A Computed Tomography Assessment of Hindfoot Alignment in Patients with Tarsal Coalitions

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ABSTRACT

Background: The aim of this study is to analyze the hindfoot alignment with computed tomography (CT-scan) in patients with tarsal coalitions. **Materials and Methods:** Eighty-five patients (78 feet) between 9 and 17 years of age were included and divided into 3 groups: A) without coalitions (control group, N 29), B) with calcaneal-navicular coalitions (CNC group, N 31), and C) with talo-calcaneal coalitions (TCC group, N 25). Five measurements were assessed: Inftal-Suptal, Inftal-Hor, Inftal-Supcal, Suptal-Infcal, and Talo-calcaneal angle (TCA). **Results:** Demographic data revealed no differences between groups with respect to the patient's age and sex (p = 0.3630 and 0.2415 respectively). Patients with tarsal coalitions presented significantly higher values in all measurements compared to the control group (p = <0.05 Kruskall-Wallis / ANOVA). TCA measurements in the patients with CNC and TCC were significantly superior to the control group (10.09 ± 4.60, 17.77 ± 11.28 and 28.66 ± 8.89 respectively, p = <0.0001). TCA distribution in the patients with CNC presented great variability, while group 3 (TCC) presented mostly a valgus alignment pattern. We did not find a direct correlation between the TCA and Inftal-Hor values (Spearman 0.27013, p = 0.1916). **Conclusion:** Patients with tarsal coalitions show an increased valgus orientation of the hindfoot. The deformity is greater in patients with TCC, while in those with CNC there is great variability. The increase in the hindfoot valgus does not necessarily indicate an increase in the inclination of the subtalar joint, so the latter must be evaluated separately at the time of preoperative planning.

Key words: Tarsal coalition; computed tomography; alignment; foot; children.
Level of Evidence: III

Análisis tomográfico de la alineación del retropié en pacientes con coaliciones tarsianas

RESUMEN

Introducción: El objetivo de este estudio es describir la morfología del retropié mediante cortes coronales con tomografía computarizada en pacientes con coaliciones tarsianas. **Materiales y Métodos:** Se incluyeron 85 pies de 78 pacientes de entre 9 y 17 años. Fueron divididos en 3 grupos: 1) grupo de control (n = 29), 2) con coaliciones calcáneo-escafoideas (CCE) (n = 31) y 3) con coaliciones astrágalo-calcáneas (CAC) (n = 25). Dos observadores valoraron cinco medidas: Inftal-Suptal, Inftal-Hor, Inftal-Supcal, Suptal-Infcal y el ángulo astrágalo-calcáneo (AAC). **Resultados:** Los grupos no presentaron diferencias en la distribución por edad y sexo. Los pacientes con coaliciones tarsianas tuvieron valores significativamente superiores en todas las mediciones comparados con el grupo de control (p <0,05 Kruskall-Wallis/ANOVA). Las mediciones del AAC en los pacientes con CCE y CAC fueron significativamente superiores a las del grupo de control (10,09 ± 4,60; 17,77 ± 11,28 y 28,66 ± 8,89, respectivamente, p <0,0001). La distribución del AAC fue muy variable en los pacientes con CCE, mientras que, en la mayoría del grupo CAC, tuvo un patrón de alineación en valgo. No hubo una correlación directa entre los valores del AAC e Inftal-Hor (Spearman 0,27013; p = 0,1916). **Conclusiones:** En los pacientes con coaliciones tarsianas, la orientación del valgo del retropié suele estar aumentada. La magnitud de esta deformidad es mayor en pacientes con coaliciones CAC, mientras que, en aquellos con CCE pueden manifestarse con una gran variabilidad. El aumento del valgo del retropié no implica necesariamente un aumento de la inclinación de la articulación subastragalina, por lo que esta última debe evaluarse por separado en la planificación preoperatoria.

Palabras clave: Coalición tarsiana; tomografía computarizada; alineación; pie; niños.
Nivel de Evidencia: III

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INTRODUCTION

Tarsal coalitions are congenital anomalies in which there is a fibrous, cartilaginous, or bony connection between two or more bones in the midfoot and hindfoot.[1] Fusions between the calcaneus and tarsal scaphoid, and between the talus and calcaneus represent the most frequent locations. The approximate incidence rate is 1%,[2] with a variable distribution by sex between 1: 1 and 4: 1 (male: female) in the different series. 50% are bilateral[3] and 3.8% of the cases have more than one coalition on the same foot.[4]

Those patients who suffer pain are usually managed initially with conservative treatment, but the effects obtained do not usually last.[5,6] The type of surgical treatment is usually based on the location of the pain, the type and size of the coalition, the alignment of the foot, and the presence of degenerative signs in the foot joints.[7] Although foot alignment is one of the main decision-making factors, there is little published information on the morphological characteristics of the foot in patients with tarsal coalitions.

The objective of this study is to describe the morphology of the hindfoot using coronal computed tomography (CT) planes in patients with calcaneonavicular (CNC) and talocalcaneal (TCC) tarsal coalitions.

MATERIALS AND METHODS

This study was approved by the ethics committee of our institution before starting. In a computerized search, patients between 9 and 17 years of age with foot scans performed between January 2010 and January 2019 at the same institution were identified. The patients were separated into three groups: with CNC, with TCC and a third control group formed by a healthy population (without coalitions), paired by age and sex. Patients with non-localized tarsal fusions between the calcaneus and the tarsal scaphoid or between the talus and the calcaneus, and those who had already undergone surgery, were excluded from the first two groups. Patients with displaced hindfoot fractures and sequelae of foot or ankle fractures that could alter the axis were also excluded from the control group.

CT Technique

All the images were taken in the same institution, with the same technique. The studies were performed with a Siemens Somatom Sensation tomograph with support, with sections <3 mm. If it both feet had to be evaluated, this was done in the same study. Two professionals analyzed the images with the Carestream PACS system, using the relevant measurement tools. To determine the angles, the sagittal plane was used, which allows observing the base of the second metatarsal, drawing a line that passes through 50% of the posterior subtalar joint. This section was then transferred to the coronal plane. In the coronal plane, five angles were measured: 1. *Inftal-Suptal:* angle between a line on the lower articular surface of the talus (subtalar) and another on the upper surface of the same bone (talar dome), 2. *Inftal-Hor:* angle between the subtalar joint line and a horizontal line parallel to the support mark, 3. *Inftal-Supcal:* angle between the inferior articular surface of the talus and the superior border of the calcaneus, 4. *Suptal-Infcal:* angle between the superior articular surface of the talus and the inferior border of the calcaneus and 5. *Talocalcaneal angle (TCA):* angle formed between a line perpendicular to the talar dome and another perpendicular to the lower edge of the calcaneus in its most prominent portion (Figure 1). The first four angles were described by Probasco et al.,[8] while the last (TCA) is an adaptation by the author[9] to the angle described by Wilde et al.,[10] and represents the overall alignment of the hindfoot.

Imaging evaluation

Image analysis and storage were performed with Kodak Carestream PACS Version 10.2 imaging program. Two observers evaluated the images separately and then defined the measurements by consensus. The demographic data and morphology of the coalitions were documented. The CNCs were classified according to Upasani et al.[11] in four types: forme fruste, fibrous, cartilaginous, osseous. For the TCC, we used the tomographic classification based on the 3D reconstruction proposed by Rozansky et al.[12] This classification groups CACs into five types: type I: linear, type II: linear with posterior hook, type III: shingled, type IV: osseous, and type V: posterior.

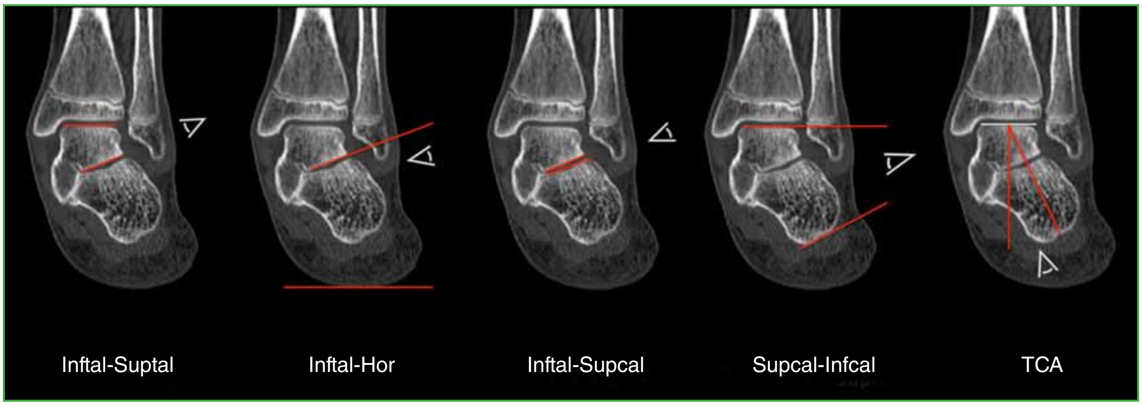

Figure 1. Measurement method of the angles analyzed in the coronal plane (computed tomography).
TCA = talocalcaneal angle.

Statistical analysis

The reproducibility of the Inftal-Suptal, Inftal-Hor and Inftal-Supcal angles has been evaluated in previous studies.[8] The inter- and intra-observer reproducibility of the TC angle was previously evaluated by the authors in a recent publication.[9] Statistical analysis was performed with the R 3.5.0 program (A Language and Environment for Statistical Computing, R Core Team, R Foundation for Statistical Computing, Vienna, Austria). The numerical variables were subjected to the Shapiro-Wilk test to know their distribution. The comparison between groups was made with ANOVA for variables with normal distribution and with the Kruskall-Wallis test for those without normal distribution. The contrasts between groups were made with the Tukey test. The correlation study was carried out with the Pearson correlation coefficient for variables with normal distribution and Spearman for those without normal distribution. A p value ≤0.05 was considered statistically significant.

FINDINGS

Eighty-five feet of 78 patients (45 men) were included. The average age of the sample was 11.5 ± 1.6 years. Groups were formed as follows: Group A (control, n = 29), group B (CNC, n = 31) and group C (TCC, n = 25). No statistically significant differences were found in the distribution by age and sex (p = 0.3630 and 0.2415, respectively) (Table 1).

Table 1. Characteristics of the sample

Characteristic	Group 1 (control) n = 29	Group 2 (CNC) n = 31	Group 3 (TCC) n = 25	p*
Age	10.90(2.43)	11.61(2.31)	11.84(1.64)	0.3630
Sex				
Female	7 (33.3%)	9 (39.1%)	3 (15.8%)	0.2415
Male	14 (66.7%)	14 (60.9%)	16 (84.2%)	

Values represented as average (standard deviation), absolute frequency (percentage).
*ANOVA, chi-square test
CNC = calcaneonavicular coalition, TCC = talocalcaneal coalition.

According to the classification by Upasani et al.,[11] CNCs had the following distribution: forme fruste (n = 5, 16%), fibrous (n = 5, 16%), cartilaginous (n = 17, 55%) and osseous (n = 4.13%). According to the Rozansky et al. classification,[12] TCCs were presented as type I: linear (n = 8, 32%), type II: linear with posterior hook (n = 2, 8%), type III: shingled (n = 4.16%), type IV: osseous (n = 9, 36%) and type V: posterior (n = 2.8%).

When comparing the measurements between the groups, the patients with tarsal coalitions presented significantly higher values than those of the control group (p <0.05 Kruskall-Wallis / ANOVA) (Table 2). The comparison of group by group measurements is shown in Table 3. TCA measurements in patients with CNC and TCC were significantly higher than in the control group (10.09 ± 4.60, 17.77 ± 11.28 and 28.66 ± 8.89, respectively, p <0 , 0001). The distribution in patients with CNC showed great variability, while the majority of group 3 (TCC) had a valgus alignment pattern (Figure 2). We did not observe a direct association when correlating the TCA and Inftal-Hor values (Spearman 0.27013, p = 0.1916) (Table 4).

Table 2. Comparison of measurements between groups

Measurement	Group 1 (control) n = 29	Group 2 (CNC) n = 31	Group 3 (TCC) n = 25	p
Inftal-suptal	10.84(7.35)	11.24(7.74)	17.28(10.21)	0.0371†
Inftal-hor	10.99(7.58)	15.44(7.35)	18.72(8.59)	0.0020*
Inftal-suptal	2.09(1.59)	3.52(1.93)	3.88(2.84)	<0.001†
Suptal-Infcal	14.48(7.58)	29.90(14.89)	44.10(11.06)	<0.0001*
TCA	10.09(4.60)	17.77(11.28)	28.66(8.89)	<0.0001†

Values expressed as mean (standard deviation). †Kruskall-Wallis test, *ANOVA of a factor.
CNC = calcaneonavicular coalition, TCC = talocalcaneal coalition.

Table 3. Group by group comparison of measurements

Measurement	Group 1 (Control) n = 29	Group 2 (CNC) n = 31	Group 3 (TCC) n = 25	Difference (IC95%)**	p
Inftal-suptal	10.84(7.35)	11.24(7.74)		0.40(-4.79-5.59)	0.9818†
Inftal-suptal	10, 4(7.35)		17.28(10.21)	6.44(0.96- 11.92)	0.0171†
Inftal-suptal		11.24(7.74)	17.28(10.21)	6.04(0.64- 11.44)	0.0245†
Inftal-hor	10.99(7.58)	15.44(7.35)		4.45(-0.37-9.27)	0.0762*
Inftal-hor	10.99(7.58)		18.72(8.59)	7.74(2.65- 12.82)	0.0014*
Inftal-hor		15.44(7.35)	18.72(8.59)	3.29(-1.73-8.30)	0.2668*
Inftal-suptal	2.09(1.59)	3.52(1.93)		1.42(0.10- 2.74)	0.0318†
Inftal-supcal	2.09(1.59)		3.88(2.84)	1.79(0.39- 3.18)	0.0085†
Inftal-suptal		3.52(1.93)	3.88(2.84)	0.36(-1.01-1.74)	0.8028†
Suptal-Infcal	14.48(7.58)	29.90(14.89)		15.42(8.22- 22.62)	<0.0001*
Suptal-Infcal	14.48(7.58)		44.10(11.06)	29.62(22.01- 37.22)	<0.0001*
Suptal-Infcal		29.90(14.89)	44.10(11.06)	14.20(6.70- 21.69)	<0.0001*
TCA	10.09(4.60)	17.77(11.28)		7.68(2.27- 13.09)	0.0030†
TCA	10.09(4.60)		28.66(8.89)	18.57(12.86- 24.28)	<0.0001†
TCA		17.77(11.28)	28.66(8.89)	10.89(5.27- 16.52)	<0.0001†

Values expressed as mean (standard deviation). †Kruskall-Wallis test, *ANOVA of a factor, **Differences derived from ANOVA, average comparisons between groups with Tukey contrasts.
CNC = calcaneonavicular coalition, TCC = talocalcaneal coalition.

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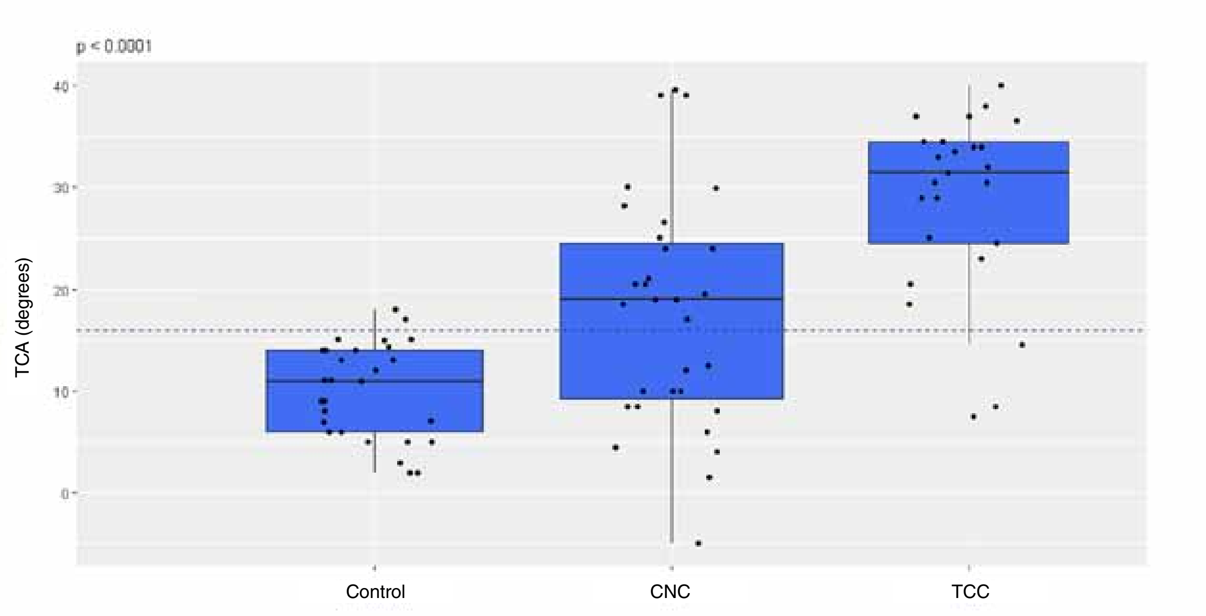

Figure 2. Distribution of the measurements of the talocalcaneal angle in the three groups evaluated. The dotted line marks the 16 ° of valgus considered as the limit value for the decision to reconstruct according to some authors.[16,22]
CNC = calcaneonavicular coalition, TCC= talocalcaneal coalition.

Table 4. Correlation between Inftal-Hor and the talocalcaneal angle

Group	Correlation	r^2	p	Spearman	p
Control	0.2663(-0.1110-0.5765)	0.0709	0.1626	-	-
CNC	0.3285(-0.0292-0.6116)	0.1079	0.0712	-	-
TCC	0.4085(0.0159- 0.6919)	0.1668	0.0426	0.27013	0.1916

CNC = calcaneonavicular coalition, TCC = talocalcaneal coalition.

DISCUSSION

Tarsal coalitions have been studied extensively. Most of the publications are oriented to diagnostic and therapeutic strategies to increase the success rate with surgical treatment.[13-17] Although some studies mention the characteristics of foot alignment,[7,10,11,18] the subject has not yet been adequately addressed in the literature. The main finding of our study is that the presentation of the coalitions has a great variability, for example, from patients with very severe valgus deformities to others with mild varus and multiple intermediate forms. Furthermore, we observed that the incidence of presentation of severe valgus deformities and the magnitude of this deformity is significantly higher in patients with TCC. Finally, it was observed that there is no direct relationship between hindfoot valgus and subtalar joint orientation.

Recent studies evaluating patients with TCC[7,18,19] indicate that the coalition is only part of the problem, since the deformity that usually accompanies the condition often requires treatment when it is severe. Some authors[20] consider that, in this scenario, it is convenient to treat with excision, regain mobility of the joint and later, only when the symptoms continue or the deformity progresses, realign the foot through osteotomies. Other authors[7,18,19,21,22] prefer to perform the realignment in the same stage. Although several authors[6,18] use the TCA (>

16 °) as a parameter to perform hindfoot realignment, we believe that the orientation of the subtalar joint should also be taken into account. In our study, the orientation of the subtalar joint (represented by the Inftal-Hor and Inftal-Suptal angles) was significantly greater (arranged more vertically) in patients with tarsal coalitions (Table 3). However, according to our results, there would not be a direct correlation between the TCA and Inftal-Hor values (Spearman 0.27013, p 0.1916). In other words, an increase in hindfoot valgus does not necessarily imply an increase in subtalar joint inclination and they could present as separate events (Figures 3 and 4). This fact would explain why some series report favorable results after isolated excision, a TCC with valgus >16 °.[23] However, when a patient undergoes an isolated excision and exhibits an increase in valgus associated with a marked inclination of the subtalar joint, the loss of the tension band effect subjects this joint to shear forces. If we associate this with the fact that the weight-bearing surface is smaller than normal after resection, the expected result is joint degeneration, pain, and loss of function.[7] In patients with CNC and severe valgus deformity, it is likely that the effect of resecting the coalition will have less consequences on the subtalar joint, although the biomechanical alteration resulting from the deformity does not allow the symptoms to be completely resolved. Quinn et al.[24] report that the valgus position of the calcaneus in patients with CNC would predispose to pathological and morphological changes of the calcaneus, fibula and subtalar joint. In their series, radiographic parameters improved significantly in patients treated with resection associated with foot realignment, although the indications for realignment were not clearly described.

The results of this study must be interpreted in the context of its limitations. Although the size of the series allows us to detect differences between the two most common types of coalitions (CNC and TCC) with a control group, the sample is not large enough to establish whether there is a relationship between morphology and level of deformity. For this purpose, a larger study involving several centers would be required. Second, the images were obtained with a tomograph with support, not weight-bearing. This could lead to a certain underestimation of the angular values obtained. We believe that the introduction of weight-bearing cone beam computed tomography[25,26] will increase the precision in the assessment of this pathology and probably modify current treatment recommendations. Third, despite the fact that we tried to gather a control group of subjects without pathologies that affected the alignment of the foot and who were paired by age and sex, we did not take into account other confounding factors, such as weight or the alignment of the lower limbs, which could affect the results. Another

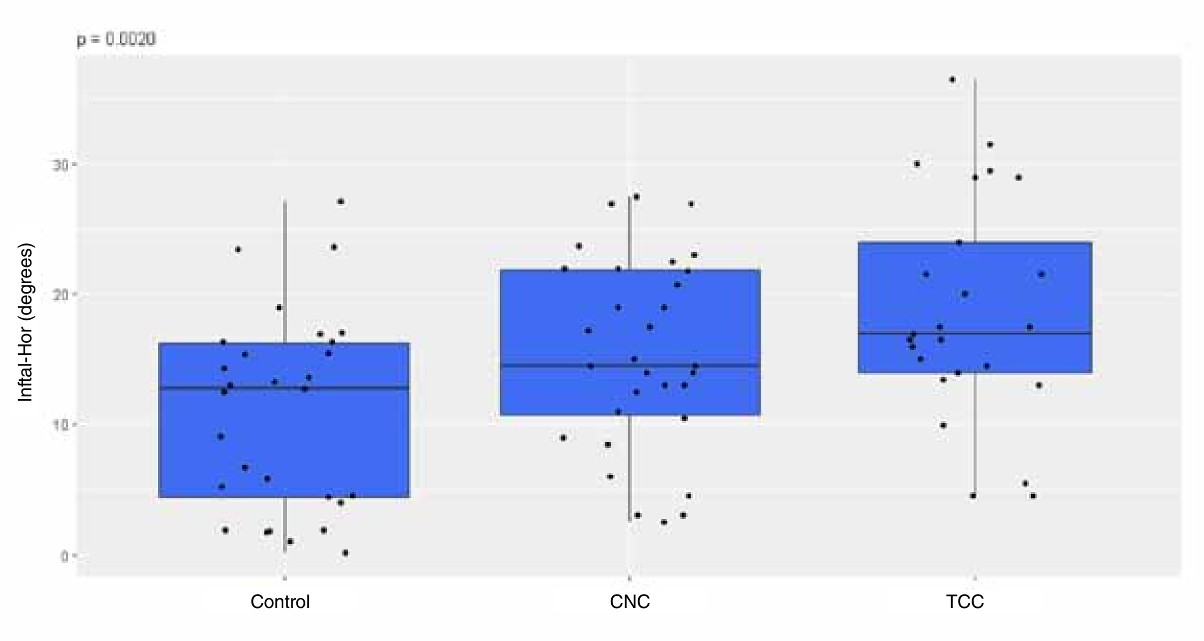

Figure 3. Distribution of the measurements of the Inftal-Hor angle in the three groups evaluated. CNC = calcaneonavicular coalition, TCC = talocalcaneal coalition.

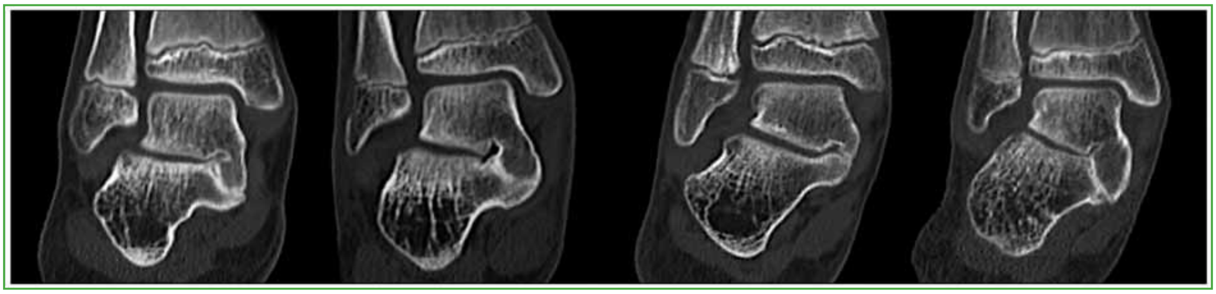

Figure 4. Hindfoot characteristics in four patients with talocalcaneal coalition. Note that the two cases on the left with marked valgus deviation (talocalcaneal augmentation) have a subtalar joint with an orientation almost parallel to the articular surface of the ankle, while the two on the right have a more vertically oriented subtalar joint.

potential limitation is the possibility that this study has evaluated a unique subset of patients with tarsal coalitions. Since most of the patients in the series required surgical treatment, it is possible that the cohort may have had a higher-than-average level of deformity at the time of evaluation. Finally, this study assesses the deformity in a single plane (coronal). Despite these limitations, we consider that this study provides additional information on hindfoot alignment in patients with tarsal coalitions that can be used for decision-making when planning surgery. Although hindfoot valgus alignment is often the current indicator of realignment, the deformity is three-dimensional and affects multiple joints. Patients with this condition usually have soft tissue contractures (gastrocnemius, soleus and peroneal) and variable degrees of external tibial rotation, midfoot abduction with lack of coverage of the talonavicular joint, and forefoot supination, so the deformity should be assessed as a whole.

In conclusion, patients with tarsal coalitions generally present an increased valgus orientation of the hindfoot compared to controls. The magnitude of this deformity is significantly greater in patients with TCC, while in those with CNC it can manifest with great variability. Increased hindfoot valgus does not necessarily imply increased subtalar joint inclination, so the latter should be evaluated separately when planning surgery.

Conflict of interests: The authors declare they do not have any conflict of interests.

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