Cavus foot, from neonates to adolescents

P. Wicart

Paris Descartes University, Necker–Sick Children Hospital (AP–HP), 149, rue de Sèvres, Paris 75015, France

Accepted: 10 July 2012

Summary Pes cavus, defined as a high arch in the sagittal plane, occurs in various clinical situations. A cavus foot may be a variant of normal, a simple morphological characteristic, seen in healthy individuals. Alternatively, cavus may occur as a component of a foot deformity. When it is the main abnormality, direct pes cavus should be distinguished from pes cavovarus. In direct pes cavus, the deformity occurs only in the sagittal plane (in the forefoot, hindfoot, or both). Direct pes cavus may be related to a variety of causes, although neurological diseases predominate in posterior pes cavus. Pes cavovarus is a three-dimensional deformity characterized by rotation of the calcaneo pedal unit (the foot minus the talus). This deformity is caused by palsy of the intrinsic foot muscles, usually related to Charcot-Marie-Tooth disease. The risk of progression during childhood can be eliminated by appropriate conservative treatment (orthosis to realign the foot). Extra-articular surgery is indicated when the response to orthotic treatment is inadequate. Muscle transfers have not been proven effective. Triple arthrodesis (talocalcaneal, talonavicular, and calcaneocuboid) accelerates the mid-term development of osteoarthritis in the adjacent joints and should be avoided.

© 2012 Published by Elsevier Masson SAS.

Introduction

All forms of pes cavus are characterised by a high arch in the sagittal plane of the foot. The corollary is a bulge on the dorsum of the foot. Weight is borne posteriorly on the calcaneal tuberosity and anteriorly on the heads of the metatarsal bones. Pes cavus is usually acquired, although a minority of cases are congenital.

Background

The foot can be divided in the sagittal plane into a lateral column (calcaneus, cuboid, and 4th and 5th metatarsals) and a medial column (talus, navicular, three cuneiform bones, and first three metatarsal bones). In the coronal plane, the hindfoot is separated from the midfoot by the transverse tarsal joint and the midfoot from the forefoot by the tarsal-metatarsal joints (Lisfranc joint).

The calcaneo pedal unit (CPU), which is the foot minus the talus, and its articulation with the talar-tibial-fibular
Morphological variants of normal

The foot may have a cavus in the absence of any disease. This shape is simply a variant of the normal foot. The pitch angle of the calcaneus relative to the ground may affect the shape of the foot: it is usually less than 10° in the normal flatfoot variant and greater than 25° in the high-arch variant (Fig. 1).

Familiarity with these variants is important, as an abnormal acquired deformity may develop on a pre-existing unit (TTFU) via the subtalar joint complex are crucial to the understanding of pes cavovarus [1].

Radiological analysis

The various forms of direct pes cavus can be distinguished by radiological analysis (Fig. 2). The Djian-Annonier and Hibbs angles between the calcaneus and the sesamoid bones and first metatarsal, respectively, reflect the overall degree of opening of the compass but fail to show the location of the

Table 1  Classification of the 262 pes cavus deformities treated surgically at the Saint-Vincent-de-Paul Teaching Hospital, Paris, France, by R. Seringe (1978–2010). The cavus deformity is listed first when it was the predominant abnormality and second otherwise.

<table>
<thead>
<tr>
<th>Pes cavovarus</th>
<th>No CMT</th>
<th>CMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pes varus cavus</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Idiopathic talipes equinovar with cavus deformity</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Pes calcaneovarus</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Pes cavus equinus</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Pes cavus valgus</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Non-idiopathic talipes equinovar with cavus deformity</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Flatfoot with cavus deformity</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
<tr>
<td>Miscellaneous forms of pes cavus</td>
<td>No CMT</td>
<td>CMT</td>
</tr>
</tbody>
</table>

CMT: Charcot-Marie-Tooth.

Table 2  Causes of the 262 pes cavus deformities (Table 1).

<table>
<thead>
<tr>
<th>Neurological disorders: 173</th>
<th>CMT</th>
<th>Other peripheral neuropathies</th>
<th>Dysraphism</th>
<th>Central nervous disorder</th>
<th>Myopathy</th>
<th>Not identified</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurological disorders: 89</td>
<td>Idiopathic CTEV</td>
<td>Other congenital deformities</td>
<td>Syndromic deformity</td>
<td>Post-traumatic deformity</td>
<td>Miscellaneous</td>
<td>total</td>
<td></td>
</tr>
</tbody>
</table>

CTEV: congenital talipes equinovar; CMT: Charcot-Marie-Tooth.

variant that imparts a completely different shape to the foot.

Reimers et al. reported that the proportion of children with high-arched feet increased from 2% at 3 years of age to 7% at 16 years of age [2].

Direct pes cavus

The deformity is entirely located in the sagittal plane. Comparison to a compass (Pierre Queneau) is useful.

Clinical presentation

Anterior pes cavus is characterised by closure of the anterior branch of the compass, i.e., direct descent of the forefoot and midfoot relative to the hindfoot. This deformity was designated “total pes cavus” by Robert Méary [3], who described “irreducible plantar flexion of the forefoot relative to the hindfoot”, a step-off between the forefoot and hindfoot, or true equinus of the midfoot and forefoot. An excessively horizontal orientation of the talus (“inadequate dorsal slope” [4]) compensates for the equinus of the midfoot and forefoot and the step-off between the forefoot and hindfoot during weight bearing. A variant of anterior pes cavus is congenital pes cavus, which is due to abnormal foetal position in utero.

Posterior pes cavus consists in isolated verticalisation of the calcaneus, with compensatory plantar flexion of the ankle.

In mixed pes cavus, both branches of the compass are closed.

Regardless of whether the cavus deformity is anterior, mixed, or posterior, the apex of the lateral and medial arches is not in contact with the ground and the pencil sign is positive (a pencil can be slipped transversely under the sole). The reduction in the weight-bearing area of the foot results in increased pressure with metatarsalgia in patients with direct pes cavus. Excessive pressure on the calcaneal tuberosity may result in plantar ulcers in patients with sensory impairments (e.g., due to spina bifida).

Figure 1  High calcaneal pitch angle: high-arch morphological variant.

Cavus deformity. Their use is criticisable, since the posterior measurement point is located on the lateral column and the anterior measurement point on the medial column.

**Causes**

The combination of neurological impairments and growth-related changes results in the early development (before 10 years of age) of rapidly progressive deformities (Table 3).

**Treatment**

The management depends on the radiological characteristics. Any motor impairments due to a neurological disease must be corrected before the induced osteoarticular deformities are treated. To avoid having to perform triple arthrodesis at growth completion [5], preference should be given to surgery during growth to correct the muscle imbalances. Osteotomies may or may not be performed. Treatment options are as follows:

- posterior pes cavus: surgery before growth completion can stop the progression of the deformity. The first step consists in transferring one or more dorsal flexors (tibialis anterior, extensor digitorum longus, peroneus tertius, peroneus brevis) to the calcaneal tuberosity to compensate for the triceps surae weakness. Then, an osteotomy is performed to displace the calcaneal tuberosity upwards and posteriorly, thereby increasing the moments of the transferred muscles (Fig. 3);
- anterior pes cavus: plantar fascia release with or without dorsal tarsectomy is indicated;
- mixed pes cavus: a combination of the above-described techniques is used.

**Pes cavovarus**

Pes cavovarus is also known as pes cavus varus or medial pes cavus (Fig. 4).

**Aetiology**

Pes cavovarus is a rare deformity usually caused by a neurological disorder (Charcot-Marie-Tooth [CMT] disease in two-thirds of cases) [6,7]. Among patients with CMT
Idiopathic flatfoot deformity, 80% have pes cavovarus deformity [7]. A number of other central and peripheral neurological diseases can cause pes cavovarus. Non-neurological causes are less common; they include skeletal dysplasia syndromes, birth defects, progression of congenital idiopathic clubfoot, and trauma. Idiopathic pes cavovarus is exceedingly rare.

Pathophysiology and pathology

Pes cavovarus was classically ascribed to weakness of the tibialis anterior muscle responsible for plantar flexion of the first ray, whereas the claw-toe deformity was ascribed to compensatory activity of the toe extensor muscles [3]. In CMT disease [8], denervation may affect the intrinsic foot muscles first [9] then the toe flexors and extensors, followed by the peroneal muscles and tibialis posterior and, finally, by the tibialis anterior. Therefore, weakness of the tibialis anterior muscle cannot explain the development of pes cavovarus, since this abnormality occurs late in the course of the deformity [10]. The fibularis longus muscle may be less severely affected than the fibularis brevis and tibialis anterior muscles [11]. The flexor hallucis longus muscle may be spared, and the posterior leg compartment muscles are usually normal, except in advanced stages of CMT disease.

The pathophysiology of pes cavovarus has been elucidated in published studies and via observation of patients with CMT disease, whose initial valgus flatfoot deformity progresses to pes cavovarust at about 3 to 6 years of age (Fig. 5). Weakness of the intrinsic foot muscles (interosseous muscles and lumbricals) or disorders of muscle synergy are crucial to the pathophysiology of pes cavovarus [9,12]. The intrinsic foot muscles stabilise the metatarsophalangeal joints during dorsal ankle flexion and toe extension. Their paralysis results in extension of the metatarsophalangeal joints. This deformity is perpetuated by the new dorsal trajectory of the interosseous muscle tendons, which become dorsal flexors of the metatarsophalangeal joints.

Fig. 6 summarises the pathophysiology of pes cavovarust. The plantar fascia attaches to the proximal end of the first phalanges. Consequently, extension of the metatarsophalangeal joints puts the fascia under tension, causing cavus deformity; there is no contracture of the fascia. The anatomical characteristics of the plantar fascia and the medial to lateral decrease in the diameter of the metatarsal heads acting as pulleys explain the development of pes cavovarus deformity, whose apex is at the cuneiform bones, and of irreducible foot pronation. Pes cavovarus is not related to isolated plantar flexion of the first ray [10,13,14]: to maintain tripod weight-bearing on the calcaneal tuberosity and heads of the first and fifth metatarsals, the CPU topples into supination [3]. This displacement combines a
Cavus foot, from neonates to adolescents

Figure 6  Pathophysiology of pes cavovarus.

<table>
<thead>
<tr>
<th>Anterior pes cavus (disruption of Méary’s line)</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperextension of the metatarso-phalangeal joints + excessively vertical orientation of the metatarsals</td>
<td></td>
</tr>
<tr>
<td>Clinical test: heel walking</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exaggerated forefoot pronation</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavus that increases from lateral to medial (plantar fascia)</td>
<td></td>
</tr>
</tbody>
</table>

| - Growth = osteoarticular deformities with the apex at the cuneiform bones | TM |
| - irreducible forefoot pronation with a dorsal bulge = intermediate and lateral cuneiform bones | |

<table>
<thead>
<tr>
<th>Compensation by overall supination of the calcaneopedal unit</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>- heel in neutral position then development of calcaneal varus</td>
<td></td>
</tr>
<tr>
<td>- lateral rotation of the talar-tibial-fibular unit</td>
<td></td>
</tr>
<tr>
<td>- twisting of the calcaneopedal unit</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Growth and an imbalance between the peroneus brevis and tibialis posterior muscles result in</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>- mid-tarsal adduction</td>
<td></td>
</tr>
<tr>
<td>- irreducibility of the subtalar and mid-tarsal deformities</td>
<td></td>
</tr>
</tbody>
</table>

| Structural pes cavovarus + compensatory lateral torsion of the two bones of the legs | TM |

three-dimensional helical twisting movement [3] of the CPU (forefoot pronation and hindfoot supination and, therefore, varus of the heel) and lateral rotation of the TTFU on the CPU (adduction of the CPU under the TTFU and/or transverse tarsal joint). These displacements are reducible initially. Lateral torsion of the leg bones to compensate for the adduction develops during the last few years of the growth period. This concept differs from the classical pathophysiologic descriptions, even those reported recently [14]. Although the first metatarsal creates a considerably more prominent bulge at the sole of the forefoot compared to the other metatarsals, the apex of the cavus deformity is not located on the first ray but is found instead on the second and third rays (intermediate and lateral cuneiform bones).

Compensatory flexion of the interphalangeal joints causes claw-toe deformities that predominate on the medial toes and progress independently from the other deformities. The claw-toe deformities may be lacking [15] and their severity does not correlate with that of the cavus deformity [3].

Symptoms

During growth, pes cavovarus deformity may become more severe, particularly during puberty, causing symptoms that may develop early (before 10 years of age). Excessive pressure on the head of the first metatarsal or base of the fifth metatarsal during weight bearing may cause pain. Ankle instability may manifest as recurrent tibiotarsal or subtalar sprains (hindfoot varus and weakness of the peroneus brevis muscle). Persistence of these abnormalities may result in chronic ankle instability, which has a severe impact on functional outcomes and progression of the deformity [10].

Physical findings

The patients may be seen before 5 years of age for evaluation of valgus flatfoot deformity. The neuro-orthopaedic assessment is crucial as it can detect the presence of a neurological disease. The heel-walking test is used. Normal children have no difficulty walking on their heels. The ankles are flexed dorsally and the toes harmoniously extended. The sagittal alignment of the torso, hips, and knees is maintained. Impairment of the intrinsic foot muscles results in hyperextension of the toes and prominence of the extensor tendons at the anterior aspect of the ankle, including the tibialis anterior tendon, but without dorsal flexion of the ankle. Retroposition of the tibia and excessive knee extension and/or anterior projection of the torso occur (Fig. 7). The child is unable to walk on the heels. During this manoeuvre, dynamic pes cavovarus deformity develops, strongly suggesting a neurological disorder.

With the child in the standing position, the pes cavovarus deformity, overall adduction, convexity of the lateral edge of the foot, and varus of the heel can be assessed (Fig. 4). The reducible nature of the deformities, described in the literature, deserves comment. The term “reducibility” is not appropriate to describe the primary structural and irreducible abnormality of the forefoot (pes cavovarus deformity and pronation), which, at best, can be decreased via specific manoeuvres. The secondary deformities (adduction of the CPU and varus of the heel) are completely or
partly reducible early on but become permanent structural deformities as growth progresses. Reducibility of this component is assessed during weight bearing. If the deformity is reducible, medial leg rotation diminishes the depth of the medial arch and corrects the heel varus (lateral rotation of the CPU under the TTFU and untwisting of the CPU). The Coleman block test [16] corrects the forefoot pronation because the forefoot drops off the side of the block while the heel is lifted. This test corrects the heel varus to a variable extent. The oblique block test [17] uses the same principle but maintains weight bearing on the forefoot (Fig. 8). Reducibility of the heel varus has also been assessed by having the child kneel at the edge of the table or lie down in the prone position [13, 18].

The excessive forefoot pronation is combined with restriction of dorsal ankle flexion, although true equinus deformity is rare. Examination of the sole of the foot may show hyperkeratosis indicating excessive pressure on the head of the first metatarsal and base of the fifth metatarsal. Increased lateral laxity of the ankle, sometimes with perceptible cracking sounds, may be found in adolescents.

Imaging studies

Lateral weight-bearing radiograph of the foot
The cavus deformity, located anteriorly, can be measured by the lateral talar-first metatarsal angle (Méary’s angle) [3]. The lateral radiograph underestimates the depth of the arch: the abnormalities in the transverse plane hinder the interpretation of the image, because the longitudinal axes of the talar bone and first metatarsal bone are not located in the same sagittal plane. This difficulty can be overcome by using the oblique block test to correct the transversal abnormalities [17], thereby allowing interpretation of the lateral radiograph (Fig. 8).

Dorsoplantar weight-bearing radiograph
This view shows the secondary abnormalities in the transverse plane. Lateral rotation of the TTFU above the CPU manifests as a decrease in the angle of talocalcaneal divergence. This abnormality is readily corrected by the oblique block test (Fig. 8). Adduction in the transverse plane of the residual tarsus (angle between the calcaneus and fifth metatarsal) indicates progression to a structural deformity with calcaneocuboid subluxation and deformities of the navicular and medial cuneiform bones.

Anterior-posterior radiograph of the ankles with anklets (Méary)
This view is useful for quantifying heel varus.

Dynamic varus/valgus radiographs of the ankle
These views may show varus instability in adolescents.

Global scores
The classification scheme described by Paulos et al. [19] rests on clinical criteria (correction of the forefoot and
hindfoot deformities) and subjective criteria (patient satisfaction). Wicart and Seringe developed a classification scheme [17] (Table 4) based on functional, morphological (orientation of the hindfoot), radiological, and outcome criteria (triple arthrodesis indicates treatment failure).

Orthotic treatment

Children
Orthotic treatment is classically described as ineffective [6,20,21]. This view is wrong. When a child with pes cavovar varus deformity is in the supine position, the cavus deformity
Table 4  Score for pes cavovarus. The influence of hindfoot malalignment, when mild, is modulated by correction of the cavus deformity and vice versa.

<table>
<thead>
<tr>
<th>Heel axis</th>
<th>Méary's angle (M)°</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>VG, N or slight VR</td>
<td>0 ≤ M &lt; 15 or 0 ≤ M &lt; 5</td>
</tr>
<tr>
<td>Good</td>
<td>VG</td>
<td>15 ≤ M &lt; 20 or –5 ≤ M &lt; 0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>5 ≤ M &lt; 20</td>
</tr>
<tr>
<td></td>
<td>VR</td>
<td>5 ≤ M &lt; 15</td>
</tr>
<tr>
<td>Fair</td>
<td>VG or N</td>
<td>M &gt; 20 or M &lt; –15</td>
</tr>
<tr>
<td></td>
<td>VR</td>
<td>15 ≤ M &lt; 20</td>
</tr>
<tr>
<td>Poor</td>
<td>Recurrence or need for triple arthrodesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VG: valgus; VR: varus; N: neutral.

Untwisting plaster boot cast. The objective is to correct established pes cavovarus (Fig. 9).

Untwisting Perlstein-type orthosis for night wear. The use of this orthotic device is rational in three situations (Figs. 10–12):

- at onset of the first evidence of pes cavovarus (to prevent or slow progression);
- as follow-on therapy after the use of a derotating plaster boot cast;
- and after surgical treatment in a child to prevent recurrence due to growth and to the neurological disorder. The rate of repeat surgical treatment ranges from 38% to 50% [10,17,20].

The use of a derotating long leg cast extending from the thigh to the foot and keeping the knee in at least 20° of flexion improves correction in the transverse plane.

A recent study confirmed the effectiveness of this management strategy [21]. Outcomes at growth completion were satisfactory for half the feet, obviating the need for surgical treatment. Orthotic therapy delayed surgery by 5 years on average, thus allowing surgery at a more favourable age. No patients required triple arthrodesis.

Adolescents

Physical therapy prevents the development of contractures and preserves proprioception. Splints to be worn at night are classically recommended to combat the development of equinus deformity.

Surgical treatment

The challenges raised by the surgical treatment of pes cavovarus [22] explain the large number of available techniques.

Surgery on the soft tissues

Soft tissue release procedures. Plantar fascia release. Simple selective fasciotomy can be performed through a small incision in the sole of the foot. Steindler [23] described an extensive procedure consisting in incision via a medial approach of the plantar fascia, flexor
Cavus foot, from neonates to adolescents

Figure 10   Derotating Perlstein orthosis: keeping the ankle flexed at 90° decreases the height of the arch (b); the forefoot is placed in supination (correction of the pes cavovarus deformity) (a and c); the hindfoot is displaced in valgus (d); an oblique dorsal strap placed under tension from lateral to medial corrects the pes cavus deformity (a and b).

hallucis brevis, abductor digiti minimi, abductor hallucis, and plantar calcaneocuboid ligament. This procedure corrects the cavus deformity by allowing plantar gaping of the foot joints but does not produce sustained results [3,24].

Anteromedial release. Medial release of the talonavicular joint and, in some cases, of the subtalar and/or calcaneocuboid joint is combined with lengthening of the posterior tibial tendon, detachment of the abductor hallucis muscle, and division of the medial plantar septum. This procedure is indicated in patients with persistent adduction of the CPU and/or transverse tarsal joint after correction of pes cavovarus. Excision of the anterior extremity of the calcaneus [25] is in order when the lateral edge of the foot remains convex after medial release of the mid-tarsal soft tissues (most notably in case of calcaneocuboid subluxation).
Figure 11  Orthotic treatment: untwisting cast then untwisting brace until growth completion (11-year-old patient with Charcot-Marie-Tooth disease). a: Méary’s angle with the block = 29°. Note the marked abnormalities in the transverse plane; b: outcome at 18 years of age: the cavus deformity and transverse abnormalities are fully corrected.

Figure 12  Bilateral pes cavovarus in a 10-year-old patient with Charcot-Marie-Tooth. The deformity is more marked on the left than on the right (a). Outcome at 18 years of age (b) after surgery on the left foot (plantar opening-wedge osteotomy of the cuneiform bones, selective plantar fascia release, and Dwyer’s osteotomy) and orthotic treatment on the right (untwisting cast and untwisting brace worn at night).
Surgery on the tendons and muscles.

Tendon lengthening procedures. Lengthening of the Achilles tendon is best avoided, as this tendon serves as a counterbrace to correct the cavus deformity [26]. The tibialis posterior tendon can be lengthened to diminish the normal adducting effect of the muscle. Lengthening can be achieved either at the white/red junction behind the tibia or, preferably, via posterior displacement of the distal attachment site. This procedure should be considered with discernment, as the tibialis posterior tendon can be used for tendon transfer surgery in adulthood.

Tendon transfers. Several tendon transfer procedures can be used at the hindfoot:

- transfer of the fibularis longus tendon to the fibularis brevis [10,13] eliminates the pronation and plantar flexion induced by the fibularis longus and increases the abduction due to the fibularis brevis;
- transfer of the tibialis posterior tendon to the dorsum of the foot is performed to restore active dorsal flexion of the foot. This procedure decreases the varus-inducing effect of the tibialis posterior muscle.

Transfers at the midfoot include transfer of half or all of the tibialis anterior tendon [10] to the cuboid or lateral cuneiform bone, transfer of the extensor hallucis longus tendon to the cuboid or lateral cuneiform bone (Hibbs procedure), and transfer of the peroneus tertius tendon. The effect is often limited to tenodesis [10].

Finally, tendon transfers can be performed at the forefoot:

- The extensor hallucis longus tendon can be transferred to the neck of the first metatarsal bone, as described by Jones. Interphalangeal arthrodesis must be performed concomitantly to prevent distal claw-toe deformity [27]. This isolated transfer procedure was first described as a method for correcting great-toe claw deformity in polio patients and provides good outcomes in half the cases of pes cavovarus.
- Similarly, extensor digitorum longus tendon transfer to the necks of the metatarsal bones has been used.

Few data are available on the outcomes of these soft-tissue procedures in patients with CMT disease. Most of the case-series studies were heterogeneous in terms of both the patient population and the surgical techniques used [28]. One study showed that triple arthrodesis was not necessary in any of the patients after a mean follow-up of 14 years [29].

Osteotomies

Several osteotomy procedures have been described.

Dwyer calcaneal osteotomy [15]. A 10-mm wide lateral wedge is removed from the body of the calcaneus to obtain non-anatomical valgus of the hindfoot. Studies have shown that the Dwyer procedure has little influence on the midfoot and forefoot abnormalities, most notably the high arch [24,30]. In contrast, this procedure is usually required after correction of the primary midfoot and forefoot abnormalities, as secondary hindfoot supination is then insufficiently reducible. To obtain a greater degree of correction, curved osteotomies can be used [31]. Absence of calcaneal osteotomy after midfoot surgery is associated with a high rate of residual hindfoot varus [10].

Metatarsal osteotomies. Dorsiflexion osteotomy of the first metatarsal has been advocated [10,13]. This procedure cannot fully correct the high arch or forefoot pronation and is illogical because it does not involve the apex of the deformity. When performed concomitantly with dorsal closing wedge osteotomy of the medial cuneiform bone, overall correction ranged from 30° to 60° [13] and secondary osteotomies of the second and third metatarsals were therefore often required. Neither is there a sound rationale for performing osteotomies of all the metatarsal bones [32,35].
In contrast, adjunctive dorsiflexion osteotomy of the base of the first metatarsal is in order when the plantar bulge produced by the first metatarsal persists after correction of the high arch and mid/forefoot pronation [17].

*Tarsometatarsal* osteotomies. Dwyer suggested a dorsal closing-wedge tarsometatarsal osteotomy to achieve the legitimate goal of preserving hindfoot mobility. However, the loss of tarsal-metatarsal joint mobility and the distal location of the osteotomy relative to the apex of the arch explain that this technique was not further developed.

*Plantar opening-wedge osteotomy of the cuneiform bones* [17]. This procedure has several advantages. The cuneiform bones are at the apex of the deformity. The osteotomy involves all three cuneiform bones and therefore corrects the overall pronation of the forefoot. The plantar opening with a dorsal osteoperiosteal hinge is maintained via the insertion of a bone graft, which corrects the cavovarus deformity (Figs. 13 and 14). The loss of mobility is confined to the inter-cuneiform joints. Plantar opening-wedge osteotomy confined to the medial cuneiform bone [33] acts only on the first ray and fails to correct the overall forefoot pronation.

*Wedge tarsectomy.* The objective of wedge tarsectomy (Méary) [32] was to correct "the verticalisation of the first metatarsal bone and the pronation of the forefoot" (Figs. 15 and 16). These goals explain the use of a closing-wedge osteotomy removing a wedge of navicular, cuneiform, and cuboid bone with a dorsal and medial base. Méary suggested adding plantar fascia release to the procedure. Because a plantar hinge is kept, correction of the high arch induces lengthening of the foot.

Several variants or adjuncts can be suggested:

- removing a bone fragment of maximal thickness from the intermediate and lateral cuneiform bones (apex of the deformity in the coronal and sagittal planes) avoids exacerbation of the initial adduction, which would occur after maximal resection of the medial cuneiform bone (Fig. 17);
- dividing the short plantar ligament is neither necessary nor desirable;
- Dwyer’s osteotomy corrects residual hindfoot varus, which is common. This fact led Méary [32] to conclude that “combining anterior tarsectomy with Dwyer’s osteotomy can constitute an elegant solution”;
- dorsiflexion osteotomy of the base of the first metatarsal bone is indicated in the event of persistent prominence of the head of the first metatarsal bone at the sole of the foot;
- claw-toe deformity shows little or no response to tarsectomy, as it develops late during growth, and therefore requires an additional corrective procedure.

**Figure 14** Treatment with plantar opening-wedge osteotomy of the cuneiform bones, Dwyer’s osteotomy, and selective plantar fascia release. a: preoperative appearance (12 years of age): Méary’s angle = 20°; b: three months postoperatively: Méary’s angle = 0°, full correction of the abnormalities in the transverse plane; c: at growth completion: the correction is sustained, in part via the use of an un-twisting brace at night.

**Triple arthrodesis (subtalar, talonavicular, and calcaneocuboid arthrodesis)**

This procedure is not desirable. The bone resections are located proximal to the apex of the deformity. Medium- and long-term complications can develop as a result of excessive mechanical stress on the ankle and distal foot joints, which are particularly deleterious in patients with impairments of deep sensation [34]. Varus instability of the ankle
with rapidly progressive osteoarthritis may begin to appear before 30 years of age (Fig. 18).

**Selection of the therapeutic strategy**

The treatment aims to correct the deformity while preserving range of motion of the transverse tarsal and subtalar joints.

The development of pes cavovarus deformity indicates a need for treatment with the derotating Pearlstein orthosis, preceded in patients with marked deformities by a derotating plaster cast. This orthotic treatment may postpone or obviate the need for surgery or allow the use of less invasive procedures. It is extremely effective before 10 to 12 years of age (Fig. 12).

**Figure 15** Clinical appearance before surgery (at 16 years of age) and after dorsal tarsectomy/Dwyer's osteotomy/dorsiflexion osteotomy of the first metatarsal bone of the right foot (at 18 years of age). a: note the correction of the hindfoot varus; b: note the relative increase in foot length and improved footprint distribution.
Progressive symptomatic pes cavovarus (despite appropriate orthotic therapy) requires surgery before the end of the growth period, in keeping with the joint-sparing principle [10,13,17,35].

Three age groups should be distinguished:

- children (< 10 years in girls and < 12 years in boys): plantar opening-wedge osteotomy of the cuneiform bones after selective plantar fascia release, combined with Dwyer’s osteotomy [17]. The wedge removed during Dwyer’s osteotomy is inserted into the plantar opening fashioned in the cuneiform bones. Medial soft-tissue release is indicated in patients with persistent CPU adduction and/or adduction of the transverse tarsal joint. An osteotomy to shorten the lateral column [25] is performed in the event of persistent convexity of the lateral edge of the foot after soft-tissue release. When the head of the first metatarsal bone is seen to bulge into the sole of the foot compared to the head of the second metatarsal bone at the end of the procedure, dorsiflexion osteotomy of the first metatarsal bone is in order. The osteotomies are adjusted via plaster casting, and no internal fixation is needed. Postoperative immobilisation relies on a derotating plaster boot (worn for 3 months) fashioned on the 7th postoperative day under general anaesthesia. Then, the derotating Perlstein orthosis is used at night to prevent recurrence of the deformity due to growth and to the persistence of the neurological impairments. Whether orthotic or surgical treatment is used, the claw-toe deformity resolves, further supporting the use of early treatment;

- adolescents (11 to 14 years in girls and 13 to 16 years in boys): the limited reducibility of the deformity and the risk of recurrence after surgical treatment warrant postponement of surgery until growth is completed. A derotating orthosis should be worn at night to prevent the exacerbation of the deformity seen at the end of the growth period;

- end of the growth period: dorsal tarsectomy [32] with the above-described variants and adjuncts, to obviate the need for triple arthrodesis. In the absence of previous treatment the claw-toe deformity will have progressed and may require surgical treatment.

![Figure 16](image_url)

**Figure 16** Radiographs taken before surgery (at 16 years of age) and after dorsal tarsectomy/Dwyer’s osteotomy/dorsiflexion osteotomy of the first metatarsal bone of the right foot (at 18 years of age).

![Figure 17](image_url)

**Figure 17** Tarsectomy. a: correct (technical variant): remove a very small bone fragment from the medial cuneiform bone to avoid inducing adduction / the wedge is thickest at the intermediate cuneiform bone, which is the apex of the arch / remove as much of the cuboid bone as needed to correct the adduction; b: incorrect (original technique): removal of a wedge having a dorsomedial base causes adduction, which is not desirable, as adduction is among the components of the initial deformity.
Conclusion

Considerable advances in the knowledge of pes cavus deformities have been achieved over the last 25 years [6]. Taking normal morphological variants into account has refined the diagnosis. A clinical study and a critical review of the literature have established that pes cavovarus is due to weakness of the intrinsic foot muscles, in contradiction to classical theories. A modern treatment strategy for the orthotic and surgical treatment of pes cavovarus in children is suggested.

Disclosure of interest

The author declares that he has no conflicts of interest concerning this article.

References