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The role of arthroereisis of the subtalar joint for flatfoot in children and adults

Alessio Bernasconi[1]
François Lintz[2]
Francesco Sadile[1]

- Subtalar arthroereisis has been reported as a minimally-invasive, effective and low-risk procedure in the treatment of flatfoot mainly in children but also in adults.
- It has been described as a standalone or adjunctive procedure, and is indicated in the treatment of flexible flatfoot, tibialis posterior tendon dysfunction, tarsal coalition and accessory navicular syndrome.
- Different devices for subtalar arthroereisis are currently used throughout the world associated with soft-tissue and bone procedures, depending on the surgeon rather than on standardised or validated protocols.
- Sinus tarsi pain is the most frequent complication, often requiring removal of the implant.
- To date, poor-quality evidence is available in the literature (Level IV and V), with only one comparative non-randomised study (Level II) not providing strong recommendations. Long-term outcome and complication rates (especially the onset of osteoarthritis) are still unclear.

Keywords: arthroereisis; subtalar joint; screw; flatfoot

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Introduction

Flatfoot (also called pes planus) is a complex multiplanar deformity that is a very common reason for referral in orthopaedic clinics, both in children and adults. As widely reported over the last decade, a clear definition of flatfoot is lacking and the limit between a physiological flatfoot (assumed as normal) and a pathological flatfoot (needing to be treated) is still uncertain.[1,2]

At present, no data are available to explain why a flexible flatfoot either remains asymptomatic or becomes painful, with the exception of those (few) cases of advanced deformity and subsequent gait dysfunction. Foot kinematics in symptomatic and asymptomatic flatfeet do not differ significantly, therefore pain may depend on tissue wear and subjective pain thresholds.[3] However, the current trend is towards treatment of the deformity when it is painful and limiting activity, to provide relief from symptoms by restoring foot balance and alignment.[1]

Another important basic distinction must be made between childhood and adult flatfoot. It is widely accepted that flatfoot is physiological in newborns, and related to the fat pad and to the laxity of musculoskeletal structures. A medial longitudinal arch may be seen at two years of age and is expected to further develop up to six to ten years of age, although in some children a flat shape may persist, being considered pathological if painful, as mentioned above.[2]

On the other hand, adult flatfoot is mainly secondary to the tibialis posterior tendon dysfunction (TPTD), causing the collapse of a pre-existing medial arch with a progressive stiffening of the deformity.[4] This leads to disabling pain, footwear problems and difficulty with walking. Moreover, rupture of the calcaneo-navicular plantar (otherwise known as 'spring') ligament may follow, due to its inability to compensate for the lack of active support (the tibialis posterior), thus worsening the deformity and symptoms.

With regard to different treatments proposed for flatfoot, primary randomised high-quality studies are lacking whilst a number of case series have been published.[5] Some authors have documented the inconsistency of conservative treatment. On the contrary, some surgical approaches have provided encouraging results. In particular, most recent studies have focused on the efficacy and safety of subtalar arthoereisis, a surgical alternative considered minimally invasive and safer than soft-tissue and bony procedures (osteotomies and arthrodeses). However, the results of the efforts of some authors in analysing the literature and defining the place of such procedures in the treatment of childhood and adult flatfoot[6-8] do not show a clear consensus.[5]

In this context, we performed a critical review of the scientific literature in order to define the role of arthroereisis in the treatment of flatfoot based on recent evidence, thus clarifying the current state of understanding and highlighting the areas where knowledge is still lacking.

Flatfoot

Flatfoot is a common deformity characterised by medial rotation and plantar flexion of the talus, eversion of the calcaneus, collapsed medial arch and abduction of the forefoot.[6] Most authors usually refer to the child or adolescent flatfoot and adult flatfoot as two different entities.

In children

A distinction must made between rigid and flexible forms. The former are mostly symptomatic and related to neurological or neuromuscular conditions, bone coalitions, rheumatoid or post-traumatic arthritis, or other underlying causes.[9,10] The latter are idiopathic and clinically characterised by the possibility of restoring a medial arch at physical examination when standing on tip toes or with the Jack's test (rise of the medial arch with great toe passive dorsiflexion).[11]

There is general consensus and evidence that within the first years of life a flat shape of the foot has to be considered physiological, often spontaneously correcting by the age of ten years.[12] Despite this, the abnormal foot shape can often become a reason for concern for parents and triggers subsequent medical referral.[13,14] Usually children are able to walk without symptoms, but sometimes they may complain of pain located over the medial aspect of the heel, the sinus tarsi, the distal fibula and the medial aspect of the midfoot.[11]

Classification

A footprint-based classification of flatfoot was proposed by Denis in 1974, dividing flatfeet into grade 1 (in which support of the lateral edge of the foot is half that of the metatarsal support), grade 2 (in which the support of the central zone and forefoot are equal) and grade 3 (in which the support in the central zone of the foot is greater than the width of the metatarsal support).[15] This method has often been used in epidemiological studies assessing the prevalence of the deformity in pre-school or school children, with results varying from 3% to 59%.[16-18] Other similar footprint-based methods were proposed in 1987 by Staheli et al[19], who described the Plantar Arch Index, and by Cavanagh et al[20] with the Arch Index. Over time, many flaws have been detected with footprint measurments, therefore they are not currently used in everyday practice.[7] On the contrary, weight-bearing radiographs have been deemed more adequate for detecting and quantifying flatfoot; they are requested as complementary to the clinical assessment for assessing flatfoot severity and in making decisions about treatment.[7] They are also used in post-operative assessment to verify alignment, even though their role and limitations in this context remain debated as well.[21,22]

In adults

Amongst adults pes planus is more frequent in African-American populations than in Caucasians (38% *versus* 16%),[23] and is more frequently related to tibialis posterior tendon dysfunction,[24] classified according to clinical and radiographic criteria by Johnson and Strom[25] (implemented by Myerson[26]). Causes may be divided into osseous (congenital or post-traumatic), articular (connective tissue disease, rheumatoid arthritis, degenerative primary midfoot and hindfoot arthritis), and neurological or neuromuscular disorders.[27,28] Generally in adults, flatfoot represents an acquired deformity remaining permanently. When symptomatic (it is unknown in what percentage of cases) it may cause pain in daily activities, difficulties in footwear fitting and chronic functional dysfunction associated with a lack of propulsive gait, generally getting worse in the absence of treatment.[22,28]

Treatment in children

At present, there is no definite agreement on the indications to treat flatfoot when painful and causing dysfunction.

Conservative treatment includes activity modifications, stretching, supportive footwear with medial arch supports, orthotics, mild analgesics or non-steroidal anti-inflammatory drugs. The first choice usually consists of prescribing insoles, which in some cases have been reported as a way to achieve relief from pain.[29] Their anti-pronation effect is reached through a medial navicular support together with a heel medial wedge, most frequently using pre-fabricated models as to date custom-made devices have not proven superior.[30] Other more sophisticated orthotics have also been introduced as options, but in children compliance may be an issue, thus their use is not widespread.[31-33] Corrective shoes are also a common prescription from physicians to tackle severe hindfoot deformities.[33] In cases of equinus deformity, Achilles stretching exercises may also be proposed.[33] All these solutions have been deeply criticised over the last 30 years. In fact, some studies on children have shown no difference between treated and untreated subjects, strengthening the hypothesis that the improvements documented in other studies were more likely the result of the physiological spontaneous development of the longitudinal arch rather than of medical treatments.[34,35] Additionally, even if some authors have documented beneficial effects of insoles[36] and foot exercises,[37] a few recent systematic

reviews have concluded that there is little evidence in favour of orthotics, bracing and stretching exercises for children[13] and of orthotics for adults.[38] Therefore, only in cases of severe non-operable forms of flatfoot should customised orthopaedic footwear be prescribed.[28] Notwithstanding this, a significant number of prescriptions and overprescriptions still exist in Western countries in current daily practice.[16]

Regardless of the kind of treatment, after the failure of conservative measures surgery should be considered. Surgical approaches to flatfoot in children consist of soft-tissue procedures, bony procedures (osteotomies or arthrodeses) or subtalar arthroereises, all being performed alone or combined and aiming to restore a well-balanced foot.

Among soft-tissue procedures, an operative release of the gastrocnemius complex or of the Achilles tendon (a gastrocnemius recession and a tendo-Achilles lengthening, respectively) is usually indicated in cases of contracture.[39-41] The flexor digitorum longus tendon transfer may help to restore tibialis posterior tendon function, while a spring ligament plication aims to reinforce the medial position of the talar head.[24,40] In more advanced forms, a peroneal tendon transfer is indicated rarely. Amongst bony procedures, the most common is the medialising calcaneal osteotomy (according to Myerson),[41] but the lateral column calcaneal lengthening osteotomy (Evans and reverse Dwyer osteotomies)[28] and the medial cuneiform opening-wedge osteotomy (Cotton procedure)[24,40] are widespread procedures as well. Obviously, in cases of accessory navicular bone a surgical excision is recommended.[24] Fusion procedures of the hindfoot and midfoot have a limited indication in children, as the preservation of joint movement during growth is one of the main goals.[33] Therefore, when arthrodesis is required, selective procedures should be always preferred.

Treatment in adults

In adults, flatfoot generally corresponds to stage II, III and IV TPTD. According to the literature, flexible flatfoot (stage II TPTD) is firstly approached using orthotics that have proven useful in some studies.[42,43] In cases of failure, a minimally-invasive tendoscopic synovectomy[44] with the possibility of reconstructing the calcaneo-navicular plantar ligament[45] has also been proposed, but its efficacy is still not validated. Thus, traditional surgery remains the most popular choice. The most effective way to restore tibialis posterior function relies on the augmentation with the flexor digitorum longus tendon, a procedure that has been shown to be effective but not sufficient to solve the condition.[46] Therefore, bony procedures are required, employing osteotomies of the calcaneus and medial cuneiform. Sometimes, a more stiffening subtalar or medial column arthrodesis may be indicated as well. Regarding rigid flatfoot (stage III TPTD), joint-sparing correction is not feasible. Thus fusion of subtalar, talonavicular and calcaneocuboid joints (alone or combined) are needed to relieve pain, but with the drawback of eliminating joint mobility and overloading the nearest articular compartments.[28]

Subtalar arthroereisis

Generalities

Derived from the fusion of the Greek roots arthro- (joint) and -ereisis (the action of sustaining, supporting, pushing against something), 'arthroereisis' is a surgical option in the treatment of flatfoot with the aim of re-establishing a medial foot arch and limiting the movement of the subtalar joint without blocking it.[47] The concept of 'manipulation' of the subtalar joint in approaching flatfoot was firstly reported in 1946 by Chambers,[48] who described the impaction of a wedge-shaped bone block into the anterior border of the posterior facet of the calcaneus (a so-called "abduction block") in order to limit the excessive anterior displacement of the talus upon the calcaneus and correct the deformity. Pursuing the same goal, some years later Baker and Hill[49] proposed a lateral opening-wedge osteotomy of the posterior joint surface, while Haraldsson firstly termed 'arthrohisis' the introduction of a wedge graft into the sinus tarsi.[50,51] It was only in 1970 that Lelièvre coined the word 'arthroereisis' to describe a similar procedure, that is to say, the insertion of a bone graft in the sinus tarsi fixed by a temporary staple.[52] Very soon the idea of placing an external synthetic implant in the sinus tarsi to support the talus on the calcaneus developed. Following the first device proposed in 1974 by Subotnick,[53] a number of solutions have been introduced, varying essentially in the shape (block, sphere, screw, cap, cylinder), material (silastic, polyethylene, titanium, a combination of these) and mechanism of action (absorbable poly-L-lactic acid, polylactic acid or polyglycolic acid).

The biomechanical classification currently used was introduced in 1987 by Vogler,[54] who classified three types of implants (Fig. 1):

1) axis-altering prostheses, made up of a stem (vertically fixed in the sinus tarsi floor just anteriorly to the posterior subtalar surface) and a superior head in contact with the lateral process of the talus, in order to modify the subtalar joint axis and to limit the internal rotation of the calcaneus;
2) impact-blocking devices, similar to the former, but with the head place slightly more anterior so as to impinge with the talar lateral process limiting its anterior gliding and, consequently, its internal rotation;
3) self-locking implants, inserted in the sinus tarsi along its main axis, supporting the talar neck and avoiding contact between the talar lateral process and the sinus tarsi floor, thus limiting the talar adduction and plantarflexion.

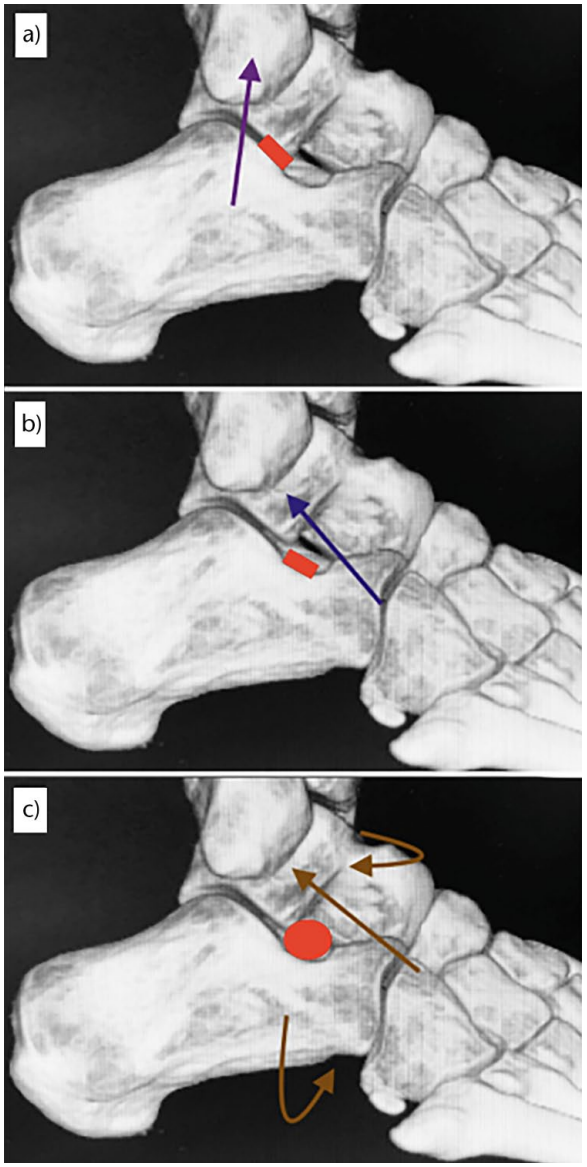

Fig. 1 The three types of subtalar implant (axis-altering in (a), impact-blocking in (b) and self-locking in (c)) are illustrated with their position in the joint (in red) and the main force generated between the talus and the calcaneus (violet, blue and brown arrows) (model by first author superimposed with a 3D CT-reconstruction).

Regardless of the type of implant, all are designed to limit the subtalar joint movement.

The current state of understanding

Subtalar arthroereisis may be performed as a standalone or as an associated procedure in treating painful congenital flexible flatfoot, while it is often used as ancillary in the treatment of tibialis posterior tendon dysfunction, tarsal coalition and accessory navicular bone syndrome.[55] Both in adolescents[56] and in adults,[41] one of the most widely-used procedures for treating tibialis posterior tendon dysfunction consists of flexor digitorum longus transfer and a medialising calcaneal osteotomy. In this context arthroereisis has been documented as performed either before the osteotomy (if the correction reached is satisfactory osteotomy may be avoided),[24,56] or after the osteotomy (to deal with the medial structures),[56] leading to satisfactory results in both cases.[24,56,57]

Technically, the surgical approach is commonly the same for all surgeons and is minimally-invasive, through a lateral 1 cm to 4 cm incision just anterior and inferior to the tip of the malleolus, parallel to the skin tension lines. After debridement of the sinus tarsi, the hindfoot is manually supinated and a correct position of the foot is restored. For self-locking implants, a blunt probe is used to find the tunnel direction and progressive trial implants are used to choose the proper size under fluoroscopy; then the permanent device is implanted (Figs. 2-3). For impact-blocking devices, a guide-wire in the calcaneus (anterograde technique) or in the talus (retrograde technique) is drilled and then the definitive screw is inserted (Fig. 2). Postoperative protocols vary depending on the surgeon. When performed as a standalone procedure, weight-bearing may be allowed immediately with[58,59] or without a cast[60] at five to ten days,[61] while it is delayed for six weeks when associated with other procedures.[24,56,57]

As shown in the literature, subtalar arthroereisis induces a triplanar modification of the foot limiting pronation through its three components, i.e. calcaneal eversion, talar adduction and plantar flexion.[62] The implant technique has been widely described, but there is a lack of understanding about the precise mechanism of re-alignment. Apart from an obvious mechanical effect, a hypothetical proprioceptive action of these prostheses (most of all impact-blocking) related to the density of receptors (mostly mechanoreptors) in and around the sinus tarsi has been long discussed.[63,64] Despite being attractive, this hypothesis has never been proved by any basic or clinical study.

Complications

Globally, complications may be divided into four main categories, including the consequences of inappropriate indications (unstable midtarsal joint, arthritis, rigid equinus), technical error (extrusion, over- or under-correction), adaptation/irritation (painful sinus tarsitis, peroneal spasm, soft-tissue entrapment), and biomaterial failure (wear or breakage) (Fig. 4).[64] Amongst these, the most common is undoubtedly sinus tarsi pain,[5,24,55] even though most authors have reported its complete resolution after implant removal.[8,65] The complication and the removal rates remain unclear. Indeed, in a recent literature review, complications are reported from 4.8% to 18.6%[4] and from 7.1% to 19.3%, respectively.[5]

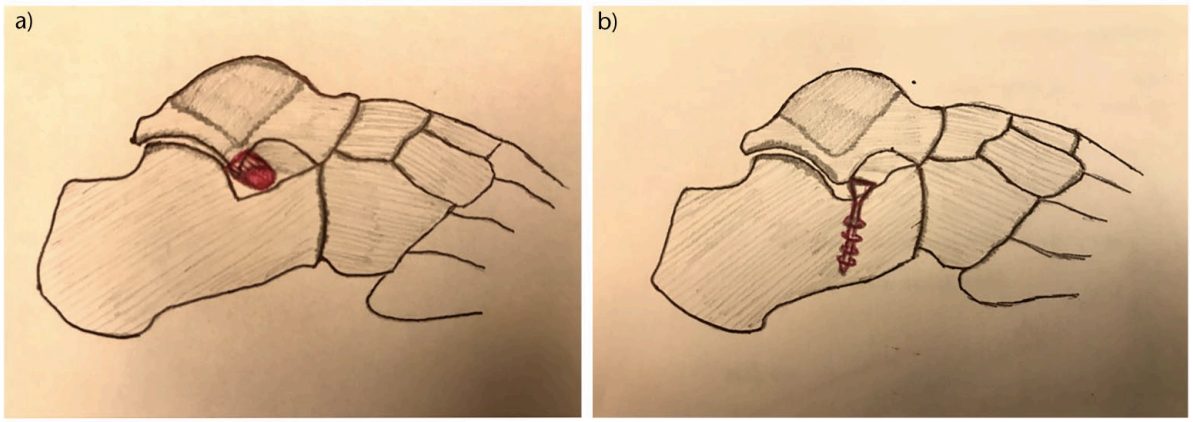

Fig. 2 The two drawings (lateral view of a hindfoot) show the difference in positioning between a self-locking (a) and an impact blocking (b) device (in red), corresponding to the implants most frequently used worldwide (model by first author).

Fig. 3 The two clinical images reproduce two important phases of the clinical examination. The young patient (12 years old) is complaining of pain in the right foot. Visually, during weight-bearing and from behind, a collapse of the medial arch and a valgus hindfoot can be seen (a). The correction of the valgus on the 'heel-rise' test (b) helps to demonstrate whether the deformity is flexible (as in the image) or not. In (c) and (d) the pre-operative and post-operative (three months) weight-bearing lateral view, respectively, shows where the improvement of the talometatarsal angle may be observed.

These figures are in contrast with the concept that not all complications require further surgery and may resolve spontaneously, as reported by most authors. Previous studies had also documented the need for implant removal in up to 40% of patients.[57] Thus, uncertainty in this field, together with the lack of long-term analyses, can only be addressed by future robust prospective studies.

In performing subtalar arthroereisis surgeons usually rely on personal experience or on suggestions in the literature rather than a structured scientific report. This is probably the main reason why nowadays the literature available on this topic looks so heterogeneous. A series of good results have been reported but it is extremely difficult to extract reliable data about the true role of a subtalar implant and its real contribution to final deformity correction.

In 2011 Metcalfe et al[5] also analysed extensively the available evidence regarding subtalar arthroereisis in treating flatfoot. Regardless of the type of implant, the authors found only *ad hoc* case reports and retrospective case

Fig. 4 A complication after subtalar arthroereisis. Weight-bearing radiographs in a patient complaining of pain at six months from the implant of a subtalar device, showing bilateral expulsion of the screw.

series. In terms of outcome, they underlined that few studies had applied validated clinical or patient-reported outcome measures and that only one study had utilised a disease- and child-specific patient-reported outcome method of analysis.[5] Also, they showed that despite a wide variation in radiological parameters used amongst different studies and their unclear relationship with clinical status, radiographic measures were often adopted as markers of success after surgery. The most used were calcaneal inclination and talar declination angles, but several other parameters have been reported to indicate arch height increase and the improvement in the hindfoot-midfoot axis.[5] Overall, Metcalfe et al[5] concluded that arthroereisis appeared capable of correcting flatfoot, but that it was still an evolving technique based more on clinical experience than evidence-based data. Obviously, they suggested the use in further studies of validated disease-specific patient outcome tools.

Our overview of the last five years

Our goal was to update the current state of understanding on subtalar arthroereisis in treating flatfoot. Therefore a review of the (English-language) evidence produced over the last five years has been undertaken.

The first important consideration is that high-quality studies are still lacking both in children and adults. The only prospective non-randomised comparative study (level of evidence II) was led in 2015 by Chong et al[59] on 24 feet treated by arthroereisis or lateral column lengthening (Evans osteotomy or calcaneocuboid fusion associated with gastrocnemius recession or peroneal tendon transfer). At about 12 months follow-up, the authors found satisfying subjective (through clinical scores) and objective results (radiographic mesures, kinematics and pedobarometry) together with a similar complication (15% *versus* 18%, respectively) and re-operation rate (15% *versus* 9%, respectively) in both methods. They concluded that subtalar arthroereisis may be considered a useful alternative, but the small sample size, the short-term follow-up and the conflict of interest declared by the authors certainly make further robust comparisons neccessary.

Apart from this, a few case series have been published. Some studies have reported excellent results in the treatment of paediatric[56,66,67] and adult[24,66–69] flatfoot with arthroereisis associated with other procedures, but, as also stated by Yen-Douangmala et al,[70] it is hard to gather reliable information mainly due to the potential confounding effect of additional procedures.

When considering arthroereisis alone, all authors reporting results on different cohorts (non-comparative studies) have concluded that this minimally-invasive procedure was an 'optimal' technique for the correction of flexible flatfoot in children[60,61] and in adults[71] providing clinical and radiological satisfying outomes. Of note, we found that in clinical assessment they still used non-validated scores (for children) and radiographic parameters not always related to the 'pathological' flatfoot and, additionally, often affected by some bias.[72]

What is more, some new rare but possible complications such as post-operative subtalar fusion and talar fracture have been documented in case reports.[73-75] However, in more recent studies the overall complication rate was considered negligable, standing between 0% and 11%.[60,71] By contrast, surprising data emerged from a web-based survey performed in 2015 documenting that out of the American Orthopaedic Foot and Ankle Society members that have performed subtalar arthroereisis over their carreer, one in three (33%) has decided to abandon the procedure, mainly because of the failure rate and the need for implant removal.[55] This suggests that the publication bias related to the tendency to publish positive results may actually be underestimated in studies dealing with subtalar arthroereisis. Additionally, this survey states that a greater percentage of non-US-based surgeons perform arthroereisis than their US counterparts; this is probably influenced by problems with payments by health insurance companies.

Concerning the device removal, older studies had suggested that an implant should be maintained in place for at least two years to allow adequate bone and soft-tissue adaptation.[52,53] In recent literature, when used as adjunctive procedure in adult flatfoot, delays of 18 to a minimum of six months have been reported in order to

Table 1. Benefits and drawbacks of subtalar arthroereisis reported in the current literature

Benefits	Drawbacks
Compared with open traditional surgery - lower invasiveness (mini-incision) - decreased post-operative oedema - shorter hospital stays - possibility of performing associated soft-tissue and bony procedures	Quality of studies available is poor Data uncertain regarding: - complication rate - implant removal rate - need (and timing) of removal in absence of symptoms - comparison between implants - long-term results

take advantage of the implant-related influence on the other surgical procedures.[24,57] In any event, no precise data are available about the minimum time required to mantain long-lasting correction. Furthermore, due to considerable unplanned explantation rates reported of up to 30% to 40%,[6,57] a few investigations have focused on possible predictive factors of implant removal in adults,[76,77] concluding that implant size (greater risk with greater implant)[77] and radiographic undercorrection of the deformity[76] are risk factors. Of note, in these studies arthroereisis was often performed as an adjunctive procedure with several types of implant;[76] what is more, looking back at the older literature, both the size and the radiographic parameters of correction do not seem to have always been related to a higher removal rate.[76,78] Therefore, a clear relationship between the explantation risk and any possible risk factor has still to be determined.

Conclusions and practice recommendations

In children

In 2017, subtatalar arthroereisis is still a debated procedure (Table 1). Different types of device (mostly self-locking and impact-blocking devices) are currently used worldwide for the treatment of flexible flatfoot as an isolated or complementary surgical procedure depending on the individual surgeon and their training. Sometimes in children it has been used even in rigid variants secondary to tarsal coalitions, being implanted after the resection of the synostosis. In many case series arthroereisis is reported as simple, effective and low-risk, but outcome assessment is heterogeneous and non-standardised. At present, according to the A, B, C, I system (where A represents good evidence, B fair evidence, C conflicting or poor-quality evidence and I insufficient evidence),[79] the subtalar arthroereisis procedure should be assigned a grade C recommendation, because of the poor-quality evidence (level IV or V studies) in studies available in the current literature. The only Level II study is prospective but non-randomised and deals with a small sample size and a short follow-up, therefore being inadequate to provide strong recommendations for or against the technique.[57] Lack of understanding still has to be addressed in terms of mechanisms, minimum time before implant removal, and superiority compared with other surgical solutions and between implants. Additionally, some concerns about long-term results and complications (osteoarthritis) are crucial in a procedure often performed in childhood or adolescence which needs to be addressed by proper medical investigations and research.

In adults

In adults, there is a wide consensus regarding the usefulness of insoles in the first approach to flatfoot (secondary to TPTD) and in proposing surgery only in case of failure. However, adult flatfoot is structural, therefore the rationale for use of arthroereisis is different from that in children. In adults, the procedure is rarely performed alone, whilst it may be useful together with soft-tissue and bony procedures in order to strengthen the anti-pronation effect and to support the tibialis posterior tendon and the medial arch. Even in adulthood, the grade of recommendation for subtalar arthroereisis should be considered as C, due to the inadequate quality of studies published. At present, several experts' opinions are available in the literature, and some of them suggest the use of subtalar implants when the correction after traditional surgery is not deemed satisfactory. According to the data here shown, precise comparative and prospective studies are needed to elucidate the real advantages and indications of such devices.

AUTHOR INFORMATION

[1]Orthopaedic and Traumatology Unit, Department of Public Health, "Federico II" Naples University, Naples, Italy.
[2]Clinique de l'Union, Saint-Jean, France.

Correspondence should be sent to: A. Bernasconi, Orthopaedic and Traumatology Unit, Department of Public Health, "Federico II" Naples University, Via S. Pansini 5, Napoli 80131, Italy.
Email: alebernas@gmail.com

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