $q>1.6$ correlated with a radiologically unstable subtalar joint while a ratio of $q<1.2$ correlated with a stable subtalar joint.

Advances in MRI have allowed better visualisation of the ligamentous anatomy. Tochigi et al. (1998) showed that ITCL rupture seen on MRI after ankle inversion injuries correlated with persistent hind foot pain and instability. The round table consensus is that radiologists should now be specifically asked to look for and comment on this ligament since it may form part of a spectrum of instability which may not be resolved with lateral ligament stabilisation.

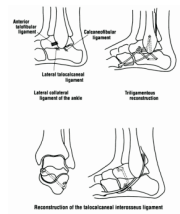
Direct visualisation with subtalar arthroscopy has identified ligament injuries in patients where clinical assessment and imaging were inconclusive (Frey et al. 1999) although advances in the quality of MRI since this was published may have obviated the need for this to happen now.

Treatment

Non-operative treatment includes:

- Physiotherapy to strengthen the dynamic stabilisers
- Achilles stretching to improve foot positioning
- Semi-rigid braces to control excessive motion (Choisne et al. 2013)
- Medial arch supports to reduce the abnormal ankle internal rotation occurring with ATFL and ITCL disruption (Tochigi 2003)

Surgery is indicated when conservative treatment has failed although the optimal timing of surgery is unknown. Various stabilisation techniques have been described. Karlsson et al. (1998) undertook imbrication of the cervical, the lateral talo-calcaneal and the calcaneo-fibular ligaments and reinforcement with the lateral root of the inferior extensor retinaculum. They showed that after 2 years, 18 of 22 (82%) patients were good or excellent, and fair or poor in 4 of 22 (18%). Kato (1995) described excellent results in all 14 patients operated using a modified Chrisman-Snook technique to reconstruct the ATFL, CFL, and lateral talocalcaneal ligament. This was coupled with reconstruction of the ITCL using Achilles tendon and synthetic graft (see below) which Kato felt was necessary to prevent the separation of the joint and to restrict anterior displacement of the calcaneus.



Most recently, Jung et al. (2015) reported excellent or good results in all patients using semitendinosus tendon allograft and interference screws to recreate the ITCL, CFL and cervical ligament. A summary of outcomes from different groups is shown below.

Study	Year	Reconstruction technique	Number of patients	Good/Excellent outcomes (%)
Larsen	1988	Pedicled peroneus brevis tendon	25	93
Kato	1995	Triligamentous and ITCL	12	92
Pisani	1996	ITCL anatomic	47	91
Thermann et al.	1997	Chrisman-Snook	34	90
Karlsson et al.	1998	Anatomic and IER reinforcement	22	82
Jung et al.	2015	ITCL, CFL and cervical ligament	20	100

Summary

Subtalar instability probably represents an under-reported group of patients since it presents in many cases with an ankle sprain. A high index of suspicion is therefore required to identify it since management symptom control may not be achieved if the subtalar joint is not stabilised in some way.

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Sinus Tarsi Syndrome

Sinus tarsi syndrome (STS) was first described in 1958 by Denis O'Connor at the 25th meeting of American Orthopaedic Academy as post-traumatic lateral hindfoot pain lasting for months or years despite physical therapy. It remains a controversial diagnosis and the incidence is thus unknown. There are in excess of 70 publications on this entity, but all but one is a case report or case series.

Clinical Assessment

The commonest presenting complaint is pain in the sinus tarsi region following an ankle sprain. On clinical examination, one would expect tenderness over the sinus tarsi classically relieved with a local anaesthetic injection. Varus stress at the ankle and hindfoot should exacerbate the symptoms in contrast to subfibular impingement which is worsened with valgus stress. The primary event of an ankle sprain may also give rise to concomitant ankle joint laxity. Plain radiographs will invariably be normal.

Pathogenesis

The pathogenesis is poorly understood and various theories have been proposed:

- Undue tension on the ligament of the tarsal sinus from a healing process (O'Connor 1958)

- Pinching of a synovial membrane herniation into the tarsal sinus (Brown 1960)

- Synovial hyperplasia, tears in the ligaments and bleeding in the tarsal sinus (Taillard et al. 1981)

- Post- traumatic fibrotic changes in the wall and surrounding tissue of the veins causing venous outflow disturbance and increased pressure (Schwarzenbach et al. 1997)

- Disorders of the nociceptive and mechanoreceptors in the synovium of the sinus tarsi (Akiyama et al. 1999)

Controversy

The main controversy appears to be in diagnosis; namely does STS exist or have we not fully understood the pathology? There has been an evolution in the literature whereby original descriptions were of an unexplained pain in the sinus tarsi but more recently, it appears that some patients labelled as suffering from STS do in fact have subtalar ligament injuries which have only been found on more modern diagnostic techniques such as MRI and arthroscopy.

O'Connor's original cohort included 45 patients with STS. Of these, 14 underwent resection of the fat pad and superficial ligamentous floor from the sinus tarsi of which the cervical ligament was a part of; complete pain relief was reported in nine cases and improvement in the remaining five.

Taillard et al. (1981) attempted to add two diagnostic criteria to STS which were arthrography of the subtalar joint showing specific abnormalities and abnormal EMG recordings of the peronei demonstrates abnormalities during walking. Mostly the abnormality was reduced activity of peroneus longus or brevis or both during walking but occasionally block contraction of both peronei during stance phase was observed. These criteria have not yet been adopted by other authors. Irrespective of this however, their treatment similarly included fat pad resection – specifically the 1-1.5 cm of tissue filling the lateral sinus. They likewise found one third of their cohort required surgical management with complete resolution or improvement in 90% of patients.

In 1999, Frey et al. asked if STS existed? They undertook a retrospective review of 14 patients labelled with STS who underwent subtalar arthroscopy. In all cases, the diagnosis changed to either:

- Ligament tear – 10

- Arthofibrosis – 2
- Arthropathy – 2

They suggested STS is therefore not a real entity and clinicians should instead make a specific diagnosis. Interestingly, their surgery which included fat pad resection led to 94% good and excellent results.

Similarly Lektrakul et al. (2001) reviewed the MR imaging of patients with STS before and after administration of intravenous gadolinium. In 18 of 37 patients, they found abnormalities which could explain symptoms:

- ITCL & CL tears – 11
- Isolated CL tear – 3
- Ganglia – 3
- PVNS – 1

The question now arises over which investigative modality is best when pain in the sinus tarsi occurs. Lee et al. (2008, 2008) compared the findings from MRI and subtalar arthroscopy in patients with STS noting that MRI could detect CL tears, alterations in the sinus tarsi fat and synovial thickening, but could not adequately detect ITCL tears. Arthroscopic diagnoses identified were:

- Partial ITCL tear – 29
- Synovitis – 18
- Partial CL tear – 11
- Arthrofibrosis – 8
- Soft-tissue impingement – 7

Outcomes were once again uniformly successful after arthroscopy with 48% of patients reporting an excellent result, 39% a good result, and 12% a fair result.

Summary

STS was first noted close to 60 years ago but no diagnostic criterion has been formally set. It remains a term overused in the literature to describe pain in the sinus tarsi. Advances in imaging and the use of arthroscopy have led many cases to be relabelled, often with a subtalar ligament tear. It is accepted through the literature that some cases will respond to non-operative treatment but a proportion will require surgery. To that end, surgery involves open or arthroscopic synovectomy of the sinus tarsi and removal any other diseased tissue. The removal of nociceptive receptors in this tissue is probably the mechanism by which such favourable outcomes occur but the long-term consequences of failing to deal with pathologies such as ligament tears in unknown.

Consensus: Who believes Sinus Tarsi Syndrome exists?

Yes – 2

No – 15

Don’t know – 7

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Tarsal Coalitions

Overview

Tarsal coalitions are congenital, abnormal bridging between 2 or more tarsal bones, usually talocalcaneal or calcaneonavicular. There are 3 types:

- Fibrous (synfibrosis or syndesmosis)
- Cartilaginous (synchondrosis)
- Bony (synostosis)

They may occur in isolation or may be associated with carpal coalition; symphalangism; phocomelia; hemimelia; Nievergelt syndrome.

They have been well reported in anatomical literature, with the earliest reports dating back to 1769 and the 2 commonest causes of rigid valgus feet:

- Calcaneo-navicular bar reported by Sloman in 1921
- Talo-calcaneal bridge reported by Harris & Beath in 1948

There is no associated spasm of peroneal muscles instead adaptive shortening occurs. Lipping of TNJ may suggest diagnosis.

Incidence

Approximately 1% of population will have a coalition; calcaneo-navicular 53%; talo-calcaneal 37%, others 10%. They are bilateral 50-60%.

Inheritance

The inheritance pattern is autosomal dominant with variable penetrance. A clinical and radiographic study of families of 31 patients with coalitions (27 CN, 4 TC) found 39% (of 98) 1st degree relatives had some type of coalition but all were asymptomatic.

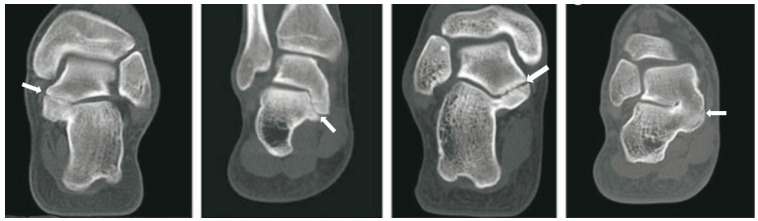
Classification

Coalitions can be classified according to site; talonavicular and subtalar. Subtalar coalitions are then further subdivided depending on the facets involved, as shown below

Type of coalition	# of coalitions (%)	# of osseous coalitions (%)
Middle facet	97 (70.2)	33 (34)
Posterior facet	2 (1.4)	0 (0)
Posteromedial subtalar	39 (28.2)	0 (0)
Total	138 (100)	33 (23.9)

Alternatively, they may be classified according to shape, as shown below

Type		No. of feet (percentage)
I	Linear with or without posterior hooking	45 (65 %)
II	Talar overgrowth	10 (14 %)
III	Calcaneal overgrowth	13 (19 %)
IV	Complete osseous	2 (3 %)



Aetiology

Normally joints are formed in cartilagenous condensations. Chondrogenesis is arrested and interzones are formed. The joint cavity formed by apoptosis. Surrounding cells develop into joint capsule. Coalitions are failure of embryonic mesenchymal differentiation and segmentation. They are probably present at birth. Symptoms appear as ossification starts and the hindfoot stiffens. Prior to this there is flexibility of the cartilage surrounding the primary ossification centres. In calcaneo-navicular coalitions ossification occurs between 8-14 years, with talo-calcaneal coalitions it is 12-18 years.

Presentation

- Hindfoot pain aggravated by activity
- Recurrent Ankle sprains
- Stiff sub-talar joint
- Medial or lateral tenderness
- Tight painful calf muscles “Peroneal spastic flatfoot

Imaging

Plain x-rays (AP, lateral and Harris views) are needed and may show the following:

- C sign on weightbearing lateral
- Talar beaking
- Wedging of talus on tip of fibula with hind foot valgus
- Calcaneal humpback sign

CT scans are best for assessing osseous coalitions and MRI for fibrous ones. CT and MRI can also assess relative size of coalition and for early degenerative changes of the joint.

Management of subtalar coalitions in children

A trial of non-operative management should be done initially, with immobilsation in a plaster or boot followed by an insole for at least 3-6 months. 30% will settle completely and avoid surgery.

Surgery is less predictable in subtalar than calcaneonavicular coalitions. A review of the literature concludes resection should be performed, and good results are achieved if the coalition is <50% surface area of the posterior facet joint. Resection can be performed open or arthroscopically. Arthroscopic resection has been described using posterior and sinus tarsi approaches, but only small numbers of patient in series. There was 12% tibial nerve injury rate and 25% had a poor outcome. Following resection interposition of soft tissue using fat or EDB is often performed.

Deformity also needs to be addressed if hindfoot valgus angle >16 degrees. This can be done at the same time as resection or in 2 stages. If there are larger coalitions, fixed deformity or degeneration then fusion should be considered; subtalar arthrodesis for subtalar arthritis and triple arthrodesis for fixed midfoot deformity.

The options for deformity correction surgery are:

- Lateral column lengthening - Mosca 2012 – best evidence for this procedure
- Lateral column lengthening with medial cuneiform osteotomy – small numbers
- Calcaneal sliding osteotomy – Dwyer – didn't specifically look at coalition patients
- Calcaneal medial closing wedge osteotomy - small case series only
- Temporary arthroereisis screw – limited evidence

Management of subtalar coalitions in adults

There is limited information on adult coalitions without any large, well-designed outcome studies. Therefore, recommendations are based on literature from adolescents. These include an initial trial of adequate non-operative treatment. This may be more effective in adults, compared to adolescents, as many are asymptomatic or only discovered after injury.

If non-operative treatment fails then surgery should be considered and be tailored to the patient depending on site, deformity and degree of arthrosis.

Calcaneo-navicular coalition resections typically involve an attempt at resection with some type of interposition. Indications for resection of subtalar coalitions are more limited in adults, as arthrosis will often be present. Resection can be attempted for small talocalcaneal coalitions that do not present with advanced arthrosis or significant hindfoot malalignment. For those patients with advanced arthrosis, more than 50% involvement of the joint or hindfoot malalignment, then subtalar or triple arthrodesis is recommended. The degree of deformity will determine whether in-situ fusion can be performed or whether corrective surgery is needed.

Outcomes

Outcomes with resection are more predictable in younger patients. Calcaneonavicular coalition resections do better than talo-calcaneal ones. Reasons for poor outcomes include:

- Incomplete resection
- Resection through incorrect plane
- Re-growth
- Too much deformity
- Missed secondary degeneration
- Deformity recurs before “corrective growth” - Possible role for temporary arthroereisis screw to prevent eversion at the level of the subtalar joint by impingement of the screw head in the lateral apophysis of the talus. There are no good studies to support this idea at present.

Experience and practice of the round table

There was consensus that calcaneo-navicular coalitions do well and resection should be attempted. Talo-calcaneal comprise of a heterogenus group of pathologies and tend to do less well, with ongoing symptoms following resection. Resection is still attempted, where appropriate, if no pre-existing arthrosis, significant deformity and< 50% surface area of coalition, but patients are counseled regarding less predictable results.

83% of surgeons routinely use interposition graft, the remainder do not.

17% of surgeons routinely do deformity correction at the time of resection, 17% did not do this initially and the remainder had no fixed practice regarding deformity correction.

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Subtalar arthrodesis

Indications and Contraindications

Subtalar arthrodesis is indicated for the following pathologies:

- Arthropathy
- Talocalcaneal coalition
- Deformity correction
- Failed ankle replacement

Absolute contraindications include:

- Active infection
- Vascular insufficiency

Caution should be undertaken in the following scenarios:

- Revision or previous local surgery
- Fused ankle
- Talar AVN
- Smoking
- Steroid therapy
- Diabetes
- Adjacent joint arthritis
- Obesity

Approaches

Three approaches are available to fuse the subtalar joint:

- Open lateral
- Open medial
- Arthroscopic

Open approaches are particularly useful in the following scenarios:

- Severe hindfoot deformity including previous calcaneal malunion
- Bone loss needed bone grafting
- Prior non-union needing careful joint preparation and bone grafting

Arthroscopy is indicated when there is mild correctible deformity. Advantages offered over the open approach are:

- Smaller incisions with less wound complications
- Theoretical preservation of the soft tissue envelope and therefore blood supply to the bone

Lateral approach: Direct and indirect lateral approaches exist. The longitudinal direct approach extends from the tip of the lateral malleolus to the base of the 4th metatarsal joint whereas Ollier's direct incision extends to

the talonavicular joint. This latter approach is less commonly used since it places the superficial peroneal nerve at risk. After incising through the skin and fat, the EDB will be the first major structure encountered. This can be elevated or split in line with its fibres and the deep ligaments divided to gain access to the joint. In the indirect approach, an L-shaped incision extends from anterior to the Achilles tendon along the edge of the heel towards the calcaneocuboid joint. Importantly, the incision passes posterior to the sural nerve which along with the peroneal tendons is elevated with the flap.

Medial approach: This is an alternative approach that starts 1cm below the medial malleolus and runs parallel to the tibialis posterior tendon. The length is adjusted to allow the talonavicular joint to be fused if necessary. Anatomical dissections have shown it to be safe with >2 cm distance between the middle facet of the talocalcaneal articulation and the inferiorly located neurovascular bundle (Galli et al. 2014) and also giving a similar amount of joint exposure as the typical dual incision (Jeng et al. 2006). However, complications of this approach include avascular necrosis (Knupp et al. 2015), and FHL tethering (Saville et al. 2011). Anand et al. (2013) reported their experience of using a single incision medial approach for double arthrodesis of hindfoot in posterior tibialis tendon dysfunction. At 2 years, union rate was 89% but there were 2/18 malunions, and 2/18 feet developed valgus ankle deformity. The overall satisfaction rate among patients was 78%. It is important to stress that one factor found in unsatisfied patients was that corrected led to symptomatic subluxation of the calcaneo-cuboid joint malunion and valgus ankle deformity and is thus a mitigating factor in why this group abandoned its use.

Arthroscopic approach: Portals can be placed laterally, posteriorly or both (see picture below). In lateral arthroscopy, the patient is placed in the lateral position and portals used include:

- Anterolateral
- Posterolateral
- Accessory anterolateral
- Accessory posterolateral
- Central

Posterior arthroscopy is performed with the patient prone and utilises posteromedial and posterolateral portals either side of the Achilles tendon. Advantages include easier assessment of coronal plane hindfoot alignment and avoiding the artery of the sinus tarsi. Disadvantages include risk to peroneal tendons and postero-medial neurovascular bundle which lie close to the portals.

Rungprai et al. (2016) recently compared the results of arthroscopic and open surgery and found that while union and complication rates were similar, patients in the former group had a quicker return to functional activity.

Whichever technique is used, correcting heel position is vital. Jastifer et al. (2013) found computer generated models that plantarflexion strength was maximized in 10 degrees of subtalar valgus when the ankle joint was

in neutral sagittal alignment and dorsiflexion strength was maximised in 5 degrees of valgus suggesting heel valgus between these two values has a biomechanical advantage.

Expected AOFAS scores after fusion range from 70-89 but it is important to recognise that high PROMs do not always equate with happy patients. Pre-operative deformity reduces patient satisfaction (Tuijthof et al. 2010) and two thirds of patients are still dissatisfied post-operatively with pain, instability or functional limitations; nonetheless three quarters would have an arthrodesis again (Chahal et al. 2006). Factors significantly associated with poorer outcomes are non-union, diabetes, secondary arthritis, and worker's compensation.

Smoking has consistently been associated with non-union and therefore must be stopped to facilitate union, while union rates are consistently higher in studies where bone graft is used so should be considered more regularly than it perhaps is now.

Summary

Subtalar fusion is a reliable operation for addressing pain and deformity of the hindfoot. Different options are available to access to the joint but the surgeon should choose the one with the lowest morbidity that still allows the hindfoot to be corrected to a functional position.

Opinion/ Experience/ Consensus:

Would you refuse to perform a primary arthrodesis in smokers?

Yes – 3

No – 21

Would you refuse to perform a revision arthrodesis for non-union in smokers?

Yes – 4

No – 8

Don't know – 12

Who performs the medial approach for subtalar arthrodesis?

Yes – 2

No – 22

Who has performed arthroscopic subtalar fusion in the last 12 months?

Yes – 7

No – 23

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Double or Triple Fusion?

The gold standard for the treatment of conditions such as Stage III tibialis posterior tendon dysfunction or residual clubfoot deformity has been a triple arthrodesis. It is a powerful deformity correction tool but an increasing body of literature questions whether a more limited double fusion will suffice.

What is a Double Fusion?

Current definitions of double fusion include the fusion of the talonavicular (TN) and calcaneocuboid (CC) joints (Mann and Beaman, 1999), or TN and subtalar (ST) joints through either a dual (Sammarco et al. 2006), or single medial incision (Brilhault, 2009).

Why consider a Double Fusion?

Biomechanics

Martin O'Malley and colleagues (1995) undertook a radiographic examination of selective fusion of the triple complex in cadaveric specimens. They recreated a severe flatfoot deformity with TN sag, hindfoot valgus, and forefoot abduction deformity with sequential soft tissue ligament releases before then recreating five different fusion scenarios: ST, CC, TN, double, and triple. They found that the most powerful joint for correction of the planovalgus foot was the TN joint and that the CC joint arthrodesis was not necessary for full correction.

Using an ultrasonic motion analysis system, Wülker et al. (2000) compared the impact of these combinations of fusion on motion at the other triple complex joints. Motion at the ST joint was not affected by CC joint fusion, reduced to one quarter by combined TN and CC joint fusion and eliminated with all other combinations. Motion at the TN joint was not affected by CC joint fusion and reduced to one third with ST joint fusion. Motion at the CC was not reduced by ST fusion but near eliminated in all fusions involving the TN joint. This complements O'Malley et al.'s work that the TN joint is the key articulation and the CC joint has no significant influence on remaining hindfoot motion.

Laboratory work therefore suggests that deformity correction is not aided by CC joint fusion. Avoiding the CC joint also helps maintain the length of the lateral column so is especially useful in the planovalgus foot, and avoids potential morbidity surgery could produce.

Cost

A double fusion has short term economical advantages. Galli et al. (2014) retrospectively analysed 47 cases which had undergone either a double (TN and ST joints) or triple arthrodesis ensuring the groups were similar for demographics and comorbidities. They estimated the following significant differences occurred in mean ± SD (range):

	Operating room time (mins)	Procedure time (mins)	Hardware costs ($)
Double	106 ± 31 (73-201)	84 ± 29 (44-163)	1197.59 ± 635.57 (463.20-2019.00)
Triple	127 ± 23 (91-200)	104 ± 23 (50-169)	2932.75 ± 736.60 (1434.00 - 3980.00)

Outcomes – Positive Reports

When undertaking a more limited procedure, the surgeon should question if the same outcomes can be achieved for deformity correction, function and whether it has any additional long-term benefits.

Few reports directly compare outcomes from double and triple fusion. DeVries and Scharer (2015) recently published the radiographic outcomes from their group of 40 patients who had undergone either double (ST and TN joint) or triple fusion. The paper does not state how it was decided if a patient should undergo a double or triple fusion but nonetheless, they found both surgeries were equal in achieving correction for the following parameters:

- AP and lateral talocalcaneal angles
- AP and lateral talar–first metatarsal angles
- Calcaneal inclination
- Talar declination

Hyer et al. (2014) investigated the impact of hindfoot fusion on developing a valgus ankle. Patients in the triple fusion group were 3.64 times more likely to have an increase in the valgus angle at the ankle compared to the double fusion group. They theorised increasing the number of hindfoot joints fused created a stronger lever arm against the medial soft tissue structures causing them to stretch. Since the double fusion was performed through a single medial incision, they refuted the theory others have suggested that late valgus occurring after hindfoot double fusion occurs because the approach violates the deltoid ligament.

Collectively, studies on both surgeries report similar improvement in AOFAS hindfoot scores between 67-77 for double fusion, and 60-81 for triple fusion.

Outcomes – Negative Reports

Recent reports of double fusion have been less favourable than previous. Duke University (Anand et al. 2013) published their outcomes of the single incision medial approach double fusion in 18 feet at 24 months. At face value, outcomes appear good with 16/18 patients uniting, and improvements in radiological parameters and physical component of SF-12. However only 5/18 cases believed the appearance of the foot was better after surgery, 8/18 believed it was the same, and 5/18 believed it was worse. Moreover only 4/18 feet had no pain, 8/18 had mild occasional pain, 3/18 had moderate daily pain, and 3/18 had severe daily pain. The senior authors of this report no longer recommend medial incision double fusion for routine use in rigid deformity secondary to posterior tibialis tendon dysfunction in lieu of triple arthrodesis.

Burrus et al. (2016) compared the outcomes of double and triple fusion with more dramatic results. At 1-1.5 years after surgery, all 7 patients in their small cohort who had a triple fusion had united whereas 4/9 feet had not-united, 3/9 only partially united. This led to 5/9 patients losing correction and average outcome scores in the double fusion group being significantly lower.

Finally the hope that fusing less joints will reduce adjacent joint degeneration appears unfounded with midfoot and ankle arthritis developing in one third of patients at three years after double fusion (Sammarco et al. 2006).

Summary

Double arthrodesis has a sound theoretical advantage over triple fusion but there are conflicting clinical reports over its success. Some authors describe unacceptably high rates of dissatisfaction and problems with union that routine use is not supported.

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Distraction bone block arthrodesis

Calcaneal Malunion

The calcaneus is the most frequently injured tarsal bone accounting for 60-70% of tarsal fractures. It results from a high-energy axial load which classically decreases the height and increases the width of the bone. Controversy exists regarding optimal management with the recently published UK Heel Fracture trial (2014) suggesting equivalent outcomes between operative and non-operative management or displaced calcaneal fractures. Concerns have been raised though that there is insufficient follow-up to assess for the long-term consequences of calcaneal malunion.

Sequelae of calcaneal malunion

The resulting deformities dictate what the consequence of malunion:

Loss of height – the talus assumes a more vertical position leading the trapezoidal shaped talus to wedge in the mortise which results in decreased ankle dorsiflexion, anterior impingement of the talus on anterior tibial plafond and subsequent arthropathy.

Loss of height – shortens the lever arm of gastrocnemius-soleus complex which impairs the ability to heel rise during gait.

Heel widening – pain from subfibular impingement of the fibula on calcaneum.

Heel widening – displacement of the normal position of peroneal tendons leading to impingement and subsequent tendinopathy or subluxation/dislocation.

Varus/valgus heel – inability to either unlock or lock respectively the transverse tarsal joint during gait.

Ultimately malunion causes post-traumatic arthropathy which may require arthrodesis. In-situ fusion will improve arthritic pain but will not correct that other problems identified above and thus a corrective fusion with bone block distraction will be needed. It would be expected that this would improve:

- Heel height
- Talar declination
- Calcaneal pitch
- Medial longitudinal arch
- Varus/valgus malalignment

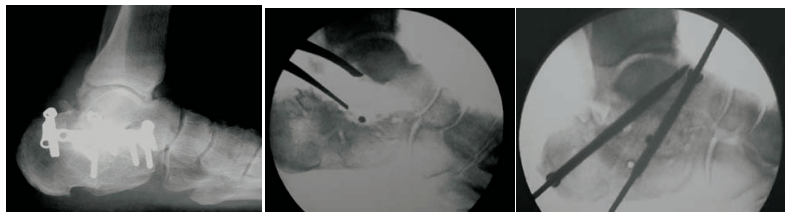
Technique

Distraction bone block arthrodesis is indicated after failed conservative treatment for the incongruent subtalar joint with either >8 mm loss of calcaneal height compared with the uninjured side (Myerson and Quill, 1993) or severe valgus deformity with lateral impingement (Marti et al. 1999). When this is not the case, in-situ fusion will likely achieve good and acceptable outcomes.

The approach is dependent upon the patient's soft tissues and previous scars, and the surgeon's preference. At the Round Table meeting, Myerson advocated using a longitudinal incision over the calcaneus (see below) to facilitate wound closure since transverse incisions may gap once calcaneal height is increased.

After superficial dissection, a widened lateral wall may need to be debrided and removed bone should be kept as graft material. The procedure then proceeds in a similar manner to subtalar fusion. A Hintermann distractor

or similar device helps expose the subtalar joint for joint preparation. Placing a laminar spreader into posterior joint will should restore the height and this should be checked under fluoroscopy to ensure satisfactory correction is achieved. The amount of bone required will then become evident and cortico-cancellous grafts such as iliac crest tricortical grafts or fresh-frozen femoral heads are best. Surgeon preference dictates if one or two bone blocks are inserted. Proponents of two blocks argue that it increases the graft material which could facilitate greater union and that varus/valgus malalignment can be corrected by using blocks of different heights. To avoid the grafts being easily ejected, a small trough can be burred into the host site for stability. Compression of the arthrodesis is then conferred with large fragment compression screw(s). One technical consideration highlighted by Michael Karski was overdistraction will excessively tension the posterior soft-tissues and sural nerve; maintaining passive dorsiflexion of the hallux is therefore a useful intra-operative guide to identify FHL tethering. Trnka et al. (2001) noted 7/41 cases developing post-operative sural nerve neuralgia. Below is a case example from Dr Myerson where the technique was employed after malunion following a calcaneal fracture and femoral head allograft was used to fill the gap. It can be seen that the talar declination has been restored thereby eliminating the anterior impingement:



Outcomes

As summary of outcomes from different authors is listed in the table below:

Author(s)	Year	Number of bone-blocks	Number of cases	Follow-up (months)	Union rate (%)	Talocalcaneal height correction (mm)
Carr et al.	1988	Single	13	22	94	6
Myerson & Quill	1993	Single	14	32	100	7
Chen et al.	1998	Single	32	71	91	11
Marti et al.	1999	Double	23	108	96	6
Trnka et al.	2001	Single	37	70	86	5
Rammelt et al.	2004	Double	31	33	100	5
Clare et al.	2005	Single	40	64	93	2.7
Garras et al.	2008	Single	21	36	91	-
Pollard & Schuberth	2008	Single	22	27	96	-
Lee & Tallerico	2010	Single	15	21	93	-
Chung et al.	2014	Double	10	58	100	5.6

The results show that union rates are high whether a single or double bone block is used. Furthermore while not detailed above, all studies that published outcome scores showed improvements in AOFAS ankle-hindfoot scores from 21-47 to 68-84.

Cautions

Although arthrodesis is not contraindicated in smokers and talar osteonecrosis, Clare et al. (2005) and Trnka et al. (2001) noted the only patients not to unite in their groups were those with these two underlying conditions respectively.

Summary

The literature supports distraction bone block arthrodesis for treatment of the calcaneal malunion with subtalar arthropathy. Union rates are high and the technique works well if there is loss of calcaneal height and anterior impingement.

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Non-union and malunion after subtalar joint arthrodesis

Non-union

Frequency

Easley, 2000, found 30 of 148 (20%) subtalar fusions resulted in non-union.

Diagnosis

Clinically – symptoms of non-union arepain and motion at the operated joint on physical examination. Fluoroscopically guided injection of 3–5 mL of 0.5% bupivacaine into the operated joint relieved the patients' pain and help with diagnosis.

Radiographically – plain x-rays have a low sensitivity with only 7 of 13 non-unions detected with radiographs. CT scanning is more sensitive and can quantify the extent of union, with 33-66% union arbitrarily taken as 'partial' union. Stable unions were found to have 33-100% bony union on CT.

Management options

- Surgeon factors – there is insufficient evidence to conclude that lack of surgeon experience is a risk factor for the development of a non-union
- Biological factors – smoking, diabetes, Vitamin D, NSAIDS, bone graft - allograft/autograft/free flaps, BMPs
- Mechanics - screw size and number, configuration
- Adjuncts – Low energy pulsed ultrasound, electrical stimulation

Smoking – non union rates 18.6- 31.6% in smokers, compared to 7.1-10.2% in non-smokers. If patients stop smoking prior to surgery their non-union rate reduces to 11.15. Therefore, it may be justifiable to withhold surgery for smokers.

Diabetes – Good diabetic control is important to reduce risk of infection and poor diabetic control has a direct affect on the biology of union. In addition, even a subtle neuropathy can reduce union rates, although neuropathy cannot be alleviated, knowing of it's presence can help you advise patients as to their risks of non-union.

Vitamin D – Up to 1/3 of the population are vitamin D deficient. Vitamin D levels are not an accurate reflection of a patient's calcium homeostasis and parathyroid hormone levels are a more useful test of this. Deficiency of vitamin D can increase non-union rates in tibial fractures but there is no evidence that it effect union in elective foot and ankle surgery at present. Risks of prescribing vitamin D are low and it is cheap and therefore it should be considered.

NSAIDS - Strong animal evidence suggesting even 1 dose can decrease rates of union but conflicting clinical evidence in humans and there are no foot and ankle studies. If other analgesics are available and effective, it may be best to avoid NSAID use.

Bone graft – Options include auto graft from sites such as iliac crest, tibia, free vascularised graft or use of a reamer irrigator aspirator (RIA). Bovine xenograft should be avoided due to inflammatory reaction. There are small case series reporting the use of trabecular metal or cages to aid non-unions. There is no definite correlation of union with use of bone graft in primary subtalar fusions although a meta-analysis favoured its use. In revision surgery for non-unions there is insufficient evidence to confirm the effectiveness of bone grafts

however our experience is that it is often used. Revision cases may often have areas of bone deficit, where necrotic tissue and fibrous tissue has been excised and bone graft can be useful if filling these voids.

BMPs -1 retrospective review supports its usage with 95% union rate in 41 patients.

Screw diameter - Increasing the screw diameter from 6.5 to 8.0 mm resulted in no additional stability of the arthrodesis in synthetic bone models.

One versus two screws -2 studies evaluated this. DeCarbo et al. (2001) found there was no significant difference observed in nonunion rate, postoperative complication incidence, or subsequent surgeries. Tuijthof et al., (2001) found using 2 screws was superior and placing them in divergent in a delta configuration gave the stiffest construct.

Ultrasound – Jones, 2006, used ultrasound on 10 subtalar nonunions post-revision surgery, there was only 1 further nonunion (10%). Coughlin, 2008, reported a 100% union rate when ultrasound is used after primary fusion surgery in 15 patients.

Electrical bone stimulators – for hind foot non-unions there is only conflicting or poor quality evidence

Outcomes –Non-union rates following revision surgery is 10-29%

Summary

- Non-union occurs in up to 20% of subtalar fusions and in smokers rates are up to 31.6%.
- There is good evidence modifying patient factors particularly smoking and diabetic control improves union rates. Revision surgery should be avoided until person has stopped smoking.
- There is fair evidence for the use of 2 screws rather than 1.
- There is a paucity of evidence regarding use of bone grafts and adjuncts but many surgeons find them helpful.

Malunion

Varus malunion

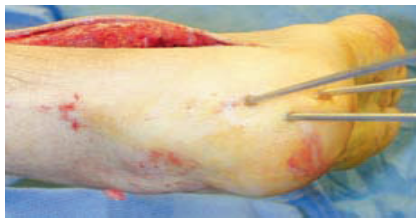
This develops from internal rotation of the subtalar joint. The distance from the base of the 5th metatarsal to the floor, will be increased in varus mal-union.

If you remove a wedge from the subtalar joint to correct varus it decreases the height of the hindfoot, and further increases the pressure on the 5th metatarsal. Correction requires rotation. This can only be done through the transverse tarsal joint. It is Mr Myerson's opinion that a varus malunion of a subtalar fusion can only be corrected with a triple arthrodesis.

Valgus mal-union

This is more common when performing subtalar fusion after calcaneal fractures as the hindfoot is deformed and more difficult to reduce.

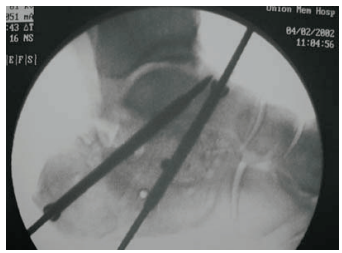

It may be useful to do a calcaneal osteotomy to correct the deformity or alternatively correction can be done through the arthrodesis. A vertical incision is useful to use for malunion correction, particularly when increasing talar height, to avoid wound healing problems. An osteotomy can then be performed and the arthrodesis should be freed, a laminar spreader inserted and the deformity corrected. Wires are useful to temporarily stabilise the foot. Bone graft can then be inserted and finally screws inserted.



Anterior impingement

Anterior impingement of the ankle is an under-appreciated type of mal-union. The patient may be in neutral alignment but still have symptoms, particularly in forward flexion. There is usually change in height of talus in relation to inferior floor of calcaneum resulting in anterior impingement of the talus on the tibia

This can successfully be corrected using a subtalar arthrodesis with a bone-block graft via a posterior incision.



Cages filled with morcellised bone graft can be a useful for correcting malunions and gaining height. When bone blocks or cages are used to increase height the Achilles tendon may require release.

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Functional foot orthoses

Orthoses are external devices that are designs to augment movement. They can either be functional in that the correct foot position or accommodative which would be prescribed in fixed deformity. Often a functional foot orthosis will be prescribed for flexible pes planus but the question arises of whether they are helpful since many patients discontinue them or find them uncomfortable.

Review of the literature is difficult since pes planus may be termed overpronation without defining what this means. Only three randomised trials have been identified for this condition but all are low quality.

Rome and Brown (2004) undertook a randomised study of 50 patients with 'clinically diagnosed excessively pronated feet' and studied their balance. They found over-the-counter rigid foot orthoses reduced medial-lateral sway and concluded thus may have improved postural control by stabilising the rear foot and controlling internal rotation of the tibia thereby reducing counter-rotatory motion at the knee and lower leg.

Esterman and Pilotto (2005) studied the effect of three-quarter-length, flexible, shoe inserts on military recruits with flexible flat feet. Interestingly only half of the orthotic group wore them most or all of the time and at the end of the 8 weeks, there was no difference in pain, injury, foot health, or quality of life.

Kulig et al. (2009) randomly assigned patients with stage 1 and 2 tibialis posterior tendon dysfunction to 1 of 3 groups to complete a 12-week program of: (1) orthoses and stretching; (2) orthoses , stretching, and concentric progressive resistive exercise; or (3) orthoses, stretching, and eccentric progressive resistive exercise. All groups improved but group 1 improved the least from which it may be inferred that orthoses have less of a role to play than good exercises.

In conclusion, there is at present only weak evidence advocating functional foot orthoses in the management of the flexible flat foot. It may be helpful for some patients although variations in foot posture and difficulty in knowing if they are properly fitted limits us from drawing firm conclusions.

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Arthroresis screws in children and adults

Definition

An operation to limit motion in a joint in cases of undue mobility.

Potential Indications

- Flexible flat feet in children and adults
- As an adjunct to treat tibialis posterior dysfunction, accessory naviculae, hallux valgus with valgus hindfoot

It may be used as an alternative to more extensive procedures such as fusions, osteotomies and tendon transfers and is reversible with screw removal.

Current NICE guidelines

- Current evidence on safety and efficacy is inadequate
- Therefore, this procedure should only be used with special arrangements for clinical governance, consent and audit or research
- Sinus tarsi implant insertion is not appropriate for most children with mobile flatfoot. The procedure may be used in selected children with persistent mobile flatfoot due to neuromuscular disorder, skeletal dysplasia or systemic ligamentous laxity, whose treatment is supervised by a multidisciplinary team. The procedure may be indicated rarely in highly selected adult patients.

How does it work?

It is a self-locking wedge that alters the axis of movement

- Calcaneus displaces medially
- Moves into varus
- Rotates medially
- NOT simple lateral opening

In many case the screw is removed after a period of time and some are bio-absorbable, however there is some evidence to suggest the altered hind-foot shape is maintained to some extent even after screw removal.

Evidence

<u>Flexible flat feet in children</u>

Its use is controversial. The underlying pathology is often poorly defined and patients may be being unnecessarily treated as there is very little evidence for nonsurgical intervention to affect the shape of the foot or to influence potential long-term disability. Koning, 2009 suggested it was a simple minimally invasive procedure with good outcome.

Gutierrez, 2005, assessed outcomes of 65 feet following arthroresis screw, with a mean age of 9. They found pain was reduced, the foot print was better and radiographic appearances were improved at 26 months, however many of the patients (up to 50%) did not have pre-operative pain and therefore the indication for surgery is questionable.

Brancheau, 2012, assessed 60 feet in patients following arthrosesis screw implantation, with a mean age 14.3yrs (5 to 46). Radiographic angles improved. Clinical results were assessed at 12-55 months, 23 were satisfied, 21 did the same or increased level of sport. There was 1 failure due to too big an implant

Pellegrin et al (2014) looked at 485 patients, 732 feet (1990 – 2012), aged – 11.5 (5-18) years, who underwent arthroresis screw treatment for painful flexible flat feet. 93.7% achieved excellent results clinically and radiologically. 6.35 experienced complications, including ankle joint effusion, painful contracture of peroneal muscles and fourth metatarsal bone stress fractures. 76 patients (121 feet) were evaluated after screw removal on average 2.9 years after implantation. There was no statistically significant loss of position.

Long-term outcomes are not known.

Flexible flat feet in adults

There is limited evidence to support their use. Needleman, 2006, assessed 128 adult feet treated with an arthroresis screw and found 78% were satisfied. However, the patients had a mixture of pathologies, including flexible flat feet, neurological conditions and tibialis posterior tendon dysfunction, and had a mixture of procedures preformed in conjunction with the screw insertion. 39% had the screw removed for sinus tarsi pain.

Tibialis posterior dysfunction

There is limited evidence and insufficient long-term studies. Viladot, 2003, studied patients - aged 55(20-76), who had repair of tibialis posterior +/- FDL transfer and a kalix arthroereisis screw. 19 patients were reviewed, 17 were satisfied.

Complications

- Implant removal in up to 40%
- Sinus Tarsi Pain, possibly linked to oversized implants
- Reaction to Implants
- Over correction
- Fracture
- AVN of talus

Opinions of the round table

- 9 of the 20 surgeons present have performed the procedure
- 8 of the 20 surgeons felt they could be useful in children with painful flexible flat feet
- There was consensus they should not be used in painless flat feet, as these do not require surgical intervention
- 1 surgeon felt they were beneficial for use in adults
- There was consensus that current evidence is poor and there are insufficient studies of long-term outcomes

Summary

- Arthroresis screws may be useful in the management of paediatric flat feet **only when they are painful**
- There is insufficient evidence to support their use in other pathologies and in adults
- There are high rates of implant removal
- They are a reasonable reversible alternative for a condition which otherwise would require highly invasive procedures

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