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Reliability of hindfoot alignment measurements from standard radiographs using the methods of Meary and Saltzman

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ABSTRACT

Background: Few methods have been described for measuring hindfoot alignment from an anteroposterior view. The objective of this study was to compare two methods of angular measurement based on the views of Meary and Saltzman.

Methods: Thirty asymptomatic volunteers were included. Four radiographs were performed: the views of Meary and Saltzman with parallel feet and with the Fick correction. The reproducibility was determined by the inter- and intraobserver variability (ICC).

Results: Meary's method revealed a mean valgus angulation of 3.9° (SD 3.47°). The reliability was extremely variable with a mean ICC of 0.59. The best reproducibility was obtained with Meary's method with and without Fick correction.

Conclusion: The results of this study show that the reliability of the angular measurements depends on the radiographic view and measurement method chosen. The lateral Fick correction did not counteract the influence of tibial rotation. The same method should be used consistently.

1. Introduction

The calcaneus is essential for the initial heel strike and later in the stance phase of the walking gait cycle. Many pathologies of the foot and ankle can disturb hindfoot alignment, in which case calcaneal osteotomy may be needed to realign the heel support in the frontal plane. In order to assess the extent of deformity, radiographic measurements are needed to build a strategy for correction. Two methods have been described for measuring hindfoot alignment from an anteroposterior view under weight-bearing conditions: the method of Meary et al. [1–3], which is principally used by the French-speaking community, and the hindfoot alignment view (HAV) described by Saltzman and el-Khoury [4] which is more extensively used by the Anglo-American community.

Unfortunately, the angular measurements from radiographs provide only a static representation of the hindfoot: the measurements taken from an anteroposterior view, even though walking occurs in slightly external rotation. In addition, the position of the radiopaque film or metal markers (for Meary's angle) and the choice of bone markers are essential to ensure the reproducibility of the measured angles. The disadvantages have been widely acknowledged: standard radiographs generally provide only two-dimensional (2D) representations of 3D anatomical structures and the variation in the angulation of the images or the rotation of the tibial segment has a deleterious effect on the angular measurements [2,3]. For these reasons, various authors have suggested alternative methods: different radiographic views [5–9], methods of correction [9,10], scanographic or biplane analysis [11,12], and even 3D reconstruction [8].

The objective of this study was to compare two methods of angular measurement based on the views of Meary and Saltzman. We sought to quantify the reproducibility of each method and to assess its impact on the measure of hindfoot alignment.

2. Methods

2.1. Participants

Thirty asymptomatic volunteers were included in this study after giving informed consent: 15 men and 15 women. The inclusion period ran from 1 January 2011 to 1 September 2011. The research protocol was approved by the institutional ethics committee. We confirmed the asymptomatic status by clinical examination of both feet and excluded any volunteer with a history of trauma or pain in the foot and ankle or any podoscopic

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abnormality. The mean age of the participants was 37.1 ± 10.6 years (21–60).

2.2. Radiographic techniques (Fig. 1)

In all cases, imaging was performed in bilateral weightbearing conditions with shoes removed. For Meary's method, the feet were "parallel" to the axis of the second metatarsal, which was placed in the centre beam axis. The outline of the hindfoot and ankle was traced with a radiopaque metal wire taped to the skin. A frontal radiograph was performed in the axis of the second metatarsal (criterion of rotational validity) with a horizontal beam focused on the centre of the ankle. The mechanical axes of the two hindfeet were constructed by taking into account bone and soft tissues [1,2]. With this technique, a normally oriented hindfoot has a physiological valgus of 2°–5° [13,14].

For Saltzman's HAV, the feet were parallel and the participants were standing on a radio transparent film cassette. The beam was oriented to 20° from the horizontal, and the plate was inclined and perpendicular to the beam. The calcaneal axis was traced from its central point (or the centre of the cancellous bone of the tuberosity, with a metallic marker on either side of the calcaneus). The angle between the calcaneal axis and the tibial axis was measured with respect to the centre of the ankle [4].

Last, the same views were obtained (Meary's frontal view and Saltzman's HAV) with a 15° lateral rotation of the ankle to correspond to natural walking, known as the Fick correction [15] (Fig. 1).

2.3. Protocol for angular measurement (Fig. 2)

Four radiographs were performed for each participant: the views of Meary and Saltzman with parallel feet, and the views of Meary and Saltzman with the Fick correction. Hindfoot alignment was measured on each plate by the tibiocalcaneal angle, which is the angle between the diaphyseal axis of the tibia and the longitudinal axis of the calcaneus, as described in the original works [1,4].

For Meary's view, the angular measurement was made with a metal wire or malleolar pincers. For Saltzman's HAV, we applied two types of correction to specify the construction of the calcaneal longitudinal axis. These two corrections could also be combined:

– for the correction of Van Dijk [9], we used the centre of the intersection of two horizontal lines drawn 7 and 20 mm from the most distal point of the calcaneus. After verifying the reliability of this protocol, we used the centre of the 7 and 40 mm intersections, called the modified Van Dijk correction.

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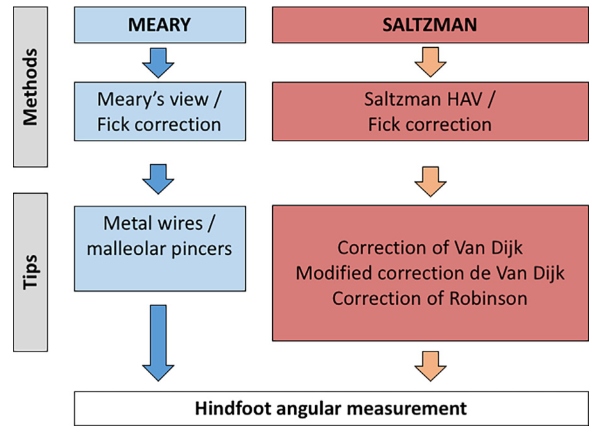

Fig. 2. Protocol for the angular measurement of hindfoot alignment with details on views and correction methods.

the correction of Robinson et al. [10] does not to use the middle of the heel width (50/50) but instead places a marker located 40% along the length of this line on the side of its lateral edge (60/40). The examples of the different methods of measurement and correction are illustrated in Fig. 3.

2.4. Analysis of reproducibility and statistical analysis

The reproducibility of each method was determined by the inter- and intraobserver variability and expressed by the intraclass correlation coefficient (ICC) of Eliasziw et al. [16] The angular measurements with each method were made on the same day by two independent examiners (PM and MM), who repeated a second series of measurements one month later. The literature shows that an ICC ≥0.85 is required to justify using a method for routine clinical practice [17].

Statistical analysis was performed with SPSS Statistics (version 20.0.0 for Mac OS X, IBM, NY). $P < 0.05$ was considered statistically significant for all analyses, with a confidence interval of 95% (95% CI). The variability in the angular measurements was expressed as a function of the mean angular deviation and the standard deviation (SD) corresponding to each series of measurements. A variability of 2 SD made it possible to approximate the 95%CI around each measurement method.

3. Results

The mean measurements of the tibiocalcanean angle and their variability (SD) with the two methods are presented in Fig. 4, as are

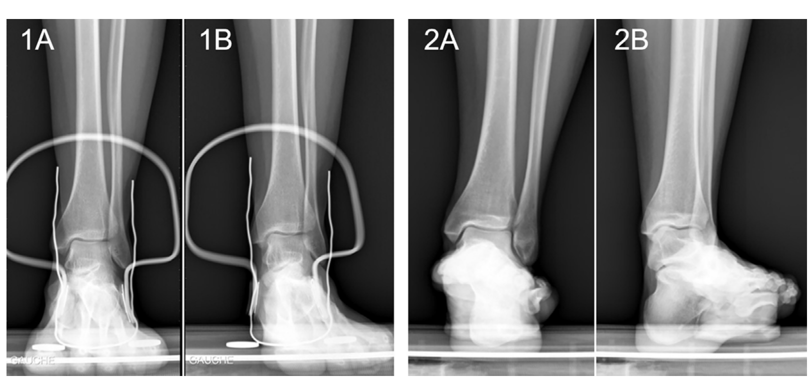

Fig. 1. Radiographic protocol with either Meary's view (1A) or Saltzman's hindfoot alignment view (2A), and with 15° of lateral rotation: the Fick correction (1B and 2B respectively).

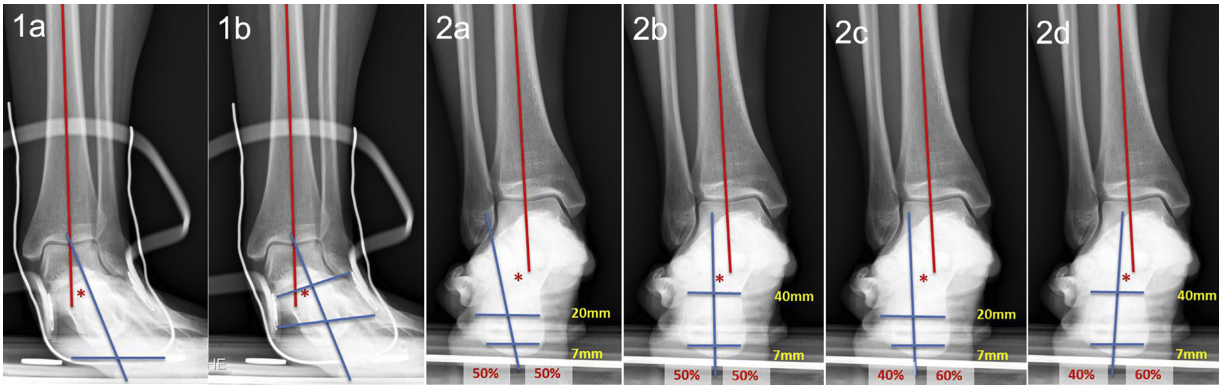

Fig. 3. Illustration of the different methods of measuring hindfoot alignment (*): Meary's view using (1a) metal wire and (1b) malleolar pincers; Saltzman's view plus (2a) the van Dijk 7–20 mm correction, (2b) the modified Van Dijk 7–40 mm correction, (2c) the combination of the van Dijk 7–20 mm correction and the Robinson correction, and (2d) the combination of the Van Dijk 7–40 mm correction and the Robinson correction.

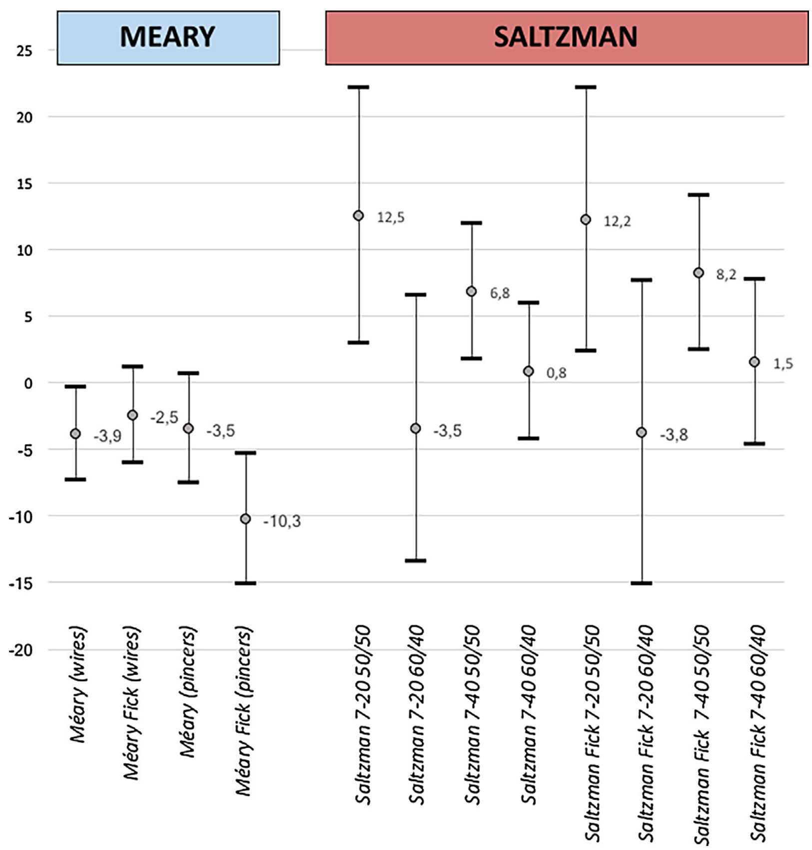

Fig. 4. Means and standard deviation (SD) of angular measurements using the different methods. Hindfoot valgus is denoted negatively.

the findings on reproducibility. Meary's method revealed a mean valgus angulation of 3.9° (SD 3.47°) in the healthy volunteers. This same mean value was found with Meary's method plus the Fick correction and Meary's method using pincers. The angulation measured on the HAV radiograph showed wide variation depending on the method plus correction used, ranging from a mean valgus angle of 3.5° [SD 10.05] to a mean varus angle of 12.5° [SD 9.57]. Although not significant, a tendency was noted for greater dispersion in the measurements with Fick's lateral rotation correction, whether for Meary's or Saltzman's method.

The reproducibility of the methods was extremely variable (Table 1), with a mean ICC of 0.59 (SD 0.22). The best reproducibility was obtained with Meary's method (ICC: 0.92 and 0.88 respectively) and Meary's method plus the Fick correction (ICC: 0.95 and 0.96).

4. Discussion

Hindfoot malalignment is observed in many types of foot and ankle pathology, such as flat foot, high arches, posttraumatic malunion or talocrural osteoarthritis. It is affected by both local morphological parameters of the foot and ankle (such as the collapse of the medial arch in flat foot) and regional parameters of the lower limb, such as a total knee prosthesis [6,18]. Angular measurements are therefore crucial for assessing the static foot as a whole, evaluating the need for surgical correction, and planning

Table 1
Reproducibility based on the method and correction used, with inter- and intraobserver variability expressed by the intraclass correlation coefficient (ICC). The lateral rotation correction is marked Fick, the Van Dijk correction is denoted 7–20 (intersections at 7 and 20 mm from the most distal point of the calcaneus), the modified Van Dijk correction is denoted 7–40 (intersections at 7 and 40 mm from the most distal point of the calcaneus), and Robinson's correction is denoted 60/40 (marker located 40% along the heel width from the lateral edge).

	Mean ± standard deviation	Interobserver variability (ICC)	Intraobserver variability (ICC)
Méary	$-4° \pm 3.5°$	0.92*	0.88*
Méary Fick	$-2.5° \pm 3.6°$	0.95*	0.96*
Pincettes	$-3° \pm 4.1°$	0.81	0.78
Pincettes Fick	$-10.35° \pm 4.9°$	0.62	0.74
Saltzman 7–20 50:50	$12.5° \pm 9.6°$	0.22	0.71
Saltzman 7–20 60/40	$-3.5° \pm 10°$	0.60	0.81
Saltzman 7–40 50/50	$6.9° \pm 5.1°$	0.36	0.78
Saltzman 7–40 60/40	$0.8° \pm 5.1°$	0.60	0.81
Saltzman Fick 7–20 50/50	$12.2° \pm 9.9°$	0.50	0.72
Saltzman Fick 7–20 60/40	$-3.6° \pm 11.4°$	0.44	0.66
Saltzman Fick 7–40 50/50	$8.1° \pm 5.8°$	0.50	0.88*
Saltzman Fick 7–40 60/40	$1.5° \pm 6.2°$	0.55	0.89*

the degree of correction. Nevertheless, many authors have pointed out the poor reliability of standard radiographic measurements for this evaluation, whether in functional weightbearing or non-weightbearing conditions [5,9–14,19]. To our knowledge, this is the only study comparing the reliability of several methods for measuring hindfoot alignment that includes Meary's method, as the only other comparison between the two views involved ankle alignment [20]. In addition, earlier studies on the reliability of Meary's measurement did not appear in international journals [1,2,21].

The mean value and the dispersion of the angular measurements differed significantly with the method used. Mean valgus angles of 3.5° were found using Meary's method and Saltzman's HAV with the Van Dijk correction (7–20) and with the Robinson correction (60/40) with or without the Fick correction. Saltzman's method nevertheless presented a larger dispersion of values than Meary's (3.5° vs 10°). The modified Van Djik correction (7–40) was the only technique for finding a neutral alignment close to 0°. The other HAVs with corrections showed high mean values, varying between 6° and 12°. The difference in angular measures between the two views has been noted by others [20]. In terms of reproducibility, Meary's view with a metal wire circling the heel resulted in the best inter- and intraoperator reproducibility. The use of metallic pincers did not improve reproducibility more than with the use of the metal wire alone. The low reproducibility of Saltzman's HAV has already been emphasized in the literature. Reilingh et al. compared Saltzman's HAV with the "long axial view" or LAV [9]. The main difference between the two was the angulation of the beams with respect to the ground, respectively of 20° and 45°. The authors concluded that the HAV measurements showed low accuracy, particularly regarding interoperator variability (ICC: 0.58). Our results are consistent with this finding, with mean interoperator variability of 0.47, depending on the correction method. Saltzman and el-Khoury noted excellent interoperator reproducibility of 0.97 using the measurements obtained with their method [4]. Reilingh et al. explained the variability in their results as being due to differences in the measurement protocols: the lower beam inclination produces a lower projected height of the calcaneus and increases the measurement error around the construction of the longitudinal axis of the calcaneus [9]. To extend the comparison with Saltzman's HAV, we performed measurements using several types of correction, in line with these authors [9]. The interest of the Robinson correction (60/40) is that it better represents the bisection of the hindfoot and insertion of the calcaneal tendon. The modified Van Dijk correction (7–40 mm) seems to be more suitable for constructing the longitudinal axis of the calcaneus, similar to the LAV. The two points of construction being farther away, this correction minimizes the construction errors, with smaller measurement variability and greater intraoperator reproducibility. Only the combination of HAV with the modified Van Dijk correction resulted in intraoperator ICC >0.85.

We also quantified the impact of the lateral rotation correction on the angular measurements and their reproducibility (Fick correction). Ikoma et al. pointed out the difficulties of analyzing hindfoot alignment given calcaneal morphology and the interpretation of its bone limits [5]. Moreover, several factors increase the angular variability: the radiographic superposition of the foot bones on the views, the difficulty of selecting the calcaneal points of contact, and the dependence of the projected measurement on tibial rotation. The lateral Fick correction did not counteract the influence of tibial rotation. We explained this result because the correlation between static and dynamic measurements has not been reported in the literature and the Fick correction is probably associated to a great variability in normal population and particularly in pathological feet. The authors of studies on hindfoot alignment have insisted on the fundamental importance of describing the position of the weightbearing foot. Baverel et al., for example, studied the influence of rotation on the angular measurement from conventional radiographs [12]. The value of the tibiocalcaneal angle was maximal when the view was centered on the second metatarsal, and it then varied according to the tibial rotation in parabolic form. According to their results, lateral or medial rotation underestimated the value of the tibiocalcaneal angle. Although Meary's method yielded good reproducibility, two sources of measurement bias should be noted: ankle rotation and dependence on the second metatarsal, the position of which can be modified in pathological conditions, such as metatarsus adductus.

Standard radiographs must therefore be used with caution, and several alternatives have been considered in the literature to improve hindfoot evaluation: vary the radiological views, develop new methods for angular measurement, or use new imaging systems. Although some authors have proposed other radiographic views to improve angular measurement reliability (LAV) [9], others have suggested new imaging techniques to assess weightbearing hindfoot alignment. Burssens et al. compared weightbearing CT (PedCAT) to conventional X-ray analysis and proposed a new method of CT-based angular measurement [8]. The talocalcaneal angle measured with respect to the vertical showed better reproducibility for valgus and varus analysis of the hindfoot. Nevertheless, this method required the identification of a single weightbearing point. This point corresponded to the most distal point of the large calcaneal tuberosity, and some authors have stressed the difficulty of identifying this region of interest despite its possible acquisition in 3D space [7]. Burssens et al. associated an ICC >0.7 to the construction of this point in conditions of valgus or varus deformity, but acknowledged the greater difficulty of identifying it in a normally aligned hindfoot [8]. It is thus reasonable to question whether this measure would be valid for routine clinical practice, given that identifying a normally aligned hindfoot is as important as identifying pathological hindfoot in consultation. Lintz et al. suggested combining the position of the forefoot, the ground reaction forces and the calcaneal offset rather than using the tibiocalcaneal angle [7]. This mathematical tool can be used with standard radiographs (Meary's view) but its main utility is in assessing the extent of surgical correction. These authors supported 3D imaging to minimize the errors that occur when 3D data is extracted from 2D images [7]. In line with this principle, the EOS imaging system (EOS Imaging, Paris, France) allows the calibration and correspondence of biplane radiographic views and thus theoretically minimizes these errors. This biplane imaging technique has been validated for standard 2D measurements of the foot and ankle [22]. Although Rungprai et al. did not incorporate angular measures of the hindfoot into their protocol, Sutter et al. evaluated the contribution of EOS acquisitions for doing so [11]. The authors concluded that biplane imaging is more reliable than LAV in terms of reproducibility ($ICC > 0.88$), with independent analysis of the rotated foot position in the imaging booth. This study used acrylic and plastic phantoms and the promising results should be confirmed in a patient sample.

The limitations of the present study should be noted. The participants were all volunteers and this may explain the high variability in the angular values and the dispersion around the values (Table 1). Nevertheless, a sample of healthy volunteers seemed appropriate to obtain a representative sample of the population seen in consultation. In addition, the dispersion of values did not influence the interoperator variability [9]. Regarding our finding that the reproducibility was greater using Meary's technique, it should be underlined that this cannot be explained solely by the French-speaking authors' familiarity with it. The difficulties of implementing Saltzman's protocol have been confirmed by several authors, notably the difficulty of reproducing the tibial rotation [9,20]. The results of our study should be confirmed by a study in pathological conditions of hindfoot alignment, as the dearth of studies on Meary's technique preclude comparisons at the present time.

5. Conclusion

The results of this study show that the reliability of the angular measurements from radiographs depends on the radiographic view and measurement method chosen. Whatever the technical choices, the same method should be used consistently. Obtaining measurements with different methods and views within the same hospital setting inevitably leads to error and should be avoided. Saltzman's hindfoot alignment view measured with the modified Van Dijk correction (7–40 mm) and Robinson's 60/40 correction was the only method showing values close to the neutral axis. Meary's method had the best inter- and intraoperator reproducibility. New weightbearing 3D imaging systems will improve the reliability of hindfoot alignment measurements in the future.

Conflict of interest

None.

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