Gait & Posture 69 (2019) 112–120

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Review

Anatomical reference marks, evaluation parameters and reproducibility of surface topography for evaluating the adolescent idiopathic scoliosis: a systematic review with meta-analysis

Isis Juliene Rodrigues Leite Navarro*,[1], Bruna Nichele da Rosa[1], Cláudia Tarragô Candotti[2]

Physical Education, Physiotherapy and Dance School of Universidade Federal do Rio Grande do Sul (UFRGS), ESEFID/LAPEX/BIOMEC, Rua Felizardo, 750, Porto Alegre, RS, CEP 90690-200, Brazil

ARTICLE INFO

Keywords:
Scoliosis
Topography
Reproducibility
Radiography

ABSTRACT

Background: Surface topography is a radiation-free examination that provides relevant information for the evaluation of patients with Adolescent Idiopathic Scoliosis (AIS). However, its usage is not standardized, which restricts the applicability of this instrument.

Research questions: (a) To identify the anatomical reference markers used on surface topography; (b) to identify the parameters used on surface topography; and (c) to pool correlation and reproducibility results.

Methods: Systematic searches were conducted following MOOSE (Meta-analysis of Observational Studies in Epidemiology) guidelines. The methodological quality was assessed according to Brink & Louw appraisal tool.

Results: Twenty-three studies were included for the qualitative synthesis. The most commonly used anatomical reference markers were: the prominent vertebra (C7 or T1), the posterior superior iliac spines (PSISs) and the sacrum (S1). The parameters for the evaluation of the AIS by surface topography are: spinal inclination angle (analogous to Cobb), gibbosity, thoracic kyphosis angle, lumbar lordosis angle, pelvic obliquity, spine length, apex of the curve, C7-S1 distance (frontal plane), and C7-S1 displacement (sagittal plane). Data from eleven studies were metanalyzed and evidenced the correlation of the surface topography with X-ray exams and the reproducibility of the surface topography in the sagittal and frontal planes.

Significance: The findings of this study recommend the use of a protocol for the application of the equipment. The analyzed studies predict the use of only four markers for anatomical reference. The evaluation of the AIS can be carried out observing nine parameters. Surface topography correlates with radiography when the spinal inclination angle (Cobb angle), thoracic kyphosis angle and lumbar lordosis angle are compared. Also, surface topography presents inter and intra-rater reproducibility in the sagittal plane and intra-rater reproducibility in the frontal plane.

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional deformity of the spine and trunk, with prevalence of 2–3% in the general population [1], that implicates on esthetical detriments of the body shape of the affected subjects [2]. Diagnostic investigation and curve progression follow-up can be carried out using non-radiological methods [1]. In this sense, many researchers have been working to develop new instruments and to improve new techniques and tools [3,4].

Surface topography is a quick and practical exam that can be used in the investigation and follow-up of AIS. This technology, based on the rasterstereography, originated a diverse number of equipments like InSpeck, ISIS, Vert3D, Quantec and Formetric. They all have the purpose of three-dimensionally reproducing the back surface of the evaluated individuals. The different mathematical processing of the images provides parameters for the identification and quantification of postural changes and deformities [5].

* Corresponding author at: Postal Address: ESEFID/LAPEX/BIOMEC, Rua Felizardo, 750, Porto Alegre, RS, Brazil.
E-mail addresses: isis.juliene@ufrgs.br (I.J.R.L. Navarro), bruna.nichele@ufrgs.br (B.N.d. Rosa), claudia.candotti@ufrgs.br (C.T. Candotti).

[1] Researcher of Grupo de Investigação da Mecânica do Movimento (BIOMEC) in Laboratório de pesquisa do exercício (LAPEX) at Universidade Federal do Rio Grande do Sul – UFRGS Brazil.

[2] Professor and researcher of Grupo de Investigação da Mecânica do Movimento (BIOMEC) in Laboratório de pesquisa do exercício (LAPEX) at Universidade Federal do Rio Grande do Sul – UFRGS Brazil.

https://doi.org/10.1016/j.gaitpost.2019.01.001
Received 15 April 2018; Received in revised form 30 December 2018; Accepted 1 January 2019
0966-6362/

Although the surface topography is a useful tool for the AIS evaluation, there is no stablished protocol of evaluation that explicitly shows which are the anatomical markers to be used, neither a standardized interpretation of results through predetermined parameters. These limitations lead to distinct procedures in the use of the equipment and in the interpretation of results, which do not stimulate health professionals to use the equipment [6].

In this context, this systematic review with meta-analysis aims (a) to identify the anatomical reference markers used on surface topography; (b) to identify the parameters measured by surface topography; and (c) to pool correlation and reproducibility results.

2. Methods

2.1. Type of study

The present study is a systematic review with meta-analysis, registered on PROSPERO (http://www.crd.york.ac.uk/PROSPERO_REBRANDING/display_record.asp?ID=CRD42016047556).

2.2. Search strategies

Systematic searches were conducted in July 2018, on the PubMed, Embase, SciELO, Cochrane and Scopus databases, following MOOSE (Meta-analysis of Observational Studies in Epidemiology) guidelines [7].

The terms and Boolean operators used on the systematic search were: Scoliosis [MeSH] OR scoliosis OR scolioses OR "adolescent idiopathic scoliosis" OR "idiopathic scoliosis" OR "spinal curvatures" AND rasterstereography OR rasterstereographic OR "surface topography". The search strategy used on PubMed can be observed on Table 1. In addition, there was no restriction for language or publication date. Also, manual searches were performed on the references of the included studies and on the database of the Brazilian Federal Agency for Support and Assessment of Post-graduate Education (CAPES).

2.3. Eligibility criteria

The eligible studies filled the following criteria: (1) patients diagnosed with AIS, (2) the use of surface topography examination, (3) the description of the anatomical reference markers adopted on surface topography for AIS identification, and (4) validity and/or reproducibility study.

2.4. Studies selection and data extraction

The bibliographic details of all retrieved articles were stored in an EndNote file. Two independent reviewers selected potentially relevant studies, according to their titles and abstracts. When a study did not provide enough information to be excluded, the text was integrally read.

In the next step, the reviewers have read the studies integrally and selected them according to the eligibility criteria. Studies that comprised patients over age 18, and/or patients with any diagnosable cause of scoliosis, and/or patients submitted to physical therapy, brace or spinal surgical intervention were excluded. Discordant cases were solved by consensus or by a third reviewer.

Only the included studies were submitted to data extraction and methodological quality evaluation. The informations were extracted to a standardized form that included: author, year of publication, age, sample size, type of topography and the gold standard used. The outcomes were: (1) anatomical reference markers; (2) parameters for identifying the scoliosis; and (3) Pearson's correlation coefficient (r) and/or Intraclass Correlation Coefficient (ICC).

2.5. Quality assessment

The assessment of the methodological quality and the risk of bias was performed using a critical appraisal tool, proposed by Brink & Louw [8], for assessing validity and reliability of results from studies. The scale consists of 13 items, of which five items relate to both validity and reliability studies, four items to validity studies only and four items to reliability studies. The scale was used by the same independent reviewers. The included studies were considered as high methodological quality if reached the score of ≥ 60%, as proposed by previous studies [9].

2.6. Statistical analysis

The data was metanalyzed on the Comprehensive Meta-Analysis V3 software. The studies were grouped according to the correlation coefficient (r or ICC) and the anatomical plane of analysis (frontal or sagittal). In the frontal plane analysis, the data was divided in two groups: (1) Thoracic Cobb angle and (2) Lumbar Cobb angle. In the sagittal plane analysis, the data was also divided in two groups: (1) kyphosis angle and (2) lordosis angle. The random-effect model was selected for the analysis. The statistical data originated from Pearson's coefficient or ICC were interpreted as follows: ≤.25 very low correlation, .26–.49 low correlation, .50–.69 moderate correlation, .70–.89 high correlation and ≥.90 very high correlation. Heterogeneity was verified by the Higgins Inconsistence test (I^2).

3. Results

Initially, 536 studies were identified on the systematic searches; 467 were excluded, resting 93 for the full-text reading. So, based on the eligibility criteria, 70 studies were excluded, resting 23 studies for the qualitative analysis and 11 for the quantitative analysis. Fig. 1 shows the flowchart [10]. of the included studies Table 2 summarizes the characteristics and the outcomes of the studies included in the qualitative analysis.

The number of anatomical reference markers used on surface topography examination ranged from 0 to 28. The reference markers most commonly used were: the spinous process of the prominent vertebra (C7 or T1) (n = 15) [11–25], the PSISs (n = 11) [12–17,19,20,22–24] and the sacrum (S1) (n = 8) [11–16,18,24]. Seven studies did not use reference markers [26–32].

The spinal inclination angle, analogous to the Cobb angle on radiography, was the most commonly used parameter (14 of 23 studies) [11,12,14–18,20,22–24,26,28,33]. Also, the following parameters were extracted from surface topography: gibbosity (measured in cm or degrees) (n = 13) [12–16,18,19,22–24,26,28,29]; thoracic kyphosis angle and lumbar lordosis angle (n = 8) [14,18–20,22,24,26,33]; pelvic obliquity (cm or degrees) (n = 6) [14,19,22,24,26,33]; spine length (n = 5) [16,19,20,22,26]; apex of the curve (n = 6) [14,13–16,24,26,28]; C7-S1 distance (frontal plane) (n = 5) [14,15,19,20,24]; C7-S1 displacement (sagittal plane) (n = 4) [14,19,20,24]. The POTSI (Posterior Trunk Symmetry Index) and DAPI

Table 1
Search Strategy of PubMed.

#3	Search (#1 AND #2 AND)
#2	Search ("rasterstereography" OR "rasterstereographic" OR "surface topography")
#1	Search ("Scoliosis" [Mesh] OR scoliosis OR scolioses OR "adolescent idiopathic scoliosis" OR "idiopathic scoliosis" OR "spinal curvature")

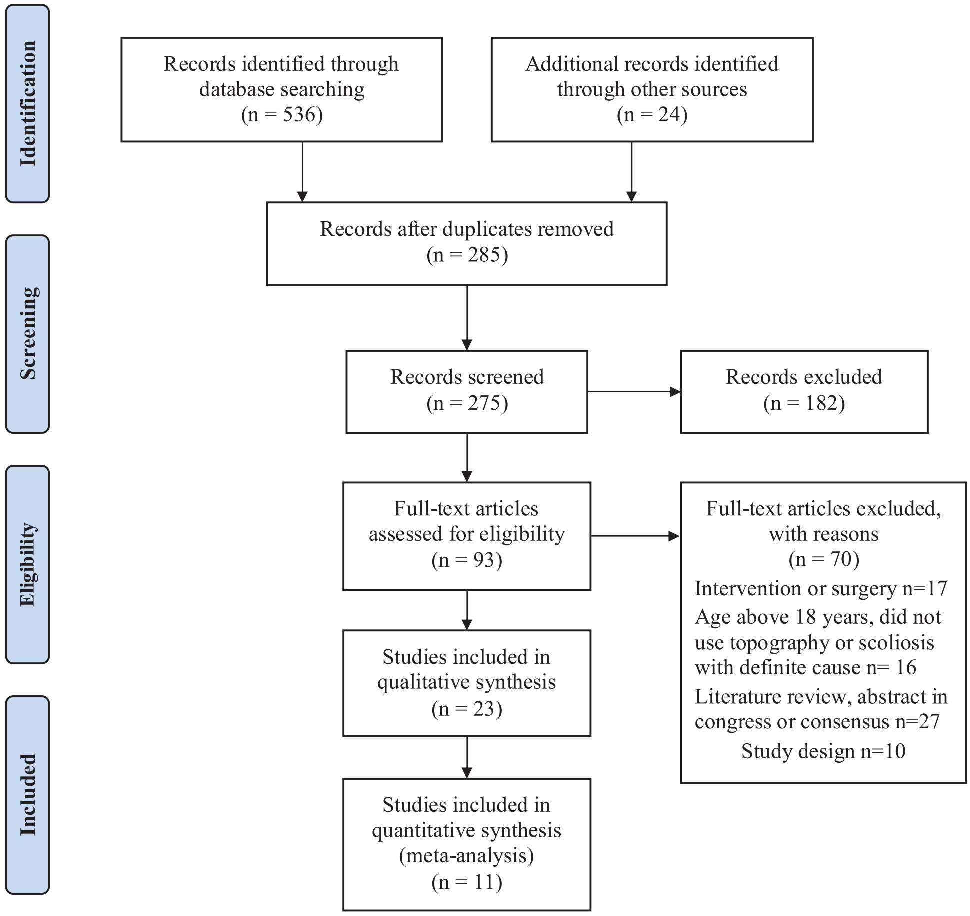


Fig. 1. Flowchart of included studies according to PRISMA [10].

(Deformity in the Axial Plane Index) or DHOPI (Deformity in the Horizontal Plane Index) parameters were found in five studies [20,21,30–32].

About the outcomes of the meta-analyses (Fig. 2), it was possible to extract the coefficients from 11 studies. Seven studies presented Pearson correlations [18,21,23,26,30,31,33] and five studies presented ICCs [14,20,22,24,33]. The correlation between topography and X-ray examinations in the frontal plane was high and significant for thoracic curves and moderate for lumbar curves (I^2 = 22.2% and I^2 = 37.8%, respectively). In the sagittal plane, the correlation between topography and X-ray examinations was high and significant, with very low heterogeneity (I^2 = 0%) for thoracic kyphosis and lumbar lordosis.

For the reproducibility meta-analyses (Fig. 3), three studies provided ICC for kyphosis angle and lordosis angle for the inter-rater [14,20,22] and intra-rater analyses [22,24,33]. In the intra-rater and inter-rater analyses of the thoracic kyphosis and lumbar lordosis, the ICCs ranged from high to very high and significant, and the heterogeneity (I^2) ranged from 0% to 37.3%. In the frontal plane, two studies [22,24] provided ICCs for intra-rater reproducibility analysis of the spinal inclination angle, analogous to the Cobb angle. The ICCs were very high and significant, and the heterogeneity was equal to 0%. This analysis considered only a single spinal inclination angle, regardless the region of the spine (thoracic or lumbar) where it occurred.

In the evaluation of the methodological quality and the risk of bias, 14 studies ranked high quality (score ≥ 60%). The average score of the methodological quality appraisal was 62% (Table 3). The main methodological weaknesses found in the validity and reproducibility studies (n = 10) concerned the blinding process between evaluators, the lack of randomness in the order of the evaluators or the subjects, the description of the gold standard used and the description of the sample losses.

4. Discussion

The surface topography examination is a useful tool for the identification and the follow-up of vertebral deformities. With this tool, it is possible to quantify the magnitude of certain parameters and explore the three-dimensional surface of the back, pointing the progression rate of the spinal deformity under different aspects [33]. For an adequate use of the exam, it is important to define which are the anatomical markers that will guide the analysis of the parameters [6]. The objective of this study was exactly to identify the anatomical reference markers, the parameters used by the surface topography for the identification of AIS and to conduct meta-analyses to examine the correlation between the topographical exam and the X-rays.

In the qualitative analysis, we got information about which and how many anatomical reference markers were used by distinct equipments. The number of markers varied from zero [26–32] to 28 [20]. Komeili et al. [27] defend that the use of markers generates errors, which would be related to palpation and fixation of the markers on patients. However, we emphasize that taking into consideration the three-dimensional nature of the exam, the markers will serve as a local system of coordinates and they will facilitate the retrieval of the 3D coordinates from the body surface. So, caution is suggested when adopting a protocol without markers. The number of markers must be sufficient for running an analysis, but it should maintain the practicality of the exam and ensure the accuracy of its parameters. The results found in relation to the anatomical markers evidence the lack of standardization for the use of surface topography when evaluating the AIS. To avoid compromising the data extraction, we suggest the use of four markers because it is easier to palpate and mark a small number of structures, it will take less time for the performing of the examination and it will reduce the

Table 2
Characteristics of the studies, reference markers and parameters used.

Author and Year	Age and (n)	Type of Topography	Used Markers	Parameters Evaluated	Precision and accuracy measures
Adankon, 2013* [13]	between 10 and 18 years n = 58	Optical surface digitalizing system (Creaform Inc., L´evis, QC, Canada)	PSIS, suprasternal notch, xiphoid process, SP C7-T1, point between PSIS, iliac crest R and L laterally, lower thoracic cage limit R and L	Cobb	No
Berryman, 2008** [14]	n = 60	ISIS2	PSIS, C7 or T1 and sacrum	Cobb and gibbosity height	Average difference (gibbosity −0.08mm ± 4.2mm)
Chowanska, 2012*** [15]	11 ± 1 years n = 996	CQ Electronic System (Poland)	SP from C7 to S1 and EIPS	Surface trunk rotation	intra-observer error (surface trunk rotation 1.9°) inter-observer error (surface trunk rotation 0.8°)
De Séze, 2013** [16]	n = 46	BIOMOD™ L system (AXS MEDICAL SAS, Mérignac, France)	SP from C7 to the intergluteal fold and PSIS	Frontal pelvic balance (in degrees), lateral deviation of C7, sinuous column angle (cobb), arrow of C7 plumb line, thoracic arrow, lumbar arrow, kyphosis angle, lordosis angle, inflection point height and gibbosis .	TEM (kyphosis angle 4.3° lordosis angle 2.7°)
Drerup, 1994* [17]	n = 113	Rasterstereography	prominent vertebra, PSIS and sacrum	midline deviation of the column (frontal projection in mm), rotation deviation, lateral curve amplitude, rotation amplitude, apex height and estimated Cobb	No
Drerup, 1996* [18]	n = 114	Formetric	C7, PSIS and medium point between PSIS (sacrum)	Apex height, Cobb and column length	No
Frerich, 2012* [28]	between 9 and 17 years n = 64	Formetric 4D system by Diers Medical Systems (Germany)	No markers	Trunk lenght, trunk imbalance, pelvic inclination, thoracic kyphosis, lumbar lordosis, maximum trunk rotation at R, maximal trunk rotation at L, maximum apical deviation at R, maximum apical deviation at L, and scoliosis angle (cobb).	Validity: Average Difference (Lumbar Curve 9,4°, Thoracic Curve 7°, Thoracic Kyphosis 10,6°, Lumbar Lordosis 8°) Reproducibility: Average Standard Deviation
Klos, 2007* [19]	single curve group age 12.2 ± 2 n = 105 double curve group age 12.9 ± 2 n = 62	Quantec Spinal Imaging System, Leigh, UK	SP of T1 to L5, PSIS, tip of the upper side of the scapula	Quantec Angle (cobb)	No
Knott, 2006* [20]	n = 42	Ortelius 800 by Orthoscan Technologies, Inc.	SP of C7 to S1	Thoracic rotation, thoracolumbar rotation, lumbar rotation, lumbar curve (cobb), thoracic curve (cobb) and kyphosis	No
Knott, 2016* [35]	13.2 years n = 199	DIERS Formetric (Diers Medical Systems, Chicago, IL)	PSIS only in obese patients	Kyphosis angle, lordosis angle, vertical coronal axis, vertical sagittal axis, pelvic obliquity angle and angle of scoliosis (Cobb)	Validity: Average difference (thoracic curve 5.8°, lumbar curve 8.8°, Thoracic kyphosis 9.3°, Lumbar lordosis 9.7°) Reproducibility intra-rater: Average Standard Deviation (thoracic curve 2.5°, lumbar curve 2.6°, Thoracic kyphosis 2.1°, Lumbar lordosis 2.1°)
Komeili, 2014* [29]	between 10 and 18 years n = 46	Four VIVID 910 3D laser scanners (Konica Minolta Sensing Inc., Ramsey, NJ, USA)	No markers	Better symmetry plane, symmetry contour map	No
Komeili, 2015* [30]	between 10 and 18 years n = 100	Four VIVID 910 3D laser scanners (Konica Minolta Sensing Inc., Ramsey, NJ, USA)	No markers	number, direction and curves location, height of the apex of the curve and magnitude of the curve (cobb)	No
Liu, 2001* [21]	11.8 year n = 119 single curve n = 129 double curve	Quantec Spinal Image System (QSIS, Leigh, UK)	SP of T1 to L5, PSIS and tip of the upper side of the scapula	T1-S1 angle, T1-S1 deviation, T1-GC angle, T1-GC deviation, angle of difference between the maximum angles of inclination on each side of the curve, trunk length, angle of inclination of the pelvis, angle of rotation, % volume R and L, Suzuki, kyphosis, lordosis and trunk asymmetry	No

(*continued on next page*)

Table 2 (*continued*)

Author and Year	Age and (n)	Type of Topography	Used Markers	Parameters Evaluated	Precision and accuracy measures
Liu, 2013** [22]	13.4 years n = 10	Milwaukee Topographic System (MTS)	SP of T1 to L5, acromioclavicular joint, PSIS, more prominent scapula, deeper lumbar SP	T1-GC angle, T1-S1 angle, T1-S1 deviation, Kifose, Lordosis, POTSI, Suzuki, trunk length, Cobb curve, axial maximum surface rotation from T1 to L5, right and left trunk, right and trunk volume in% and right trunk volume and trunk in mL	No
Manca, 2018* [26]	between 10 and 17 years n = 66	Formetric (DIERS Medical Systems, Chicago, IL)	prominent vertebra, PSIS and sacrum	Trunk inclination (frontal plane), trunk imbalance (sagital plane), pelvis imbalance, pelvis torsion, pelvis tilt, kyphosis angle, lordosis angle, surface rotation (rms), surface rotation (amp), side deviation (rms), side deviation (amp), scoliosis angle (cobb)	No
Mangone, 2013* [31]	14 ± 3 years n = 25	Formetric 4D	automatic location	Spinal angle rotation	No
Mínguez, 2007* [23]	control group 17.26 ± 5 yrs n = 56 scoliosis group 14.8 ± 6 yrs n = 30	Experimental device based on structured light projection	C7, GC, left shoulder,shoulder R, armpit L, armpit R, waist L, waist R, most prominent point of scapula L, most prominent point of scapula R, least prominent point of waist line L, least prominent point of waist line R, most prominent point of the gluteus L and most prominent point of the gluteus R	DAPI (transversal plane) and POTSI (coronal plane)	No
Pino-Almero, 2017* [33]	13.2 ± 2 years n = 88	Surface topographic method	No markers	POTSI (frontal plane) DHOPI (axial plane) e PC (sagittal plane)	No
Pino-Almero, 2016* [32]	between 7 e 17 years n = 31	Surface topographic method	No markers	POTSI (frontal plane) DHOPI (axial plane) e PC (sagittal plane)	No
Pino-Almero, 2017* [34]	13.3 years n = 155	Surface topographic method	No markers	POTSI (frontal plane) DHOPI (axial plane) e PC (sagittal plane)	No
Tabard-Fougère, 2016* [24]	13.1 ± 2 years n = 35	Formetric 4D (Diers, International GmbH, Schlangenbad, Germany)	C7 or T1 , PSIS, apical vertebrae of the patients obviously with Scoliosis	Lordosis, pelvic obliquity, vertebral rotation amplitude, maximum vertebral rotation, rms of vertebral rotation, angle of scoliosis (Cobb), kyphosis and trunk length	SEM (Thoracic kyphosis 6.1 °, Lumbar lordosis 4.6°) MDC (Thoracic kyphosis 16.8 °, Lumbar lordosis 12.7°)
Terheyden, 2018* [27]	15.9 years n=40	Diers International, Wiesbaden, Germany	SP of C7 and acromioclavicular joint bilaterally	Outer shoulder height difference, inner shoulder height difference, acromion angle, axillary angle and trapezius angle	SEM
Thometz, 2000* [25]	12.3 years n= 149	Quantec Inc., Lancashire, England)	SP of T1 to L5, PSIS, lower angle of the upper side of the scapula	Q Angle (cobb) and axial surface rotation	Average Difference (Thoracic Curve 5.7 ± 9°, Lumbar Curve 4.9 ± 7°)

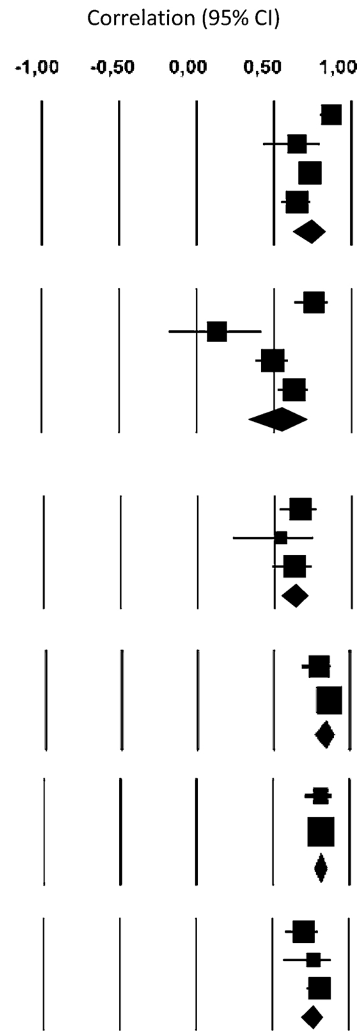
PSIS – posterior superior iliac spine; SP – spinous process; GC – gluteal cleft; R – right; L – left; TEM – typical error of measurement; SEM – standard error of measurement; MDC – minimal detectable change; Gold-standard.

* X-ray.

** not applicable.

*** scoliometer.

Author, year	r	Lower limit	Upper limit	Z-value	p-value	I^2 (%)
			Thoracic Cobb (frontal plane)			
Frerich, 2012	0.87	0.80	0.92	10.48	0.00	
Knott, 2006	0.65	0.43	0.80	4.83	0.00	
Knott, 2016	0.73	0.66	0.79	13.09	0.00	
Thometz, 2000	0.65	0.55	0.73	9.37	0.00	
	0.74	0.62	0.83	8.34	0.00*	22.2
			Lumbar Cobb (frontal plane)			
Frerich, 2012	0.76	0.63	0.85	7.74	0.00	
Knott, 2006	0.13	-0.18	0.42	0.83	0.41	
Knott, 2016	0.49	0.38	0.59	7.54	0.00	
Thometz, 2000	0.63	0.52	0.72	8.96	0.00	
	0.55	0.34	0.71	4.53	0.00*	37.8
			POTSI X cobb (frontal plane)			
Mínguez, 2007	0.67	0.53	0.77	7.35	0.00	
Pino-Almero, 2016	0.54	0.23	0.75	3.19	0.00	
Pino-Almero, 2017	0.63	0.48	0.74	6.82	0.00	
	0.63	0.54	0.71	10.48	0.00*	0.0
			Kyphosis (saggital plane)			
Frerich, 2012	0.80	0.69	0.87	8.56	0.00	
Knott, 2016	0.87	0.83	0.90	18.49	0.00	
	0.84	0.77	0.90	11.25	0.00*	0.0
			Lordosis (saggital plane)			
Frerich, 2012	0.81	0.71	0.88	8.87	0.00	
Knott, 2016	0.82	0.76	0.86	16.07	0.00	
	0.82	0.77	0.85	18.35	0.00*	0.0
			DHOPI ou DAPI X cobb (axial plane)			
Mínguez, 2007	0.71	0.58	0.80	8.01	0.00	
Pino-Almero, 2016	0.77	0.57	0.88	5.39	0.00	
Pino-Almero, 2017	0.81	0.72	0.87	10.39	0.00	
	0.76	0.69	0.82	12.07	0.00*	0.0



(r) Pearson correlation coefficient, *Statistical significance, CI - Confidence Interval, squares and/or rectangles - r values from each study, horizontal lines - lower and upper limits, diamond - metanalized r value

Fig. 2. Meta-analysis of the correlation (r values) of surface topography, in the frontal, sagittal and axial planes, in relation to the X-ray examination.

bias derived from palpation [34].

According to the consensus stablished in 2009 by the Scoliosis Orthopaedic Rehabilitation and Treatment (SOSORT), the following surface topography parameters must be observed in the evaluation of patients with AIS: spine length, C7-S1 distance (frontal plane), C7-S1 displacement (sagittal plane), measures of the main curve, measures of the compensatory curve, apex of the curve, thoracic kyphosis, lumbar lordosis, trunk rotation main curve, trunk rotation compensatory curves, PSIS height and PSIS depth [6]. From this review, we can observe that nine of 12 parameters recommended by SOSORT were found in the studies. Among them, the spinal inclination angle was the most frequent.

Based on the data obtained through the meta-analyses, the correlation indexes (r) varied from moderate to high in the comparison of the spinal inclination angle (frontal plane) between surface topography and X-ray exams. This analysis indicates that the surface topography is strongly correlated with the X-ray exams. Nonetheless, we highlight that this statistical procedure is not enough to determine the validity of topography in relation to X-rays [35].

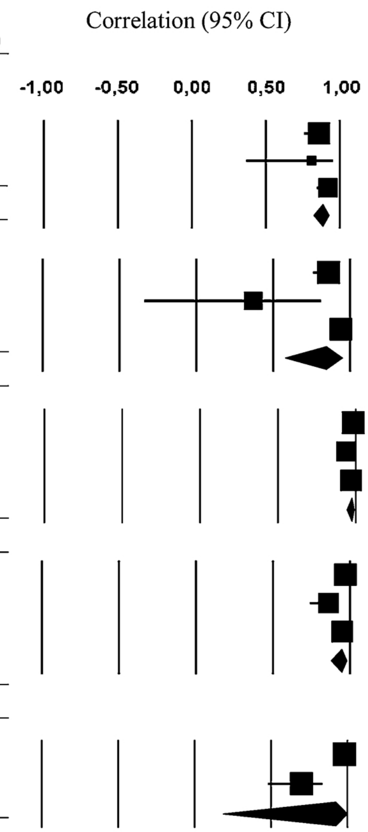
Still, in the frontal plane, we found a moderate correlation of the POTSI parameter in relation to the Cobb angle on X-rays. In the axial plane, the analyzed parameter was only the DHOPI or DAPI and it presented high correlation. Although they are named differently, DHOPI and DAPI are the same parameter according to the mathematical definition provided by the authors. Anyway, these parameters (POTSI and DHOPI) are not recommended by SOSORT.

We highlight the correlation found between the POTSI and DHOPI (DAPI) parameters performed in the comparison between the surface topography and the X-rays was reported by three studies. These parameters were evaluated by the same researchers. Although they presented high methodological quality, the authors did not clearly describe the equipment of surface topography they used. Mínguez et al. (2007) [21] described the use of an experimental device based on the projection of structured light, while Pino-Almero (2016 and 2017) [30,31] reported the use of a method of surface topography. Still, these parameters for surface topography were found in five studies, and four of them were written by the same researchers.

Among the studies included in the reproducibility meta-analysis in the frontal plane, only two out of seven studies presented low methodological quality. Knott et al. [20] used the Orthoscan (surface topography) and found very low correlation of the lumbar Cobb angle, while Frerich et al. [28] used the Formetric 4D and found a high correlation for this parameter. In all cases, regardless the equipment used, the thoracic region presented the best correlations.

Once more, we emphasize the lack of standardization in the use of the exam, which in fact, can interfere in the results, culminating in

Author, year	ICC	Lower limit	Upper limit	Z-value	p- value	I²(%)
Kyphosis (inter-rater)						
De Séze, 2013	0.86	0.75	0.92	8.48	0.00	
Liu, 2013	0.81	0.37	0.95	2.98	0.00	
Tabard-Fougère, 2016	0.92	0.85	0.96	8.98	0.00	
	0.88	0.82	0.93	11.95	0.00*	0.0
Lordosis (inter-rater)						
De Séze, 2013	0.86	0.76	0.92	8.48	0.00	
Liu, 2013	0.37	-0.34	0.81	1.03	0.30	
Tabard-Fougère, 2016	0.94	0.88	0.97	9.83	0.00	
	0.84	0.58	0.95	4.21	0.00*	37.3
Kyphosis (intra-rater)						
Knott, 2016	0.98	0.98	0.99	33.74	0.00	
Tabard-Fougère, 2016	0.94	0.88	0.97	9.83	0.00	
Manca, 2018	0.97	0.95	0.98	16.61	0.00	
	0.97	0.94	0.99	11.14	0.00*	4.0
Lordosis (intra-rater)						
Knott, 2016	0.97	0.96	0.98	29.29	0.00	
Manca, 2018	0.95	0.92	0.97	14.54	0.00	
Tabard-Fougère, 2016	0.86	0.74	0.93	7.32	0.00	
	0.94	0.87	0.97	8.35	0.00*	17.0
Scoliosis angle X Cobb frontal plane (intra-rater)						
Manca, 2018	0.98	0.97	0.99	18.24	0.00	
Tabard-Fougère, 2016	0.70	0.48	0.84	4.91	0.00	
	0.92	0.18	0.99	2.22	0.03*	0.0



(ICC) Intraclass Correlation Coefficient, *Statistical significance, CI - Confidence Interval, squares and/or rectangles - ICC values from each study, horizontal lines - lower and upper limits, diamond - metanalized ICC value

Fig. 3. Meta-analysis of the inter and intra-rater reproducibility (ICC values) of surface topography in the frontal and sagittal planes.

Table 3
Quality assessment through the critical evaluation tool proposed by Brink & Louw.

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	%
Adankon, 2013	y	n	y	n/a	n/a	n/a	n	n/a	y	y	n	y	n	56
Berryman, 2008	n	n	n/a	n/a	n	n	n/a	y	n/a	y	n/a	n	y	33
Chowanska, 2012	y	n	y	n	n	n	y	y	y	y	y	y	n	62
De Séze, 2013	y	n	n/a	n	n/a	n	n/a	y	n/a	y	n/a	y	y	56
Drerup, 1994	n	n	y	n/a	n/a	n/a	y	n/a	y	y	y	y	n	67
Drerup, 1996	n	n	y	n/a	n/a	n/a	n	n/a	y	y	n	n	n	33
Frerich, 2012	y	y	y	n/a	n	n	y	y	y	n	n	n	y	54
Klos, 2007	y	n	y	n/a	n/a	n/a	y	n/a	y	y	n	n	y	44
Knott, 2006	n	y	y	n	n/a	n	y	y	y	y	n	n	y	54
Knott, 2016	y	n	y	n/a	n	n	y	y	y	y	y	n	y	62
Komeili, 2014	y	y	y	n	y	n	n	y	y	y	n	y	y	69
Komeili, 2015	y	n	y	n/a	n/a	n/a	y	n/a	y	y	n	n	y	67
Liu, 2001	y	n	y	n/a	n/a	n/a	y	n/a	y	y	n	n	y	67
Liu, 2013	y	n	n/a	y	n	n	n/a	y	n/a	y	n/a	n	y	56
Manca, 2018	y	n	n/a	n/a	n	n	n/a	y	n/a	y	n/a	y	y	56
Mangone, 2013	y	n	y	n/a	n/a	n/a	y	n/a	y	y	y	y	y	89
Mínguez, 2007	y	y	y	y	n	n	n	y	y	y	n	n	y	62
Pino-Almero, 2016	y	y	y	n	n	n	n	n	y	y	y	y	y	62
Pino-Almero, 2017	y	n	y	n/a	n/a	n/a	n	n/a	y	y	y	y	y	78
Pino-Almero, 2017	y	n	y	n	n	y	n	n	y	y	y	y	y	62
Tabard-Fougère, 2016	y	y	y	y	y	n	y	y	y	y	n	y	y	85
Terheyden, 2018	y	n	y	n/a	y	n	y	y	y	y	y	y	y	77
Thometz, 2000	y	y	y	n/a	n/a	n/a	y	n/a	y	y	n	y	y	89

1.Description of the sample; 2. Evaluators Characterization; 3. Use of gold standard for comparison; 4. Inter-evaluators blindness; 5. Intra-evaluators blindness; 6. Randomization of evaluators or subjects; 7. Period of time between the test collection; 8. Time interval between repeated measures; 9. The studied test is not part of the gold standard; 10. Description of the collection procedures from experimental test; 11. Description of the gold standard collection procedures; 12. Description of cases of sample loss; 13. Adequacy of the statistical method. y = yes; n = no; n / a = not applicable; % = final score reached by the study.

divergent outcomes. Another important aspect, that could explain the results for the thoracic region, is related to the anatomical differences between the regions of the spine (thoracic and lumbar) like the number of vertebrae and the presence of the shoulder blades on the rib cage. The deformity of the ribs in the transversal plane, mostly can contribute to the higher correlation of the thoracic region, since the raster-stereography is designed to evaluate the shape of the back surface [2].

For the meta-analysis of reproducibility in the sagittal plane, the results also presented a high correlation (r) and low heterogeneity among the studies, indicating that the surface topography strongly correlates to X-ray exams. This analysis included data from only two studies; one study scored low and the other scored high methodological quality.

With respect to reproducibility, the best results were found for the intra-rater analysis. In the frontal plane, the spinal inclination angle presented very high and significant correlations. However, the analysis included data from two studies only. Still, the methodology for the calculation of the spinal inclination angle proposed by Manca (2018) and Tabard-Fougère (2016) provides a single angle in the frontal plane, regardless the region (thoracic or lumbar) where it occurred. In this way, it is not possible to compare the thoracic region with the lumbar region in the analysis of reproducibility. So, we suggest caution when assuming reproducibility of the spinal inclination angle in surface topography, based on this meta-analysis.

The concordance and reliability of the evaluation methods are key indicators and should be taken under consideration before the selection of an instrument. A method to determine the concordance between measures originated from two distinct tools is the Bland & Altman plot analysis. However, none of the studies included in the meta-analysis carried out that analysis. Thus, it was not possible to determine the validity of the exam. This also hindered the interpretation of results, since the statistical procedures were limited to correlation analyses only.

Residual analysis, precise measures and accuracy are important indicators concerning the performance of an instrument. None of the included studies presented the root mean square (RMS) error. This statistical procedure identifies measurement differences of a variable assessed by a new proposed instrument in comparison to the gold standard method. In the studies included for validity analysis, Frerich (2012), Knott (2016) and Thometz (2000) presented the mean difference between instruments [23,26,33]. In the studies included for the reproducibility De Sèze (2013) presented the TEM (Typical Error of Measurement) [14], Knott (2016) presented the mean standard deviation, while Tabard-Fougère (2016) presented the SEM (Standard Error of Measurement) and the MDC (Minimal Detectable Change) [22]. Statistical procedures for appraising precision and accuracy must be properly performed to determine validity and/or reproducibility of new evaluation instruments.

Two limitations of this review must be emphasized. Firstly, we have only metanalyzed correlation coefficient to identify the validation of topography. Despite the high correlation between topography and X-rays, other statistical procedures are necessary for the determination of validity of surface topography. The second limitation concerns the lack of standardization in the use of surface topography among the studies. It is important to highlight two fundamental facts about this limitation: (1) the lack of standardization in the execution and interpretation of surface topography justifies this review and it is the main purpose of this study; and (2) even though all the studies included in the meta-analysis applied the same technique (rasterstereography) for surface topography, it should be mentioned that the inclusion of data from different equipments and protocols may have affected the results.

Finally, the use of surface topography can contribute for the diagnosis and follow-up of the AIS. However, we recommend the application of a standardized protocol for the use of surface topography, from the proceeding of the examination to the analyses of results. Due to the three-dimensional nature of the AIS, it is noticeable the limitation of radiography (a two-dimensional exam), which in general, is used isolatedly in the diagnosis or follow-up of the AIS patients.

5. Conclusion

The present review provides anatomical reference markers and parameters for the evaluation of the AIS by surface topography to clinicians and researchers. The meta-analysis confirms that thoracic and lumbar measures in the sagittal plane and thoracic measures in the frontal plane (Cobb) demonstrate high correlations with radiography which are moderate for lumbar measures in the frontal plane. Those results are sustained by good reproducibility (over 0.8). The best results of all analyses derived from the thoracic region.

Conflict of interest statement

The authors have no conflict of interest to disclose.

Declarations of interest

None.

Disclosure statement

All authors have approved the final article.

Acknowledgments

No acknowledgments to declare.

References

[1] S. Negrini, S. Donzelli, A.G. Aulisa, D. Czaprowski, S. Schreiber, J.C. de Mauroy, H. Diers, T.B. Grivas, P. Knott, T. Kotwicki, 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth, Scoliosis Spinal Disord. 13 (2018) 3.
[2] M. Monticone, E. Ambrosini, D. Cazzaniga, B. Rocca, S. Ferrante, Active self-correction and task-oriented exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomised controlled trial, Eur. Spine J. 23 (2014) 1204–1214.
[3] G.H. Bonagamba, D.M. Coelho, A.S. de Oliveira, Confiabilidade interavaliadores e intra-avaliador do escoliômetro, Rev. Bras. Fisioter. 14 (2010) 432–437.
[4] T.S. Furlanetto, C.T. Candotti, T. Comerlato, J.F. Loss, Validating a postural evaluation method developed using a Digital Image-based Postural Assessment (DIPA) software, Comput. Methods Programs Biomed. 108 (2012) 203–212.
[5] X.C. Liu, J.G. Thometz, J.C. Tassone, L.C. Paulsen, R.M. Lyon, Historical review and experience with the use of surface topographic systems in children with idiopathic scoliosis, ISIS 2 (2013) 1–8.
[6] T. Kotwicki, S. Negrini, T.B. Grivas, M. Rigo, T. Maruyama, J. Durmala, F. Zaina, Methodology of evaluation of morphology of the spine and the trunk in idiopathic scoliosis and other spinal deformities-6 th SOSORT consensus paper, Scoliosis 4 (2009) 1–26.
[7] D.F. Stroup, J.A. Berlin, S.C. Morton, I. Olkin, G.D. Williamson, D. Rennie, D. Moher, B.J. Becker, T.A. Sipe, S.B. Thacker, et al., Meta-analysis of observational studies in epidemiology: a proposal for reporting, JAMA 283 (2000) 2008–2012.
[8] Y. Brink, Q.A. Louw, Clinical instruments: reliability and validity critical appraisal, J. Eval. Clin. Pract. 18 (2012) 1126–1132.
[9] E. Pappas, K. Refshauge, L. Cohen, M. Simic, S. Dennis, S. Kobayashi, Non-radiographic methods of measuring global sagittal balance: a systematic review, Scoliosis Spinal Disord. (2017) 1–12.
[10] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, P. Group, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, PLoS Med. 6 (2009) e1000097.
[11] M.M. Adankon, N. Chihab, J. Dansereau, H. Labelle, F. Cheriet, Scoliosis follow-up using noninvasive trunk surface acquisition, IEEE Trans. Biomed. Eng. 60 (2013) 2262–2270.
[12] F. Berryman, P. Pynsent, J. Fairbank, Measuring the rib hump in scoliosis with ISIS2, Stud. Health Technol. Inform. 140 (2008) 65–67.
[13] J. Chowanska, T. Kotwicki, K. Rosadzinski, Z. Sliwinski, School screening for scoliosis: can surface topography replace examination with scoliometer? Scoliosis 7 (2012) 9, https://doi.org/10.1186/1748-7161-7-9.
[14] M. de Seze, T. Randriaminahisoa, A. Gaunelle, G. de Korvin, J.-M. Mazaux, Inter-observer reproducibility of back surface topography parameters allowing assessment of scoliotic thoracic gibbosity and comparison with two standard postures, Ann. Phys. Rehabil. Med. 56 (2013) 599–612, https://doi.org/10.1016/j.rehab.2013.10.003.

[15] B. Drerup, E. Hierholzer, Back shape measurement using video rasterstereography and three-dimensional reconstruction of spinal shape, Clin. Biomech. 9 (1994) 28–36.
[16] B. Drerup, E. Hierholzer, Assessment of scoliotic deformity from back shape asymmetry using an improved mathematical model, Clin. Biomech. Bristol Avon. 11 (1996) 376–383.
[17] S.S. Klos, X.-C. Liu, R.M. Lyon, J.C. Tassone, J.G. Thometz, Reliability of a functional classification system in the monitoring of patients with idiopathic scoliosis, Spine 32 (2007) 1662–1666.
[18] P. Knott, S. Mardjetko, D. Nance, M. Dunn, Electromagnetic topographical technique of curve evaluation for adolescent idiopathic scoliosis, Spine 31 (2006) E911–E915.
[19] X.C. Liu, J.G. Thometz, R.M. Lyon, J. Klein, Functional classification of patients with idiopathic scoliosis assessed by the Quantec system: a discriminant functional analysis to determine patient curve magnitude, Spine 26 (2001) 1274–1279.
[20] X.-C. Liu, J.C. Tassone, J.G. Thometz, L.C. Paulsen, R.M. Lyon, C. Marquez-Barrientos, S. Tarima, P.R. Johnson, Development of a 3-dimensional back contour imaging system for monitoring scoliosis progression in children, Spine Deform. 1 (2013) 102–107.
[21] M.F. Mínguez, M. Buendía, R.M. Cibrián, R. Salvador, M. Laguía, A. Martín, F. Gomar, Quantifier variables of the back surface deformity obtained with a noninvasive structured light method: evaluation of their usefulness in idiopathic scoliosis diagnosis, Eur. Spine J. 16 (2007) 73–82.
[22] A. Tabard-Fougere, A. Bonnefoy-Mazure, S. Hanquinet, P. Lascombes, S. Armand, R. Dayer, Validity and reliability of spine rasterstereography in patients with adolescent idiopathic scoliosis, Spine 42 (2016) 98–105, https://doi.org/10.1097/BRS.0000000000001679.
[23] J.G. Thometz, R. Lamdan, X.C. Liu, R. Lyon, Relationship between Quantec measurement and Cobb angle in patients with idiopathic scoliosis, J. Pediatr. Orthop. 20 (2000) 512–516.
[24] A. Manca, M. Monticone, L. Cugusi, C. Doria, P. Tranquilli-Leali, F. Deriu, Back surface measurements by rasterstereography for adolescent idiopathic scoliosis: from reproducibility to data reduction analyses, Eur. Spine J. (2018) 1–9.
[25] J.H. Terheyden, M. Wetterkamp, G. Gosheger, T. Lange, A. Schulze Bövingloh, T.L. Schulte, Rasterstereography versus radiography for assessing shoulder balance in idiopathic scoliosis: a validation study relative to patients' self-image, J. Back Musculoskelet. Rehabil. (2018) 1–9.
[26] J.M. Frerich, K. Hertzler, P. Knott, S. Mardjetko, Comparison of radiographic and surface topography measurements in adolescents with idiopathic scoliosis, Open Orthop. J. 6 (2012) 261–265, https://doi.org/10.2174/1874325001206010261.
[27] A. Komeili, L.M. Westover, E.C. Parent, M. Moreau, M. El-Rich, S. Adeeb, Surface topography asymmetry maps categorizing external deformity in scoliosis, Spine J. Off. J. North Am. Spine Soc. 14 (2014) 973–983, https://doi.org/10.1016/j.spinee.2013.09.032 e2.
[28] A. Komeili, L. Westover, E.C. Parent, M. El-Rich, S. Adeeb, Monitoring for idiopathic scoliosis curve progression using surface topography asymmetry analysis of the torso in adolescents, Spine J. Off. J. North Am. Spine Soc. 15 (2015) 743–751, https://doi.org/10.1016/j.spinee.2015.01.018.
[29] M. Mangone, P. Raimondi, M. Paoloni, S. Pellanera, A. Di Michele, S. Di Renzo, M. Vanadia, M. Dimaggio, M. Murgia, V. Santilli, Vertebral rotation in adolescent idiopathic scoliosis calculated by radiograph and back surface analysis-based methods: correlation between the Raimondi method and rasterstereography, Eur. Spine J. 22 (2013) 367–371.
[30] L. Pino-Almero, M.F. Mínguez-Rey, S. Sentamans-Segarra, M.R. Salvador-Palmer, R.M.C.-O. de Anda, Quantification of topographic changes in the surface of back of young patients monitored for idiopathic scoliosis: correlation with radiographic variables, J. Biomed. Opt. 21 (2016) 116001.
[31] L. Pino-Almero, M.F. Mínguez-Rey, R.M. Cibrián-Ortiz de Anda, M.R. Salvador-Palmer, S. Sentamans-Segarra, Correlation between topographic parameters obtained by back surface topography based on structured light and radiographic variables in the assessment of back morphology in young patients with idiopathic scoliosis, Asian Spine J. 11 (2017) 219–229.
[32] L. Pino-Almero, M.F. Mínguez-Rey, D. Rodríguez-Martínez, R.M. Cibrián-Ortiz de Anda, M.R. Salvador-Palmer, S. Sentamans-Segarra, Clinical application of back surface topography by means of structured light in the screening of idiopathic scoliosis, J. Pediatr. Orthop. B 26 (2017) 64–72.
[33] P. Knott, P. Sturm, B. Lonner, P. Cahill, M. Betsch, R. McCarthy, M. Kelly, L. Lenke, R. Betz, Multicenter comparison of 3D spinal measurements using surface topography with those from conventional radiography, Spine Deform. 4 (2016) 98–103.
[34] B. Drerup, Rasterstereographic measurement of scoliotic deformity, Scoliosis 9 (2014) 22, https://doi.org/10.1186/s13013-014-0022-7.
[35] J.M. Bland, D. Altman, Statistical methods for assessing agreement between two methods of clinical measurement, Lancet 327 (1986) 307–310.