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Review Article

Validity and Reliability of Non-Invasive Methods for Evaluating Kyphosis and Lordosis Curvatures: A Literature Review

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ABSTRACT

Introduction: A few instruments are accessible for clinical estimation of the thoracic and lumbar curvatures. This methodical survey aims to identify the validity and reliability of non-invasive thoracic kyphosis and lumbar lordosis measurements.

Materials and Methods: This research is a literature review. The process was performed on articles in credible databases, such as Medline, Embase, AMED, CINAHL, PubMed, and Biomedical Reference Collection, Expanded, Sport Discus, Science Direct, Web of Science, searching for the terms thoracic kyphosis, lordosis, spinal curvature, lordosis and reliability, lordosis and validity, kyphosis and reliability, kyphosis and validity, test, measure, flexi curve, radiograph, spinal mouse, inclinometer, kyphometer, image processing, Cobb, during 1960 to 2020.

Results: The result of the systematic search revealed that ten methods among all related papers have inclusion criteria, 3D ultrasound, Arco meter, DE Brunner's kyphometer, digital inclinometer, electro goniometer, goniometer, flexi curve angle, image processing, pantograph, and spinal mouse.

Conclusion: The validity and reliability of non-invasive methods for estimating kyphosis and lordosis curvatures were indicated in 26 papers. Based on the current little evidence, non-invasive procedures have high to very high reliability and moderate to high validity.

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1. Introduction

The spine as a base of the skeleton is a complicated structure that has various roles, including trunk positioning and making a place for the connection of several muscles and limited ligaments [1]. The spine also makes a column that provides support and stability to help maintain a standing posture, linking the head to the trunk, and supporting the spinal cord. The spinal curves include the normal concave and convex curves of the spine, and play a vital role to keep stability, flexibility, and distribution- the absorption of the force on the spine. While the vertebra column absorbs the loads [2], however, some aspects include incorrect moving habits, weakness of back muscles, and stiffness of muscles and also the factors, such as neuromuscular, congenital, post-traumatic, post-infective, and idiopathic problems [3], kyphosis and lordosis deformities could appear [1, 4]. The thoracic hyperkyphosis and lumbar hyper lordosis are the most common spinal deformities. Hyperkyphosis is defined as excessive of the upper back arch and hyperlordosis is defined as excessive of the lower back arch [5].

Two factors usually evaluated in the measurement of spinal posture are kyphosis and lordosis curvatures. Hyperkyphosis and lumbar lordosis are due to an increase of the thoracic and lumbar arches in the sagittal plane, therefore precise estimation of these angles is very crucial for the treatment of these abnormalities [6]. Hyperkyphosis is referred to the excessive of the upper back in the range of T1 and T12 spinal [7, 8]. However, lumbar lordosis refers to an excessive inward curve in the lumbar.

Measuring the exact quantitative values of these lordosis and kyphosis curves is a vital factor in the medical and research field. Due to this importance, various methods have emerged and these methods are very diverse, from expensive and accurate methods, such as X-ray to simpler methods, such as goniometer. As it is, a few instruments are accessible for clinical estimation of kyphosis and lordosis curvatures. The devices, such as a flexible ruler (flex curve) [9-15], Kyphometer [16], inclinometer, the spinal mouse [17-20], 3D ultrasound [21], pantograph, and finally image processing [12] methods can be considered as the crucial non-invasive methods that can apply to assessing the thoracic and lumbar vertebral curvatures. These instruments permit a rapid, simple, and non-invasive measurement of the curves in medical areas. The validity and reliability of methods are vital factors to select any devices for clinical and research training [22, 23]. Validity refers to how well an instrument or piece of research measures what it sets out [24, 25]. Reliability is defined as the degree that estimation is stable and errorless when utilized by the same results (intra-rater reliability), or various raters (inter-rater reliability) [26]. Current ways and psychometric variables have not been explicitly investigated; therefore, this methodical survey was conducted to identify the reliability and validity of non-invasive thoracic kyphosis and lumbar lordosis measurements.

2. Materials and Methods

Search strategy

This research is a literature review. The survey was performed on articles in credible databases, such as Medline, Embase, AMED, CINAHL, PubMed and Biomedical Reference Collection: Expanded, Sport Discus, Science Direct, Web of Science, searching for the terms thoracic kyphosis, lumbar Lordosis, spinal curvature, kyphosis reliability, validity, test, measure, flexi curve, radiograph, spinal mouse, inclinometer, kyphometer, image processing, Cobb, during 1960 to 2020. The data was directed utilizing a search from four fundamental branches of areas, thoracic kyphosis ("thoracic kyphosis", "spinal curvature", "thoracic curvature", kyphosis), lumbar lordosis ("lumbar lordosis", "spinal curvature", "lumbar curvature", lordosis) psychometric properties (reliability, validity, affectability, responsiveness, and properties) and physical tests (instrument, tool, test, measure, flexi curve, radiograph, spinal mouse, inclinometer, kyphometer, image processing, Cobb) (Figure 1). The boolean operators "or"-"and" were utilized to combine the search terms inside and between every one of the four fundamental branches of areas respectively. A word from every area was required in the title or abstract of the research. An extra search was conducted in the other databases, such as Google Scholar web index.

Study selection

Two authors (HZ & MY) independently reviewed the eligible studies based on the titles and abstracts. Then, the relevant full-text articles were read carefully according to the inclusion criteria. Any disagreements were resolved by consensus or the third and fourth researchers.

Inclusion and exclusion criteria

The inclusion criteria included articles accessible in full text, articles accessible in English, a nonpartisan thoracic and lumbar curvatures value angle recorded, spinal deformities were the result of mechanical, congenital, post-traumatic, and post-infective problems. The exclu-

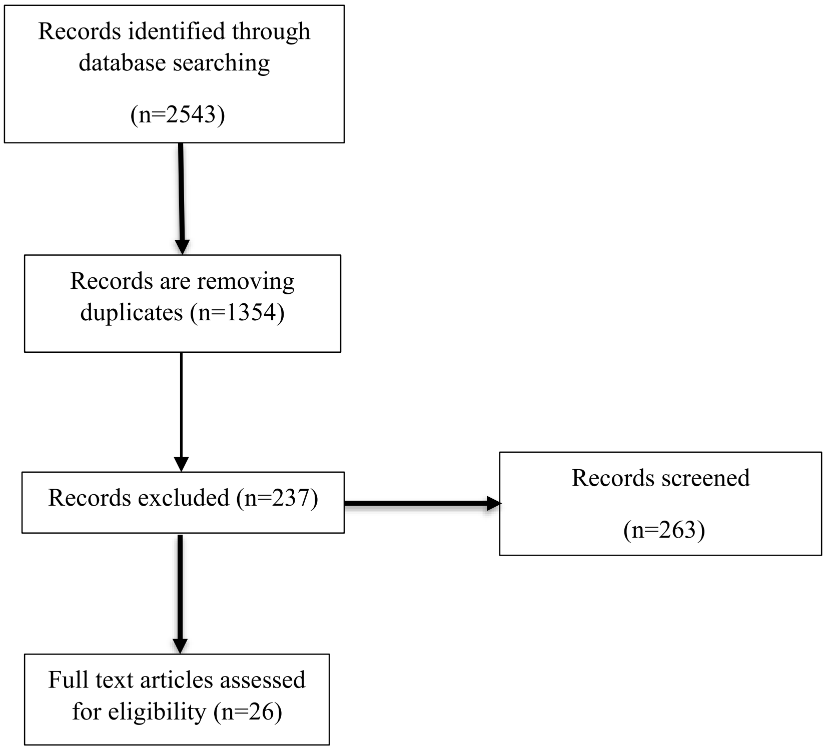

Figure 1. Algorithm for selecting articles based on inclusion criteria

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sion criteria included radiographic estimation systems only, full text in English couldn't be found, and thoracic kyphosis and lumbar lordosis angle are detailed in thoracic flexion or extension only [27].

Extraction of data

The information, such as year of publication, location, intervention applied, frequency, duration of follow-up, outcome measures, and main findings were extracted from the included trials.

Evaluation methods

Ultrasound method

Ultrasound measuring system performs a three-dimensional (3D) motion analysis by measuring the propagation time of ultrasound pulses. The device consists of the head containing three ultrasound transmitters, the triplet with three receivers to eliminate the movements of the pelvis, and the pointer containing two microphones to determine the shape of the spine. The transmitters emit ultrasonic signals from the head that are recorded by the receivers (the measuring frequency is 100 Hz). From the known ultrasound velocity, which is appropriate to the temperature, and from the measured propagation time the distance can be calculated between each transmitter and receiver. The spatial coordinates of the receivers can be calculated at any time during the measurement from the spatial coordinates of the transmitters and the distance between the three-head sensors with the method of triangulation, that calculation can be performed for all receivers. The spatial position of the receivers and the spatial position of the spinous processes of the vertebrae were recorded and numerically stored by Win Spine measurement driving software, Zebris FDM 1.12 (Zebris Medizintechnik GmbH, Isny, Germany). The processes are briefly known as ultrasound-based spine examination [28].

Arco meter method

The Arco meter consists of 3 rods, including the upper, middle, and lower rods. To evaluate the thoracic and lumbar curvatures with the Arco meter, the evaluators positioned the upper and lower rods of the instrument on the spinous processes T1, T12, L1, and L5 at which point FA, and FB measures were obtained as seen in Figure 2. Soon after, the evaluators identified the apex of the curvature using the middle rod corresponding to measure f, the scale on the instrument was read to obtain the measures h1 and h2 corresponding to the distance between the upper vertebra and the point of the apex of the curve, and between the apex of the curvature and the lower vertebrae, respectively. This repeated procedure collects data on both the thoracic and lumbar curvatures

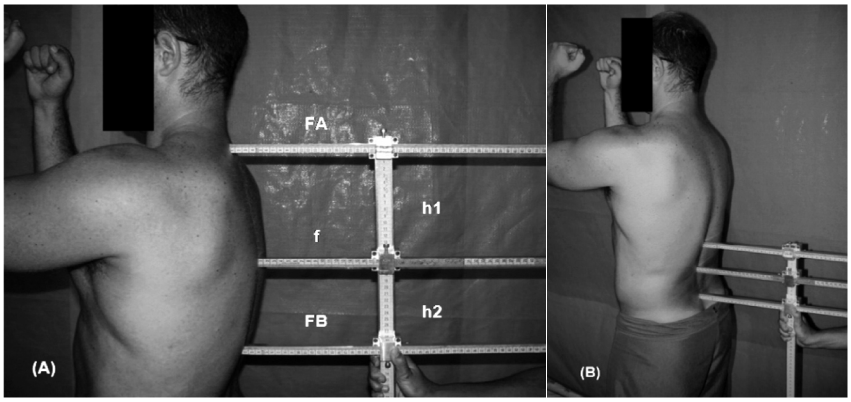

Figure 2. Fa, h1, f, FB, h2 index in arco meter [30]

for each of the two evaluators [29]. The data from the Arco meter, i.e. the values of h1, h2, f, FA, and FB of the thoracic and lumbar curvatures of the subjects were included in equations adapted from Leroux (2000) and based on three trigonometric relations; the angles of the thoracic and lumbar curvatures were calculated in degrees (Equation 1) [30]:

1. $\Phi 1=180-2\times Atan\ (h1/f),\ \Phi 2=180-2\times Atan\ (h2/f)$

DE Brunner's kyphometer

The DE Brunner's kyphometer consists of a protractor mounted on two arms, the ends of which are positioned on specified bony landmarks; then the kyphosis angle is read from the protractor. The upper arm of the DE Brunner kyphometer was placed on C7 and the lower arm on T12. The circumscribed kyphosis angle was read from the protractor (Figure 3) [31].

Digital inclinometer

The digital inclinometer is becoming a popular tool to assess the musculoskeletal system, including the anteroposterior curvatures of the spine, in both clinical practice and research [32] (Figure 4). To assess the angle of the sacral slope, the inclinometer reader was reset in the horizontal position and then placed on the lumbosacral junction found by palpation (LS point). The measurement of the hyperlordosis angle began by resetting the inclinometer reader at the LS point, and then applied to a palpated point on the thoracolumbar junction (ThL point). The angle of hyperkyphosis was determined after the inclinometer was reset at the ThL point, and the reading was taken at the cervicothoracic junction (CTh point). Additionally, the size of the upper and lower thoracic kyphosis was determined. To assess the former, the inclinometer reset at the ThL point and the reading was taken at the Th6-7 motion segment.

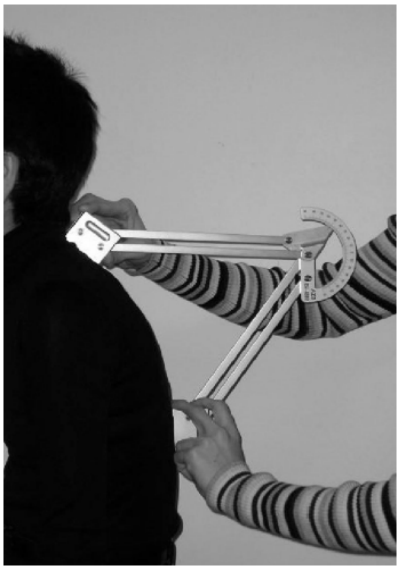

Figure 3. DE Brunner's kyphometer [31]

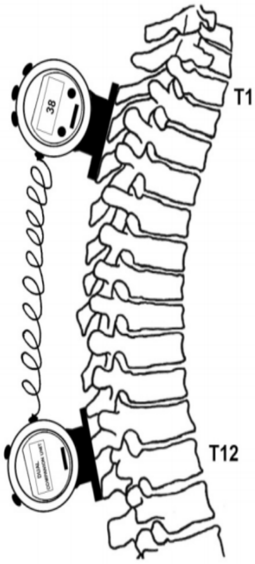

Figure 4. Digital inclinometer [32]

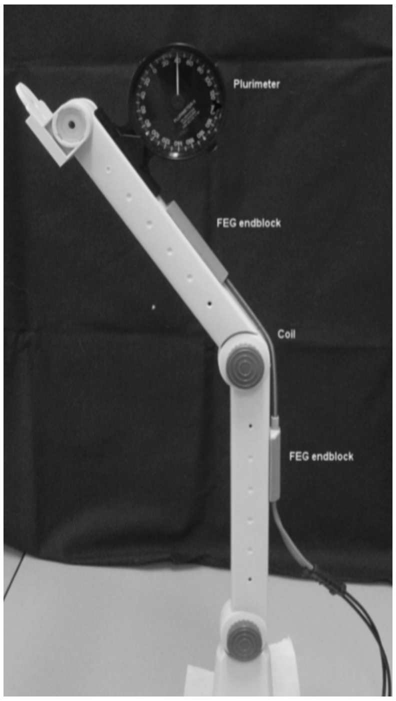

Figure 5. Electro goniometer [7]

Figure 6. Spinal pantograph [33]

Goniometer

The flexible electro goniometer (FEG), which can record joint angles over time outside the laboratory, has been used to measure other joints. Also, the only dynamic device that can record angular motion outside the laboratory is the biometrics flexible electro goniometer [7] (Figure 5). The FEG allows continuous measurement of the angular displacement between 2 lightweight plastic end blocks at either end of a coil containing 2 strain gauges mounted at 90° to each other. The flexible electro goniometer has an accuracy within ±1° and has been used extensively to measure the angles of limb joints during performance activities [7].

Image processing

This method is a relatively recent method in which some points on the body are marked using a computer and then the deviation of the points, compared to the natural mode, is calculated and reported using mathematical methods and computer programming. A limited number of experiments were performed to study the malformations of the spine through the image processing method. Learoux et al. used in image processing method and reported its validity as adequate. According to the findings of Yousefi et al. this method can be used as one of the non-contact methods in studying the malformations of the spine [12].

Pantograph

The spinal pantograph consists of a pantograph with an arm, at the end of which a low-friction wheel is mounted (Figure 6). The decreasing scale can vary between 1:2 and 1:20. In the present study, 1:4 was chosen as the most suitable for this purpose. A drawing table was fixed below the pantograph to record the decreased contour line of the trunk. The pantograph and the drawing table are mounted on a tripod, which can be raised or lowered. The tripod also allows the pantograph to work in both the sagittal plane for recording kyphosis/lordosis and the transversal plane for describing the hump deformity seen in structural scoliosis. For the measuring, the patients stand in front of the spinal pantograph, in an erect, relaxed position supporting their weight equally on both legs. The spinal processes of C, and L, are marked by dermograph. By letting the wheel of the pantograph lightly follow the spinal processes between these two landmarks, the thoracic and lumbar curvatures are recorded on a paper roll on the drawing table. By indicating C, and L, on the contour line on the paper, even the height of the thoracolumbar spine can be evaluated. During the recording of the asymmetry of the rib hump in structural scoliosis, the pantograph is placed horizontally. Here the rotational deformity can be estimated in a standing position [12].

Figure 7. Flexi curve [35]

Spinal mouse

The spinal mouse consists of an electromechanical device like a computer mouse. To measure spinal curvature using a spinal mouse, each rater first determined by palpation on the skin surface and marked with a pencil the spinous process of C7 (starting point) and the top of the anal case (endpoint). Particularly, the C2 spinous process is identified by palpating the midline just below the external occipital protuberance. Starting from C2, the examiner then counted the spinous processes caudally until C7 by using a cervical extension-flexion motion test. The L4-5 interspace is palpated against the uppermost iliac crest. The S1 vertebra was located by using the technique described by Hoppenfeld and the T12 spinous process palpate by counting from S1. The electromechanical device then guided along the midline of the spine (or slightly paravertebrally in particularly thin children with prominent spinous processes (from the starting point until the end [34].

Flexi curve

The flexi curve (trident) is a flexible plastic-covered metal ruler, 80 cm in length, marked at 1 mm intervals. This instrument can be molded into rounded structures. The assessment procedure with the flexi curve consisted of molding the instrument to the shape of the spine from the C7 to the S1 spinal processes [35] (Figure 7).

As a result, the DE Brunner's kyphometer, digital inclinometer, goniometry, electrogoniometry, and Arco meter consist of several arms or rulers located on some part of the spinal curve, like the Cobb angle calculation. On the other hand, the pantograph, spinal mouse, and flexi curve make a schematic view of the vertebral column. The 3D ultrasound performs a three-dimensional motion analysis by measuring the propagation time of ultrasound pulses and the body landmark analyzer (BLA) method [36] simulated spinal curves using an image processing technique.

3. Results

Table 1 presents the summary of reliability and validity studies, including test-retest reliability, validity with X-ray, limits of agreement, and standard error of measurement. Also, Table 2 presents the summary of validity, reliability, and standard error of measurement (SEM) of ten non-invasive measurement methods.

4. Discussion

This methodical survey was conducted to identify the reliability and validity of non-invasive thoracic kyphosis and lumbar lordosis measurements. Pearson's r, Cronbach α, and intra-class correlation coefficients (ICC) statistics were interpreted as follows, ≤0.29 very low correlation, 0.30–0.49 low correlation, 0.50–0.69 moderate correlation, 0.70–0.89 high correlation, and ≥0.90 very high correlation [37]. An agreement evaluated by SEM, when data were available, was calculated according to the Equation 2 [26].

2. $SEM = standard\ deviation\ (SD) \div \sqrt{1\text{-}reliability\ coefficient}$

The result of the systematic search revealed that ten methods among all related papers have inclusion criteria, 3D ultrasound, Arco meter, DE Brunner's kyphometer, digital inclinometer, electro goniometer, goniometer, flexi curve angle, image processing, pantograph and spinal mouse. Table 1 presents the summary of reliability and validity studies, including test-retest reliability, validity with X-ray, limits of agreement, and standard error of measurement. The DE Brunner's kyphometer, digital inclinometer, goniometry, electro goniometry, and Arco meter consist of several arms or rulers located some parts of the spinal curve, like the Cobb angle calculation. On the other hand, the pantograph, spinal mouse, and flexi curve make a schematic view of the vertebral column. The 3D ultrasound performs a three-dimensional motion analysis by measuring the propagation time of ultrasound pulses and BLA method [36] simulated spinal curves using an image processing technique. However, reliability of all the above ten methods was high to very high and the validity of these methods was moderate to high (although validity less studied compared to reliability). Only four studies report standard error of measurement, the lowest belongs to the electro goniometer [7] and the highest belongs to the spinal mouse [6, 38]. Of all ten-measurement methods, only two of them, flexi curve index and DE Brunner's kyphometer have high evidence for reliability and no one has high validity evidence. It seems that researchers tend to evaluate more simple methods to measure thoracic kyphosis, and lumbar lordosis.

Table 1. Test-retest reliability, validity (X-ray), limits of agreement, and SEM

Methods	Researchers	ICC Test-retest Reliability	Validity With X-ray	Bland-Altman 95% Limits of Agreement	SEM
3D ultrasound	Fölsch et al. 2012 [21]	0.95 intra	-	Within clinical acceptable margins	3.7
Arco meter	D'Osualdo, 1997 [40]	0.99 intra-inter	0.98	-	-
	Chaise et al. 2011 [29]	0.98 inter, 0.99 intra	0.94	-	-
DE Brunner's kypho-meter	Kado et al. 1976 [39]	-	0.68	-	-
	Ohlen et al. 1989 [16]	0.92-0.93 intra, 0.91, 0.94 inter	-	-	-
	Korovessis et al. 2001 [49]	0.84 inter, 0.92 intra	0.759	-	-
	Greendale et al. 2011 [48]	0.96 to 0.98	0.62 to 0.69	-	-
	Agnvall et al. 2015 [39]	-	0.67 to 0.83 for kyphosis and 0.33 to 0.5 for lordosis	-	-
Digital inclinometer	Czaprowski et al. (2012) [5]	0.9>α≥0.8	-	-	3.8
	Barrett et al. 2013 [5]	0.92 intra and 0.9 inter rater	-	-	-
Electro goniometer	Perriman et al. 2010 [10]	0.94 to 0.98	0.53 to 0.87	-	-
	Johnson et al. 2012 [10]	Inter 0.85 to 0.94 and intra 0.86 to 0.95	-	-	1 to 2.3
Flexi curve angle	Oliveira et al. 2012 [35]	0.94 inter, 0.82 intra	0.7	-	-
	Barrett et al. 2013 [35]	Intra-rater (ICC 0.94) and inter rater (ICC 0.86)	-	-	-
	Barrett et al. 2018 [35]	-	0.96	Within clinical acceptable margins	-
	Yanagawa et al. 2000 [35]	Kyphosis height (0.89) index kyphosis (0.93	-	-	-
	Hinman. 2004 [11]	Kyphosis 0.94 and Lor-dosis 0.6	-	-	-
	Teixeira and Carvalho, 2007 [46]	0.87 intra, 0.94 inter	0.528-0.906	-	-
	Sedrez et al. 2016[46]	Kyphosis test retest 0.82 Intra 0.68 inter 0.72 Lordosis Test retest 0.66 Intra 0.5 Inter 0.56	-	-	-
Goniometer	Perriman et al. 2010 [10]	0.9-0.95 intra	0.53 to 0.87	-	-
	Gravina et al. 2012 [10]	-	Kyphosis 0.89 Lordosis 0.52	-	-
	Gravina et al. 2017 [10]	Kyphosis 0.836 and Lordosis 0.831	-	Within clinical acceptable margins	
Image processing	Yousefi et al. 2012 [12]	-	-	-	-
Pantograph	Willner et al. 1981 [33]	-	0.94	-	-
Spinal mouse	Mannion et al. 2004 [18]	0.73-0.88 intra to 0.83-0.87 inter	-	-	4.2 to 2.8
	Kellis et al. 2008 [20]	0.81-0.87 intra, 0.88-0.89 inter	-	-	2.3 to 2.7 intra, 1.4 to 2.1 inter

SEM: Standard error of measurement; ICC: Intra-class correlation coefficients.

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Table 2. Validity and reliability non-invasive methods

Method	Reliability	Evidence	Validity	Evidence	Max SEM	Evidence
Ultrasound system	Very high intra rater reliability	Low	-	-	3.7	Low
Arco meter	Very high intra+inter rater reliability	Low	Very high validity	Low	-	-
DE Brunner's kyphometer	Very high intra, inter-rater reliability	High	Moderate to high validity	Low	-	-
Digital inclinometer	High intra-rater reliability	Low	-	-	3.8	Low
Electro goniometry	Very high intra+inter-rater reliability	Low	Moderate to High validity	Low	2.3	Low
Flexi curve index	Very high inter-rater reliability	High	Moderate to very high validity	Low	-	-
Goniometer	Very high intra+inter-rater reliability	Moderate	Moderate to high validity	Low	-	-
image processing	-	-	High validity	Low	-	-
Pantograph	-	-	Very high validity	Low	-	-
Spinal mouse	High intra+inter-rater reliability	Low	-	-	4.2	Low

SEM: Standard error of measurement.

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The flexi curve (trident) is a flexible plastic-covered metal ruler, 80 cm in length, marked at 1 mm intervals. This instrument can mold into rounded structures. The assessment procedure with the flexi curve consisted of molding the instrument to the shape of the spine from the C7 to the S1 spinal processes [35]. The flexi curve has very high inter-rater reliability and moderate to very high validity for evaluating the thoracic and lumbar curvatures. The DE Brunner kyphometer consists of a protractor mounted on two arms, the ends of which are positioned on specified bony landmarks; the kyphosis angle is read from the protractor. The upper arm of the DE Brunner kyphometer was placed on C7 and the lower arm on T12. The circumscribed kyphosis angle is read from the protractor [39]. DE Brunner kyphometer has very high inter-intra rater reliability and moderate to high validity for evaluating the thoracic and lumbar curvatures. All methods have low evidence in the literature for reliability and validity, except the goniometer, which has moderate evidence. The reliability of all other methods is high to very high and the validity of these methods is moderate to high.

Validity

Validity is one of the most important factors to select any devices for clinical and research training [22, 23]. Validity refers to how well an instrument or piece of research measures what it sets out [24, 25]. Although the validity of the spine curves measurements is considered in various reports, however, in some studies, this validity was not sufficiently satisfactory [34]. To validate, a non-invasive tool should be compared with golden methods, such as Cobb angle to be carefully considered as valid methods for analyzing kyphosis and lordosis curvatures. The validity of thoracic kyphosis and lumbar lordosis measurement methods, except the Cobb angle [7, 40], is based on the centroid [41] and posterior tangent [42] methods. Although all measurement methods use a different way to measure kyphosis and lordosis curvatures, including using several arms or rulers to locate some parts of the spinal curve (The DE Brunner's kyphometer, digital inclinometer, goniometry, electro goniometry, and Arco meter), making a schematic view of the vertebral column (pantograph, spinal mouse and flexi curve) and image processing, however, searching on validity researches showed no considerable differences in validity confident between either method. Only Arco meter and pantograph have very high validity coefficients. All methods of measurement have low evidence in the literature for validity and except the two above methods and image processing with high validity coefficient, others have moderate to high validity (0.5 to 0.9).

Reliability

Reliability is characterized as the degree to which estimation is steady and free from error when utilized by the same (intra-rater reliability), or various raters (inter-rater reliability) [26]. Subsequently, depicting standard error of measurement is a critical element of reliability, since it contributes to the clinical interpretation of the results [25]. Some factors exist that have the potential to challenge the reliability of the spine palpation, variability of spinal curvature from one day to another day as a result of physical activity, fatigue, job activity [40, 43], repeated testing [11, 20], and reposition of markers [44, 45]. Some prefer to use techniques, such as performing the same test within the same day (test, re-test method) [17, 18, 21, 29, 30, 35, 40, 43, 46-50]. Others used techniques such as using the same light and temperature situations [50] and prevent excessive physical activities between test days [21]. Another potential challenge to taking reliable measures is the accurate palpation of spinal landmarks. The validity of palpation of the vertebra has been reported to be poor in the human spine [10, 11, 18, 20, 29, 30, 35, 40, 43-45, 48, 51-54]. It has been reported that the precision of palpation can depend on the skill of the tester [53, 55]. However, the contribution of the tester experience to the reliability of spine curvature measuring is unclear. Several studies did not remove markers of palpated landmarks between raters [10, 18, 29, 34, 35]. Using the same marked points likely increased the reliability of measurements between raters. The reliability of the lower cost and simpler methods, such as flexi curve index and DE Brunner's kyphometer investigated to a lesser extent than more technical methods. The reliability of these simple methods was very high for both inter-rater and intra-rater with a high degree of evidence. The spinal mouse also has high evidence for reliability in the literature, a system with wirelessly connected mouse shape, but has high inter-intra rater reliability (below 0.9) but unlike the above methods, can be used to measure sagittal balance. Other methods that are more complicated than the three mentioned methods, all have high to very high inter-intra rater reliability but with moderate (goniometer) or low evidence (electro goniometry, digital inclinometer, and Arco meter).

Application

Measuring the exact quantitative values of these lordosis and kyphosis curves is a vital factor in the medical and research field. Therefore, it is due to the expensive and accurate methods, such as X-ray, and the need to provide simpler and more accurate methods for evaluating these abnormalities in different situations. Therefore, in this study, we summarized the simpler noninvasive methods to assess this lordosis and kyphosis to help the medical community choose the best methods according to the facilities.

5. Conclusion

Among ten measurement methods reviewed in the study, there appears to be high evidence of reliability for more simple methods, such as flexi curve index and DE Brunner's kyphometer, but all non-invasive have high to very high reliability and moderate to high validity.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Conceptualization, supervision, methodology, data collection, data analysis, funding acquisition and resources: Hamidreza Zanguie and Mohammad Yousefi; Investigation, Writing-original draft, and Writing-review & editing: All authors.

Conflict of interest

The author declared no conflict of interest in the publication of this article.

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