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Special Article

Hindfoot alignment using weight-bearing computed tomography: a new measurement for pes cavovarus

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Abstract

Measurement of hindfoot malalignment and flexibility is essential for treatment decision-making in cavovarus foot deformity. Weight-bearing computed tomography (WBCT) shows greater diagnostic accuracy and allows the study of osteoarticular alignment in the physiological upright position. The most commonly used method for measurements on WBCT scans is the foot and ankle offset (FAO), which is based on the structural tripod of the foot: the calcaneus and the first and fifth metatarsal heads. During the Coleman block test, the first metatarsal head is not resting on the ground and, therefore, does not represent the physiological support of the tripod. We describe a new measurement, the forefoot/hindfoot offset (FHO), for assessing hindfoot alignment on WBCT scans.

Level of Evidence V; Diagnostic Studies; Expert Opinion.

Keywords: Talipes Cavus/diagnostic imaging; Weight-Bearing/physiology; Tomography, X-Ray computed/methods; Bone malalignment.

Introduction

Hindfoot malalignment is a common finding that can result from different etiological factors. The accepted physiological alignment is defined as a hindfoot valgus angle of 0° to 5°, while malalignment is defined as a hindfoot valgus angle greater than 10° or any degree of hindfoot varus[1].

Measurement of hindfoot alignment is essential for surgical planning and treatment decision-making: soft tissue procedures, osteotomy, arthrodesis, or arthroplasty[2]. Cavovarus foot deformity is associated with extensive clinical variability, from subtle and flexible to severe and rigid. Although the term "pes cavus" refers only to an abnormal elevation of the medial longitudinal arch, this deformity is associated with varying degrees of hindfoot varus, ankle equinus, and forefoot adduction[3].

Traditionally, hindfoot alignment has been measured with conventional weight-bearing radiographs in the coronal plane using a long axial view that allows tibiocalcaneal angle measurement[4,5]. Conventional computed tomography (CT) allows better assessment of joint congruity and three-dimensional (3D) images, but it does not allow the assessment of the physiological joint behavior when the foot is loaded[6]. In addition, this technology allows the generation of digitally reconstructed radiographs (DRRs) with no rotation bias[7].

Several studies have compared weight-bearing computed tomography (WBCT) to other imaging modalities and reported greater accuracy of WBCT due to its 3D nature, which avoids bone overlap and allows the assessment of osteoarticular alignments in the physiological upright position[6]. The most commonly used method to measure hindfoot alignment on WBCT scans is the foot and ankle offset (FAO), a semiautomatic 3D biometry that considers the forefoot that interacts with the ground as a reference instead of the tibia[8].

This article describes a new hindfoot alignment measurement that is easy to perform, can assist in the assessment of foot deformities and can quantify the alignment of the forefoot in relation to the hindfoot.

Study performed at the Lab. Prof Manlio Mario Marco Napoli, Hospital das Clinicas HCFMUSP, Faculdade de Medicina, Universidade de Sao Paulo, SP, Brazil.

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Description of the forefoot/hindfoot offset (FHO) measurement

Weight-bearing computed tomography (WBCT) scans are obtained with the patient in an upright position, standing barefoot with the feet and ankles parallel to one another while facing forward in the direction of the longitudinal axis of the feet. The WBCT scanner allows imaging of the foot and ankle simultaneously. The parameters used for image acquisition are as follows: tube voltage, 120 kVp; tube current, 5.0mA; CT dose index (CTDI), 2.171 mGy; field of view (FOV), 20 cm high x 35 cm wide; and slice thickness, 0.3mm. After image acquisition (LineUp®; CurveBeam, Philadelphia, PA, USA), the WBCT scans are assessed with Cubevue® software (CurveBeam, Warrington, PA, USA).

According to a preestablished research protocol approved by the ethics committee of the institution where the study was conducted, 3 sequential WBCT images are acquired in feet clinically diagnosed as flexible cavovarus feet: the first with the patient standing upright, and the other 2 with the patient performing the Coleman block test. At this stage, each image is acquired with one foot resting on a block, while only the first ray of the other foot is not touching the block, keeping the lateral rays resting on it (Figure 1).

After image acquisition, DRRs are examined to confirm the deformity under study using the following radiographic parameters: Meary angle (Figure 2A), calcaneal pitch angle (Figure 2B), and Saltzman view (Figure 2C). Among WBCT measurements, hindfoot angle measured on the inferior point of the calcaneus (HA_{IC}) and FAO can also confirm a hindfoot varus (Figure 3).

To perform the measurement proposed in this study, configuration of sagittal plane alignment is not necessary, as the rotation of the limb does not affect its measurement. Sagittal reconstruction of the foot and ankle is performed with thicker slices so that the metatarsals can be assessed in 3D in the axial plane.

Figure 2. Digitally reconstructed radiographs (DRR). A. Lateral DRR – Meary angle. B. Lateral DRR – Calcaneal pitch. C. DRR measurements of the hindfoot alignment – Saltzman view.

Figure 1. Clinical assessment of flexible cavovarus feet. A. Note the bilateral hindfoot varus. B. Note the elevation of the longitudinal arch of the right foot. C and D. Coleman block test showing right hindfoot flexibility.

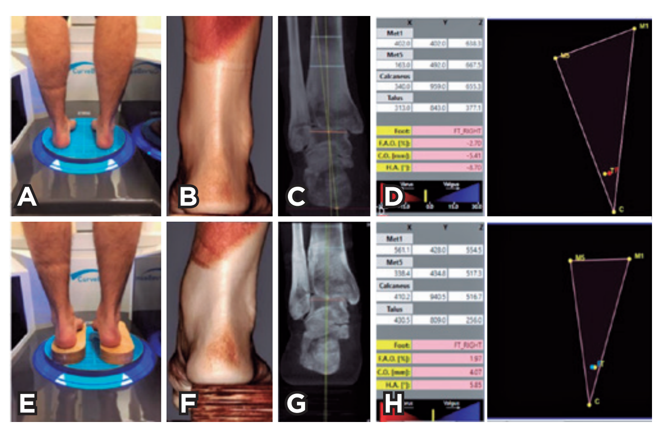

Figure 3. A and B. Protocol for weight-bearing computed tomography (WBCT) scanning in an upright position. C. Hindfoot angle measured on the inferior point of the calcaneus (HA_{IC}) in an upright weight-bearing position showing varus. D. Foot and ankle offset (FAO) in an upright weight-bearing position. E and F. WBCT scanning during the Coleman block test. G. HA_{IC} during the Coleman block test showing hindfoot valgus. H. FAO during the Coleman block test

A line is drawn running along the long axis of the second metatarsal, equidistant from the 2 diaphyseal cortices of the second metatarsal. The line is drawn through the midpoint of 2 lines that connect 2 cortices in the diaphyseal region of the second metatarsal (Figure 4A). After defining the axis of the second metatarsal, the slices that were thickened during sagittal reconstruction are returned to the original minimum thickness of image acquisition (0.3mm). In the axial plane, the shortest distance from this line to the weight-bearing point of the calcaneus is then measured. The weight-bearing point of the calcaneus is determined as the lowest point of the heel in the 3 available planes (axial, sagittal, and coronal). Measurements passing laterally to the weight-bearing point are considered positive, while those passing medially are considered negative (Figure 4B and 4C) (Table 1).

Table 1. Assessment of hindfoot alignment

	Regular	Coleman block test
Calcaneal pitch	31°****	
Meary angle	11°	
Saltzman view	9.5°	
FAO*	-2.7	1.9
HA**	-8.5°	-1.7°
FHO***	21.9mm*****	7.4mm

*Foot and ankle offset
**Hindfoot alignment
***Forefoot/hindfoot offset
****degrees
*****millimeters

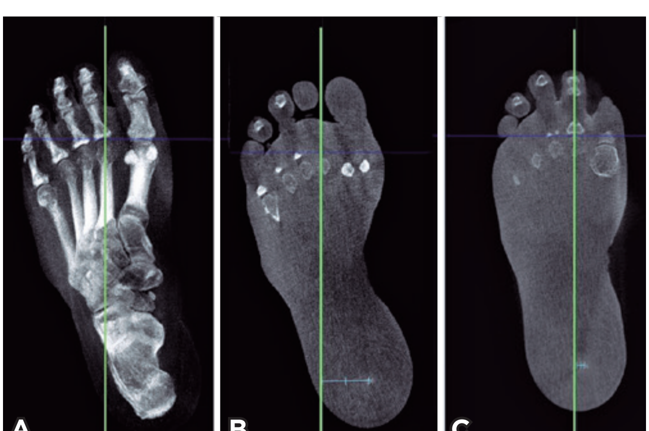

Figure 4. Forefoot/hindfoot offset (FHO). A. DDR – long axis of the second metatarsal. B. FHO – regular cavovarus foot. C. FHO – cavovarus foot, Coleman block test.

Discussion

Cavus foot deformity has been studied for decades. It is known that its pathophysiology is mainly due to a muscle imbalance in the feet[9]. In 1977, Coleman described the first test to assess hindfoot flexibility in cavovarus feet. This test is used worldwide to evaluate the behavior of the hindfoot when the first metatarsal is unloaded, which is responsible for hindfoot varus – the "tripod" effect[10]. In 1995, Saltzman described a radiographic view for measuring hindfoot alignment in relation to the tibia with the patient standing upright[4]. To this end, the second toe (forefoot axis) was standardized as a reference for the positioning of the foot during the test. Although widely used, it is known that this radiographic assessment of hindfoot alignment can change depending on the positioning of the forefoot[11].

In 2012, Lintz et al. published a mathematical model to calculate hindfoot alignment on radiographs using the forefoot as a radiographic parameter, regardless of the tibial axis. With the development of WBCT, this measurement was transformed into a software called Torque Ankle Lever Arm System (TALAS). Through a semiautomatic measurement, the software produces a 3D biometric measurement called FAO[8]. Although WBCT has tools capable of repositioning the foot on its sagittal axis, thus eliminating the positioning bias of radiographs, the assessment of hindfoot alignment in relation to the forefoot is already well established in the literature[7].

Although numerous radiographic measurements have been described for the assessment of foot alignment, only Graham et al. described a measurement to assess the behavior of the forefoot in relation to the hindfoot in standing position, called the talar-second metatarsal angle. The authors advocate the use of the second metatarsal axis because it is the most stable structure in the forefoot[12]. Measurement of the forefoot/hindfoot offset uses the same parameter as the forefoot – long axis of the second metatarsal – differing only in the parameter of the hindfoot.

Studies have shown that osteotomy to elevate the first metatarsal alone is not able to reproduce the hindfoot valgus observed during the Coleman block test in all patients[13]. Myerson and Myerson reported only 38% of satisfactory results in the correction of flexible cavovarus feet according to the Coleman block test. The authors believe that, because of its subjective nature, the Coleman block test creates a false impression of the real flexibility of the cavovarus foot[14].

There has been discussion among experts as to the validity of the FAO associated with the Coleman test, since, during the test, the first metatarsal head is not resting on the ground and, therefore, does not represent the physiological support of the tripod. The measurement proposed here allows to quantitatively measure forefoot alignment in relation to the weight-bearing point of the hindfoot in cavovarus feet, which can be useful in the surgical planning for correction of these feet. In addition, low radiation exposure along with high-speed acquisition of high-resolution 3D images by the WBCT scanner makes it possible to assess the real flexibility of cavovarus feet using only 2 image captures, with the patient standing upright and performing the Coleman block test.

The evident globalization of this technology and the development of new measurements, such as the one described here, will produce more reliable data and, consequently, better biomechanical compression of the foot, thus contributing to the reduction of unsatisfactory surgical results. We believe that future studies may also use this measurement to assess foot deformities such as metatarsus adductus and valgus flatfoot, among others[6].

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