Article

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Impact of Coleman Block Test on Adult Hindfoot Alignment Assessed by Clinical Examination, Radiography, and Weight-Bearing Computed Tomography

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Abstract

Background: Cavovarus foot constitutes a complex 3-dimensional deformity. The Coleman block test has traditionally been used to distinguish between forefoot- and hindfoot-driven deformity. However, there has been no objective evaluation of the Coleman block test using radiographs or weightbearing computed tomography (WBCT). The purpose of this study was to compare hindfoot alignment in adult cavovarus feet with and without the Coleman block using clinical examination, radiography, and WBCT.

Methods: Six feet in 6 patients with a clinical diagnosis of cavovarus foot deformity were prospectively enrolled. All feet underwent clinical photography with the camera positioned at 0 degrees to the heel, hindfoot alignment view radiography with the beam positioned 20 degrees off the ground, and WBCT, both with and without the Coleman block in place. Clinical photos were characterized using the standing talocalcaneal angle (STCA), radiographs were characterized using the hindfoot alignment angle (HAA), and WBCTs were characterized using manual and automated hindfoot alignment angle (HAA) and foot and ankle offset (FAO). Using paired analyses, measurements taken with the Coleman block in place were compared to those taken without the Coleman block. Finally, the different methods of measuring hindfoot alignment were tested for correlation with each other. Mean age was 56 years (range 38-69).

Results: On clinical photography, the STCA decreased by 3.8 degrees with addition of the block (from 10.0 ± 6.6 degrees varus without block to 6.2 ± 7.1 degrees varus with block; $P = .001$). On radiograph, HAA decreased by 9.0 degrees with addition of the block (from 16.8 ± 8.4 degrees varus without block to 7.5 ± 6.3 degrees varus with block; $P = .07$). On WBCT, hindfoot alignment angle changed an average of 3.2 degrees (33.4 degrees varus without block, 30.2 degrees varus with block; $P = .008$). On WBCT, FAO decreased by 1.4% (from 11.3% varus without block to 10.1% varus with block; $P = .003$). Clinical examination and automated WBCT measurements were strongly correlated with each other.

Conclusion: Clinical examination, radiograph, and WBCT demonstrated improvements in hindfoot varus using the Coleman block test in adults, but no patient demonstrated complete resolution of deformity regardless of the measurement modality. Clinical examination correlated strongly with automated WBCT measurements.

Level of Evidence: Level IV, retrospective case review.

Keywords: cavovarus, Coleman block, weightbearing CT, hindfoot alignment

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Table 1. Patient Demographics and Characteristics.

Patient Number	Age	Sex	Body Mass Index	Underlying Diagnosis	Meary Angle (degrees)	Calcaneal Pitch (degrees)
1	47	Male	36.6	Idiopathic	4.5	34.4
2	65	Male	34.4	Idiopathic	5.5	41.5
3	69	Male	29.2	Childhood poliomyelitis	17.8	29.2
4	53	Male	35.0	Idiopathic peripheral neuropathy	11.6	33.8
5	38	Male	33.5	Idiopathic	9.6	25
6	62	Male	35.7	Idiopathic peripheral neuropathy	6	28.6

Introduction

Cavovarus foot constitutes a complex 3-dimensional deformity.[1,13,18] Surgical planning for symptomatic deformities includes assessment of whether deformity originates in the forefoot or hindfoot, and whether it is flexible enough to perform a joint-sparing procedure.[1,10,13,14,18] These parameters have traditionally been assessed by use of the clinical Coleman block test (CCBT). First described by Coleman and Chestnut in 1977 and later studied by Paulos and Coleman in a case series in children, this test involves placing a block under the lateral foot, allowing the first ray to plantarflex freely.[5,21] The authors postulated that in deformities originating from a plantarflexed first ray, the block negates the "kickstand" effect of the ray.[5,10,20] If the subtalar joint is flexible, the heel may then assume a normal valgus position.

The ability of the CCBT to predict hindfoot flexibility and whether a joint-sparing procedure can be performed has been challenged.[19] Authors have suggested that the CCBT overestimates the flexibility of deformity, leading surgeons to choose operations that are underpowered to perform the necessary correction.[19] Interestingly, the CCBT has never been rigorously validated using radiographic means. There are no studies objectively correlating clinical hindfoot alignment with radiographic hindfoot alignment before and after Coleman block testing.

More recently, weightbearing CT (WBCT) has become available. The advent of this modality permits accurate assessment of complex foot deformity 3-dimensionally, such as pes planovalgus and hallux valgus.[4,6-9,11,13,15] WBCT overcomes the well-documented operator and anatomical biases of previous modalities such as projection and rotation issues,[2,3,23] and standardized 3-dimensional biometrics have been validated to study hindfoot deformity.[16] WBCT has also been found to be more accurate than traditional CT for evaluation of the foot and ankle.[12]

The purpose of this study was to compare hindfoot alignment in adult cavovarus feet with and without the Coleman block using clinical examination, radiograph, and WBCT. We hypothesized that the CCBT would overestimate the flexibility of hindfoot alignment when compared to WBCT. We also hypothesized that clinical examination would not strongly correlate with hindfoot values obtained by WBCT.

Methods

Patient Enrollment

Our institutional review board approved this study. Patients with a diagnosis of cavovarus foot deformity were initially identified as potentially eligible. Diagnosis of cavovarus foot deformity was made based on physical examination performed by fellowship-trained orthopedic foot and ankle surgeons and radiographs demonstrating a positive Meary angle. Patients were ineligible if they had any prior midfoot or hindfoot osteotomy or arthrodesis, or were younger than 18 years. Eligible patients were approached and invited to participate in the study. Demographic data including age, body mass index, underlying diagnosis (eg, Charcot-Marie-Tooth), and whether the patient had prior soft tissue surgery about the foot and ankle were recorded.

Demographics

Ten patients and 10 feet were recruited to the study. Four patients and 4 feet were excluded because of poor foot position on the Coleman block on either radiograph or CT imaging. A table of patient demographics is provided (Table 1). All patients were male. The average patient age was 56 (range 38-69), and the average body mass index was 34 (range 29.2-36.6). Three patients' underlying diagnosis was idiopathic cavovarus foot, 2 had idiopathic peripheral neuropathy diagnosed by a neurologist, and 1 had a history of childhood poliomyelitis. One patient had a history of prior peroneus brevis to longus tenodesis and lateral ligament reconstruction. The average Meary angle was 9.2 degrees (range 4.5-17.8 degrees), and the average calcaneal pitch was 32 degrees (range 25-41.5 degrees).

Data Collection

The Coleman block examination was performed in the same manner for clinical, radiographic, and CT testing, as described by Coleman and Chestnut.[5] Specifically, a 1.5-inch block was placed underneath the heel and lateral foot, allowing the first and second metatarsals to hang freely off of the block (Figure 1). Each of the following studies was performed both with and without the Coleman block in place.

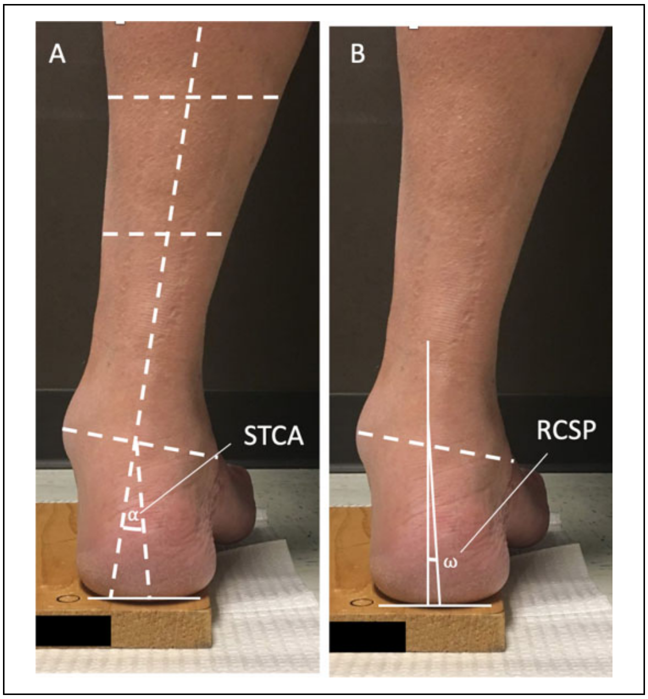

Figure 1. Examples of clinical hindfoot alignment measurements with the Coleman block. (A) Standing tibiocalcaneal angle (STCA) is represented by angle α, and (B) resting calcaneal stance position (RCSP) is represented by angle ω.

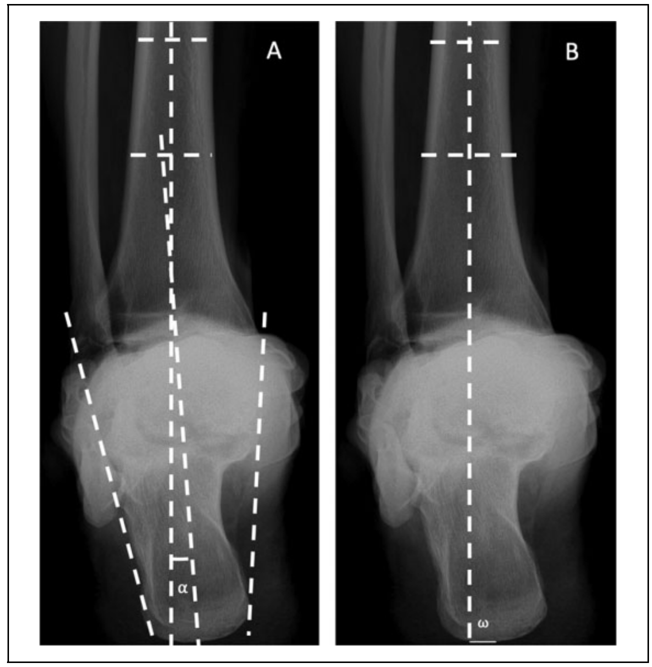

Figure 2. Examples of radiographic hindfoot alignment measurements without Coleman block. (A) Hindfoot alignment angle (HAA) represented by angle α, (B) hindfoot moment arm (HMA) represented by ω.

First, patients underwent clinical photography to document clinical hindfoot alignment. Digital photographs of the posterior were taken at ground level as described in detail by de Cesar Netto et al.[6] Feet were positioned at shoulder-width apart. Hindfoot alignment was calculated using the photographs based on 2 methods as previously described: standing tibiocalcaneal angle (STCA) and resting calcaneal stance position (RCSP) (Figure 1).[6] Briefly, for STCA, the first line (1) was made in line with the axis of the limb. A second line (2) was made connecting the most medial aspect of the medial malleolus and the most lateral aspect of the lateral malleolus. A third line (3) parallel with the floor was made connecting the borders of the lowest discernable level of the heel. A fourth line (4) was made connecting the center of line 2 to the center of line 3. The angle between lines 1 and 4 represented the STCA. For RCSP, a line (1) parallel with the floor was made connecting the borders of the lowest discernable level of the heel. A second line (2) was drawn perpendicular to the first line. A third line (3) was made connecting the most medial aspect of the medial malleolus and the most lateral aspect of the lateral malleolus. A fourth line (4) was made connecting the center of lines 1 and 3. The angle between line 2 and line 4 represented the RCSP.

Second, patients underwent hindfoot alignment plain-film radiograph views. The x-ray beam was directed 20 degrees downward, centered on the ankle, and the film was oriented perpendicular to the beam. Hindfoot alignment angle (HAA) was calculated using the resulting images as described by Williamson et al[25] (Figure 2). Specifically, a line representing the tibial axis was made by bisecting 2 points on the tibial shaft cortex drawn 100 and 150 mm proximal to the tibial plafond. Another line was made bisecting the medial and lateral contours of the calcaneus. The angle between the two represented the HAA. Hindfoot moment arm was calculated as defined by Saltzman and el-Khoury (Figure 2).[24] Specifically, the tibial axis was drawn the same as for the HAA. The moment arm was defined as the distance connecting the most inferior aspect of the calcaneus to a line drawn perpendicular to the tibial axis.

Finally, all patients had WBCTs performed using a Ped-CAT unit (CurveBeam LLC, Hatfield, PA). Measurements of hindfoot alignment were made using 2 different methods. The first method measured hindfoot alignment angle in a similar manner to that described by Williamson et al[25] and Saltzman and el-Khoury[24] for radiographs (Figure 3). The center of the tibia shaft was identified on coronal and sagittal views. On the coronal view at this position, a line representing the longitudinal axis of the tibial shaft was created by bisecting 2 lines connecting medial and lateral cortices 100 and 150 mm proximal to the tibial plafond. The weightbearing section of the calcaneus was then determined on coronal and sagittal views by finding the most inferior surface. On the coronal view at this position, the calcaneal axis was determined by bisecting 2 transversals between 2 lines adapted to the lateral and medial osseous contours of the calcaneus. The angle between the tibial and calcaneal axes

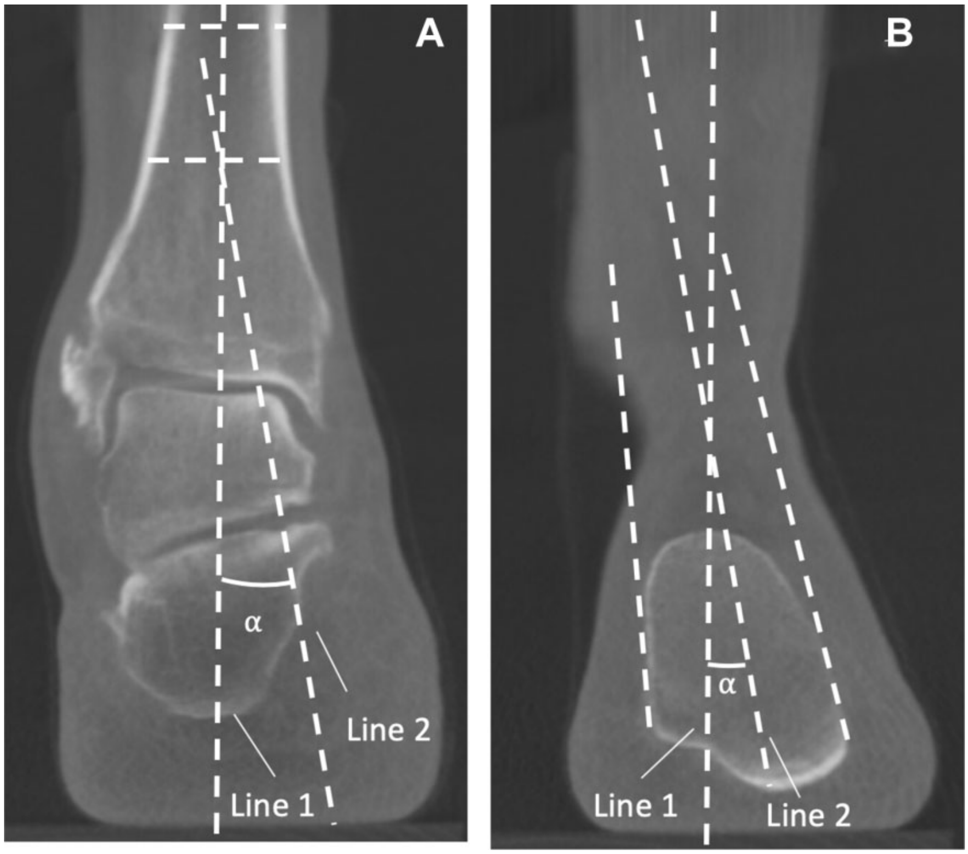

Figure 3. Example of manual CT hindfoot alignment angle (HAA). (A) The HAA (α) was calculated from the tibial axis (line 1) determined from coronal section (A), (B) and the calcaneal axis (line 2) determined from coronal section.

was defined as the "CT manual hindfoot angle" or CT manual HAA. The second method measured 3-dimensional biometrics using CurveBeam's built-in software, CubeView. Specifically, we utilized the semiautomated metrics of the Torque Ankle Lever Arm System (TALAS; Curvebeam LLC) to calculate the foot and ankle offset (FAO), calcaneal offset, and hindfoot alignment angle (Figure 4). As described by Lintz et al,[16] the FAO represents the offset between the hindfoot-to-forefoot midline and the talus and is given as a percentage of foot length to normalize FAO value to foot size. The calcaneal offset was defined as the distance between a theoretically neutral position of the calcaneus and the actual position of the calcaneus, presented in millimeters. This value is analogous to the radiographic hindfoot moment arm. The TALAS program also calculates the hindfoot alignment angle, which it defines by the center of the talar dome projected on the ground plane forming the vertex, and the ideal and actual position of the calcaneus forming the endpoints of the angle. We refer to this biometric as the "CT automated hindfoot alignment angle" (CT automated HAA) to differentiate it from our manual measurements of CT hindfoot alignment angle obtained as described above. We measured a "manual" hindfoot angle as described above in addition to this automated value because it can be readily replicated by surgeons who do not have a weightbearing CT scanner and TALAS software available.

Analysis

Average changes in clinical, radiographic, and CT hindfoot alignment before and after Coleman block testing were calculated within groups using paired 2-tailed *t* tests. Differences in clinical, radiographic, and CT hindfoot alignment (both manual CT HAA and automated CT HAA) between groups with and without the Coleman block were calculated using 1-way 4-factor ANOVA testing with Tukey post hoc testing. Correlations between STCA, radiographic HAA, CT manual HAA, CT automated HAA, radiographic hindfoot moment arm, and CT FAO were calculated between each group using Pearson correlation coefficients.

Results

Changes in hindfoot alignment after Coleman block testing after clinical, radiographic, and CT interrogation are summarized in Table 2.

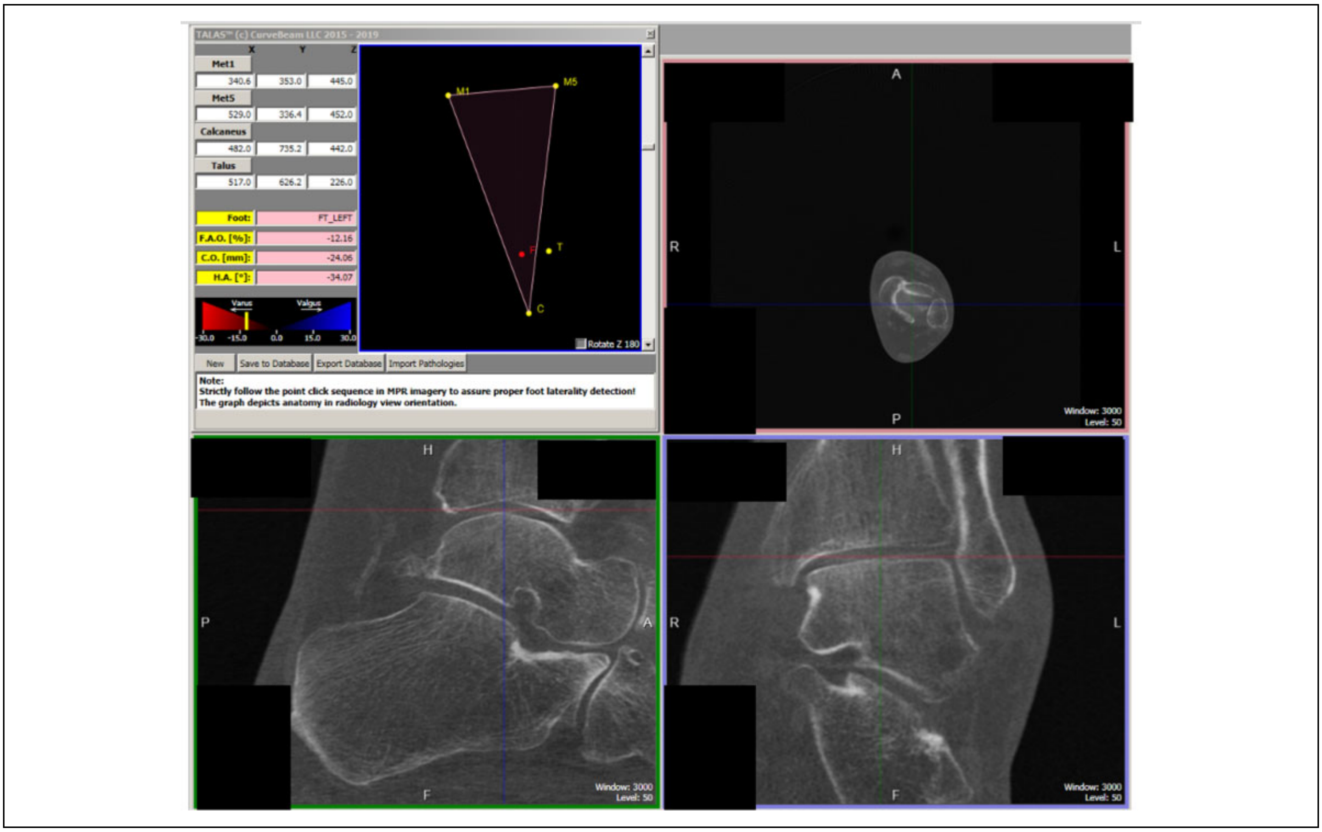

Figure 4. Example of calculation of foot ankle offset, calcaneal offset, and automated CT hindfoot alignment angle with the TALAS software (Curvebeam LLC). The top left box demonstrates the elements required to calculate these values, including M1 (first metatarsal weightbearing point), MS (fifth metatarsal weightbearing point), C (weightbearing calcaneus point), T (vertex of talar dome). 'F' is the calculated by the TALAS software and represents the center of the foot weightbearing surface. The inferior two boxes demonstrate how the vertex of the talar dome is determined by manual placement of x.y.z coordinates (green, red, and blue lines).

Table 2. Average Hindfoot Alignment Values Before and After Coleman Block Testing.

	STCA (Degrees)	Radiograph HAA (degrees)	Radiograph HMA (mm)	CT Manual HAA (degrees)	CT Automated HAA (degrees)	CT FAO (percentage)	CT CO (mm)
Without Coleman block	−10.0	−16.8	−25.1	−17.3	−33.4	−11.3	−22.0
With Coleman block	−6.2	−7.5	−15.0	−12.4	−30.2	−10.17	−19.8
Change with and without block 95% confidence interval	−6.3 to −1.4	−20.0 to 1.4	−17.1 to −3.1	−9.5 to −0.2	−5.1 to −1.3	−1.7 to −0.6	−3.2 to −1.1
P value	.01	.08	.01	.04	.008	.003	.003

Abbreviations: CO, calcaneal offset; FAO, foot ankle offset; HAA, hindfoot alignment angle; HMA, Hindfoot moment arm; STCA, Standing tibiocalcaneal angle.

Clinical Measurements

Hindfoot alignment changed after Coleman block testing on clinical examination. The STCA changed by 3.8 degrees from an average of 10.0 ($\pm$6.6) degrees of varus before block testing to an average of 6.2 ($\pm$7.1) degrees of varus after block testing ($P = .01$). Resting calcaneal stance position changed by the same amount of 3.8 degrees from an average of 9.5 ($\pm$4.4) degrees of varus to 5.6 ($\pm$3.9) degrees of varus after block testing ($P = .08$). When controlling for outliers, STCA and RCSP also had excellent correlation ($R > 0.9$, $P < .05$). We therefore arbitrarily used STCA when comparing clinical examination to the remainder of the imaging modalities.

Radiograph Measurements

Radiograph hindfoot alignment angle did not change statistically with and without the Coleman block (9 degrees of change from 16.8 ($\pm$8.4) degrees of varus to 7.5 ($\pm$6.3) of varus, $P = .07$). Radiograph hindfoot moment arm did

Table 3. Pearson Correlation Coefficients Between Clinical Examination, Radiograph, and Weightbearing CT Hindfoot Alignment Measurements.[a]

	STCA	Radiograph HAA	CT Manual HAA	CT Automated HAA	CT FAO
STCA	–	0.69*	0.42	0.82*	0.85*
Radiograph HAA	0.69*	–	0.31	0.71*	0.57
CT Manual HAA	0.42	0.31	–	0.23	0.28

Abbreviations: CO, calcaneal offset; CT, computer tomography; FAO, foot ankle offset; HAA, hindfoot alignment angle; HMA, hindfoot moment arm; STCA, standing tibiocalcaneal angle.
*Statistically different.
[a]Correlations between CT automated HAA and CT FAO were not performed as these were derived from the same data set.

change by 10.1 mm from 25.1 (±11.2) mm to 14.9 (±6.9) mm (P = .01).

WBCT Measurements

Manual CT HAA changed by 4.9 degrees from 17.2 (±4.8) degrees of varus to 12.4 (±7.7) degrees of varus (P = .04). Automated CT HAA changed 3.2 degrees from 33.4 (±15.1) degrees of varus to 30.2 (±16.5) degrees of varus (P = .008). Foot ankle offset (FAO) changed an average of 1.4% from 11.3% (±5.2%) varus to 10.1% (±5.6%) varus (P = .003).

Automated CT HAA measured significantly larger varus angles both before and after Coleman block testing as compared with clinical SCTA, radiograph HAA, and CT manual HAA (P < .05 on Tukey post hoc testing). However, the change in hindfoot alignment from pre- to post-Coleman block testing did not reach clinical significance between any of the groups, although being close to a statistically significant difference on Tukey post hoc testing between radiograph HAA and automated CT HAA (P = .05).

CT calcaneal offset changed by 2.2 mm from 22.0 (±10.0) mm to 19.8 (±10.7) mm (P = .003). There was no difference between radiograph hindfoot moment arm and CT CO before or after Coleman block testing (P > .05).

Correlation Between Measurements

Correlation between the different hindfoot alignment measurements are summarized in Table 3. There were strong correlations between SCTA and CT FAO (R = 0.8447, P < .001), between SCTA and automated CT HAA (R = 0.8192, P < .05), between SCTA and radiograph HAA (R = 0.6913, P < .05), and between radiograph HAA and automated CT HAA (R = 0.7137, P < .05). There was a moderate correlation between radiograph HAA and CT FAO (R = 0.5738, P = .05). Conversely, there was poor correlation between manual CT HAA and examination, radiograph, and automated CT measurements.

There was a strong correlation between radiograph hindfoot moment arm and CT calcaneal offset (R = 0.7829, P < .05).

Discussion

Coleman block testing resulted in improvements in hindfoot varus for adult cavovarus feet whether measured by clinical examination, radiograph, or WBCT. No patient demonstrated complete resolution of hindfoot varus with the block (ie, return to a valgus heel foot position), regardless of the modality used. In fact, no patient showed improvement even to neutral on WBCT imaging. There are several possible explanations for this. One explanation is that either the forefoot was a partial (but never a complete) "driver" of hindfoot varus deformity. Another is that there was a degree of rigidity in the hindfoot in all patients tested. This may suggest that in adults, cavovarus deformity correction is inadequate without significant hindfoot alignment correction. Another possible explanation is that the Coleman block test is not an accurate means of determining flexibility in adult cavovarus feet.

There were no differences between the hindfoot alignment angle measurements made by clinical examination, radiograph HAA, or manual CT HAA either before or after Coleman block testing. The automated WBCT HAA obtained through use of the TALAS program did suggest greater amounts of hindfoot varus both before and after Coleman block compared to clinical examination, radiography, and manual CT HAA, but found a similar *change* in varus from pre- to post-block testing compared with these other modalities. One potential explanation for this is that the automated CT HAA uses the center of the talar dome as the vertex of the angle as opposed to the other measurements that use a line through the tibial longitudinal axis. Radiograph HAA did seem to exaggerate the correction that was obtained by Coleman block testing when compared to automated WBCT HAA. This is likely related to issues of rotation, and difficulty in obtaining standardized radiographs from patient to patient, especially in the setting of significant deformity.

Interestingly, we found that clinical examination and radiograph correlated most strongly with the WBCT FAO and automated HAA measurements made using the TALAS program. This suggests that CCBT may be a reliable and inexpensive means of estimating the hindfoot alignment in cavovarus feet. This should not be construed to mean that WBCT is unnecessary in surgical planning. Hindfoot alignment is only a single parameter among many that can be assessed with WBCT (such as overall foot shape and deformity personality).

Surprisingly, manual measurements using WBCT showed poor correlation to other means of measurement. We hypothesize that this is because it is challenging and likely unreliable to select which coronal slices to use to draw the angles for measurement. We do not rule out the possibility that there may be better means of manually measuring HAA using WBCT, but we recommend caution when attempting these measurements.

Based on these results, we reject our hypothesis that CCBT overestimates hindfoot alignment flexibility as compared to WBCT. We also reject the hypothesis that CCBT does not correlate with WBCT hindfoot alignment.

Weightbearing CT is an excellent modality for understanding complex 3-dimensional foot deformities including pes planovalgus and hallux valgus.[4,6,7,9,11,13] Lintz et al[16] demonstrated in a series of 135 feet that the FAO provides a highly reproducible means to measure hindfoot alignment with excellent inter- and intra-rater reliability. WBCT has also been shown to be more accurate than 2D imaging obtained via radiographs.[23] WBCT avoids the well-documented problems associated with 2D radiographs such as rotation and operated-related bias.[2,3,22] WBCT is also more accurate for measuring foot and ankle deformity than conventional CT[12] and uses less radiation.[17] Given the complexity of cavovarus foot deformity and surgical reconstruction, we believe further consideration should be given to in-depth study with WBCT. In this vein, Lintz et al[15] recently demonstrated that WBCT was used to make an association between hindfoot varus and chronic lateral ankle instability.

Although our study suggests that CCBT may be a reasonable surrogate to judge hindfoot alignment angle, it does not invalidate other investigators' concerns about the reliability of the Coleman block test to predict outcomes of surgical deformity correction. The amount of deformity correction obtained with the Coleman block may not be correlated with the deformity correction that can be achieved with isolated forefoot or midfoot surgery (eg, dorsiflexion osteotomy of the first ray). Additionally, it is unclear how much deformity correction is necessary to achieve a good clinical outcome.

The authors believe this is the first study to correlate clinical Coleman block measurements objectively with either radiograph or CT data. Although the original case series by Paulos et al[21] performed clinical examination and radiographs, no attempt was made at correlating or validating the clinical and radiographic data.

This study has limitations. This was a retrospective study with only 6 patients included for data analysis, which creates potential for selection bias. Four patients had to be excluded because of poor position on the Coleman block despite training of our radiograph technologists. Investigators considering using the Coleman block with WBCT should consider having an outline of where patients' feet should be in the block to limit this problem. Although all patients had cavovarus feet, they did not all have the same underlying diagnosis or degree of deformity. Given the relative rarity of cavovarus deformity and the significant costs of performing this study, it would have been impractical for us to recruit a homogenous population. One patient did have a Brostrom procedure with a peroneus to longus to brevis transfer prior to the study, which theoretically could have affected the dynamic effect of the Coleman block. It should be noted that the patient's weightbearing foot radiographs prior to this procedure did not differ from postoperative radiographs in terms of Meary angle or talocalcaneal angles. We did not include any children in our study, and we hypothesize that children likely achieve larger corrections with the Coleman block because of greater innate flexibility and lesser contracture of the soft tissues. It may be interesting to study this population in the future, although the radiation associated with WBCT would need to be considered.

Conclusion

Clinical examination, radiography, and WBCT demonstrated improvements in hindfoot varus using the Coleman block test in adults, but no patients demonstrated complete resolution of deformity regardless of the measurement modality. Fortunately, clinical examination correlated strongly with automated WBCT measurements in determining the relative correctability with the Coleman block test. Further research is needed to determine the parameters required to evaluate cavovarus deformities and our current surgical procedures' ability to provide correction. Perhaps future evaluation of postsurgical correction with these modalities can provide additional guidance.

Ethics Approval

Ethical approval for this study was obtained from the Rush University Institutional Review Board (Approval # 17080602-IRB01-CR01).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

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