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Original Article

A modified method for measuring the calcaneal moment arm on weight-bearing computed tomography

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Abstract

Objective: This study introduced a modified weight-bearing computed tomography to measure the calcaneal moment arm (WBCT-CMA) and compared the CMA values between the original and modified techniques.

Methods: The WBCT scans of 10 healthy feet were loaded in the CubeVue software, correctly oriented in the transverse plane. Instead of using a specific single coronal cut of the tibia, as in the original WBCT-CMA method, the modified method includes the full thickness of the tibia in the coronal plane to better define the tibia axis. The CMA of each foot was evaluated using both methods. Intraclass correlation coefficient (ICC) model was used to assess the intra- and interobserver reliabilities of both techniques.

Results: There was no statistically significant difference between the CMA values generated from the two measurement techniques ($p = 0.99$). Both methods demonstrated excellent intra- and interobserver reliabilities (0.93 and 0.97 for the modified WBCT-CMA, and 0.93 and 0.94 for the original WBCT-CMA).

Conclusion: The modified WBCT-CMA is equivalent to the original WBCT-CMA in both intra- and interobserver reliabilities. Instead of using a relatively shorter tibia from one specific single cut, as in the original technique, the modified WBCT-CMA provides a reconstructed tibia with a longer and clearer shaft for measurement. This has the potential advantages of being easy to perform and less time-consuming, also reducing errors.

Level of Evidence III; Retrospective comparative study.

Keywords: Weight-bearing; Joint instability; Orthopedic procedures; Tomography, x-ray computed.

Introduction

In 1976, Cobey[1] introduced the posterior roentgenogram of the foot, a two-dimensional method for radiographically imaging the leg and heel in the coronal plane. This innovation made direct evaluation of the hindfoot alignment on X-rays possible. In 1995, Saltzman and El-Khoury[2] introduced the hindfoot alignment view and the parameter of apparent moment arm, which was quickly accepted and popularized as one of the main measurements of the hindfoot alignment.

In 2012, weight-bearing computed tomography (WBCT) was introduced to the field of foot and ankle[3]. This technology captures three-dimensional images whilst the patient is fully weightbearing. It has the advantages of overcoming the overlap of structures that is inevitable in the x-ray path, reducing operator-related bias[4], diminishing projection bias, and overall better demonstrating the geometry and health status of bones and joints in the foot[5] when compared to two-dimensional X-rays. It also better demonstrates the alignments of bones and joints in their biomechanical weight-bearing status when compared to traditional non-weight-bearing CT scans[6]. Therefore, WBCT is gaining more and more recognition and usage in evaluating the hindfoot alignment, as a strong addition to the traditional two-dimensional X-ray.

Study performed at the University of Colorado School of Medicine, Aurora, Colorado, United States.

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In 2021, Arena et al.[7] introduced the new technique for measuring the calcaneal moment arm (CMA) on WBCT scans (WBCT-CMA). However, the authors of this study have found that the WBCT-CMA technique leaves room for further inquiry in perspectives of accuracy, thoroughness, and ease of use.

The goal of this study was to modify the WBCT-CMA method into a new version, which was therefore called the modified WBCT-CMA, and compare the intra- and interobserver reliabilities between the modified and original WBCT-CMA techniques.

Methods

Subjects

This was a retrospective study using WBCT scans captured as part of routine clinical care. The study was conducted with institutional review board approval. Inclusion criteria were feet without remarkable foot and ankle deformities. The WBCT scans of 10 feet without remarkable deformities were used, with five scans from each laterality. Eight scans were from males (80%) and two scans were from females (20%). The age of subjects ranged from 22 to 51 years, with an average age of 35 years (SD = 11.18 years).

Measurement methods and data collection

The main difference between the modified WBCT-CMA and the original WBCT-CMA is that, instead of using a specific single coronal cut of the tibia as described in the original method, the modified method includes the full width and length of the tibia in the coronal plane to better and easier define the tibia axis[8].

All WBCT scans were imported into the CubeVue software (CurveBeam LLC, USA). The foot was first aligned in the transverse plane to a neutral 0° position in terms of internal and external rotation, based on the long axis going through the second metatarsal head and posterior base of the heel. Then, the calcaneus weight-bearing point was determined, as corroborated in the sagittal, coronal, and transverse planes. In the sagittal plane, thickness of one scan slice was increased to include the full width and length of the tibia in the coronal view, being careful as to not let the fibula occlude the lateral cortex of the tibia (Figure 1). By doing this, a reconstructed view of the full tibia in the coronal plane was obtained. In this view, two circles were drawn, with the distal circle tangent to the tibia plafond and both the medial and lateral cortexes of the distal tibia, while the proximal circle is in the most proximal aspect of the tibia, tangent to both the medial and lateral cortexes of the proximal tibia. The bisecting line connecting the midpoints of both circles and extending distally to the weight-bearing surface was used as the axis of the tibia. The calcaneus weight-bearing point was relocated in the coronal view using the intersection of axial lines. A line parallel to the ground was drawn between the calcaneus weight-bearing point and the extension of the tibial axis to measure the modified WBCT-CMA in the coronal view. When the weight-bearing point of the calcaneus fell on the medial side of the tibial axis, a negative modified WBCT-CMA value was recorded, indicating a varus hindfoot alignment; when the weight-bearing point of the calcaneus fell on the lateral side of the tibial axis, a positive modified WBCT-CMA value was recorded, indicating a valgus hindfoot alignment. Each value was measured twice by two independent observers.

Statistical analysis

An intraclass correlation coefficient (ICC) model was used to assess the intra- and interobserver reliability of CMA values (Table 1). The ICC values were interpreted as follows: less than 0.50, representing poor reliability; between 0.5 and 0.75, representing moderate reliability; between 0.75 and 0.9, representing good reliability; and greater than 0.90, representing excellent reliability[8]. A paired t-test was used to compare the average difference between the modified WBCT-CMA and original WBCT-CMA values. Statistical analysis was completed using the EXCEL and SAS software. A p value <0.05 was considered to indicate statistical significance.

Figure 1. In the original WBCT-CMA technique (top), the tibia axis is determined only in one specific coronal cut, denoted by the slice that has "the widest tibial diaphyseal distance at the most proximal edge of the image"[7] (top left). Alternatively, in the modified WBCT-CMA technique (below), the tibia axis is drawn on a reconstructed coronal view involving the full length and width of the tibia.

Results

There was no statistically significant difference in both intra- and interobserver reliabilities between the modified WBCT-CMA and original WBCT-CMA techniques. Both methods demonstrated excellent intra- and interobserver reliabilities (0.93 and 0.97 for the modified WBCT-CMA technique, and 0.93 and 0.94 for the original WBCT-CMA method). There was also no statistical difference between the CMA values generated using the two measurement techniques (average difference between both methods was 0.003 mm, p = 0.99).

Table 1. Intra- and interobserver reliability of both CMA measurements

	ICC	SD	95% CI	
			Lower	Upper
Overall				
Interobserver	0.93	0.02	0.87	0.96
Intraobserver	0.95	0.02	0.91	0.98
Original WBCT-CMA				
Interobserver	0.93	0.03	0.84	0.97
Intraobserver	0.94	0.03	0.85	0.97
Modified WBCT-CMA				
Interobserver	0.93	0.03	0.84	0.97
Intraobserver	0.97	0.02	0.93	0.99

ICC: Intraclass correlation coefficient; SD: Standard deviation; CI: Confidence interval; WBCT-CMA: Weight-bearing computed tomography to measure the calcaneal moment arm

Discussion

Hindfoot malalignment can lead to pain, disability, and joint degeneration[9]. The accuracy and precision in evaluating the hindfoot alignment is critical to clinical practice. This study introduced a modified WBCT-CMA method with the goal of increasing the accuracy and ease of use of the measurement.

Mainly, the modified WBCT-CMA differs from the original WBCT-CMA in the way how the tibia axis is established. In the original WBCT-CMA, the tibia axis is drawn in a single coronal slice which has the "widest tibial diaphyseal distance at the most proximal edge of the image." However, this methodology could be easily biased by interpretation, human error, and radiographic inadequacy. For example, one observer may determine slice "A" has the widest proximal tibial diaphyseal distance, while another observer may identify an entirely different cut slice "B," millimeters away. Furthermore, a single coronal cut based purely on the proximal edge of the image may be compromised by radiographic inadequacy, an incomplete view, or an image that does not capture detailed architecture. Most importantly, as demonstrated in Figure 2, the cut with the "widest tibial diaphyseal distance at the most proximal edge of the image" chosen for drawing the proximal circle in the original WBCT-CMA technique does not guarantee inclusion of the tibial plafond for placing the distal circle. Likewise, the cut including the whole tibial plafond may not be the one with the "widest tibial diaphyseal distance at the most proximal edge of the image." In essence, the "single cut" window is too restrictive to allow including the maximal

Figure 2. At the widest tibial diaphyseal distance at the most proximal edge of the image, the first image demonstrates how the tibia plafond may not be in view, whilst the third image (following the WBCT-CMA method[7]) demonstrates a cut where the tibia plafond was in view. With the distal tibial plafond secured, the middle image demonstrates how the most proximal edge of the image is poorly defined, thus the proximal circle had to be placed more distally to adequately capture the edges of the tibia.

width of the tibia both proximally and distally. To address the aforementioned issues, the modified WBCT-CMA method includes multiple coronal cuts and stacks them together to reconstruct the full coronal width of the tibia. Thus, there is no compromise in defining the tibia axis both proximally and distally. By doing so, it also increases the possibility of including more of the proximal tibia in view. A short tibial view might be deceiving in patients with deformity or other anatomic deviation in the proximal tibia, such as genu varum and genu valgum, or an anteriorly/posteriorly bowing tibia or leaning tibia due to dorsiflexion or plantarflexion of the ankle. Especially in the example of an anteriorly/posteriorly leaning tibia, the position of a single coronal slice drastically alters the resulting image, with the risk of capturing a truncated tibia (Figure 1). Incorporating the whole length of scanned tibia allows a measurement more proximal on the tibial diaphysis and, therefore, better reflects the long axis of the tibia. Moreover, the thicker coronal slice yielded more anatomic detail (Figure 1) and a greater view of the hindfoot and surrounding structures for the alignment assessment, particularly in legs with deformities. Improved anatomic detail provides clearer and sharper proximal aspects of the tibia and has the additional benefit of creating less difficulty in placing the proximal circle, also reducing the laborious task of finding the "one" specific cut for establishing the tibial axis.

Statistically speaking, both methods are equivalent. However, the modified method is more reliable in determining the view in which to measure the tibia axis. Thus, bias in selection is reduced, allowing for more robust measurements and the ease of duplicity.

The modified WBCT-CMA and the original WBCT-CMA have some common limitations. Firstly, how close the long axis generated from bisecting the tibia proximally and distally is to the real alignment of the tibia highly depends on how much of the tibia has been scanned. It may not reflect the natural curvature of the tibia and might lead to over- or underestimations of valgus or varus deformities. Secondly, the CubeVue software (version 3.9.195, CurveBeam LLC, 2021) only has the ellipse feature, without the function of drawing a perfect circle. This inevitably introduces human error. Thirdly, as for the anterior-posterior as well as medial-lateral correction that has been described above, rotation on the axial plane was not standardized in either method. Rotation of the foot during acquisition of axial radiographs or rotation of the axial WBCT image will significantly affect the outcome of hindfoot measurements. However, this was the topic of a paper recently published and was not the focus of this study[8].

Conclusion

In sum, the modified WBCT-CMA has equivalent intra- and interobserver reliability when compared to the original WBCT-CMA. In addition, it has the potential advantages of ease of use, less consumption of time, and reduced selection bias by including full thickness of the tibia in the coronal plane.

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