Flexible flatfoot is one of the most common deformities of the human body.\(^1\) Whereas this condition is sometimes asymptomatic, it can also cause pain, difficulty walking, and physical impairment.\(^2\)

The techniques used to correct this deformity can be grouped into three procedure categories: soft tissue, bone (osteotomies and arthrodesis) and arthroereisis.\(^3\) The first (soft tissue) should always be combined with bone or arthroereisis, inasmuch as a stable, lasting correction is rarely obtained with the application of the soft tissue procedure alone.\(^4\) Arthroereisis procedures were originally designed for pediatric treatment and generally involve joint-sparing techniques that correct the flatfoot deformity while preserving foot function.\(^5\) This approach stems from extraarticular subtalar arthrodesis, first described by Grice\(^6\) in 1952 “for correction of paralytic flatfeet in children,” striving to correct the deformity without stunting foot growth.\(^7\) A number of poor results, however, were seen with Grice’s original technique because grafting a block of corticocancellous bone harvested from tibia or iliac crest was...
difficult to perform. The risks associated with this technique were having a graft slip out of position postoperatively resulting in the recurrence of the valgus deformity or, to fit the graft tightly, the hindfoot being forced into a varus position resulting in overcorrection.

The most significant modification of the Grice technique was devised by Batchelor, with a fibular peg inserted blindly from the talus neck through the sinus tarsi, but this technique resulted in a high nonunion rate.

Dennyson and Fulford then devised something very close to arthroereisis procedures, substituting the fibular graft with a screw and placing cancellous bone graft into the sinus tarsi, with a union rate of 95%. In any case, this technique was still an extraarticular fusion rather than a mechanical stop.

Haraldsson and Lelievre first pointed out the possibility of blocking the sinus tarsi, restricting subtalar motion avoiding any fusions. This technique is the birth of the arthroereisis procedures, with Lelievre introducing the term lateral arthroereisis for a temporary staple across the subtalar joint.

Since then, two different approaches for this same procedure have been developed. On one side, Subotnick initially described an endo sinus tarsi implant using a block of silicone elastomer, followed by Viladot’s popular technique of using a cup-shaped silicone implant, having a reported success rate of 99% in 234 patients. Finally, many different implants in very different shapes and materials are being designed and used. Vogt recently classified the implants as self-locking wedges, axis-altering implants, and impact-blocking devices.

On the other hand, Recaredo developed an eso sinus tarsi technique for limiting motion in the subtalar joint: the calcaneo-stop procedure. He inserted a cancellous screw into the calcaneus bone to interfere with talus movement in proximity of the screw head. The entry point was located in the sinus tarsi. Magnan and colleagues reported 83% good results in 475 cases with 12 to 112 months follow-up time with this procedure.

Castaman described a modification of this technique using a cancellous screw inserted into the talus (anterograde calcaneo-stop) with Roth reporting excellent results in 48 children (94 feet) in 91.5% of the patients with a 5-year average follow-up.

An interesting phenomenon described for both endo sinus tarsi arthroereisis and eso sinus tarsi calcaneo-stop procedures is the maintenance of the correction even after hardware removal. It is likely that this finding had biomechanics and neuroproprioception explanations.

BIOMECHANICS

It is important to understand that flexible flatfoot is a normal foot shape, present in many infants and adults. There is no consensus among health care providers as to whether flatfoot represents a deformity or a variation of normal foot shape. What is clear is that the arch elevates spontaneously in most children during the first decade, with no evidence of treatment efficacy for shoe modifications and insoles. In fact, Helfet stated that insoles could even be dangerous, leading to dependency or what he called a “life sentence” with long-term negative psychological effects, according to Driano.

Although “the child foot is not just a smaller version of the adult foot” and the causes are numerous in the pediatric population, the pathomechanics, over time, are comparable with adult-acquired flatfoot deformities.

In this light, Scarpa’s observations of nearly 200 years ago are really quite interesting, noting similarities between subtalar and hip joints. He compared the
acetabulum to the so-called acetabulum pedis, made up of navicular, spring ligament and anteromedial and anterolateral calcaneal subtalar articular facets. The hip is, of course, a pure ball-and-socket joint with one central rotation between two bones with an intraarticular ligament and an articular capsule, whereas the subtalar joint is not. In any case, embryologic and histologic reasons drove Pisani\textsuperscript{32} to stress this idea, introducing the term \textit{coxa pedis}, which describes the subtalar joint as a reverse hip.

In fact, the stable structure in the hip is the acetabulum (the socket), whereas that of the subtalar joint is the talus (the ball). Furthermore, Pisani described a medial peritalar instability with posterior tibial tendon dysfunction as being both a possible cause and consequence of spring ligament injuries, referring to them as \textit{degenerative glenopathy}.\textsuperscript{33} The acetabulum pedis presents a panniculus adiposus in the middle and, then, medially the bone structure with navicular posterior facet and calcaneal anterior facets. In between them it is possible to identify a glenoidlike fibrocartilage on which superomedial and plantar branches of the spring ligaments converge. In this system, the superficial branch of the deltoid ligament and the insertional portion of the posterior tibial tendon act as strengthening elements for the glenoid, laterally completed by the calcaneonavicular branch of the bifurcate (Chopart) ligament.\textsuperscript{34} This model is consistent according to Basmajian and Stecko’s\textsuperscript{35} findings. Their electromyographic studies previously showed intrinsic static bone-ligament foot stability with no muscle activity for structural integrity, later confirmed in studies by Mann\textsuperscript{36} and Inman.\textsuperscript{37}

Although the foot is not a single bone, Paley’s\textsuperscript{38} concept of the center of rotation of angulation (CORA) of the deformity can be applied to the foot as well. Considering that, in flatfoot deformities, the intersection site of talus and first metatarsal axis happen mostly at talonavicular joint, biomechanically the calcaneo-stop procedure acts at the CORA of the deformity.

According to Pisani’s theory, Koutsogiannis-Myerson calcaneal medial displacement osteotomy\textsuperscript{39} is comparable to Chiari’s pelvis osteotomy,\textsuperscript{3} whereas a successful arthroereisis procedure for the hip is still missing. This result represents the success factor of this minimal invasive procedure, especially considering Nigg’s\textsuperscript{40} biomechanics study.

In fact, Benno Nigg confuted the old podiatric idea that ground reaction forces on the forefoot significantly affect foot function according to the position of the oblique Lisfranc joint axis,\textsuperscript{41} subsequently applying the concept of rigid body rotating around subtalar joint axis to the foot complex.\textsuperscript{42} This theory fits for every structure whose component deformations are insignificant compared with the motion of the entire structure as one entity.

A similar model closely reflects Huson’s theory, which describes tarsal movement mechanism as a constraint type, later confirmed by the three-dimensional kinematics study by Cornwall and McPoil\textsuperscript{43} and by stereophotogrammetry studies by Van Langelaan Benin and Lindberg, and Svensson.\textsuperscript{44}

Hence, biomechanically speaking, calcaneo-stop is a minimally invasive procedure that acts at the CORA of the deformity in a constraint structure.

\textbf{Neuroproprioception}

Many investigators claim a proprioceptive function for the calcaneo-stop procedure,\textsuperscript{2,4,15,19,20,23} emphasizing proof that with this active self-correction there is weak screw penetration in the calcaneus and a relatively small percentage of screw breakage, compared with what can be expected from a purely passive mechanical mechanism.
Similar observations find their scientific explanation in Japanese neurohistologic studies. Neural structures were found in 22 cadaveric feet, after gold chloride impregnation. Most of these structures were free nerve endings for nociception, but it was also possible to identify mechanoreceptors as Pacini, Golgi, and Ruffini corpuscles.

An active self-correction could be also a good reason for Pisani’s observation of contralateral side deformity improvement in patients treated monolaterally, especially after the recent description of a new population of cortical neurons: the mirror neurons.

This special group of neuronal cells can be activated by any external stimulus (such as sight stimulus, but even proprioceptive stimulus) and facilitates adaptive active changing in the whole body. However, this is still a hypothesis. The authors advocate further studies to better acknowledge this one last principle.

**SURGICAL INDICATIONS**

**Pediatrics**

There are no controlled prospective studies showing the avoidance of long-term pain or disability by prophylactic nonoperative or operative treatment of asymptomatic flatfoot.

There is, on the contrary, an abundance of studies advocating the absolute inefficiency of conservative treatments (shoe modifications and insoles) for correction of flatfoot deformity, with the exception of heel cord stretching exercise in case of concomitant Achilles brevis. Furthermore, according to Morley, nearly 100% of 2-year-old children are flatfooted, with a drop to 4% at age 10. This incidence makes it even more difficult to choose the correct timing in the decision-making process.

Nowadays the problem for the physician is more difficult than in the past. The choice is no longer between conservative and surgical treatment, but whether to treat the patient or not, and, if so, when.

As in the past, clinical features are more important than any other assessment. Radiographs should not dictate treatment, even with abnormal values. Whereas radiographs are effective in defining static relationship between bones, absolutely no information on pain, flexibility, or function is provided.

Orthopedic surgeons share the opinion that surgical indication rate should be around 4% of the entire pediatric flexible flatfoot population, with symptomatic flexible flatfoot being candidates for surgery. Clinical assessment should be focused on deformity reducibility, which can also be addressed by bilateral and single heel rise test and by Jack test.

The Silfverskiold test is important to determine the type of any potential Achilles contracture. It is necessary to look at forefoot position with the hindfoot reduced into neutral position to assess additional surgical intervention. Of course, barefoot and shoe-clad gait must be observed, paying particular attention to atypical wear patterns on shoes.

Finally, the optimal timing for this surgery is debated. Good results have been reported in the 8 to 14 age group, but Carranza and colleagues suggest performing the operation around age 12 to avoid the development of cavovarus deformity in those feet operated on at a very early age, as reported by Viladot. On the other hand, Roth and colleagues argued that, for patients older than 14 years, not enough correction could be reached because of the limited bone growth potential.

Therefore, considering the number of variables in this decision-making progress, it is extremely important that the referring physician for these little patients
and their parents be a well-trained orthopedic surgeon skilled in foot and ankle and/or in pediatrics, rather than any other health care provider.

**Adults**

There is scarce literature on arthroereisis procedures in adults, with most reports being related to endo sinus tarsi arthroereisis procedures. In these cases, the main concern should not be the satisfaction rate at a short-time follow-up, but the removal rate. In an adult-structured foot it is difficult to imagine a proprioceptive active correction, and it is reasonable that the biomechanical impact be predominant. Therefore, there is clearly a high risk of correction loosening due to implant removal.

According to these principles, in a study conducted on 23 adults, Needleman\(^5\) referred to 46% of sinus tarsi pain at an average follow-up of 44 months. He reported a 39% implant removal rate with sudden improvement of functional scores and symptoms release.

Theoretically, the calcaneo-stop procedure, being completely extraarticular, should result in less biomechanical stress symptoms and presumably work better than other endo sinus tarsi arthroereisis procedures.\(^2\) Nevertheless, this theory, as well as its surgical indications, has yet to be documented.

In any case, arthroereisis cannot be a stand-alone procedure in adults but must be considered as a CORA\(^3^8\) procedure in protection of other soft tissue CORA procedures (spring ligament repairing, for instance) and associated with other procedures that address proximal and distal pathologic conditions.

**IMAGING**

Radiographs should not dictate the treatment in flexible flatfoot and are not necessary for diagnosis.\(^2\) Nonetheless, they can be useful to study uncharacteristic pain, decreased flexibility, and, of course, any surgical planning.\(^2,^3\)

In the absence of weightbearing images, the radiographic relationships between the bones will not represent the true clinical deformities, making weightbearing anteroposterior, lateral, and oblique views mandatory. In fact, a calcaneonavicular coalition is best seen on the external rotation 45° oblique view, and a talonavicular tarsal coalition can be better detected on the axial view.\(^2,^3,^2^0\) To look for accessory navicular, an internal rotation oblique view has to be done.\(^4^9\)

A number of radiographic measurements have been described for the measurement of flatfoot, but the most popular is the talar-first metatarsal angle (or Meary angle). It is subtended by the line drawn through the long axis of the talus and the navicular in relation to the first metatarsal axis in the lateral view: the flatfoot has negative or a plantar apex Meary angle.\(^5^0\)

The lateral view could also be useful in determining the CORA of the deformity in a modified version, even if the foot is not a single bone, as in Paley’s original concept. The site of Meary angle could approximate the CORA—most often located in the head of talus or at the talonavicular joint. In these cases any arthroereisis procedure acts at the CORA of the deformity. However, the CORA can also be located more proximal to the body of the talus, indicating a skewfoot deformity—an arthroereisis procedure contraindication.\(^3\) Otherwise, the CORA could be located more distal within the body of one of the midtarsal bones and could be better addressed by a Miller-Hoke procedure.\(^5^1,^5^2\)

On the anteroposterior view it is important to consider the percentage of talar head uncoverage, often revealing which surgical management is more fitting following surgical indication.
The authors stress, in accordance with Kwon and Myerson,\textsuperscript{2} the importance of the weightbearing views of the ankle joint to address any eventual proximal deformity and instability. Furthermore, the authors believe the hindfoot alignment should also be studied using the Saltzman and El Khoury view.\textsuperscript{53}

Computed tomography scan and magnetic resonance imaging should be considered only for uncommon causes of flatfoot deformity such as coalition or tumor.\textsuperscript{3}

**Surgical Technique**

**The Calcaneo-Stop Procedure**

The calcaneo-stop behaves as an “internal orthotic device” and can be placed almost percutaneously with a very short recovery time and very low morbidity\textsuperscript{2} (Fig. 1). Surgical treatment is usually performed under general anesthesia, with or without a tight tourniquet. A 2-cm incision is made over the sinus tarsi. Soft tissue dissection is performed bluntly, taking care to avoid the sural nerve. Under fluoroscopic control, a guide wire is vertically inserted into the calcaneus, keeping the heel well-reduced. It is 3.2-mm overdrilled. Then, a 6.5 cancellous screw is inserted. The screw should be long enough to impinge with its head against the lateral aspect of the talus preventing eversion of the subtalar joint. The common length should be around 30 to 35 mm.\textsuperscript{4}

**Anterograde Calcaneo-Stop Procedure**

Castaman\textsuperscript{20} and other investigators\textsuperscript{4} popularized the anterograde calcaneo-stop technique with apparently a shorter incision (around 1-cm) centered on sinus tarsi (Fig. 2). Once the lateral process of the talus is located, under fluoroscopy, an entry hole with a trocar is performed into talus. Then a 6.5 cancellous screw is inserted at a 35°direction in the sagittal and 45° in the coronal plane. The length of the screw is similar to the original technique with the nonthreaded portion conflicting with the lateral border of the calcaneus.

Even though these two alternative techniques seem to have no significant differences regarding surgical complexity and postoperative care, the authors still recommend the traditional one based on Roth and colleagues\textsuperscript{14} experience describing a
7.45% screw malposition, posing the risk of damaging both the subtalar and ankle joints (Figs. 3–5).

Additional Procedures

Pediatric
In the pediatric population, the calcaneo-stop can be an isolated procedure. In fact, a passive and active correction is presumably achievable thanks to its biomechanical and proprioception properties. Furthermore, other combined procedures should address problems that frequently, but not always, are related to flatfoot. The presence of an accessory or prominent navicular should be addressed with a Kidner procedure. Of course, a short Achilles tendon in children should be lengthened, preferably with a Strayer procedure.

Adults
Any remodeling activity in adult hindfoot is not to be considered. Hence, the main concern should be the removal rate, which has been described by Needleman for endoarthrorereisis procedures in adults at around 39%.

Theoretically, this rate should be lower in the calcaneo-stop technique. The most common complications in endorthesis, such as granuloma formation, implant displacement, biomaterial failure, tissue staining, implant irritation, and sinus tarsi pain, would not be expected with calcaneo-stop. Regardless, this expectation is still a hypothesis and not a documented fact.

The authors recommend considering calcaneo-stop in adults as a possible accessory procedure to protect a medial soft tissue repairing, to be combined with any bony procedure necessary to achieve a plantigrade foot.

Fig. 2. Anterograde calcaneo-stop procedure.

Fig. 3. Anterograde calcaneo-stop: screw malpositioning on the contralateral side of the same patient.
CONTRAINDICATIONS

Pediatric

Surgical management of the flexible flatfoot is indicated for patients with pain and dysfunction. Patients not fitting this definition should not be candidates for this surgery. Therefore, the absence of pain and dysfunction is a contraindication for the calcaneo-stop procedure. In any case, not all pediatric patients will complain of the classic symptoms such as medial foot pain or lateral impingement. There is, in fact, a large spectrum of other aspecific symptoms that the physician should investigate, like shoe problems history, difficulty running, and nonspecific aches in legs.²,³

An inflexible flatfoot is not a surgical indication for this treatment, because it can subtend other pathologic conditions. For instance, tarsal coalition is a contraindication for the calcaneo-stop, at least as a single procedure. In these cases, a preview removal of the

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Fig. 4. Computed tomography scan: anterograde screw malpositioning (same patient).

Fig. 5. Salvage procedure: talonavicular fusion.
coalition is advisable and, of course, if more than one-third of the joint is affected, a subtalar fusion would be the right choice over an arthroereisis procedure.\textsuperscript{3}

Children outside the mentioned age group (8–14 years) represent a contraindication for this surgery. In patients undergoing the surgery too early, Viladot\textsuperscript{15} described the risk of developing a cavovarus foot later in life. On the contrary, once the patient is too old, there is no more modeling residual potential.

Finally, both neurologic and neuromuscular diseases are contraindications.

**Adults**

The authors stress the idea that in adults the calcaneo-stop procedure should be combined with any other soft tissue and bone procedure to achieve a plantigrade foot, especially considering the high removal rate described for arthroereisis procedures.\textsuperscript{4}

Considering that this procedure in some way limits subtalar joint movement, subtalar and midfoot arthritis represent a contraindication to this surgical choice for the major stress incurred after this procedure.

Rigid flatfoot and neurologic and neuromuscular diseases are absolute contraindications for this surgical treatment.

**RESULTS**

**Pediatric**

To the authors’ knowledge, all published studies refer to encouraging results for the calcaneo-stop procedure in the pediatric population.\textsuperscript{4,20} The satisfaction rate ranges between 90% and 95%, with similar results for endorthesis.\textsuperscript{5}

All the previous studies reported a significant statistical improvement of the Meary angle around 15° with, once again, similar results for endorthesis.

Few pedographic studies are present in literature. The most relevant one available, by Kellermann and colleagues\textsuperscript{4} shows a significant change for “relative contact time” with a postoperative increase in the lateral midfoot region (this parameter represents the actual contact time of the region divided by the contact time of the total foot in percent).

The drawback is that most of the studies have less than a 2-year follow-up—not enough to detect possible problems to the adjacent joints. Conversely, published studies on subtalar and triple arthrodesis stress transfer to adjacent joint with degenerative arthritis were not reported on prior to 10-year follow up.\textsuperscript{3}

In addition, these implants lead to resorption of the adjacent cortical surface of the talus and calcaneus. At this time the authors cannot predict the long-term effect of this occurrence.

Some further concerns about the anterograde calcaneo-stop technique are a reported 7.45% of screw malpositioning and 2% screw penetration into the calcaneus from above with a consistent risk of subtalar damage.\textsuperscript{4}

**Adults**

Short-, medium-, and long-term follow-up studies are missing.\textsuperscript{3} To estimate the hypothetical advantage of this procedure we must to refer to endorthesis results and problems according to short-term follow-up studies. Needleman\textsuperscript{5} refers to a lower satisfaction rate than in children (78%), with sinus tarsi pain in 46% and hardware removal in 39% at 44-month follow-up.

These studies can be explained through magnetic resonance imaging studies by Saxena and Nguyen,\textsuperscript{56} who recently found that the tarsal canal is smaller in height
and length than the implants sizes generally used. Theoretically, the calcaneo-stop technique, being totally extra sinus tarsi, should not have this problem. In any case, with such a high rate of hardware removal expected and the potential high risk of residual deformity, the calcaneo-stop procedure should be considered a procedure acting at the CORA of the deformity, to be associated with any soft tissue and bone procedures necessary to obtain a well-aligned plantigrade foot.

**SUMMARY**

Flexible flatfoot is one of the most common deformities. Arthroereisis procedures are designed to correct this deformity. Among them, the calcaneo-stop is a procedure with both biomechanical and proprioceptive properties. It is designed for pediatric treatment. Results similar to endorthesis procedure are reported.

Theoretically the procedure can be applied to adults if combined with other procedures to obtain a stable plantigrade foot, but medium-term follow up studies are missing.

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