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Systematic Review

Validity, reliability, and clinical usefulness of instruments for measuring thoracic kyphosis: a systematic review and meta-analysis

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Thoracic hyperkyphosis is related to different health conditions, requiring precise evaluation in clinical settings. Several instruments have been proposed for assessing thoracic kyphosis, and previous studies have investigated their reliability and validity.

Aims: Systematically review studies evaluating the validity and reliability of instruments designed to measure thoracic kyphosis and classify their clinical utility.

Methods: MEDLINE and EMBASE (via Ovid) databases were used to search studies published until December 2023, and additional searches were conducted in Google Scholar and by hand search. Studies that analyzed the reliability and validity of noninvasive instruments for measuring thoracic kyphosis, regardless of population, study design, and language, were included. Two independent reviewers analyzed the titles, abstracts, and full text and assessed the methodological quality. Clinical utility was assessed using a 10-point scale.

Results: Seventy-two studies were included, and 15 instruments had their measurement properties explored: seven were grouped in a meta-analysis for validity, seven for intra-rater reliability, and six for inter-rater reliability. Despite the heterogeneity of estimated data, they presented a strong to moderate correlation with the gold standard and excellent intra- and inter-rater reliability. The instruments most frequently studied were the Flexicurve Angle and the Analog Inclinometer.

Conclusion: The meta-analysis demonstrated that the Analog Inclinometer, Flexicurve Angle and Index, Photogrammetry, Smartphone applications, and Spinal Mouse were valid and reliable for assessing thoracic kyphosis. Also, the utility analysis suggested that the Analog Inclinometer, Flexicurve Angle, and Smartphone applications are recommended for clinical settings.

Introduction

In clinical practice, physical therapists usually assess thoracic kyphosis using visual inspection.[1] This method may not accurately quantify changes associated with different health conditions, aging, and treatments. Previous studies demonstrated that thoracic hyperkyphosis is associated with the presence of neck and low back pain,[2–4] reduced lung function,[5] impaired performance during gait,[6] and increased risk of falls and mortality.[7–8] Furthermore, evidence suggests that corrective exercises for thoracic hyperkyphosis can improve posture and balance in patients with kyphosis angles greater than 40°.[9–10] Therefore, assessing thoracic kyphosis in clinical settings is essential for understanding, monitoring, and planning treatment for patients with several health conditions.

The Modified Cobb angle is the gold standard for measuring thoracic kyphosis using radiography (X-ray) due to its proven accuracy in assessing spinal curvature, its ability to provide detailed images of bone structures, and its widespread use in clinical practice as a reliable tool

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for diagnosis.[11] However, this assessment has limitations, including the time required for X-ray acquisition and interpretation, high costs, limited equipment portability, and radiation exposure, which is particularly concerning for repeated assessments in pediatric populations and young individuals.[12] Previous studies observed that the normal range of thoracic kyphosis varies between 20° and 40° in adolescents and younger adults.[11,13] Although the definition of pathological hyperkyphosis is not a consensus, an angle greater than 50° has been adopted for this diagnosis.[14] On the other hand, kyphosis angles < 20° characterize hypokyphosis.[15]

Using portable, easy-to-use, low-cost instruments may be beneficial for assessing thoracic kyphosis in clinical settings as it allows a quick, comfortable, and accurate measurement. However, instruments should not be used without evidence about their measurement properties.[16] Previous studies investigated the validity and reliability of several instruments developed to assess thoracic kyphosis.[12,17–39] Given the variety of instruments, clinicians must use instruments that ensure the proper assessment of thoracic kyphosis in clinical settings. This assessment enables monitoring to prevent or minimize negative consequences and evaluate treatment effectiveness related to thoracic hyper and hypokyphosis.

In 2014, a systematic review included 28 studies published up to October 2012 about the validity and reliability of non-radiographic methods for assessing thoracic kyphosis.[40] Findings showed that the validity of methods varied from low to very high, with reliability levels ranging from high to very high; however, no meta-analysis was performed. Despite the substantial number of studies included in this review, several additional studies investigated the measurement properties of instruments that assess thoracic kyphosis from October 2012 to the present day.

Therefore, this systematic review performed a meta-analysis of studies that assessed the validity and intra- and inter-rater reliability of clinical instruments proposed to quantify thoracic kyphosis in any population and classified the instruments according to their clinical utility.

Methods

Protocol

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[41] and is registered in PROSPERO (CRD42019124956).

Search strategy

The search was initially conducted in March 2019 and updated in December 2023 in MEDLINE, EMBASE (via Ovid), and Google Scholar databases. In addition, the reference lists of previous reviews and included studies were also hand-searched. The search terms were related to thoracic kyphosis, thoracic posture, measurement properties (validity and reliability), and clinical instruments. The search strategy is detailed in Supplementary material 1.

Eligibility criteria

The ideal instrument should be portable, precise, accurate, and affordable, thus allowing quick and safe assessment of thoracic kyphosis in clinical settings.[42] Studies that assessed the validity or intra- or inter-rater reliability of clinical instruments proposed for measuring thoracic kyphosis were included. No language, publication date, sample characteristics, or study design restrictions were applied. Moreover, for the validity studies, instruments should be compared to an X-ray examination (gold standard) to be included. Studies that did not analyze the orthostatic posture of the thoracic region in the sagittal plane were excluded.

Study selection and data extraction

Two independent reviewers (APFAN and ACC) analyzed titles and abstracts; ineligible studies were excluded. Then, two reviewers (APFAN and ACC) performed the full-text analysis. A third reviewer (RAR) resolved any disagreements in these steps. Data extraction was performed by one reviewer (APFAN). Descriptive information included sample characteristics (e.g., number of participants, sex, age, health condition, height, and body mass) and the instrument used to assess thoracic kyphosis. When applicable, the values of concurrent validity (Pearson correlation – r), intra- and inter-rater reliability (intraclass correlation coefficient - ICC), standard error of measurement (SEM), minimum detectable change (MDC), and Bland-Altman agreement analysis [(Mean Difference (MD) ± Standard Deviation (SD) and limits of agreement (LA)] were extracted. When two references for intra-rater reliabilities were reported, the ICC value of the most experienced rater or the higher value was chosen.

In addition, when studies measured the erect and relaxed thoracic kyphosis, only the value of the relaxed posture was considered, as it was adopted in most studies. Data were analyzed independently in the meta-analysis when the same study evaluated two or more instruments and different populations. Authors of validity studies that did not present the Pearson correlation and reliability studies that did not present the ICC value and 95 % confidence interval (95 % CI) were contacted by email to request data.

Methodological quality assessment

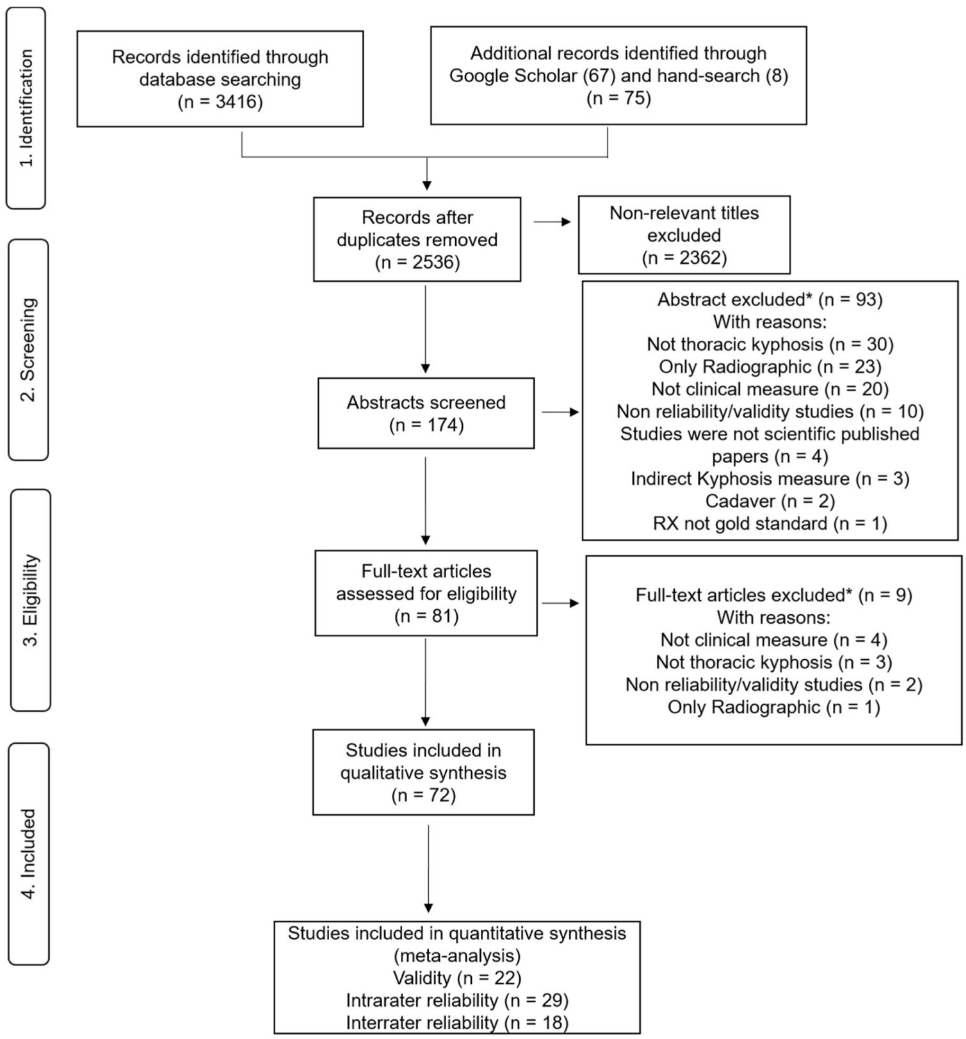
Two independent reviewers (APFAN and ACC) evaluated the methodological quality of the studies using the critical appraisal tool (CAT) checklist by Brink and Louw.[43] A third reviewer (RAR) resolved disagreements regarding the scoring of the studies. The CAT was structured to critically evaluate the measurement properties of instruments used in clinical settings and encompasses 13 items related to characteristics of population and evaluators, risk of bias, and methodological quality of the studies. Following the procedures adopted in previous systematic reviews, studies scoring above 60 % were considered to have high methodological quality.[40,44–45] In this assessment, Kappa showed an overall agreement of 0.89 between the two independent reviewers (APFAN and ACC).

Data analysis

Concurrent validity and intra- and inter-rater reliabilities of individual studies were grouped using a random effects model and analyzed using Comprehensive Meta-analysis software (version 4.0). I^2 statistic was used to evaluate heterogeneity between studies.[46] Findings of individual studies and combined estimates were presented in a forest plot with a 95 % CI.

The concurrent validity was classified as very low ($r < 0.25$), low to reasonable ($0.25 \leq r < 0.50$), moderate to good ($0.50 \leq r < 0.75$), and strong ($r \geq 0.75$).[16] In addition, we also reported Bland Altman's limits of agreement.[16] The intra- and inter-rater reliabilities were classified as low (ICC < 0.40), good to moderate (0.40 ≤ ICC < 0.74), and excellent (ICC ≥ 0.75).[47]

To be recommended for clinical use, an instrument must meet rigorous criteria, including validity ($r > 0.80$), reliability (ICC > 0.80), sensitivity (MDC), and a score of 9 or higher on a 10-point clinical utility scale. This scale evaluates factors such as portability, cost, evaluation time, measurement analysis, and interpretation. Specifically, cost is scored as follows: ⟨ £100 scores 3, £100 - £500 scores 2, £500 - £1000 scores 1, and ⟩ £1000 or unknown scores 0. Evaluation time is evaluated based on duration: <10 min scores 3, 10–30 min scores 2, 30–60 min scores 1, and >1 h scores 0. The necessity of specialized equipment or



*Abstracts and potentially relevant full-texts could be excluded due to more than one inclusion criterion.

Fig. 1. - PRISMA flow-chart of studies through the review.

professional training is also considered, with “No” scoring 2, “Yes, but only simple, easy to use equipment, which does not need specialist training” scoring 1, and “Yes” or “Unknown” scoring 0. Finally, portability is evaluated as follows: “Yes, easily (e.g., can fit in a pocket)” scores 2, “Yes, but requires a briefcase or trolley” scores 1, and “No or very difficult” scores 0.[48–49]

Results

Flow of studies

The search strategy identified 2536 titles after excluding duplicates. After screening titles and abstracts, 81 studies were included for full-text review. Four studies were excluded because they did not use clinical instruments, three for not measuring thoracic kyphosis, one because they were not validity or reliability studies, and one because thoracic kyphosis was measured only on the X-ray films. The studies excluded by full-text are listed in a table in the Supplementary material 2. Therefore, 72 studies were included. The review flowchart is presented in Fig. 1.

Characteristics of the included studies

The characteristics of the studies are described in Tables 1 and 2. Fifteen instruments were identified: Analog Inclinometer, Archometer, Baseline® Body Level/ Scoliosis meter, Debrunner Kyphometer, Electrogoniometer, Digital Inclinometer, Dual Digital Inclinometer, Flexicurve (Angle and Index), Kypholordometer, Microsoft Kinect Sensor, Photogrammetry, Smartphone app, Spinal Mouse, Spinal Pantograph, and Spinal Wheel. Among the included studies, 31 verified the concurrent validity by comparing the instrument with an X-ray in the sagittal plane,[12,17,19–20,23–24,29,31,33–34,50–70] 57 evaluated the intra-rater reliability,[12,17–18,20–28,30–32, 35–39, 42, 50–52,54–57,63–65,67–69,71–94] and 40 the inter-rater reliability.[12,17,20–24,27–28, 30, 32–33, 35,51,54–57,64–65, 68–74,78–80,82–83,87–91,93,95–96]

The studies sample size ranged from 11 to 139 participants. Regarding the sample of the studies, 33 (45.83 %) evaluated healthy individuals, 20 (27.77 %) included patients with kyphosis or scoliosis, eight (11.11 %) included patients with musculoskeletal pain in different body regions, five (6.94 %) included patients with osteoporosis or reduced bone mass, five (6.94 %) included individuals who had been referred for a thoracic spine X-ray, three (4.16 %) evaluated athletes, two (2.77 %) evaluated patients with Parkinson’s, one (1.38 %) evaluated individuals with some orthopedic condition and one (1.38 %) did not characterize the sample. Regarding the age group, 14 studies (19.44 %) evaluated individuals aged ≥ 60 years, 40 (55.94 %) evaluated adults aged between 18 and 60 years, and 20 (27.77 %) evaluated children and

Table 1
Characteristics of the included validity studies.

Authors and year of the study	Instrument	Study Population	Validity levels
Azadinia et al. 2021[50]	Photogrammetry (Digimizer Image Analysis Software version 5.3.4 -MedCalc Software; BVBA, Ostend, Belgium)	*n* = 50 Mean age ± SD = 13.72 ± 1.85 years; BMI (kg/m^2)19.37 ± 2.87 Sex (M/F) 26/24 Adolescents with hyperkyphosis	*r* = 0.94 BA = 3.91° (MD); SD = NR LA = 10.2° to - 2.4°
Azadinia et al. 2014[51]	Dual Digital inclinometer (DDI) Flexicurve Angle (FA)	*n* = 81 Mean age ± SD = 14.69 ± 4.11 years (range 10 - 30 years); height (cm) 157 ± 13.5; mass (kg) 50.7 ± 15.3 BMI$_C$ (kg/m^2) 20 Sex (M/F) 26/55 Patients with Hyperkyphosis *n* = 21 Mean age ± SD = 65.76 ± 4.6 years (range 50 - 80 years); height (cm) 156.8 ± 5.7; mass(kg) 66.48 ± 8.93 BMI$_C$ (kg/m^2) 26 Sex (M/F) 3/18 Patients with Hyperkyphosis	*r* = NR ICC$_{DDIRX}$ = 0.89 BA$_{DDI}$ = 4.85°(SD) MD = NR; LA = NR ICC$_{FARX}$ = 0.51 BA$_{FA}$ = 9.30° (SD) MD = NR; LA = NR *r* = NR ICC$_{DDIRX}$ = 0.81 BA$_{DDI}$ = 4.93°(SD) MD = NR; LA = NR ICC$_{FARX}$ = 0.50 BA$_{FA}$ = 8.03° (SD) MD = NR; LA = NR
Barauna et al. 2005[52]	Kypholordometer	*n* = 30 Mean age ± SD = 39 ± 15.8 years BMI = NR Sex (M/F) NR Scheuermann's Disease (*n* = 3) Postural kyphosis (*n* = 25) Ankylosing Spondylitis (*n* = 2)	*r* = 0.78 BA = NR
Barrett et al. 2017[53]	Analog Inclinometer (AI) Flexicurve Angle (FA)	*n* = 11 Mean age ± SD = 40.9 ± 20.1 years BMI (kg/m^2) 24.4 ± 5.4 Sex (M/F) 7/4 Patients with pain (*n* = 6 low back pain; *n* = 4 with thoracic pain; *n* = 1 with inter-scapular pain)	r$_{AIRX}$ = 0.86 BA$_{AI}$ = 4.8° ± 8.9° (MD ± SD) LA = 22.28° to −12.64° r$_{FARX}$ = 0.96 BA$_{FA}$ = 20.2° ± 6.1° (MD ± SD); LA = 32.27° to 8.29°
Büyükturan et al. 2018[54]	Spinal Mouse	*n* = 46 Mean age ± SD = 68.12 ± 2.67 years BMI (kg/m^2) 29.45 ± 4.67 Sex (M/F) 17/29 Healthy older individuals	*r* = 0.93 BA = NR
Chaise et al. 2011[24]	Arcometer	*n* = 52 Mean age ± SD = 53.7 ± 14.9 years BMI (kg/m^2) 26.1 ± 4.4 Sex (M/F) NR Persons with prescription for an X-ray	*r* = 0.94 BA = −1.4° ± 6.06° (MD ± SD); LA = 10.53° to −13.24°
de Oliveira et al. 201,2[55]	Flexicurve Angle	*n* = 47 Mean age ± SD = 44.9 ± 19.4 years BMI (kg/m^2) 27.5 ± 5 Sex (M/F) Both sex Persons with prescription for an X-ray	*r* = 0.70 BA = 0.8° ± 8.0° (MD ± SD); LA = 17.0° to −15.3°
D'Osualdo et al.1997[56]	Arcometer	*n* = 32 Mean age 15.5 years BMI = NR Sex (M/F) 9/23 Patients with kyphosis and scoliosis, and for postural rehabilitation	*r* = 0.98 BA = NR
Faramarzi et al. 2020[57]	Smartphone app (Goniometer-Pro app)	*n* = 31 Mean age ± SD = 25.09 ± 4.02 years; BMI (kg/m^2) 22.07 ± 1.44 Sex (M/F) NR Persons with prescription for an X-ray	*r* = 0.81 BA = 1.79° ± 5.40° (MD ± SD) LA = NR
Fortin et al. 2010[34]	Photogrammetry (Fringes Acquisition and Processing Software - InSpeck Inc., Montreal, Canada)	*n* = 70 (validity *n* = 40) Mean age ± SD = 15.7 ± 2.5 years BM (kg) 51.9 ± 9.3 Height (cm) 161 ± 9.5 BMI$_C$ (kg/m^2) 20 Sex (M/F) 10/60 Children with Scoliosis	*r* = - 0.77 BA = NR
Giglio and Volpon, 2007[58]	Spinal Pantograph	*n* = 718 (validity = 20) Mean age 11.45 years BMI = NR Sex (M/F) 350/368 Normal subjects	*r* = 0.70 BA = NR
Gravina et al. 2012[59]	Analog Inclinometer	*n* = 128 Mean age 12.7 years BMI = NR Sex (M/F) Both sex Children/adolescents idiopathic scoliosis. Scheuermann or postural kyphosis	*r* = 0.89 BA = - 0.3° (MD) SD = NR LA = 17.0° to −16°
Greendale et al. 2011[12]	Debrunner Kyphometer (DB) Flexicurve angle (FA) Flexicurve index (FI)	*n* = 113 Mean age ± SD = 75.3 ± 7.5 years BMI (kg/m^2) 26.5 ± 4.5 Sex (M/F) 80.5 % were women Persons with Kyphosis>40°	r$_{DBRX}$ = 0.62 BA$_{DK}$ = 10.96° (SD); MD = NR; LA = NR r$_{FARX}$ = 0.68 BA$_{FA}$ = 10.24° (SD); MD = NR; LA = NR r$_{FIRX}$ = 0.68 BA$_{FI}$ = 11.26°

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Table 1 (*continued*)

Authors and year of the study	Instrument	Study Population	Validity levels
			(SD); MD = NR; LA = NR
Grindle et al. 2020[60]	Flexicurve angle (FA)	$n = 40$ Mean age 55.9 ± 24.71 years. BMI (kg/m^2) 24.7 ± 3.3 Sex (M/F) 18/22 Adult volunteers with hyperkyphosis	r = NR ICC = 0.55 (0.29 – 0.73) BA = NR
Hannink et al. 2022[61]	Dual Digital inclinometer (DDI) Flexicurve index (FI) Microsoft Kinect Sensor index (MKS)	$n = 29$ Mean age 56.9 ± 18.2 years BMI (kg/m^2) 24.7 ± 4.3 Sex (M/F) 6/23 Persons with spinal conditions	r_{DDIRX} = 0.67 BA_{DDI} = 3.51° (MD); SD = NR; LA = NR r_{FIRX} = 0.54 BA_{FI} = 0.079° (MD); SD = NR; LA = NR r_{MKSRX} = 0.70 BA_{MKS} = 0.004° (MD); SD = NR; LA = NR
Hunter et al. 2018[62]	Analog Inclinometer	$n = 78$ - 39 with shoulder impingement syndrome Mean age ± SD 57.1 ± 11.1 years; BMI (kg/m^2) 29.3 ± 5.32 Sex (M/F) 20/19 - 39 no shoulder pain Mean age ± SD 55.7 ± 10.6 years; BMI (kg/m^2) 25.7 ± 3.53 Sex (M/F) 19/20	r = 0.62 BA = 2.45° ± 8.38° (MD ± SD); LA = 18.87° to −13.97°
Kado et al. 2006[19]	Debrunner Kyphometer	$n = 120$ Mean age ± SD 68.6 ± 5.9 years BMI = NR Sex (M/F) 0/120 Women with low bone mineral density (0.68 g/cm2)	r = NR BA = NR ICC = 0.68
Korovessis et al. 200,1[20]	Debrunner Kyphometer	$n = 90$ Mean age ± SD 15 ± 2.6 years BMI = NR Sex (M/F) 44/46 Adolescents with round back or poor sagittal back appearance	r = 0.75 BA = NR
Perriman et al. 2010[31]	Electrogoniometer	$n = 12$ Mean age 68.1 (50 - 80) years. BM (kg) 75.8 (62 - 94) Height (cm) 171.2 (160–190); BMI_C (kg/m^2) 25 Sex (M/F) 6/6 Healthy older individuals	r = 0,87 BA = NR
Prowse et al. 2018[33]	Baseline® Body Level/ Scoliosis meter	$n = 31$ Mean age ± SD 13.6	r = - 0.32 BA = NR

Table 1 (*continued*)

Authors and year of the study	Instrument	Study Population	Validity levels
		± 0.6 years BMI = NR Sex (M/F) 4/27 Adolescent with scoliosis	
Sangtarash et al. 2014[63]	Dual Digital Inclinometer	$n = 20$ Mean age ± SD 57.20 ± 7.67 years BMI (kg/m^2) 27.75 ± 4.47 Sex (M/F) 0/20 Women with back pain	r = NR ICC = 0.86 BA = −1.55° ± 6.88° (MD ± SD) LA = 12.26° to −15.21°
Sedrez et al. 2014[23]	Arcometer	$n = 40$ Mean age ± SD 10.7 ± 2.7 years BM (kg) 38.7 ± 13.1 Height(m) 1.39 ± 0.17 BMI_C (kg/m^2) 20 Sex (M/F) 25/15 Children (status not reported)	r = 0.40 BA = NR
Schmidt et al. 2022[64]	Analog Inclinometer	$n = 16$ Group 1 Risser 1 or 2 Mean age ± SD 12.3 ± 1.0 years BMI (kg/m^2) 20.3 ± 3.3 Sex (M/F) NR Adolescent with idiopathic scoliosis $n = 23$ Group 2 Risser 3 or 4 Mean age ± SD 15.0 ± 1.7 years BMI (kg/m^2) 24.1 ± 4.9 Sex (M/F) NR Adolescent with idiopathic scoliosis	r_{group1} = 0.84 BA = NR r_{group2} = 0.75 BA = NR
Sharifnezhad et al. 2021[65]	Photogrammetry (Kinovea software)	$n = 18$ Mean age ± SD 42.64 ± 21.67 years BMI (kg/m^2) 23.48 ± 3.62 Sex (M/F) 8/10 Persons with prescription for an X-ray	r = 0.48 BA = NR
Spencer et al. 2019[66]	Flexicurve Angle	$n = 117$ Mean age ± SD 61.4 ± 7.0 years BMI (kg/m^2) 29.0 ± 5.5 Sex (M/F) 0/117 Postmenopausal women with upper back pain	r = 0.64 BA = −2.48° (MD) SD = NR LA = 14.92° to −19.88°
Tabard-Fougere et al. 2019[67]	Analog Inclinometer	$n = 51$ Mean age ± SD 13.5 ± 2.0 years BMI (kg m^2) 18.9 ± 2.8 Sex (M/F) 19/32 Adolescent with idiopathic scoliosis	r = 0.73 BA = NR
Teixeira et al. 2007[68]	Flexicurve Angle	$n = 56$ Mean age ± SD 66.7 ± 9.37 years	r = NR BA = NR ICC = 0.90

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Table 1 (*continued*)

Authors and year of the study	Instrument	Study Population	Validity levels
		BMI = NR Sex (M/F) 21 /35 Healthy older individuals	
Todd et al. 2015[69]	Debrunner Kyphometer	$n = 92$ Mean age ± SD 17.7 ± 1.39 years BMI (kg/m²) 22.9 ± 3.27 Young athletic elite alpine skiers ($n = 75$) Sex (M/F) 30/35 Non-athletic population ($n = 27$) Sex (M/F) 9/18	$r = 0.60$ BA = 4.5° (MD); SD = NR LA = 7.7° to −16.8°
Tran et al. 2016[70]	Debrunner Kyphometer (DK) Flexicurve Index (FI)	$n = 72$ (FI); $n = 71$ (DK) Mean age ± SD 77.8 ± 7.1 years BMI (kg/m²) 25.3 ± 4.6 Sex (M/F) 20/52 Persons recruited from Community with thoracic kyphosis	$r_{DBRX} = 0.65$ BA = NR $r_{FIRX} = 0.68$ BA = NR
Willner Stig, 1981[17]	Spinal Pantograph	$n = 71$ ($n = 15$ cases with a structural scoliosis of <30°; $n = 41$ cases without any visible spinal disorder on X-ray who served as "controls"; $n = 15$ cases with Scheuermann's disease) Mean age ± SD = NR BMI = NR Sex (M/F) = NR Teenagers with or without visible spinal disorder	$r = 0.97$ BA = NR
Yousefi et al. 2012[29]	Flexicurve Angle (FA) Spinal Mouse (SM) Photogrammetry (pH)	$n = 20$ Mean age ± SD 26 ± 2 years BM (kg) 72 ± 2.5 Height (cm) 169 ± 5.5 BMI_C (kg/m²) 25 Sex (M/F) 20/0 Student volunteers	$r_{FARX} = 0.87$ BA = NR $r_{SMRX} = 0.76$ BA = NR $r_{PHRX} = 0.89$ BA = NR

Note. NR, Not reported; BMI, Body Mass Index; BMI_C, Body Mass Index calculated; SD, Standard deviation; BA, Bland-Altman analysis; BA_{AI}, BA Analog Inclinometer; BA_{DDI}, BA Dual Digital Inclinometer; BA_{FA}, BA Flexicurve Angle; BA_{FI}, BA Flexicurve Index; BA_{DB}, Debrunner Kyphometer; LM, Limits of agreement; MD, Mean difference; ICC, Intraclass Correlation Coefficient; ICC_{DDIRX}, Intraclass Correlation Coefficient Dual Digital Inclinometer x RX; ICC_{FARX}, Intraclass Correlation Coefficient Flexicurve Angle x RX; r, Correlation; r_{AIRX}, Correlation Analog Inclinometer x RX; r_{FIRX}, Correlation Flexicurve Index x RX; r_{FARX}, Correlation Flexicurve Angle x RX; r_{DKRX}, Correlation Debrunner's Kyphometer x RX; r_{DDIRX}, Correlation Dual Digital Inclinometer x RX; r_{MKSRX}, Correlation Microsoft Kinect Sensor x RX; r_{SMRX}, Correlation Spinal Mouse x RX; r_{PHRX}, Correlation Photogrammetry x RX.

adolescents. Regarding sex, 56 (77.77 %) studies included individuals of both sexes, nine (12.50 %) included only women, two (2.77 %) included only men, and five (6.94 %) studies did not report the sex of the individuals.

Between the studies that reported the type of orthostatic posture during the measurement of thoracic kyphosis, 43 (59.72 %) evaluated the relaxed orthostatic posture, 16 (22.22 %) the upright orthostatic posture, and 4 (5.55 %) evaluated both postures.

Methodological quality of included studies

The methodological quality is reported in Supplementary material 3. Of the 72 studies, 62 (86.11 %) had high quality. Regarding validity, of the 31 studies, 26 (83.87 %) had high methodological quality. Of the 58 intra-rater reliability studies, 50 (86.20 %) were of high quality and 33 (82.50 %) out of the 40 inter-rater reliability studies were of high quality. The CAT items with the worst scores were related to the lack of randomization of evaluators or individuals and the lack of information about the qualifications and experience of the raters, the rater blinding process, and the time interval between the measurement by the instrument and the gold standard.

Validity

A total of 13 instruments had concurrent validity assessed in 31 studies (Table 1). The most investigated were the Analog Inclinometer and Flexicurve Angle. On the other hand, the validity of the Digital Inclinometer and Spinal Wheel was not investigated. The Baseline® Level/Scoliosis meter ($r = 0.32$),[33] Kipholordometer ($r = 0.78$),[52] Electrogoniometer ($r = 0.87$),[31] Dual Digital Inclinometer ($r = 0.67$),[61] Microsoft Kinect Sensor ($r = 0.70$),[61] and the Smartphone app ($r = 0.81$)[57] had the validity tested in only one study; thus, they were not included in the meta-analysis. Seven instruments presented the correlation coefficient with the X-ray examination reported by at least two studies; therefore, they were grouped into seven meta-analyses, one for each instrument (Fig. 2). The meta-analysis demonstrated that the Analog Inclinometer, Arcometer, Flexicurve Angle, Photogrammetry, Spinal Mouse and Spinal Pantograph presented strong concurrent validity with the X-ray. The Debrunner Kyphometer and Flexicurve Index demonstrated moderate levels of concurrent validity with the X-ray (Fig. 2). Bland-Altman analysis was described for nine instruments and is presented as the mean difference between measurements (Table 1).

Intra-rater reliability

Fourteen instruments had their intra-rater reliability assessed in 55 studies (Table 2); the Analog Inclinometer, Flexicurve Angle, and Photogrammetry were the most investigated. Seven instruments had the 95 % CI of the ICC reported by at least two studies and were grouped into seven metanalyses, one for each instrument. The following instruments demonstrated an excellent level of intra-rater reliability: Analog, Digital Inclinometer, Flexicurve Angle, Flexicurve Index, Photogrammetry, Microsoft Kinect Sensor, Smartphone app, and Spinal Mouse (Fig. 3). This analysis was not performed in studies that used the Baseline ® Level/Scoliosis meter.[33] The Kipholordometer[52] and Spinal Pantograph[17] instruments did not have the ICC reported. The Electrogoniometer (ICC = 0.90)[31] and Spinal Wheel (ICC = 0.98),[32] evaluated in only one study each, showed excellent intra-rater reliability. The Arcometer was evaluated in three studies: one did not report the ICC,[56] and the other two demonstrated levels of intra-rater reliability ranging from good to excellent (0.50 to 0.99) but did not report the 95 % CI of the ICC[23–24]; therefore, they were not included in the meta-analysis. The Debrunner Kyphometer[12,20–21,69,84] and the Dual Digital Inclinometer[51,63] were evaluated in five and two studies, respectively, and demonstrated excellent levels of intra-rater reliability. However, they also did not present the 95 % CI of the ICC and were not grouped in the meta-analysis. The MDC and SEM were reported for six and eight instruments, respectively (Table 2).

Inter-rater reliability

Twelve instruments had their inter-rater reliability assessed by 40 studies (Table 2); the Flexicurve Angle, the Debrunner Kyphometer, and the Analog Inclinometer were the most investigated. Six of these 12 instruments had ICC and 95 % CI of the ICC data reported by at least two

Table 2
Characteristics of the included reliability studies.

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
Alderighi et al. 2016[71]	Analog Inclinometer	*n* = 34 Mean age ± SD 19.17 (4.52 years) BMI (kg/m2) 21.00 ± 2.60 Sex (M/F) 0/34 Heathy female football players (> 3 h/ week) ≥ 3 years (weekly sport hours mean 6.56)	ICC_{IAR} = 0.91 95 % CI (0.85 – 0.98) ICC_{IER} = 0.88 95 % CI (0.82 – 0.94)	SEM_{IAR} = 2.09° SEM_{IER} = 2.44° MDC_{IER} = 6.77°
Amatachaya et al. 2016[72]	Flexicurve Angle	*n* = 21 Mean age ± SD 74.1 ± 7.6 years; BMI (kg/m^2)21.6 ± 3.7 Sex (M/F) NR Older individuals with various degrees of structural kyphosis	ICC_{IAR} = 0.97 95 % CI (0.94 – 0.98) ICC_{IER} = 0.94 95 % CI (0.86 – 0.97)	SEM_{IAR} = 2.69° MDC_{IAR} = 7.43° SEM_{IER} = 3.65° MDC_{IER} = 10.08°
Azadinia et al.2021[50]	Photogrammetry Digimizer Image Analysis Software version 5.3.4 (MedCalc Software; BVBA, Ostend, Belgium)	*n* = 40 Mean age ± SD 13.57 ± 1.99 years; BMI (kg/m^2)19.28 ± 2.76 Sex (M/F) 20/20 Adolescents with hyperkyphosis	ICC_{IAR} = 0.97 95 % CI (0.94 – 0.98)	SEM_{IAR} = 1.67° MDC_{IAR} = 4.62°
Azadinia et al. 2014[51]	Flexicurve Angle (FA) Dual Digital inclinometer (DDI)	*n* = 81 Mean age ± SD 14.69 ± 4.11 years (range 10 – 30); height (cm) 157 ± 13.5; mass (kg) 50.7 ± 15.3) BMI_C (kg/m^2) 20 Sex (M/F) 26/55 Patients with hyperkyphosis *n* = 21 Mean age ± SD 65.76 ± 4.6 years; height (cm) 156.8 ± 5.7; mass(kg) 66.48 ± 8.93) BMI_C (kg/m^2) 26 Sex (M/F) 3/18 Patients with hyperkyphosis	$ICC_{IARFA\ (10-30)}$ = 0.87 $ICC_{IERFA\ (10-30)}$ = 0.68 $ICC_{IARDDI\ (10-30)}$ = 0.98 $ICC_{IERDDI\ (10-30)}$ = 0.96 $ICC_{IARFA\ (50-80)}$ = 0.86 $ICC_{IERFA\ (50-80)}$ = 0.85 $ICC_{IARDDI\ (50-80)}$ = 0.97 $ICC_{IERDDI\ (50-80)}$ = 0.92	SEM = NR MDC = NR
Barrett et al. 2013[73]	Analog Inclinometer (AI) Flexicurve Angle (FA) Flexicurve Index (FI)	*n* = 30 intrarater reliability Mean age ± SD 45 ± 16 years BM (kg) 73.9 ± 11.1; Height (cm) 172.8 BMI_C (kg/m^2) 24 Sex (M/F) 18/12 *n* = 12 interrater reliability Mean age ± SD 49 ± 18 years. BM (kg) 74 ± 15; Height (cm) 172 ± 10 BMI_C (kg/m^2) 25 Sex (M/F) 5/7 Swimmers with or without shoulder pain (swimming at least 2 X week. Average Weekly swim distance (km) intrarater 9.9 (SD ± 14) and interrater 7 (SD ± 6)	ICC_{IARAI} = 0.92 95 % CI (0.84 – 0.96) ICC_{IERAI} = 0.90 95 % CI (0.68 – 0.97) ICC_{IARFA} = 0.94 95 % CI (0.88 – 0.97) ICC_{IERFA} = 0.86 95 % CI (0.51 – 0.96) ICC_{IARFI} = 0.94 95 % CI (0.88 – 0.97) ICC_{IERFI} = 0.86 95 % CI (0.51 – 0.96)	SEM_{IARAI} = NR SEM_{IERAI} = 2.2° MDC = NR SEM_{IARFA} = NR SEM_{IERFA} = 1° MDC = NR SEM_{IARFI} = NR SEM_{IERFI} = 0.4° MDC = NR
Barauna et al. 2005[52]	Kypholordometer	*n* = 30 Mean age ± SD 39 ± 15.8 years BMI = NR Sex (M/F) both Scheuermann's Disease (*n* = 3) Postural kyphosis (*n* = 25) Ankylosing Spondylitis (*n* = 2)	ICC_{IAR} = NR	SEM = NR MDC = NR
Büyükturan et al. 2018[54]	Spinal Mouse	*n* = 46 Mean age ± SD 68.12 ± 2.67 years BMI (kg/m^2) 29.45 ± 4.67 Sex (M/F) 17/29 Healthy elderly	ICC_{IAR} = 0.85 95 % CI (0.80 – 0.89) ICC_{IER} = 0.90 95 % CI (0.88 – 0.91)	SEM_{IAR} = 2.86° MDC = NR SEM_{IER} = 3.14° MDC = NR
Carvalho et al. 2019[74]	Flexicurve Angle	*n* = 21 Mean age ± SD M: 22 ± 0.71 years; BM (kg)78.25 ± 8.83; Height 1.82 ± 0.12 m BMI_C (kg/m^2) 23 F: 22 ± 1.41 years; BM (kg) 53 ± 2.88; Height 1.61 ± 0.04 m BMI_C (kg/m^2) 20 Sex (M/F) 4/17 Healthy and asymptomatic	ICC_{IAR} = 0.94 95 % CI (0.87 - 0.98) ICC_{IER} = 0.82 IC (0.60 - 0.93)	SEM_{IAR} = 2.3° MDC_{IAR} = 6.4° SEM_{IER} = NR MDC_{IER} = NR
Chaise et al.2011[24]	Arcometer	*n* = 15 intrarater reliability; *n* = 30 interrater reliability Mean age ± SD 53.7 ± 14.9 years BMI (kg/m^2) 26.1 ± 4.4 Sex (M/F) NR	ICC_{IAR} = 0.99 ICC_{IER} = 0.98	SEM = NR MDC = NR
Czaprowski et al. 2012[28]	Digital inclinometer	*n* = 30 Mean age ± SD 23 ± 3.4 years BMI (kg/m2) 21.4 ± 2.4 Sex (M/F) 5/25 Healthy subjects	ICC_{IAR} = NR ICC_{IER} = NR	SEM = NR MDC = NR

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Table 2 (*continued*)

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
Demir et al. 2020[75]	Spinal Mouse	*n* = 28 Mean age ± SD 16.29 ± 1.08 years BMI (kg/m^2) 21.14 ± 2.88 Sex (M/F) 0/28 Asymptomatic females	ICC_{IAR} = 0.86 95 % CI (0.54 – 0.88)	SEM = NR MDC = NR
de Oliveira et al. 2012[55]	Flexicurve Angle	*n* = 15 (intrarater reliability); *n* = 47 (interrater reliability) Mean age ± SD 44.9 ± 19.4 BMI (kg/m^2) 27.5 ± 5 Sex (M/F) both sex Persons with prescription for an X-ray	ICC_{IAR} = 0.82 95 % CI (0.56 – 0.93) ICC_{IER} = 0.94 95 % CI (0.86 – 0.97)	SEM_{IAR} = 1.3° MDC = NR
Devaney et al. 2017[76]	Analog Inclinometer	*n* = 51 intrarater reliability; Mean age ± SD 46.9 ± 20.2 years BMI = NR Sex (M/F) 25/26 Persons with orthopedic conditions	ICC_{IAR} = 0.94 95 % CI (0.89 - 0.96)	SEM_{IAR} = 3.0° MDC_{IAR} = 8.0°
D'Osualdo et al.1997 [56]	Arcometer	*n* = 16 intrarater reliability Mean age 13 years BMI = NR Sex (M/F) 8/8 *n* = 97 interrater reliability Mean age/SD 14 years Sex (M/F) 22/27 BMI = NR Patients with kyphosis and scoliosis and for postural rehabilitation	ICC_{IAR} = NR ICC_{IER} = NR r_{INTRA} = 0.99 r_{INTER} = 0.99	SEM = NR MDC = NR
Dunk et al. 2004[36]	Photogrammetry GOBER, University of Guelph, Guelph, ON	*n* = 14 Sex (M/F) 7/7 Female: Mean age ± SD 22.0 ± 0.8 years; BM (kg) 66.2 ± 12.0; Height (cm) 162.0 ± 9.9; BMI_C (kg/m^2) 25 Male: Mean age ± SD 21.6 ± 1.3 years; BM (kg) 76.4 ± 5.2; Height (cm) 181.3 ± 4.4 BMI_C (kg/m^2) 23 Healthy and active young adults	ICC_{IAR} = 0.51 female ICC_{IAR} = 0.35 male	SEM = NR MDC = NR
Dunk et al. 2005[77]	Photogrammetry GOBER, University of Waterloo, Waterloo, Ontario.	*n* = 20 Mean age/SD Sex (M/F) 10/10 Female: Mean age ± SD 21.8 ± 0.6 years; BM(kg) 57.5 ± 8.5; Height (cm) 163.6 ± 6.8; BMI_C (kg/m^2) 21 Male: Mean age ± SD 22.6 ± 1.3 years; BM (kg) 76.7 ± 5.1; Height (cm) 179.1 ± 3.3; BMI_C (kg/m^2) 23 Healthy and active young adults	ICC_{IAR} = 0.63 female ICC_{IAR} = 0.72 male	SEM = NR MDC = NR
Elpeze, G et al. 2023[78]	Flexicurve Angle (FA) Smartphone (SP-app) protractor software of smartphone inclinometer	*n* = 60 Mean age ± SD 21.92 ± 1.50 BMI (kg/m2) 22.74 ± 3.46 Sex (M/F) 35/25 Subjects with thoracic kyphosis ≥ 30°	ICC_{IARFA} = 0.96 95 % CI (0.90 – 0.96) ICC_{IERFA} = 0.91 95 % CI (0.85 – 0.94) ICC_{IARSP} = 0.96 95 % CI (0.93 – 0.97) ICC_{IERSP} = 0.96 95 % CI (0.94 – 0.97)	SEM = NR MDC = NR SEM = NR MDC = NR
Faramarzi et al. 2020[57]	Smartphone Goniometer-Pro app	*n* = 20 intrarater reliability *n* = 20 interrater reliability Mean age ± SD 25.1 ± 2.1 years; BMI (kg/m^2) 22.5 ± 2. Sex (M/F) NR Persons with prescription for an X-ray	ICC_{IAR} = 0.88 95 % CI (0.75 – 0.95) ICC_{IER} = 0.91 95 % CI (0.82 – 0.96)	SEM = NR MDC = NR
Gravina et al. 2017[79]	Analog Inclinometer	*n* = 139 Mean age ± SD 12.5 ± 2.5 years BMI = NR Sex (M/F) 40/99 Normal subjects and with spinal deformities (*n* = 41 - no spine pathology; *n* = 11 - Scheuermann's disease; *n* = 38 - postural hyperkyphosis; *n* = 49 - mild idiopathic scoliosis)	ICC_{IAR} = NR ICC_{IER} = NR r_{INTRA} = 0.83 r_{INTER} = 0.84	SEM = NR MDC = NR
Greendale et al. 2011[12]	Debrunner Kyphometer (DK) Flexicurve index (FI) Flexicurve angle (FA)	*n* = 113 intrarater reliability Mean age/SD 75.3 ± 7.5 years BMI (kg/m^2) 26.5 ± 4.5 Sex (M/F) 22/92 *n* = 54 interrater reliability Mean age/SD 75.5 ± 7.7 years BMI (kg/m^2) 26.1 ± 4.3)	ICC_{IARDK} = 0.98 ICC_{IARFI} = 0.96 ICC_{IARFA} = 0.96 ICC_{IERDK} = 0.98 ICC_{IERFI} = 0.96 ICC_{IERFA} = 0.96	SEM = NR MDC = NR

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Table 2 (*continued*)

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
		Sex (M/F) 9/45 Persons with kyphosis > 40°		
Hannink et al. 2019[80]	Microsoft Kinect Sensor index	*n* = 37 Mean age/SD 51.7 ± 20.6 years BMI (kg/m^2) 24.9 ± 3.3 Sex (M/F) 57 % were female Participants without neurological conditions	ICC_{IAR} = 0.96 95 % CI (0.92 – 0.97) ICC_{IER} = 0.97 95 % CI (0.95 – 0.98)	SEM = NR MDC_{IAR} = 1.49° SEM = NR MDC_{IER} = 1.50°
Heitz et al. 2018[37]	Photogrammetry Software Clinical Photographic Postural Assessment Tool	*n* = 41 (*n* = 35 - right side) Mean age/SD 13 ± 2 years BM (kg) 43 ± 10 Height (cm)152 ± 11 BMI_C (kg/m²) 18 Sex (M/F) 3/38	ICC_{IAR} = 0.85	SEM = 2.4° $MDC_{(CI90\ \%)}$ = 5.6°
Hinman et al. 2004[95]	Flexicurve Index	*n* = 51 (25 pre-menopausal/ 26 post-menopausal) Pre-menopausal Mean age/SD 29.2 years BMI = NR Sex (M/F) 0/25 Healthy women Post-menopausal Mean age/SD 72.3 years BMI = NR Sex (M/F) 0/26	ICC_{IER} = 0.94 95 % CI (0.90 – 0.96)	SEM = NR MDC = NR
Iunes et al. 2005[35]	Photogrammetry ALCimagem-2000 Manipulando Imagens, versão 1,5	*n* = 21 Mean age/SD 24.19 ± 1.3 years BM (kg) 59.10 ± 12.27 Height (m)1.66 ± 0.05 BMI_C (kg/m²) 21 Healthy adults Sex (M/F) 4/17	ICC_{IAR} = 0.32 ICC_{IER} = 0.60	SEM = NR MDC = NR
Kellis et al. 2008[30]	Spinal Mouse	*n* = 81 Mean age/SD 10.62 ± 1.73 years BM (kg) 41.8 ± 9.3; Height (m) 1.47 ± 0.12 BMI_C (kg/m²) 19 Sex (M/F) 81/0 Healthy boys	ICC_{IAR} = 0.87 ICC_{IER} = 0.89	SEM_{IAR} = 2.79° MDC = NR SEM_{IER} = 1.47° MDC = NR
Korovessis et al. 2001[20]	Debrunner Kyphometer	*n* = 90 (*n* = 35 intrarater reliability. *n* = 90 interrater reliability) Mean age/SD 15 ± 2.6 years BMI = NR Sex (M/F) 44/46 Adolescents with round back or poor sagittal back appearance	ICC_{IAR} = 0.92 ICC_{IER} = 0.84	SEM = NR MDC = NR
Lewis et al. 2010[26]	Analog Inclinometer	*n* = 90 (*n* = 45 Adults with shoulder pain) Mean age/SD 43 (19 - 84) years; BM (kg) 71.4; Height (m) 1.7 (range 1.5 - 1.9) BMI_C (kg/m²) 24 Sex (M/F) 22/23 *n* = 90 (*n* = 45 Adults without shoulder pain) Mean age/SD 32 (range 23–56) years; BM (kg) 70.4 Height (m) 1.7 BMI_C (kg/m²) 24 Sex (M/F) 21/24	ICC_{IAR} = 0.97 95 % CI (0.94 – 0.98) ICC_{IAR} = 0.97 95 % CI (0.95 – 0.99)	SEM = 1.7° MDC = NR SEM = 1.0° MDC = NR
Lewis et al. 2005[25]	Analog Inclinometer	*n* = 120 (*n* = 15 Adults with shoulder pain) Mean age/SD 48.9 ± 15.2 years; BM (kg) 74.5 ± 12.7 Height(m) 171.2 ± 9.7; BMI_C (kg/m²) 25 Sex (M/F) 35/25 (*n* = 15 Adults without shoulder pain) Mean age/SD 34.1 ± 9.9 years BM (kg) 67.8 ± 13.4; Height (m) 170.9 ± 10.4 BMI_C (kg/m²) 23 Sex (M/F) 29/31	Subjects with symptoms ICC_{IAR} = 0.94 95 % CI (0.83 – 0.98) Subjects without symptoms ICC_{IAR} = 0.96 95 % CI (0.91 – 0.98)	SEM with symptoms 2.5° MDC = NR SEM without symptoms 1.5° MDC = NR
Lundon et al. 1998[21]	Debrunner Kyphometer (DK) Flexicurve angle (FA)	*n* = 26 Mean age/SD 18 - 56 years BMI = NR Sex (M/F) 0/26 Postmenopausal women with diagnosis of osteoporosis	ICC_{IARDK} = 0.99 ICC_{IARFA} = 0.96 ICC_{IERDK} = 0.88 ICC_{IERFA} = 0.87	SEM = NR MDC = NR
MacIntyre et al. 2014[81]	Digital inclinometer	*n* = 36 Mean age/SD 69 ± 8.1 years BMI = NR Sex (M/F) 86 % were women Adults at risk for osteoporotic fracture (89 % osteoporotic/ 11 % osteopenic)	ICC_{IAR} = 0.91 95 % CI (0.84 - 0.95)	SEM_{IAR} = 3.5° (2.90 - 4.6°) $MDC_{(CI90\ \%)}$ = 8.2°

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Table 2 (*continued*)

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
Mannion et al. 2004[82]	Spinal Mouse	$n = 20$ Mean age/SD Males 45.4 ± 7.7 years BMI (kg/m^2) 26.5 ± 5.2 Females 38.2 ± 7.6 years BMI (kg/m^2) 22.9 ± 5.7 Sex (M/F) 9/11 Healthy volunteers	$ICC_{IAR} = 0.88$ 95 % CI (0.67 - 0.94) $ICC_{IER} = 0.87$ 95 % CI (0.70 - 0.95)	$SEM_{IAR} = 2.8°$ (2.1 - 4.0) MDC = NR $SEM_{IER} = 2.7°$ (2.0 - 3.9) MDC = NR
Mellin G, 1986[27]	Analog Inclinometer	$n = 25$ ($n = 10$ intratester reliability; $n = 15$ interrater reliability) Mean age/SD 31.3 ± 5.8 years BM (kg) 67.8 ± 15.4 Height (cm) 169.1 ± 9.1 BMI_C (kg/m^2) 23 Healthy adults Sex (M/F) 9/16	$r_{INTRA} = 0.92$ $r_{INTER} = 0.83$	SEM = NR MDC = NR
Nair et al. 2017[96]	Analog Inclinometer	$n = 28$ Mean age/SD 69.7 ± 10.6 years BMI (kg/m^2) 26.3 ± 6.2 Sex (M/F) 16/12 Subjects with Parkinson Disease	$ICC_{IER} = 0.779$ 95 % CI (0.57 – 0.89)	SEM = NR MDC = 13.9°
Ohlén et al.1989[22]	Debrunner Kyphometer	$n = 31$ Mean age/SD 32 ± 11 years BMI = NR Sex (M/F) 10/21 Healthy adults	ICC = NR rIAR = 0.92 rIER = 0.94	SEM = NR MDC = NR
Perriman et al. 2010[31]	Electrogoniometer	$n = 12$ Mean age/SD 40.7 (25–61) years; BM (kg) 70.9 (50–95) Height (cm) 170.0 (156–186); BMI_C (kg/m^2) 24.5 Sex (M/F) 4/8 Healthy adults	$ICC_{IAR} = 0.90$ 95 % CI (0.70 – 0.97)	SEM = NR MDC = NR
Pakeloğlu et al. 2023[83]	Flexicurve Angle (FA) Smartphone-app (SP) Goniometer Pro app	$n = 30$ Mean age/SD 21.13 ± 1.78 years BMI (kg/m^2) 21.97 ± 3.17 Height (cm) 173.23 ± 9.54 Sex (M/F) 13/17 Healthy and asymptomatic participants	$ICC_{IARFA} = 0.87$ 95 % CI (0.75 – 0.93) $ICC_{IERFA} = 0.62$ 95 % CI (0.20 – 0.82) $ICC_{IARSP} = 0.90$ 95 % CI (0.80 – 0.95) $ICC_{IERSP} = 0.87$ 95 % CI (0.73 – 0.94)	$SEM_{IARFA} = 1.73°$ $MDC_{IARFA} = 3.39°$ $SEM_{IARFA} = 1.59°$ $MDC_{IARFA} = 3.11°$ $SEMI_{IARSP} = 1.48°$ $MDC_{IARSP} = 2.90°$ $SEMI_{IARSP} = 1.60°$ $MDC_{IARSP} = 3.13°$
Prowse et al. 2018[33]	Baseline® Body Level/Scoliosis meter	$n = 31$ Mean age/SD 13.6 ± 0.6 years BMI = NR Sex (M/F) 4/27 Adolescent with scoliosis	$ICC_{IER} = 0.94$ 95 % CI (0.87- 0.97)	SEM = 1.66cm $MDC_{IER} = 4.60$cm
Purser et al. 1999[84]	Debrunner Kyphometer	$n = 24$ Mean age/SD 68 ± 4 years BMI = NR Sex (M/F) 3/21 Community-dwelling elderly $n = 15$ Mean age/SD 75 ± 6 years BMI = NR Sex (M/F) 13/2 Community-dwelling with Parkinson disease $n = 12$ Mean age/SD 82 ± 4 years BMI = NR Sex (M/F) 0/12 Subjects with vertebral osteoporosis $n = 14$ Mean age/SD 74 ± 6 years BMI = NR Sex (M/F) 12/2 Nursing home residents	Community-dwelling elderly persons $ICC_{IAR} = 0.96$ Community-dwelling with Parkinson disease $ICC_{IAR} = 0.95$ Subjects with vertebral osteoporosis $ICC_{IAR} = 0.92$ Nursing home residents $ICC_{IAR} = 0.91$ Overall ICC = 0.95	SEM = NR MDC = NR
Quek et al. 2017[38]	Flexicurve Angle (FA) Flexicurve Index (FI) Microsoft Kinect Sensor Angle (MKA) Microsoft Kinect Sensor Index (MKI)	$n = 33$ ($n = 29$ intrarater reliability) Mean age/SD 31 ± 11.0 years BM (kg) 64.2 ± 12.0 Height (cm) 170.2 ± 8.2 BMI_C (kg/m^2) 22	$ICC_{IARFA} = 0.83$ 95 % CI (0.63 – 0.92) $ICC_{IARFI} = 0.83$ 95 % CI (0.63 – 0.92) $ICC_{IARMKA} = 0.96$ 95 % CI (0.92 – 0.98)	$SEM_{FA} = 0.99°$ $MDC_{FA} = 2.7°$ $SEM_{F\,I} = 1.11°$ $MDC_{FI} = 3.1°$ $SEM_{MKA} = 0.69°$ $MDC_{MKA} = 1.9°$

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Table 2 (*continued*)

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
		Sex (M/F) 17/16 Healthy adults	ICC_{IARMKI} = 0.98 IC 95 % CI (0.95 – 0.99)	SEM_{MKI} = 0.53° MDC_{MKI} = 1.5°
Raine and Twomey, 199,4[85]	Photogrammetry GTCO digitiser of O.lmm resolution, a Hewlett-Packard HP9836CS computer and an IBM-compatible computer	*n* = 38 (*n* = 29 intrarater reliability) Mean age/SD 22 (17 - 48) years BMI = NR Sex (M/F) 8/30 Healthy adults	Upper thoracic curvature ICC_{IAR} = 0.92 Lower thoracic curvature ICC_{IAR} = 0.94	SEM = NR MDC = NR
Roghani et al. 2017[86]	Spinal Mouse	*n* = 19 Mean age/SD 67 ± 5.0 years BMI (kg/m^2) 28.5 ± 3.4 Sex (M/F) 0/19 Women with hyperkyphosis *n* = 14 Mean age/SD 63 ± 6.0 years BMI (kg/m^2) 26.7 ± 3.4 Sex (M/F) 0/14 Women with a normal curvature	Hyperkyphosis ICC_{IAR} = 0.94 95 % CI (0.86 – 0.98) Normal Curvature ICC_{IAR} = 0.89 95 % CI (0.69 – 0.96)	Hyperkyphosis SEM = 1.56° MDC = 4.33° Normal Curvature SEM = 1.75° MDC= 4.86°
Saad et al. 2012[87]	Photogrammetry CorelDRAW software (version 11.0)	*n* = 20 Mean age/SD 23.1 + 9.0 years BMI (kg/m^2) 22.28 ± 5.27 Sex (M/F) 3/17 Participants with scoliosis	ICC_{IAR} = 0.93 (right side) ICC_{IER} = 0.97 (right side)	SEM = NR MDC = NR
Şahinoğlu et al. 2023[88]	Digital Inclinometer (DI) Smartphone-app (SP)	*n* = 80 Mean age/SD 20.42 ± 1.40 years BMI (kg/m^2) 22.58 ± 3.16 Sex (M/F) 42/38 Height (cm) 171.0 ± 0.09 Young and healthy subjects	ICC_{IARDI} = 0.94 95 % CI (0.91 – 0.96) ICC_{IERDI} = 0.82 95 % CI (0.73 – 0.89) ICC_{IARSP} = 0.94 95 % CI (0.90 – 0.96) ICC_{IERSP} = 0.80 95 % CI (0.68 – 0.88)	SEM_{IARDI} = 1.81° MDC_{IARDI} = 5.04° SEM_{IERDI} = 3.03° MDC_{IERDI} = 8.39° SEM_{IARSP} = 2.27° MDC_{IARSP} = 6.30° SEM_{IERSP} = 3.25° MDC_{IERSP} = 9.02°
Sangtarash et al. 2014[63]	Dual Digital Inclinometer	*n* = 20 Mean age/SD 57.20 ± 7.67 years BMI (kg/m^2) 27.75 ± 4.47 Sex (M/F) 0/20 Women with back pain	ICC_{IAR} = 0.92	SEM_{IAR} = 1.98° MDC = NR
Sedrez et al. 2014[23]	Arcometer	*n* = 40 Mean age/SD 10.7 ± 2.7 years BM (kg)38.7 ± 13.1 Height(m) 1.39 ± 0.17 BMI_C (kg/m^2) 20 Sex (M/F) 25/15 Children (status not reported)	ICC_{IAR} = 0.50 ICC_{IER} = 0.25	SEM = NR MDC = NR
Sedrez et al. 2016[89]	Flexicurve Angle	*n* = 40 (*n* = 38 intrarater reliability; *n* = 40 interrater reliability) Mean age/SD 10.2 ± 2.8 years BMI (kg/m^2) 19.5 ± 2.8 Sex (M/F) 25/15 Children who had undergone X-ray examination	ICC_{IAR} = 0.82 95 % CI (0.65 – 0.91) ICC_{IER} = 0.83 95 % CI (0.61 - 0.92)	SEM_{IAR} = 4.1° MDC_{IAR} = 8.1° SEM_{IER} = 4.1° MDC_{IER} = 8.0°
Schmidt et al. 2022[64]	Analog Inclinometer	*n* = 16 Mean age/SD 12.3 ± 1.0 years BMI (kg/m^2) 20.3 ± 3.3 Sex (M/F) NR Adolescent with idiopathic scoliosis - Group 1 Risser 1 or 2 *n* = 23 Mean age/SD 15.0 ± 1.7 years BMI (kg/m^2) 24.1 ± 4.9 Adolescent with idiopathic scoliosis - Group 2 Risser 3 or 4	$ICC_{IAR\ group1}$ = 0.88 $ICC_{IER\ group1}$ = 0.86 $ICC_{IAR\ group2}$ = 0.90 $ICC_{IER\ group2}$ = 0.85	SEM = NR MDC = NR SEM = NR MDC = NR
Sharifnezhad et al. 2021[65]	Photogrammetry Kinovea software	*n* = 18 Mean age/SD 42.64 ± 21.67 years BMI (kg/m^2) 23.48 ± 3.62 Sex (M/F) 8/10 Persons with prescription for an X-ray	ICC_{IAR} = 0.90 95 % CI (0.74 – 0.96) ICC_{IER} = 0.81 95 % CI (0.61 – 0.92)	SEM = NR MDC = NR
Sheeran et al. 2010[32]	Spinal Wheel	*n* = 17 Mean age/SD Male 37 ± 10.4 years; BMI (kg/m^2) 25.5 ± 6.1 Female 40 ± 10.8 years; BMI (kg/m^2) 24.5 ± 6.8 Sex (M/F) 9/8 Healthy volunteers	ICC_{IAR} = 0.98 95 % CI (0.92 – 0.99) ICC_{IER} = 0.98 95 % CI (0.95 – 0.99)	SEM_{IAR} = 1.7° SEM_{IER} = 2.0°
Stolinski et al. 2017[90]	Photogrammetry Software SCODIAC	*n* = 91 (*n* = 20 intrarater reliability; *n* = 30 interrater reliability)	ICC_{IAR} = 0.93 / 95 % CI (0.88 - 0.97)	SEM_{IAR} = 1.1° MDC = NR

(*continued on next page*)

Table 2 (*continued*)

Authors and year of the study	Instrument	Study Population	Intrarater and Interrater Reliability	SEM/MDC
		Mean age/SD 8.2 ± 1.0 years BMI = NR Sex (M/F) 47/44 Healthy volunteers	ICC_{IER} = 0.92 95 % CI (0.86 – 0.96)	SEM_{IER} = 0.9° MDC = NR
Tabard-Fougere et al. 201,9[67]	Analog Inclinometer	*n* = 51 Mean age/SD 13.5 (2.0) years BMI (kg/m²) 18.9 ± 2.8 Sex (M/F) 19/32 Adolescent with idiopathic scoliosis	ICC_{IAR} = 0.98 95 % CI (0.97 - 0.98)	SEM = NR MDC = NR
Takatalo et al. 2020[91]	Digital inclinometer	*n* = 32 Mean age/SD 39 ± 9.2 years; BMI (kg/m²) 24.5 ± 3.2 Sex (M/F) 16/16 Persons with pain in thoracic spine	ICC_{IAR} = 0.83 95 % CI (0.66 - 0.92) ICC_{IER} = 0.82 95 % CI (0.64 – 0.91)	SEM_{IAR} = 3.09° MDC = NR SEM_{IER} = 3.18° MDC = NR
Teixeira et al. 2007[68]	Flexicurve Angle	*n* = 56 Mean age/SD 66.7 ± 9.37 years BMI = NR Sex (M/F) 21/35 Healthy elderly	ICC_{IAR} = 0.87 ICC_{IER} = 0.94	SEM = NR MDC = NR
Temporiti et al. 2023[92]	Photogrammetry BHOHB system (Bhohb S.r.l., Italy)	*n* = 30 Mean age/SD 22.3 years ± 9.0 years; Mean weight 64.9 kg, SD: 9.04 kg Mean height 173.2 cm, SD: 8.1 cm BMI_C (kg/m²) 21.7 Sex (M/F) 15/15 Healthy adult volunteers	ICC_{IAR} = 0.98 95 % CI (0.96 – 0.99)	SEM = 0.78° MDC = NR
Todd et al. 2015[69]	Debrunner Kyphometer	*n* = 102 (*n* = 10 intrarater reliability; *n* = 10 interrater reliability) Mean age ± SD (reliability) 18.3 ± 1.13 years BMI (kg/m²) 22.9 ± 3.12 Sex (M/F) NR for reliability Young athletic elite alpine skiers	ICC_{IAR} = 0.83 95 % CI (0.30 – 0.96) ICC_{IER} = 0.96 95 % CI (0.85 – 0.99)	SEM = NR MDC = NR
Tran et al. 2016[70]	Debrunner Kyphometer (DK) Flexicurve Index (FI)	*n* = 71 (DB); *n* = 72 (FI); Mean age/SD 77.8 ± 7.1 years BMI (kg/m²) 25.3 ± 4.6 Sex (M/F) 20/52 Persons recruited from community with thoracic kyphosis	ICC_{IERFI} = 0.93 ICC_{IERDB} = 0.99	SEM = NR MDC = NR
van Baalen et al. 2023[93]	Analog Inclinometer AI) Smartphone (SM-app)	*n* = 17 Mean age/SD 23.7 ± 2.3 years; BMI (kg/m²) = 22.3 ± 1.6; Height 1.69 (m) ± 0.1 Sex (M/F) 13/4 Asymptomatic volunteers	ICC_{IARAI} = 0.92 95 % CI (0.84 – 0.97) ICC_{IERAI} = 0.81 95 % CI (0.55 – 0.93) ICC_{IARSP} = 0.94 95 % CI (0.87 – 0.97) ICC_{IERSP} = 0.67 95 % CI (0.08 – 0.89)	SEM_{IARAI} = 1.7° MDC_{IARAI} = 4.7° SEM_{IERAI} = 2.6° MDC_{IERAI} = 7.1° SEM_{IARSP} = 1.5° MDC_{IARSP} = 4.3° SEM_{IERSP} = 3.2° MDC_{IERSP} = 9.0°
van Blommestein et al. 2012[94]	Analog Inclinometer	*n* = 30 Mean age/SD 33 ± 11.23 years; BM (kg) 72 ± 12; Height 172 (cm) ± 11 BMI_C (kg/m²) 24 Sex (M/F) 15/15 Asymptomatic volunteers	ICC_{IAR} = 0.96 95 % CI (0.92 – 0.98)	SEM = 1.7° MDC = NR
Was et al. 2016[39]	Digital Inclinometer (DI) Smartphone (SP-app) Android 4.0.3 software with a built-in accelerometer	*n* = 40 (*n* = 20 intrarater reliability) Mean age/SD 23.2 ± 3.4 years BMI (kg/m²) 24.9 ± 3.6 (male) BMI (kg/m²) 22.5 ± 4.5 (female) Sex (M/F) 14/26 Healthy students	ICC_{IARDI} = 0.8 ICC_{IARSP} = 0.8	SEM = NR MDC = NR
Willner and Johnson, 198,3[18]	Spinal Pantograph	*n* = 1101 (*n* = 10 intrarater reliability) Mean age/SD ages of 8–16 BMI NR Sex (M/F) 565/536 Healthy children	ICC_{IAR} = NR	SEM = NR MDC = NR
Willner Stig, 1981[17]	Spinal Pantograph	*n* = 71 Mean age/SD NR Sex (M/F) NR Teenagers with or without visible spinal disorder	ICC_{IAR} = NR ICC_{IER} = NR	SEM = NR MDC = NR
Yanagawa et al. 2000[42]	Flexicurve index	*n* = 26 Mean age/SD 67.1 years BM (kg) 59.9 ± 10.6 Height (cm)158.6 ± 7.7 BMI_C (kg/m²) 23 Sex (M/F) 0/26 Women who were enrolled in the Trym Gym Osteoporosis Exercise Program	ICC_{IAR} = 0.93 95 % CI (0.85 – 0.97)	SEM = NR MDC = NR

Note. NR, Not reported; BM, Body mass; BMI, Body mass index; BMI_{C}, Body mass index calculated; 95 % CI, 95 % confidence intervals; ICC, Intraclass correlation coefficient; ICC_{IAR}, Intrarater ICC; ICC_{IER}, Interrater ICC; ICC_{IARFA}, Intrarater ICC flexicurve angle; ICC_{IERFA}, Interrater ICC flexicurve angle; ICC_{IARFI}, Intrarater ICC flexicurve index; ICC_{IERFI}, Interrater ICC flexicurve index; ICC_{IARDDI}, Intrarater ICC dual digital inclinometer; ICC_{IERDDI}, Interrater ICC dual digital inclinometer; ICC_{IARI}, Intrarater ICC analog inclinometer; ICC_{IERAI}, Interrater ICC analog inclinometer; ICC_{IARSP}, Intrarater ICC smartphone-app; ICC_{IERSP}, Interrater ICC smartphone-app; ICC_{IARDK}, Intrarater ICC debrunner kyphometer; ICC_{IERDK}, Interrater ICC debrunner kyphometer; $ICC_{IARMKSA}$, Intrarater ICC microsoft kinect sensor angle; $ICC_{IERMKSI}$, Interrater ICC microsoft kinect sensor index; ICC_{IARDI}, Intrarater ICC digital inclinometer; CI, Confidence interval 95 %; SEM, Standard error of measurement; SEM_{IAR}, Standard error of measurement of intrarater ICC; SEM_{IER}, Standard error of measurement of interrater ICC; SEM_{IARFA}, SEM_{IAR} flexicurve angle; SEM_{IERFA}, SEM_{IER} flexicurve angle; SEM_{IARFI}, SEM_{IAR} flexicurve index; SEM_{IERFI}, SEM_{IER} flexicurve index; SEM_{IARMKA}, SEM_{IAR} microsoft kinect sensor angle; SEM_{IERMKI}, SEM_{IER} microsoft kinect sensor index; SEM_{IARSP}, SEM_{IAR} smartphone app; SEM_{IERSP}, SEM_{IER} smartphone-app; MDC, Minimal detectable change; MDC_{IAR}, Intrarater MDC; MDC_{IER}, Interrater MDC; MDC_{IARFA}, MDC_{IAR} flexicurve angle; MDC_{IARFI}, MDC_{IAR} flexicurve index; MDC_{IARMKA}, MDC_{IAR} Microsoft kinect sensor angle; MDC_{IARMKI}, MDC_{IAR} microsoft kinect sensor index; r_{INTRA}, Intrarater Correlation; r_{INTER}, Interrater Correlation.

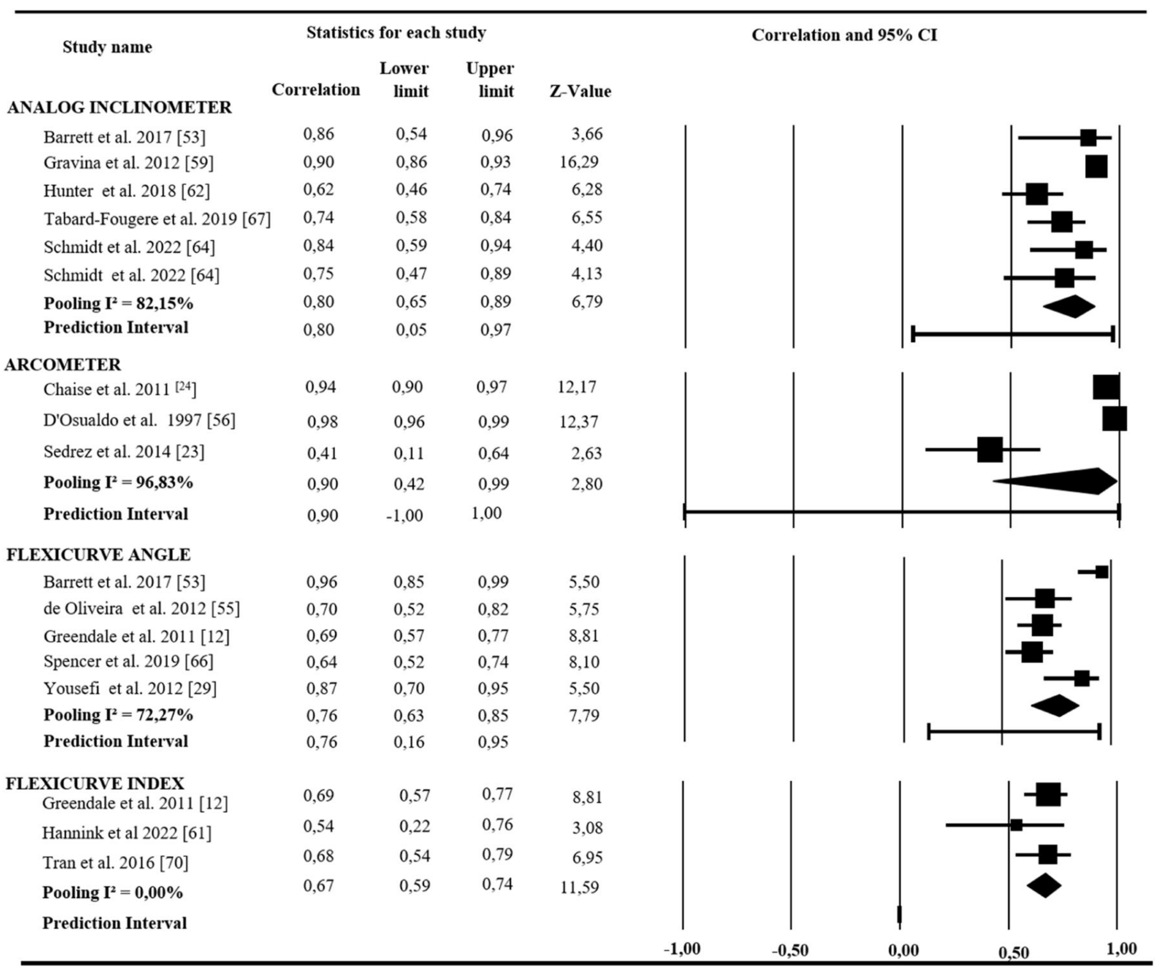

Fig. 2. - Results of the sensitive analysis of the validity for the different types of instruments.

studies. These data were grouped into six meta-analyses, one for each instrument. The following instruments demonstrated excellent inter-rater reliability: Analog Inclinometer, Digital Inclinometer, Flexicurve Angle, Flexicurve Index, Photogrammetry, Smartphone app, and Spinal Mouse (Fig. 4). Moreover, the inter-rater reliability was not assessed in studies that used the Kypholordometer[52] and Electrogoniometer.[31] The Baseline® Level/Scoliosis,[33] Dual Digital Inclinometer,[51] Microsoft Kinect Sensor,[80] and Spinal Wheel[32] were investigated in only one study each, showing excellent inter-rater reliability (Table 2). The Spinal Pantograph was explored in only one study,[17] but the ICC was not performed. The Arcometer was evaluated in three studies: one did not report the ICC,[56] and two demonstrated levels of inter-rater reliability ranging from low to excellent (0.25 to 0.98)[23–24]; however, they did not report the 95 %CI of the ICC, making the meta-analysis unfeasible. The Debrunner Kyphometer was evaluated in six studies,[12,20–22,69–70] but only one reported the 95 % CI of the ICC[69]; the meta-analysis was not performed. One study did not report the ICC,[22] and the other five showed excellent inter-rater reliability (Table 2).[12,20–21,69–70] The MDC and SEM were reported for five and seven instruments, respectively (Table 2).

Utility of the instrument

All instruments' measurement properties were investigated and classified according to clinical utility (Supplementary materials 4 and 5). Only the Analog Inclinometer, Flexicurve Angle, and Smartphone app demonstrated excellent levels for all measurement properties (> 0.80) and reported MDC data. The Microsoft Kinect Sensor did not present excellent validity; thus, this instrument was not considered. The Arcometer, Photogrammetry, and Spinal Mouse demonstrated excellent

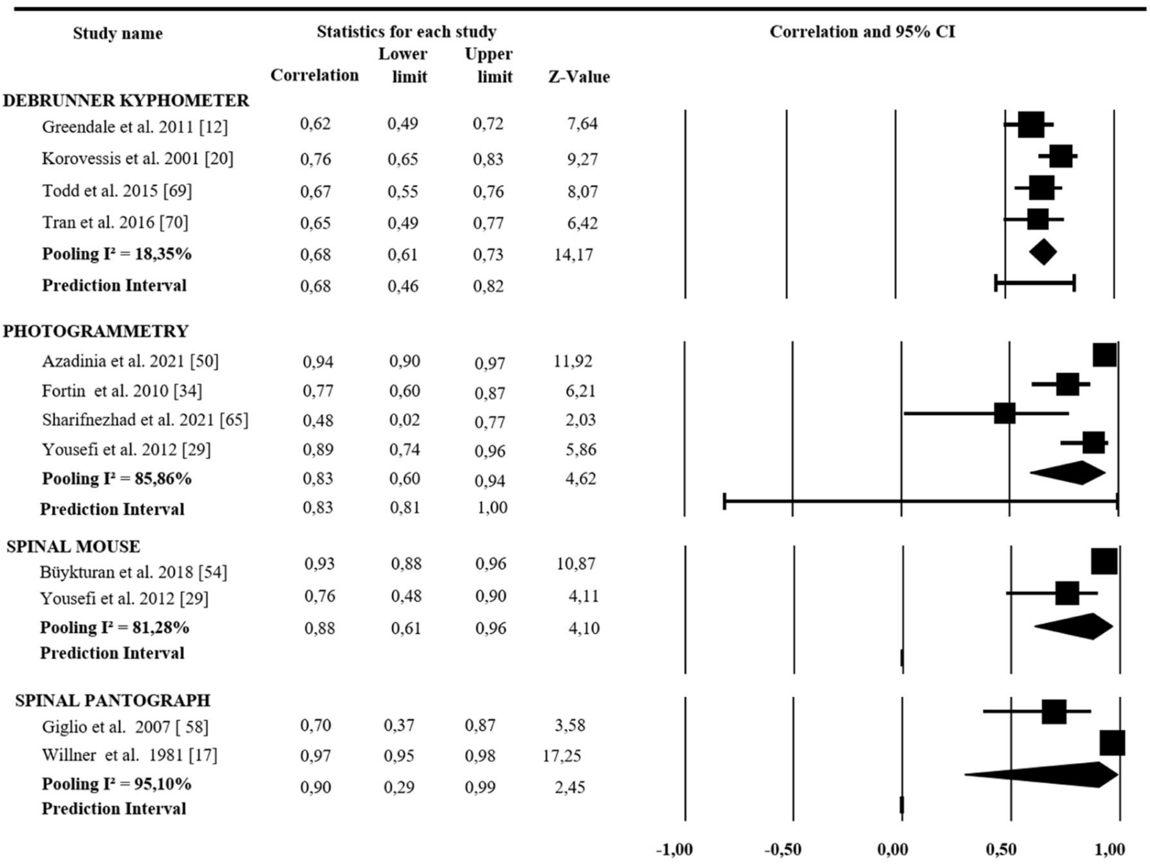

Fig. 2. (*continued*).

validity and reliability but did not have MDC data reported; therefore, they were not considered. Last, the instruments Baseline® Body Level/Scoliosis meter, Kypholordometer, Debrunner Kyphometer, Digital Inclinometer, Dual Digital Inclinometer, Electrogoniometer, Flexicurve Index, Spinal Pantograph, and Spinal Wheel did not present excellent validity and reliability levels or one or more measurement properties and cannot be considered helpful for clinical practice. Therefore, only the Analog Inclinometer, Flexicurve Angle, and Smartphone app are recommended for use in clinical settings (scores $\geq$ 9).

Discussion

The present review with meta-analysis investigated the validity, intra- and inter-rater reliability, and clinical utility of instruments designed to measure thoracic kyphosis. In the 72 included studies, 15 instruments had their measurement properties investigated; the Flexicurve Angle and Analog Inclinometer were the most investigated. Data from seven instruments were grouped in a meta-analysis for validity and intra-rater reliability and from six instruments for inter-rater reliability.

Most studies investigating validity demonstrated a moderate to strong correlation with the gold standard measure. Some factors may interfere with the correlation between noninvasive instruments and X-ray examinations. For instance, The Cobb angle quantifies the thoracic kyphosis by locating the positioning of the vertebrae on the X-ray. In contrast, the instrument is positioned on the skin and suffers the interference of soft tissue artifacts, which may generate discrepancies between measures.[24] Although all studies included in this review described the procedures for assessing thoracic kyphosis, four studies did not declare which vertebral limits were used to measure thoracic kyphosis by X-ray examination.[34,56,58–59] In addition, clinical measurements and imaging examinations are generally not standardized. Some studies measured thoracic kyphosis with the instrument positioned between C7 and T12,[53] T2/T3 and T11/T12,[69–70] and from C7 to the curve inflection point.[70] Although the measurement recommended by Cobb for X-ray examination is from T4 to T12, some measurements presented variations, such as from T1 to T10[62] and T1 to T12.[23] Another aspect that may interfere with validity is the time interval between the clinical and the gold standard measurement. Although 10 studies did not report this interval, most performed both measurements on the same day. Finally, a strong correlation with the gold standard does not ensure good agreement and measurement accuracy between the two methods.[50] A few instruments were analyzed using the Bland-Altman to verify the agreement limits. Therefore, further validity studies must perform the Bland-Altman analysis.

The Analog Inclinometer, Digital Inclinometer, Flexicurve Angle and Index, Photogrammetry, Microsoft Kinect Sensor, Spinal Mouse, and Smartphone app showed excellent levels of intra-rater reliability. Examiner experience and lack of blinding of the examiner and the time interval between measurements may help to explain these findings. Most of the studies included in the intrarater reliability analysis (65.51 %) declared that the rater was experienced in clinical practice or in using the instrument. Regarding blinding, only 14 studies declared the rater was blind to the measurements. Furthermore, most studies (86.20 %) adopted a time interval of up to seven days, allowing control over changes in posture resulting from flexibility and body mass index.[33]

The Analog Inclinometer, Digital Inclinometer, Flexicurve Angle and Index, Photogrammetry, Smartphone app, and Spinal Mouse demonstrated excellent inter-rater reliability. Although differences between examiners' experience may hinder inter-rater reliability, eight studies included in the meta-analysis (44.44 %) used examiners with different experience levels, which suggests that these instruments are user-friendly.[65,71,73,78,88,90–91,93] Few studies investigated the SEM and the

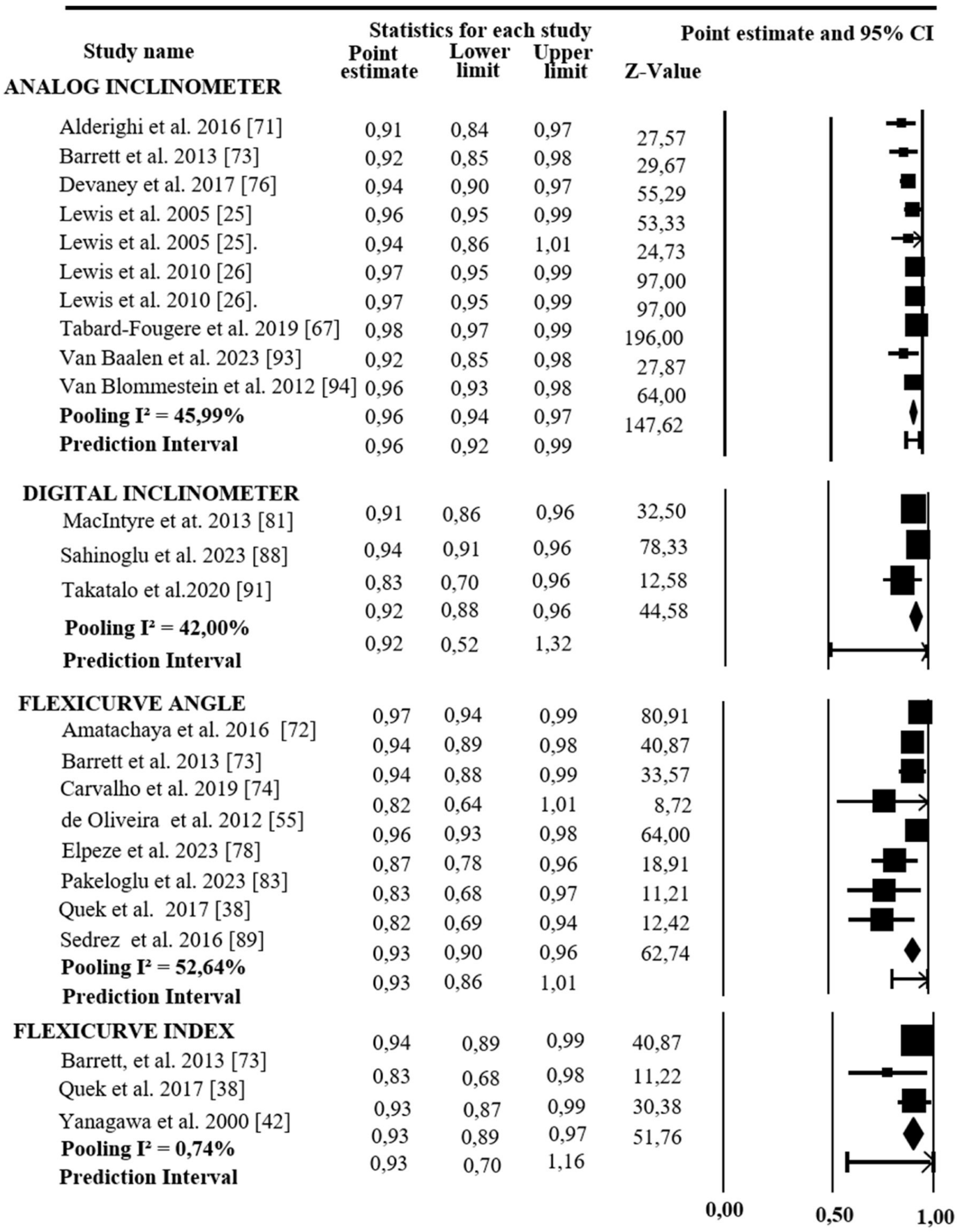

Fig. 3. - Results of the sensitive analysis of intrarater reliability for the different types of instruments.

MDC of the instruments. Some measurement errors may include the experience of the examiner in locating reference points on the skin,[71] the positioning, pressure, and speed in which the instrument is slid over the skin,[32] transfer the measurement to the paper (e.g., Flexicurve measurement),[73] the location of markers in the software,[77] and the positioning of the individual.[20] Most studies evaluated individuals in a relaxed orthostatic posture. Some studies have observed a positive correlation between thoracic curvatures measured from upright and relaxed postures and noted that the measurement is significantly smaller when performed from an upright posture.[76,96] Therefore, the choice of which posture to evaluate should consider that the measurement of the thoracic kyphosis in an upright orthostatic position will reflect structural kyphosis and minimize the effects of muscle weakness.[72]

Regarding clinical utility, this review identified that the Analog Inclinometer, Flexicurve Angle, and Smartphone app are suitable for clinical practice. Although the Flexicurve Angle presents MDC and

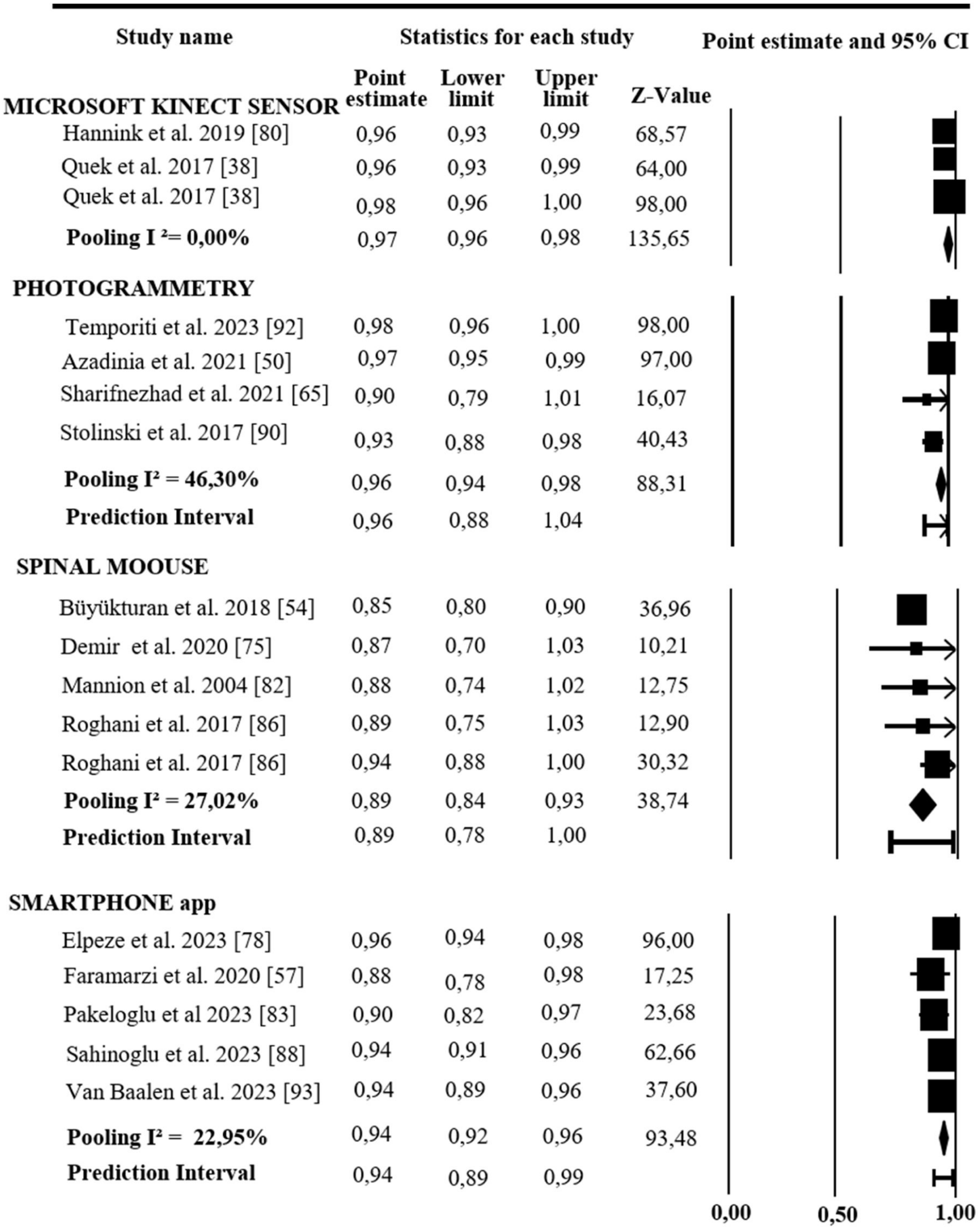

Fig. 3. (*continued*).

excellent levels of reliability and validity, the agreement between this instrument and the modified Cobb angle by the X-ray using the Bland Altman demonstrated wide limits of agreement.[53,55,66] Furthermore, the Flexicurve underestimates the magnitude of the thoracic kyphosis angle in the sagittal plane to X-ray, and this may be a problem in clinical settings when precise measurements are required.[66] Future studies could explore the measurements properties of the Digital Inclinometer and Dual Digital Inclinometer, which have a moderate cost, are portable, easy to administer, do not require specific training, and are often used in clinical settings.

The use of low-cost, portable, and precise clinical instruments can significantly improve patient outcomes by enabling quick, objective assessments and early detection of thoracic kyphosis severity, facilitating timely interventions. Continuous monitoring across various settings, such as clinics or patients' homes, supports frequent adjustments to treatment plans, resulting in better functional and postural outcomes while enhancing treatment adherence. Reliable, standardized measurements reduce intra- and inter-rater variability, ensuring consistent data and evidence-based clinical decisions. Combining precision with efficiency, these tools enable personalized rehabilitation strategies that

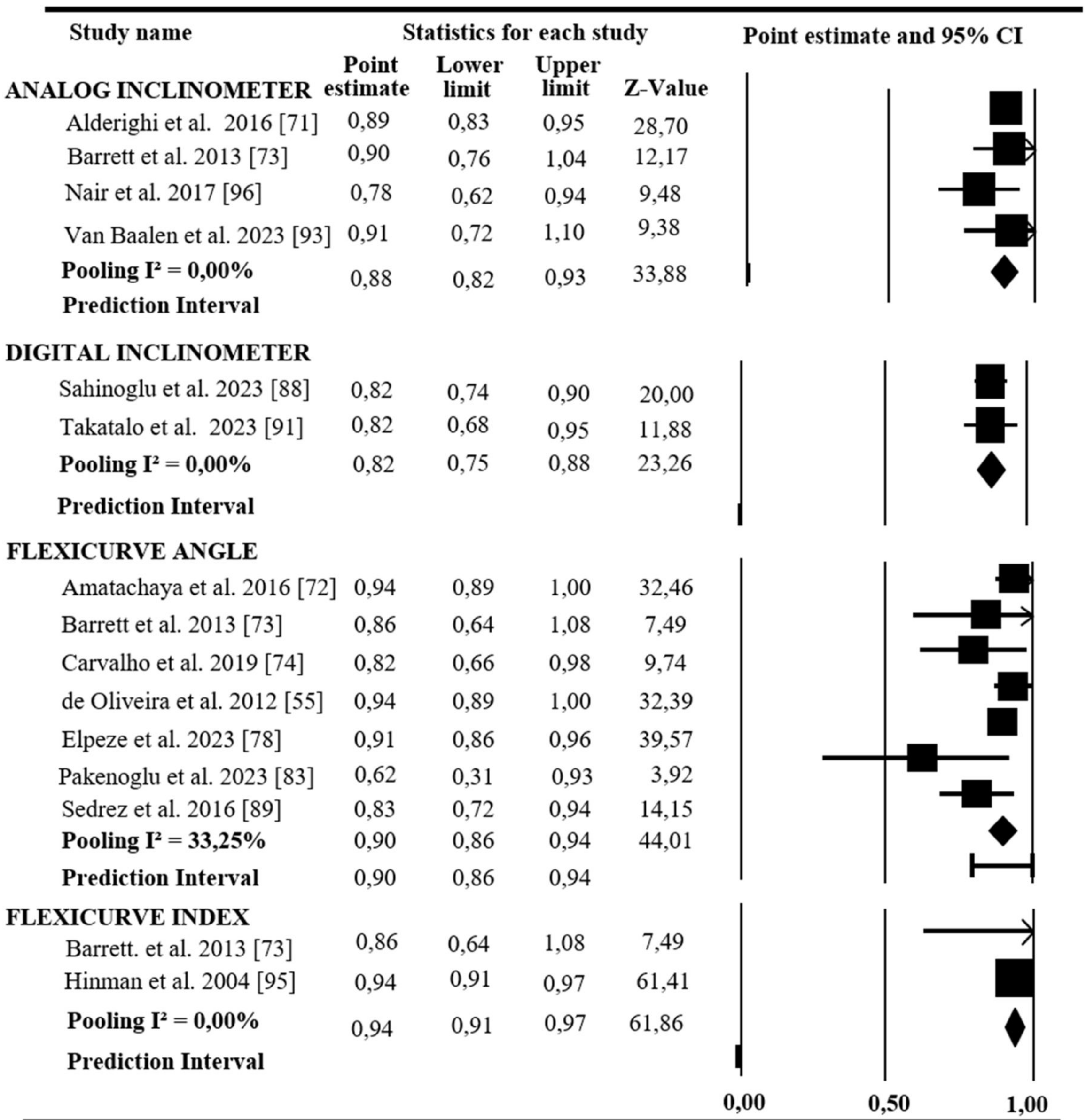

Fig. 4. - Results of the sensitive analysis of the interrater reliability for different types of instruments.

adapt to changes in the patient's condition.

This review had some limitations. Data extraction was conducted by only one author. In addition, when studies reported the experience of the rater, only the intra-rater reliability from the most experienced was extracted. When not reported, the highest reliability value was extracted, which may have overestimated the intra-rater reliability levels. Furthermore, the meta-analysis did not differentiate between ICC models due to limitations in the available data and the number of included studies, which may have impacted the interpretation of reliability measures. Additionally, subgroup analyses were not conducted due to the limited number of studies and concerns about insufficient statistical power, which could lead to unreliable and non-robust conclusions.[97]

Compared with the Barret et al. review, the present review found a higher number of studies on the topic not only in healthy individuals, but also in patients with disabilities and athletes. However, the reliability and validity of the instruments are generally specific to the investigated sample. Therefore, generalization of these findings to populations not considered in this review must be conducted cautiously.

Conclusions

The present review demonstrated the validity and intra and inter-rater reliability of 15 clinical instruments for assessing thoracic kyphosis in the sagittal plane. The meta-analysis demonstrated that the Analog Inclinometer, Flexicurve Angle and Index, Photogrammetry, and Spinal Mouse are valid and reliable for evaluating thoracic kyphosis in the sagittal plane. The analysis of the instruments' utility suggests using the Analog Inclinometer, Flexicurve Angle, and the Smartphone app to measure thoracic kyphosis in the sagittal plane in clinical settings.

Study name	Point estimate	Lower limit	Upper limit	Z-Value
PHOTOGRAMMETRY				
Sharifnezhad et al, 2021 [65]	0,81	0,70	0,92	14,46
Stolinski et al. 2017 [90]	0,92	0,87	0,97	35,38
Pooling I² = 68,49%	0,88	0,77	0,98	16,27
Prediction Interval				
SMARTPHONE app				
Elpeze et al, 2023 [78]	0,96	0,94	0,98	120,00
Faramarzi et al. 2020 [57]	0,91	0,84	0,98	25,28
Pakeloglu et al. 2023 [83]	0,97	0,86	1,07	18,13
Sahinoglu et al. 2023 [88]	0,80	0,70	0,90	15,68
Van Baalen et al. 2023 [93]	0,67	0,26	1,07	3,24
Pooling I² = 71,28%	0,91	0,84	0,97	26,41
Prediction Interval				
SPINAL MOUSE				
Büyükturan. et al. 2018 [54]	0,90	0,89	0,91	117,60
Mannion et al. 2004 [82]	0,87	0,75	0,99	13,64
Pooling I² = 0,00%	0,90	0,88	0,91	118,39
Prediction Interval				

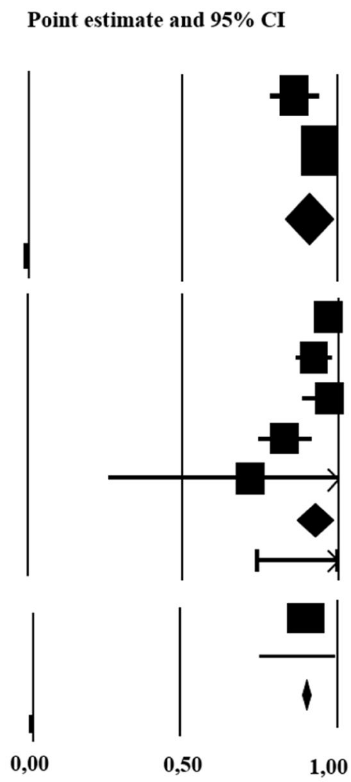

Fig. 4. (*continued*).

Declaration of competing interest

NA

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjpt.2025.101246.

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