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REPRODUCIBILITY ANALYSIS AND REFERENCE VALUES FOR THE TIBIOCALCANEAL ANGLE, THE CALCANEAL-FIRST METATARSAL ANGLE AND THE METATARSUS ADDUCTUS ANGLE: SYSTEMATIC REVIEW AND META-ANALYSIS

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ABSTRACT

Objectives: Primarily, this systematic review aimed to critically appraise, compare, and summarize or meta-analyze reliability coefficients of the tibiocalcaneal angle (TCA), the calcaneal – first metatarsal angle (C1MA) and the metatarsus adductus angle (MAA), and secondly, to estimate reference values of these measurements for adults. **Methods:** Systematic searches were conducted and were followed by study screening, data extraction, and appraisal of measurement property and quality of evidence according to the Consensus-based standards for the selection of health measurement instruments (COSMIN) guidelines. **Results:** Systematic searches identified 1532 potentially eligible studies; of these, 24 studies were included in the qualitative synthesis, and 22 were included in the meta-analyses. We ran meta-analyses of Intraclass Correlation Coefficients (ICC) and good reliability was found for the TCA – bisecting lines method (inter-rater ICC=0.951); TCA – 40% to 60% division method (intra-rater ICC=0.781) in adults; C1MA (intra-rater ICC=0.985) in young adults; MAA (intra-rater ICC=0.953) in young adults and (intra-rater ICC=0.973) in adults; and MAA (inter-rater ICC=0.942) in adults. **Significance:** TCA (bisecting lines method), C1MA and MAA demonstrated excellent intra-rater reliability. TCA (40-60% division method) and MAA demonstrated good and excellent inter-rater reliability, respectively. Nonetheless, these findings should be interpreted cautiously since the quality of evidence was low or moderate.

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INTRODUCTION

Excessive hind foot pronation/supination or low/high medial longitudinal arch of the foot are risk factors which are associated with foot and ankle injuries or chronic disabilities (Buldt *et al.*, 2015; Burns *et al.*, 2005; Carvalho *et al.*, 2011; Ribeiro *et al.*, 2011).The gold standard for assessing joint alignment of the feet is weight-bearing radiography, as flexible deformities may not be apparent without loading. Moreover, radiographs show the static relationships between bones so that normal or pathological patterns may be identified (Flores *et al.*, 2019; Mosca, 2010).

The disadvantage of x-rays exams is that the exposure to ionizing radiation is not advisable (Lin, 2010; Ribeiro *et al.*, 2020). Possibly for this reason, health professionals, in practice, use methods which are alternative to radiography, such as postural tests, measurements and evaluations. However, these alternative methods do not always have recognized validity and reliability.

The use of photogrammetry as a tool for postural assessment has been defended by many researchers for being a relatively simple and objective method which presents accurate and precise results (Furlanetto *et al.*, 2012; Furlanetto *et al.*, 2017; Menz and Munteanu, 2005; Tuijthof *et al.*, 2004). The proposition of valid, cheaper, nonharmful methods that can be used in the clinical environment brings benefits to both the patient and the healthcare professional. Nonetheless, for using this alternative tool in the postural assessment of the feet, the parameters of reliability need to be known. In this perspective, we believe that it is essential to have knowledge of reliable methods for measuring the hindfoot posture, the medial longitudinal arch height, and the forefoot posture, which can be used as the gold standard in validation studies of alternative methods for posture assessment of the foot. Hindfoot alignment has been classically determined by the tibiocalcaneal angle (TCA) in the long axial view (LAV) or in the hindfoot alignment view (HAV) on radiography.

The TCA evaluates the magnitude of pronation or supination of the hindfoot (Neri *et al.*, 2017; Reilingh *et al.*, 2010). The calcaneal – first metatarsal angle (C1MA) measures the height of the medial longitudinal arch on a lateral radiograph (Gwani *et al.*, 2017). The height of the medial longitudinal arch is the most important reference in determining the presence or the degree of pes cavus and pes planus (Yalçin *et al.*, 2010). For instance, the pes planus may be relatively asymptomatic, but it may lead to profound symptoms and dysfunction that are disabling enough to incapacitate patients (Pinney and Lin, 2006).Lastly, the metatarsus adductus angle (MAA)in dorsoplantar projection determines the relationship between the longitudinal axis of the lesser tarsus and the axis of the second metatarsus.(Griffiths and Palladino, 1992)Forefoot adduction may potentiate fifth-metatarsal fractures (Theodorou *et al.*, 1999) and it has long been implicated as a risk factor in the development of hallux valgus. MAA is important for pediatrics as it can be treated during early ages (Mann and Coughlin, 1981).

The TCA, the C1MA and the MAA presented high reliability in previous studies (Domínguez and Munuera, 2008; Neri *et al.*, 2017; Saltzman *et al.*, 1995) and the bones which form these angles can be palpated and demarcated for photographic recording. Since there is no record of a similar study, the primary purpose of this systematic review is to critically appraise, compare and summarize or meta-analyze the reliability coefficients of these radiographic angles, and secondly, to estimate reference values of these measurements for adults. Based on the outcomes of previous studies concerning the reliability of measures of the TCA, the C1MA and the MAA, we hypothesize that pooled estimates for reliability coefficients of these angles demonstrate good reliability. Also, we expect to find studies that provide information to estimate reference values for these three angles.

METHODS

This systematic review and the meta-analyses followed the Consensus-based standards for the selection of health measurement instruments (COSMIN) guideline for systematic reviews(Prinsen *et al.*, 2018) and the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher *et al.*, 2009).It is registered on PROSPERO database (International Prospective Register of Systematic Reviews) from York's University Center for Reviews and Dissemination (register code CRD42019122971).

Search methodology: The PubMed, Embase, Scopus, Web of Science, BIREME, Scielo and the Brazilian Digital Library of Dissertations and Theses databases were searched for relevant studies published up to 06February 2021. The search strategy included the following elements: population (foot OR feet), type of instrument (radiography OR synonyms), construct ("tibiocalcaneal angle" OR "calcaneal-first metatarsal angle" OR "metatarsus adductus angle" OR synonyms) and measurement property of interest ("reproducibility of results" OR "reference values" OR synonyms).

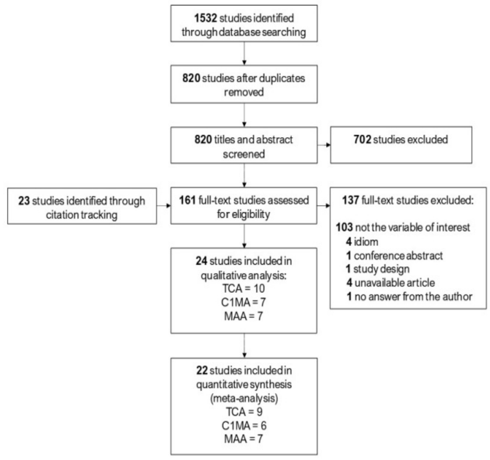

Figure 1. Flow diagram of study selection

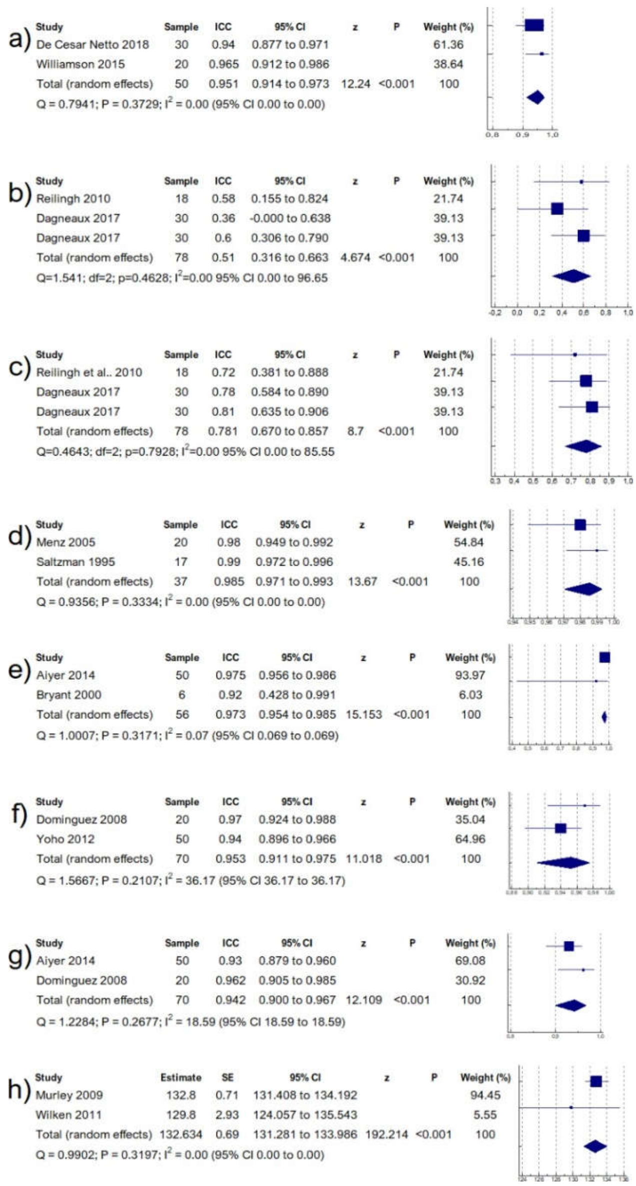

Figure 2. Meta-analysis results. Reliability coefficients for the tibiocalcaneal angle in the hindfoot alignment view (TCA-HAV) in adults: Inter-rater reliability a) method of bisecting lines, and b) method of the 40% to 60% division; c) Intra-rater reliability – method of the 40% to 60% division, d) Intra-rater reliability coefficient for the calcaneal – first metatarsal angle (C1MA) in adults/elderly; Reliability coefficients of the metatarsus adductus angle (MAA): intra-rater reliability e) in adults, and f) in young adults; and g) inter-rater reliability in adults/young adults; h) Reference values for the calcaneal – first metatarsal angle (C1MA) in young adults.

Selection criteria: As inclusion criteria, we considered eligible studies that evaluated the intra- and inter-rater reliability or reference values of the TCA, C1MA and MAA in adult patients in radiography, computed tomography, or fluoroscopy with the patient in orthostatism. Intra-rater reliability refers to the reproducibility of measurements which one rater assigns to a measure on two occasions, while interrater-reliability refers to the reproducibility of measurements among different raters (Carter *et al.*, 2010). The study should have provided detailed description of the method used. We were interested in the following methods of measurement:

- **TCA:** measured by the method of 40% to 60% division (Reilingh *et al.*, 2010) or the method of the bisecting lines (Williamson *et al.*, 2015) in the long axial view (LAV) or in the hindfoot alignment view (HAV). The ankle should be in neutral dorsiflexion.
- **C1MA:** the angle formed between a calcaneal axis and a first-metatarsal axis. The calcaneal axis is formed by a line tangent to the inferior surface of the calcaneus. The first-metatarsal axis is formed by a line tangent to the dorsum of the first metatarsal bone (Wearing *et al.*, 2012).
- **MAA:** measured by the modified Sgarlato's method. This angle is formed between the longitudinal axis of the second metatarsus and the longitudinal axis of the lesser tarsus. In this method, the longitudinal axis of the lesser tarsus uses the 5th metatarsal - cuboid joint as a reference (Dawoodi and Perera, 2012).

As exclusion criteria, we considered ineligible studies in any language other than English, German, Portuguese or Spanish.

Study selection: During the first screening, two independent investigators (G.M.G. and L.R.P.) evaluated the titles and abstracts of each citation and excluded irrelevant studies. For each potentially eligible study, the reviewers examined the full-text study and assessed whether the study fulfilled the inclusion criteria. The reference lists of relevant studies were hand searched to identify additional studies. All disagreements were resolved by consensus. The reviewers were not blind to the journal, author or year of publication, but these informations had absolutely no influence in the decision of including or excluding a study.

Data extraction: Two independent investigators (G.M.G. and L.R.P.) extracted the information of each study using a standardized data extraction form. Data extracted included author, publication year, sample size, sample gender and age, equipment and parameters for image acquisition, correlation coefficient, number of observers, qualification of observers and reference values.

Assessment of methodological quality and quality of evidence: The first step was the assessment of methodological quality according to the criteria of box six of the COSMIN Risk of Bias checklist (Mokkink *et al.*, 2018; Mokkink *et al.*, 2020). These criteria specifically approach study design requirements and statistical methods for analyzing reliability. Two evaluators used the same scoring table for assessing each study. The good reliability criteria was used to classify ICCs reported by each study as (1) sufficient (ICC ≥ 0.75), insufficient (ICC < 0.75); or indetermined (when ICC was not informed) (Mokkink *et al.*, 2018). Subsequently, based on this score of good reliability attributed to each study, we performed a general classification for the reliability of each angle of interest. In the general classification, besides the categories sufficient, insufficient, and indetermined, the reliability of an angle could also be classified as inconsistent when at least 75% of the studies were not categorized in the same criteria (sufficient or insufficient). Lastly, the quality of evidence was assigned for each angle. The general classification of each angle was then combined with an overall quality of evidence assessment using a modified version of the grading of Recommendations Assessment, Development and Evaluation (GRADE) system with four criteria: risk of bias (i.e., the methodological quality of the studies), (2) inconsistency (i.e., unexplained inconsistency of results across studies), (3) imprecision (i.e., total sample size of the available studies), and (4) indirectness (i.e., evidence from different populations than the population of interest in the review) (Prinsen *et al.*, 2018). No study was downgraded for the criteria indirectness as all studies were on adults.

As for the studies included in order to determine reference values for the angles of interest, since only cross-sectional studies were included in this systematic review, we used a modified 12-question version for assessment of non-randomized studies of the Downs & Black scale(Downs and Black, 1998) to evaluate the methodological quality. Answers to each question can be "yes" (1 point) when the study satisfies the question; "no" or "not applicable" (0 point) when the study does not satisfy the question. Studies scoring 75% or more of the criteria were ranked as high methodological quality.

Data analysis: Meta-analyses of reported ICCs (Intraclass Correlation Coefficient) and reference values were performed on MedCalc Statistical Software version 19.1.3 (MedCalc Software, Ostend, Belgium) using the random effects model. Heterogeneity was verified by the Higgins' inconsistency test (I^2). The I^2 was interpreted as might not be important (0% to 40%), may represent moderate heterogeneity (30% to 60%), may represent substantial heterogeneity (50% to 90%) and considerable heterogeneity (75% to 100%). The interpretation of the inconsistency test depends on the p value from de Chi^2 test and the confidence interval for I^2 (Higgins *et al.*, 2019).Only meta-analyses resulting in not important heterogeneity were reported in this manuscript. For the meta-analyses of the TCA, the studies considered homogeneous were grouped, firstly, according to the image view (Long Axial View – LAV or Hindfoot Alignment View – HAV), then the methodology of measurement (40% to 60% division or bisecting lines); then the type of imaging (radiography, computed tomography, or fluoroscopy); and lastly, according to the age group of the sample. For the meta-analyses of the C1MA and MAA, the studies were grouped just according to the sample age. We consider that ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.74 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (Koo and Li, 2016). So, we determined that an ICC≥0.75 is sufficient to indicate good reliability of a measure or instrument.

RESULTS

The initial electronic database search identified 1532 potentially eligible studies. After screening, 24 published studies met the inclusion criteria and were included in this review (Figure 1). Table 1 summarizes the characteristics of the included studies and the methodological quality assessment of single studies, the classification of good reliability based on the ICC values.

Reliability analysis: Nine studies investigated the reliability of the TCA (Burssens *et al.*, 2016; Burssens *et al.*, 2018; de Cesar Netto *et al.*, 2018; de Cesar Netto *et al.*, 2019; Dagneaux *et al.*, 2019; Neri *et al.*, 2017; Reilingh *et al.*, 2010; Williamson *et al.*, 2015; Zhang *et al.*, 2019) using distinct equipment (radiography or computed tomography), image view (long axial view – LAV and hindfoot alignment view – HAV) and measurement method (40% to 60% division and bisecting lines)(Table 1). In relation to the TCA-LAV in computed tomography, three studies were include in the meta-analysis of measurement reliability of the method of 40% to 60% division, (Burssens *et al.*, 2016; Burssens *et al.*, 2018; Zhang *et al.*, 2019) which presented substantial heterogeneity among studies. The quality of evidence was inconsistent with low quality of evidence. In addition, the meta-analysis including three studies, (Burssens *et al.*, 2016; Neri *et al.*, 2017; Reilingh *et al.*, 2010) which investigated this angle in radiography also demonstrated substantial heterogeneity among studies. In this analysis, all studies reported ICCs classified as insufficient with low quality of evidence. Only De Cesar Netto et al.(de Cesar Netto *et al.*, 2018) investigated the TCA-HAV in computed tomography and used the method of the bisecting lines.

Table 1. Summary of studies and methodological quality according to equipment, angle and method of measurement, author, and type of reliability

Angle/ Equipment	Reliability	Author/year	Sample		Evaluators			Age group	# of exams	ICC (95% CI)	Good reliability[a]	Methodo-logical quality	Quality of evidence
			n (gender)	Age mean age±SD (min-max)	measures per evaluator	n	Experience						
TCA-LAV 40% to 60% division in Computed Tomography	Intra-rater	Burssens 2016[36]	46	N/A	mean of 3[b]	N/A	N/A	?	30valgus 30varus	0.670 valgus 0.670 varus	Insufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) -1 Inconsistency 0 Imprecision 0 Indirectness
		Burssens 2018[37]	48 (28M/20F)	39.6±13.2	mean of 3[b]	N/A	N/A	Adult	N/A	0.740	Insufficient	Doubtful	
		Zhang 2019[38]	126	N/A	1	2	N/A	?	78 valgus 115 neutral 56 varus	0.837 valgus 0.809 neutral 0.866 varus	Sufficient	Doubtful	
	Inter-rater	Burssens 2016[36]	46	N/A	mean of 3[b]	2	N/A	?	30 valgus 30 varus	0.690 valgus 0.600 varus	Insufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) -1 Inconsistency 0 Imprecision 0 Indirectness
		Burssens 2018[37]	48 (28M/20F)	39.6±13.2	mean of 3[b]	2	N/A	Adult	N/A	0.710	Insufficient	Doubtful	
		Zhang 2019[38]	126	N/A	1	2	N/A	?	78 valgus 115 neutral 56 varus	0.858 valgus 0.756 neutral 0.927 varus	Sufficient	Doubtful	
TCA-LAV 40% to 60% division in Radiography	Intra-rater	Burssens 2016[36]	46	N/A	mean of 3[b]	N/A	N/A	Adult	30 valgus 30 varus	0.710 valgus 0.720 varus	Insufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) -1 Inconsistency 0 Imprecision 0 Indirectness
		Neri 2017[15]	22 (10M/12F)	48.5±22 (17-79)	1	1	N/A	Adult	44	0.997	Sufficient	Doubtful	
		Reilingh 2010[14]	18 (6M/12F)	29 (17-52)	mean of 3[b]	N/A	Three experienced orthopedic staff members and six orthopedic residents	Adult	18	0.930	Sufficient	Doubtful	
	Inter-rater	Burssens 2016[36]	46	N/A	mean of 3[b]	2	N/A	Adult	30 valgus 30 varus	0.710 valgus 0.710 varus	Insufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) -1 Inconsistency 0 Imprecision 0 Indirectness
		Neri 2017[15]	22 (10M/12F)	48.5±22 (17-79)	1	2	N/A	Adult	44	0.991	Sufficient	Doubtful	
		Reilingh 2010[14]	18 (6M/12F)	29 (17-52)	mean of 3[b]	3	Three experienced orthopedic staff members and six orthopedic residents	Adult	18	0.790	Sufficient	Doubtful	

Continue ….

TCA-HAV bisecting lines in Computed Tomography	Intra-rater	De Cesar Netto 2019[39]	20 (12M/8F)	52.2 (20-88)	1	1	Three foot and ankle surgeons who followed a mentored training protocol	Adult	20 (valgus)	Single Study 0.880	Sufficient	Adequate	-1 Risk of bias (only one study of adequate quality) 0 Inconsistency -1 Imprecision 0 Indirectness
	Inter-rater	De Cesar Netto 2019[39]	20 (12M/8F)	52.2 (20-88)	1	3		Adult	20 (valgus)	Single study 0.730	Insufficient	Adequate	
TCA-HAV bisecting lines in Radiography	Intra-rater	De Cesar Netto 2018[40]	29 (17M/12F)	51 (20-71)	1	2	Evaluators (qualification not described) trained in a protocol to perform the measurements on the software	Adult	30	0.95[c]	?	Adequate	0 Risk of bias (multiple studies of adequate quality) 0 Inconsistency -1 Imprecision 0 Indirectness
		Williamson 2015[27]	10 controls (6M/4F); 10 flatfeet (3M/7F)	Controls 29.1±8.3 (21.5-47.1) Flatfeet 53.4± 8 (38.5-63.5)	1	2	N/A	Adult	10 controls 10 flatfeet	0.979	Sufficient	Adequate	
	Inter-rater	De Cesar Netto 2018[40]	29 (17M/12F)	51 (20-71)	1	2	Evaluators (qualification not described) trained in a protocol to perform the measurements on the software	Adult	30	0.940	Sufficient	Adequate	0 Risk of bias (multiple studies of adequate quality) 0 Inconsistency -1 Imprecision 0 Indirectness
		Williamson 2015[27]	10 controls (6M/4F); 10 flatfeet (3M/7F)	Controls 29.1±8.3 (21.5-47.1) Flatfeet 53.4± 8 (38.5-63.5)	1	2	N/A	Adult	10 controls 10 flatfeet	0.965	Sufficient	Adequate	
TCA-HAV 40% to 60% division in Radiography	Intra-rater	Dagneaux 2017[41]	30 (15M/15F)	37.1±10.6 (21-60)	1	2	N/A	Adult	30	0.780 0.810	Sufficient Sufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Reilingh 2010[14]	18 (6M/12F)	29 (17-52)	mean of 3[b]	3	N/A	Adult	18	0.720	Insufficient	Doubtful	
	Inter-rater	Dagneaux 2017[41]	30 (15M/15F)	37.1±10.6 (21-60)	1	2	N/A	Adult	30	0.360 0.600	Insufficient Insufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Reilingh 2010[14]	18 (6M/12F)	29 (17-52)	mean of 3[b]	3	N/A	Adult	18	0.580	Insufficient	Doubtful	

Continue …

C1MA in Radiography	Intra-rater	Menz 2005[13]	95 (31M/64F)	78.6±6.5 (62 - 94)	1	1	N/A	Elderly	20	0.980 (0.950 – 0.990)	Sufficient	Adequate	-1 Risk of bias (only one study of adequate quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Saltzman 1995[22]	100 (31M/69F)	46±16	N/A	N/A	N/A	Adult	17	0.990 (1.00 – 1.00)	Sufficient	Doubtful	
	Inter-rater	Saltzman 1995[22]	100 (31M/69F)	46±16	N/A	N/A	N/A	Adult	27	0.990 (0.980 – 1.00)	Sufficient	Doubtful	-2 Risk of bias (only one study of doubtful quality available) 0 Inconsistency -1 Imprecision 0 Indirectness
MAA in Radiography	Intra-rater	Aiyer 2014[42]	587 (47M/540F)	52.5	1	1	N/A	Adult	50	0.975	Sufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Bryant 2000[43]	30 controls (12M/18F) 30 hallux valgus (03M/27F) 30 hallux limitus (09M/21F)	39.8 (23-68)	3	1	N/A	Adult	6	0.920	Sufficient	Doubtful	
		Dawoodi 2012[29]	133 (14M/119F)	50.6±15.4 (14-80)	1	1	N/A	Adult	50	0.920	Sufficient	Doubtful	
		Dominguez 2008[23]	121 (106M/100F)	23.9±2.8 (20-29)	1	2	N/A	Young Adult	20	0.970	Sufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Yoho 2012[45]	30 controls (20M/10F) 30 Jones fracture (19M/11F)	Controls 25±2.3 Jones frac. 39.1±13.2	1	1	N/A	Young Adult	50	0.940 (0.900 – 0.960)	Sufficient	Doubtful	
	Inter-rater	Aiyer 2014[42]	587 (47M/540F)	52.5	1	2	N/A	Adult	50	0.930	Sufficient	Doubtful	-1 Risk of bias (multiple studies of doubtful quality) 0 Inconsistency (meta-analysis) -1 Imprecision 0 Indirectness
		Dawoodi 2012[29]	133 (14M/119F)	50.6±15.4 (14-80)	1	2	N/A	Adult	50	0.870	Sufficient	Doubtful	
		Dessouky 2018[44]	56 (16M/40F)	54.2±15.4	1	2	A second-year medical student and a radiologist with 8 years of experience) were trained on set of six cases	Adult	56	0.410 (0.030 – 0.760)	Insufficient	Doubtful	
		Dominguez 2008[23]	121 (106M/100F)	23.9±2.8 (20-29)	3	1	N/A	Young Adult	20	0.962	Sufficient	Doubtful	

TCA-LAV: Tibiocalcaneal angle in long axial view; TCA-HAV: Tibiocalcaneal angle in hindfoot alignment view; C1MA: Calcaneal – first metatarsal angle; MAA: Metatarsus adductus angle (MAA); M: male; F: female; SD: standard deviation; CI: confidence interval; # of exams: number of exams; N/A: not applicable; [a]Good reliability is sufficient when ICC≥0.75 (per study); [b]mean of 3 measures per evaluator; [c]Pearson's r.

Table 2. Summary of findings: intra- and inter-rater reliabilities and quality of evidence.

Angle	Equipment	Reliability	Age group	n	ICC	Good reliability [a]	Quality of evidence
TCA-LAV 40% to 60% division	Computed Tomography	Intra-rater	Adult	309	Range [b] 0.670 – 0.866	Inconsistent	Low
		Inter-rater	Adult	309	Range [b] 0.600 – 0.927	Inconsistent	Low
	Radiography	Intra-rater	Adult	122	Range [b] 0.710 – 0.997	Inconsistent	Low
		Inter-rater	Adult	122	Range [b] 0.710 – 0.991	Inconsistent	Low
TCA-HAV bisecting lines	Computed tomography	Intra-rater	Adult	20	Single study 0.880	Sufficient	Low
		Inter-rater	Adult	20	Single study 0.730	Insufficient	Low
	Radiography	Intra-rater	Adult	20	Single study 0.979	Indetermined	Low
		Inter-rater	Adult	50	0.951 [c] (0.914 – 0.973)	Sufficient	Moderate
TCA-HAV 40% to 60% division	Radiography	Intra-rater	Adult	48	0.781 [c] (0.670 – 0.857)	Sufficient	Low
		Inter-rater	Adult	48	0.510 [c] (0.316 – 0.663)	Insufficient	Low
C1MA	Radiography	Intra-rater	Adult	37	0.985 [c] (0.971 – 0.993)	Sufficient	Low
		Inter-rater	Adult	27	Single study 0.990 (0.980 – 1.00)	Sufficient	Very Low
MAA	Radiography	Intra-rater	Adult	56	0.973 [c] (0.954 – 0.985)	Sufficient	Low
			Young adult	70	0.953 [c] (0.911 – 0.975)	Sufficient	Low
		Inter-rater	Adult	70	0.942 [c] (0.900 – 0.967)	Sufficient	Low

TCA-LAV: Tibiocalcaneal angle in long axial view; TCA-HAV: Tibiocalcaneal angle in hindfoot alignment view; C1MA: Calcaneal – first metatarsal angle; MAA: Metatarsus adductus angle;.[a]Sufficient when the Pooled estimate of ICCs derived from meta-analysis is ≥0.75 or when 75% of the studies reported ICC≥0.75; [b] Range between the lowest and highest ICC values reported by the studies; [c] Pooled estimate of ICCs derived from meta-analysis.

Table 3. Mean values of the angles of interest

Angle	Equipment	Age group[a]	Study	# of exams	mean±SD (min-max orCI)	Methodological quality[b]
TCA-LAV 40% to 60% division	Computed Tomography	Adult	Burssens 2018[46]	N/A	9.1±4.8	Low
			Zhang 2019[38]	115	3.2±3.1 (CI -4.7 to 10.5)	Low
	Radiography	Adult	Neri 2017[15]	44	0.73±0.1 (CI -14.7 to 15.6)	Low
TCA-HAV 40% to 60% division	Radiography	Adult	Dagneaux 2017[41]	30	6.9±5.1 0.8±5.1	Low
TCA-HAV bisecting lines	Radiography	Adult	Williamson 2015[27]	10	5.6±5.4	High
C1MA	Fluoroscopy	Adult	Balsdon 2016[47]	5	129.2±7.6	High
	Radiography	Elder	Menz 2005[13]	95	133±9	High
		Adult	Gwani 2017[16]	76	142.9±7.6	High
			Saltzman 1995[22]	100	132±10	High
			Wearing 2011[28]	30	128.1±7.9	High
		Young Adult	Murley 2009[48]	32	132.8±4.0	Low
			Wilken 2011[49]	17	129.8±12.1 (114-153)	Low
MAA	Radiography	Adult	Bryant 2000[43]	30	17.7±4.6	Low
			Coughlin 2009[50]	56	15.9±4.1	High
			Dessouky 2018[44]	56	18.5±5.7	High
		Young adult	Dominguez 2008[23]	206	21±4.5	High
			Yoho 2012[45]	30	14.3±4.6	Low

TCA-LAV: Tibiocalcaneal angle in long axial view; TCA-HAV: Tibiocalcaneal angle in hindfoot alignment view; C1MA: Calcaneal – first metatarsal angle; MAA: Metatarsus adductus angle; SD: Standard Deviation; CI:95% of Confidence Interval. [a]Males and females; [b] According to the modified Downs & Black scale.

Although the good methodological quality of the study, the level of evidence was rated as very low. Another two studies(de Cesar Netto *et al.*, 2018; Williamson *et al.*, 2015) investigated this method in radiography and the meta-analyzed ICC resulted excellent inter-rater reliability (Figure 2a) with moderate quality of evidence (Table 3). Despite the excellent inter-rater reliability of this measure, intra-rater reliability was classified as indetermined because one of the studies reported Pearson's r and the quality of evidence was low.

Dagneaux et al. and Reilingh et al.(Dagneaux *et al.*, 2019; Reilingh *et al.*, 2010) investigated the TCA-HAV in radiography using the method of the 40% to 60% division. Meta-analyzed ICCs estimated good inter-rater reliability (Figure 2b), but moderate intra-rater reliability (Figure 2c). Both findings presented low quality of evidence. In relation to the C1MA, only two studies evaluated intra-rater reliability.(Menz and Munteanu, 2005; Saltzman *et al.*, 1995)

The meta-analyzed ICC demonstrated sufficient reliability (Figure 2d) with low quality of evidence. No meta-analysis was performed for inter-rater reliability since only Saltzman et al.(Saltzman *et al.*, 1995) evaluated this measurement property. Regarding the MAA, sufficient intra-rater reliability was found in the subgroup meta-analyses of adults (Aiyer *et al.*, 2014; Bryant *et al.*, 2000) and young adults (Domínguez and Munuera, 2008; Yoho *et al.*, 2012) (Figure 2e and 2f, respectively).In addition, the subgroup meta-analysis (Aiyer *et al.*, 2014; Domínguez and Munuera, 2008) of adults presented good inter-rater reliability(Figure 2g). Both results presented low level of evidence due to the methodological quality of studies. In table 2 we synthesized the evidence for good reliability and the quality of evidence. When there was important heterogeneity among studies of a meta-analysis or it was not possible to run a meta-analysis because there was a single study or because of the differences between the methods of measurement or equipment, we presented the lowest and the highest ICCs that the studies reported for each type of reliability.

Reference values: In table 3 we listed the mean values of the angles of interest reported by the studies, and their methodological quality appraised accordingly to the Downs & Black scale. The only possible meta-analysis for the TCA included studies (Burssens *et al.*, 2018; Zhang *et al.*, 2019) on the TCA-HAV in computed tomography but there was important heterogeneity among studies. Among the studies on this the TCA, only one study was rated as high methodological quality (Williamson *et al.*, 2015). In relation to the C1MA, only the meta-analysis of the subgroup young adults (Murley *et al.*, 2009; Wilken *et al.*, 2011)presented not important heterogeneity, and it estimated a neutral range for the C1MA between 131.3° e 134° (Figure 2h). It was not possible to estimate reference values for the MAA due to important heterogeneity among studies included in the subgroup metanalyses we run.

DISCUSSION

The primary objective of this study was to critically appraise, compare, summarize or meta-analyze reliability coefficients of the tibiocalcaneal angle (TCA), the calcaneal-first metatarsal angle (C1MA) and the metatarsus adductus angle (MAA). Secondly, we intended to estimate reference values of these angles for adults.

Tibiocalcaneal angle (TCA): We verified that the method of bisecting lines in the HAV(de Cesar Netto *et al.*, 2018; Williamson *et al.*, 2015)presented the highest ICCs among the studies which investigated the TCA and the meta-analyzed ICC for inter-rater reliability resulted excellent (Figure 2a). This finding corroborates with the current literature since hindfoot alignment measurements showed better reliability when performed on HAV radiographs using the method of bisecting lines (Buck *et al.*, 2011). This was the only measure presenting moderate quality of evidence. Moreover, in radiography, literature reports that inter-rater reliability of TCA is slightly better in LAV than in HAV(Buck *et al.*, 2011; Lamm *et al.*, 2005; Reilingh *et al.*, 2010). However, the comparison between both image views (LAV and HAV) was performed only in the 40% to 60% division. Until now, no study analyzed the LAV using bisecting lines.

Perhaps in a future investigation on the method of bisected lines in the LAV, reliability may result as good as in the HAV view or even better. It has been conventionalized that neutral hindfoot alignment in relation to the tibial axis is around 0° (Mendicino *et al.*, 2008; Neri *et al.*, 2017; Reilingh *et al.*, 2010),regardless the methodology of measurement of the TCA or image view. In radiography, Neri *et al.*, 2017 found mean TCA-LAV closer to 0° (0.73±0.1°). However, for Zhang *et al.*, 2019the TCA between 0° and 7° of valgus is considered normal; if greater than 7°, the hindfoot is valgus and if lower than 0°, then it is varus. But these authors did not cite the reference for this classification. In computed tomography, their study reported mean TCA-LAV of 3.2±3.1°while Burssens *et al.*, 2018found mean TCA-LAV of 9.1±4.8°. This last study included individuals with valgus hindfoot in their sample, what can justify a higher mean. Regarding the TCA-HAV, Dagneaux *et al.*, 2019reported mean TCA of 6.9±5.1° when the second reference line was 40mm distant from the most distal point on the calcaneus and mean TCA of 0.8±5.1° when the second reference line was 20mm distant from the most distal point on the calcaneus. This may indicate that the measurement of the TCA in the method of 40% to 60% division can vary considerably according to the position of the reference line to determine the axis of the calcaneus. Nonetheless, Williamson *et al.*, 2015were the only to report mean TCA in the method of bisecting lines (Table 3).Considering the different means of the TCA reported by the studies, a very few degrees in the direction of valgus alignment still seem to represent a neutral hindfoot. It is worth mentioning that all studies determined the tibial axis no higher than mid-tibia. The literature reports that the tibial axis changes if the entire length of the tibia is not considered (Barg *et al.*, 2012; Stufkens *et al.*, 2011). For Barg *et al.*, 2015,in general, the TCA-HAV is less sensitive to changes in foot-ankle position, but there is no record of such analysis applied to the TCA-LAV.

Calcaneal – first metatarsal angle (C1MA): Only two studies in our systematic search analyzed reliability coefficients of C1MA in radiography(Menz and Munteanu, 2005; Saltzman *et al.*, 1995). The pooled ICC for inter-rater reliability resulted excellent (Table 2). The bony references for determining this angle are easily identifiable on radiography and may have contributed to good reliability. However, due to the small number of studies and the absence of important information in the reporting of one of the studies, the quality of the evidence was rated as low. As result of a meta-analysis, the reference value for neutral C1MA in young adults is between 131.3° and 134°. All studies included in this review reported mean C1MA between 128.1° and 142.9° and Murley *et al.*, 2009 suggested that angles greater than 136° (for males) and 137°(for females) indicate pes planus. Our reference value for neutral C1MA is below this, indicating an adequate reference. Besides, the highest mean C1MA (142.9°) estimated by Gwani *et al.*, 2017 may have happened because the x-ray beam was horizontally centered at the lateral malleolus. The central ray was projected from a higher position and this could have produced an angle broader than in the other studies, which positioned the x-ray beam immediately above the base of fifth metatarsal or the navicular bone.

Metatarsus adductus angle (MAA): In radiography, excellent intra- and inter-rater reliability of the MAA prevailed between studies as was the meta-analyzed ICCs. However, important flaws in the reporting of the studies downgraded the quality of the evidence to low. Regarding the reference values for the MAA, some researchers consider a MAA neutral if less than 20° (Aiyer *et al.*, 2014; Dawoodi and Perera, 2012; Dessouky *et al.*, 2018) or less than 15° (Gentili *et al.*, 1996) or between 10° and 20°(Mooney, 2014).However, it is not clear if any of these values refers specifically to the modified Sgarlato's method. Domínguez and Munuera, 2008 reported the highest mean values (21°) among the studies, while Yoho *et al.*, 2012 reported the lowest ones (14.3°), though both studies evaluated young adults. Dessouky *et al.*, 2018, who evaluated adults, reported mean MAA of 18.5° for their control group. In general, the mean angle reported by the included studies for the MAA can be classified as neutral according to the literature.

Limitations

We did not perform systematic searches on the Cochrane database and besides, this study restricted the systematic search to some specific languages. For not encompassing grey literature, we may have missed potential studies. In addition, studies with children were not included. Moreover, the meta-analyses comprised the ICCs reported by the studies, even when the study did not describe the ICC type or did not apply the adequate ICC type for statistical analysis. The quality of evidence was predominately low. Nonetheless, there is a variety of measurement methods for the TCA and the MAA and one single review cannot embrace them all. Lastly, it was not possible to appraise the measurement error of the angles of interest because none of the studies reported values of Standard Error of Measurement (SEM) or Minimal Detectable Change (MDC).

CONCLUSION

In radiography, the TCA-HAV in the method of the bisecting lines demonstrated excellent inter-rater reliability (meta-analyzed ICC=0.951) in adults with moderate quality of evidence. In the method of 40% to 60% division in adults, good inter-rater reliability (meta-analyzed ICC=0.781), but moderate intra-rater reliability (meta-analyzed ICC=0.510) were estimated, both presenting low quality of evidence. All other methods for measuring the TCA showed inconsistent reliability with low quality of evidence. The C1MA demonstrated excellent intra-rater reliability (meta-analyzed ICC=0.985) in adults/elderly, but the quality of evidence is low. The reference value for neutral C1MAin young adults is between 131.3–134.0. However, the studies demonstrated low methodological quality. Finally, the MAA presented excellent intra-rater reliability in young adults (meta-analyzed ICC=0.953) and in adults (meta-analyzed ICC=0.973), as well as excellent inter-rater reliability in adults (meta-analyzed ICC=0.942), but these estimates present low quality of evidence. Based on our outcomes, we considered promising the TCA-HAV in the method of the bisecting lines, the C1MA and the MAA to be used as the gold standard for the validity analysis of alternative methods to weight-bearing radiography in the assessment of foot posture in photogrammetry. Nonetheless, these findings should be interpreted cautiously since there was a small number of studies included in the meta-analyses due to methodological heterogeneity, and the quality of evidence for the reliability of these angles was predominately rated as low.

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