

Calaj-Tavaf-Moon-Merrill Classification System of Pes Planus: A Novel Classification Describes the Six Types of Pes Planus

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INTRODUCTION

Pes planus, commonly referred to as flatfoot, is a common deformity seen in patients of all ages. While pes planus commonly tends to be asymptomatic, it can potentially have severely debilitating effects on functionality and quality of life. Generally, it is characterized by abnormal subtalar joint pronation (1). While reviewing the current literature on pes planus, there is a lack of information on the varieties that can be seen in individuals and in how they can be properly identified and differentiated. The authors propose that there are six variations of pes planus based on age and flexibility. This will aid clinicians in the recognition and appropriate treatment.

Recognizing age and flexibility will allow physicians to accurately diagnose and propose various treatment modalities towards pes planus deformities. Currently, there is no pes planus classification system to distinguish between the etiologic and progressive variations seen in flatfoot deformities. We propose an applicable classification system providing physicians with a guideline towards the diagnosis and treatment of a pes planus foot type. Initial patient and pedal evaluation must be considered, specifically the clinical and radiographic findings.

The Calaj-Tavaf-Moon-Merrill (CTMM) Classification System of pes planus is stratified from child, teenage, and mature based on the patient's age, with subcategories Type 1 and 2 based on the flexibility of the deformity. Type C is the child, at the time of birth. Type T is the teenager age group, typically ranging from ages 10-24 years. Type M is the mature adult age group, representing fully

developed and ossified primary and secondary centers, as seen radiographically. Subcategory Type 1 reflects a flexible foot type, while Type 2 reflects a rigid foot type. There are six possible diagnoses based on the CTMM classification system. This classification should be implemented both clinically, in the diagnoses and treatment, and academically, providing stratification of a rather complex disorder (Table 1 and Table 2).

Congenital calcaneovalgus (CCV), is a common birth finding believed to be obtained secondary to intrauterine mispositioning in which the dorsum of the foot is elevated toward the anterior aspect of the leg, at times contacting the tibia (2,3). CCV is most often confused with CCPPV (congenital convex pes plano valgus). CCV immediately manifests itself on the newborn's foot, with an estimated incidence of 0.4-1.0 in 1,000 live births (4). There is notable dorsiflexion and eversion of the calcaneus, restricted plantarflexion, and common peroneal tendon subluxation. A hallmark finding in the diagnosis of CCV is the absence of any equinus involvement, rather it is accompanied by a long and relaxed Achilles tendon. A practitioner will encounter the ankle in a dorsiflexed position, often to the extent to where the first metatarsal is pushing against the tibia. Tightness may be noted to the extensor retinaculum along the deep creases to the dorsum of the foot. Contrasting CCPPV, the deformity is flexible and absent of any tarsal dislocations or subluxations (3). Clinicians should utilize lateral stress radiographs.

Table 1. CTMM CLASSIFICATION SYSTEM OF PES PLANUS

AGE	FLEXIBLE (1)	RIGID (2)
CHILD (C)	C1: CCV	C2: CCPPV
TEENAGER (T)	T1: FFF	T2: TC
MATURE (M)	M1: PTTD	M2: PTTD W/ DJD

Table 2. CTMM CLASSIFICATION SYSTEM OF PES PLANUS

C1	Congenital Calcaneovalgus
C2	Congenital Convex Pes Planovalgus
T1	Flexible Flatfoot
T2	Tarsal Coalition
M1	Posterior Tibial Tendon Dysfunction
M2	Posterior Tibial Tendon Dysfunction with Degenerative Joint Disease

Only a few radiographs have been taken regarding the present material, all confirming normal findings (5). Many authors agree that this is essentially a benign condition that can be followed clinically and does not require radiographic evaluation or active treatment (6). However as mentioned, there will be no luxation found implying that no secondary adaptive bone changes or hypoplasia are found at the time of birth. Such findings are determined radiographically (7).

CCPPV is commonly referred to as vertical talus or rocker bottom flatfoot (8) and is a pronation dislocation of the talonavicular joint. The rigidity of the deformity is the hallmark to differentiating between vertical talus and a CCV foot. Vertical talus clinically manifests on newborn feet with plantar flexion of the hindfoot and ankle, also known as equinus. Furthermore, forefoot dorsiflexion is present and the heel is in a valgus position. It is important to note deep creases on the dorsum on the feet, and the absence of creases on the plantar aspect of the feet due to the excessive dorsiflexion of the forefoot and midfoot (9,10). If hindfoot equinus is not clinically featured, then the deformity is not vertical talus and is likely positional in nature (11). Vertical talus should be detected immediately after birth, as it may be associated with genetic syndromes (12). There are four clinical patterns currently associated with vertical talus: arthrogyposis, spina bifida, NF, and isolated congenital defect (50%) (13). CCPPV has an incidence of 1 in 10,000 and affects males and females equally (14).

The radiographic anatomy associated with CCPPV has been poorly defined, with many variations in findings. Nevertheless, lateral stress radiographs (the Eyre-Brook) should be obtained to address the deformity and rule out other pathologies. CCPPV will present as a non-reducible rigid deformity (8). The most common findings and measurements noted in evaluation of CCPPV include Kohler-like changes as the navicular ossifies, a wedged shaped navicular, calcaneocuboid diastasis, elevated first metatarsal, flexion contracture of the first MPJ, and lastly an hourglass talus. The talus will present parallel to the tibia and the calcaneus will be fixed in an equinus position. The normal value of the talocalcaneal angle should measure between 25-40 degrees, an increase in this measurement will suggest excessive pronation in the rearfoot (15). A deviation of greater than 40 degrees is noted in patients with CCPPV. Another angle of deviation is the calcaneal inclination angle (CIA), which is used to differentiate between equinus, cavus, and planus deformities. The normal measurement for a CIA is 15 degrees (15). A lateral weight-bearing radiograph will demonstrate a negative CIA, a hallmark feature of CCPPV.

Flexible flatfoot is one of the most common deformities to present itself to the lower extremity, most commonly presenting as a collapse of the medial arch typically presenting in the adolescent age group. Flatfoot in general, flexible or rigid may present as isolated congenital defects,

or from other underlying abnormalities and disorders (16). Idiopathic flexible flatfoot is the most common form (17). Flexible flatfoot may present as either asymptomatic or symptomatic. There are no distinct criteria to distinguish between the two, as symptoms are uniquely based on lifestyle. (18). A hallmark feature of flexible flatfoot is a collapsing medial arch that is only present when the patient is weightbearing. This medial arch collapse is a static anatomic comparison of the height of the arch compared to the normal population (16,19). According to Mosca (19), the flexibility of the flatfoot refers to the range of motion of the subtalar joint.

Radiographic evaluation of flexible flatfoot utilizes anteroposterior and lateral weight bearing views of the foot. Non-weightbearing views tend to be insufficient and tend to misrepresent the true clinical deformities associated with flexible flatfoot (19). Three angles are of primary interest when diagnosing flexible flatfoot: the talar declination angle (TDA), CIA, and talus-first metatarsal angle (Meary's angle). A TDA greater than 24 degrees correlates with the plantar flexion of the talus as seen in flexible flatfoot, and a CIA less than 18 degrees is consistent with flexible flatfoot calcaneal plantar flexion (20). Meary's angle is useful in defining a normal longitudinal arch by drawing two lines through the mid-axis of the first metatarsal and mid axis of the talus. Normally the two form a continuous and parallel line (0 degrees), however in flatfoot, Meary (21) defined it as greater than 4 degrees with a plantar sag in which those two lines intersect. An increased TFM angle is an important correlation in symptomatic versus asymptomatic patients with flexible flatfoot (18). An anteroposterior radiograph can additionally be used to evaluate the relationship between the talus and first metatarsal. On both anteroposterior and lateral radiographs it is critical to note the center of rotation of angulation (CORA) as applied to the foot, indicating the true etiologic site of deformity, differentiating between flexible flatfoot and skewfoot, and assisting in proper surgical implications (19).

Tarsal coalition is the most common cause of juvenile or adolescent rigid flatfoot (22). A tarsal coalition is an unwanted union of two tarsal bones at a joint, therefore restricting motion in the foot. These deformities lead to stiff feet usually accompanied by chronic pain and spastic peroneal muscles. The cause of a tarsal coalition is unknown but could be acquired or congenital. It is commonly due to accessory ossicles fusing two tarsal bones or genetic mutations (10). There are three common coalitions seen in adolescent feet: talocalcaneal, talonavicular, and calcaneonavicular. Talocalcaneal and calcaneonavicular coalitions tend to be the most common, accounting for more than 90% of all coalitions (23). In talocalcaneal coalitions the middle and sometimes anterior facets will fuse. Talocalcaneal coalitions often ossify in children ages 12-16 years (23). Talocalcaneal

coalition will lead to increased trabecular patterns in the cortical bone due to compressive forces on the subtalar joint.

On radiographs, increased trabecular bone shown in a circular ring pattern is referred to as the C-sign or halo sign (23). Talar beaking can also be noted on lateral radiographs. In the case of a calcaneonavicular coalition, elongation and blunting of the tip of the anterior process of the calcaneus is seen on lateral radiographs (24). This finding is known as an anteatler sign and is pathognomonic in diagnosing a calcaneonavicular coalition. When these signs are present, a tarsal coalition can be confirmed and treatment options to correct a rigid adolescent flatfoot should be considered.

Posterior tibial tendon dysfunction (PTTD) is the most common etiology of an adult acquired flatfoot deformity (15). The average age of PTTD presentation is around 40 years old and is most prevalent in women (25). The tibialis posterior muscle is a key structure involved in maintaining the integrity of the medial arch of the foot, crucially firing throughout the gait cycle. As the posterior tibial tendon loosens, there is resultant pressure on the spring ligament, forcing the ligament to stretch. The spring ligament is the primary structure holding the navicular head in place in an attempt to avoid medial arch collapse.

The etiology of PTTD can be acute or chronic. Acutely, although rare, PTTD may occur due to trauma, falls, or sudden movements that lead to tendon tear. More commonly, PPTD is caused by chronic injuries, which result from overuse or high impact sports. The medial longitudinal arch of the foot is supported by the posterior tibial tendon, along with the spring ligament, which supports the head of the talus from the inferomedial side. Impingement of the posterior tibial tendon at the fibro-osseous groove behind the medial malleolus is the most common etiology of PTTD. It has been noted that the prevalence of PTTD increases if an accessory navicular is present (25). The dysfunction can also be due to tendonitis and degenerative changes at the point of insertion. Signs and symptoms of PTTD can present as swelling around the medial malleolus and pain upon palpation on the posterior aspect of the medial malleolus. PTTD results in inflammation or tearing of the posterior tibial tendon and as a result, the tendon is unable to support the arch of the foot.

During midstance the foot maximally pronates to absorb shock, resulting in adduction and plantarflexion of the talus, as well as forward movement of the Cyra line. On radiographic imaging, a decrease of the CIA and increased talocalcaneal and Meary's angle can be noted. When the CIA drops down, the lateral process of the body of the talus moves forward until it contacts the calcaneus and floor of sinus tarsi. If the CIA can be corrected with stress supination, this would represent a flexible flatfoot, which can be seen when comparing lateral radiographs of the patient

standing normally to those with the patient standing with a block under the medial side of the heel (26). If there is some correction of the CIA noted on the stress radiograph, the flatfoot is considered flexible and the treatments will usually be conservative.

PTTD with degenerative joint disease rigid flatfeet in the adult are mostly due to degenerative changes in the joints secondary to posterior tibial tendon dysfunction. As the adult acquired flatfoot progresses, ankle valgus will increase and eventually rigidity and arthritic changes will be observed. In these progressed situations, the patient will gradually lose normal function and will have alterations in the shape of the feet (27). As explained above, due to stretching of the spring ligament after posterior tibial tendon loosening, the medial arch will collapse due to subluxation and the secondary changes will lead to rigid flatfeet in adults.

End-stage PTTD leads to subtalar joint dislocation with the calcaneus completely pronated and lateral process of the talus in contact with the floor of the sinus tarsi. This position of the subtalar joint is the maximum amount of pronation tolerable prior to fracturing the lateral process of the talus. The bodyweight force on the maximally pronated subtalar joint is a continuous compression that will lead to arthritic changes. This will lead to decreased range of motion, rigidity, and can be extremely painful (25). In this position, the posterior process of the talus is medial to the calcaneus and the middle facet of the talocalcaneal joint cannot be seen on radiographs. If in a lateral radiograph taken with stress supination, the middle facet cannot be observed and there is no correction in the CIA, treating the flatfoot as a rigid pes planus should be considered.

DISCUSSION

As with the CTMM, exceptions are of the nature of many universally accepted classification systems. An example can be seen in the Danis-Weber system, which completely overlooks the medial side of the ankle, and has been shown to only predict outcomes for uni-malleolar ankle fractures (28). Another renowned classification system is the Lauge-Hansen, which does not apply to isolated ankle fractures of the posterior tibial margin and fails to define all possible fracture patterns (28,29). In the CTMM, although extremely rare, one can see anomalies of flatfoot in different ages, such as PTTD in children rather than as expected in adults. However, after considering the various clinical and radiographic findings, the proper underlying etiology is assured.

In conclusion the complexity of pes planus in its diagnosis and treatment has impacted practicing physicians internationally. The multitude of underlying issues that can present as flatfoot are numerous and their treatments can vary substantially. The premise of the CTMM Classification

System of pes planus is reliant on two variables: age and flexibility. The simplicity of the CTMM Classification system is evident and its use is fundamental. The CTMM system provides physicians with a guide to narrow down the potential etiologies and target the underlying disease behind the flatfoot. The CTMM explains the 6 types of pes planus clinical presentations. The idea of clinical functional classification can also be applied to cavus foot deformities.

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