Review Article

DOI: 10.7860/JCDR/2022/53685.16474

Quantification of Lumbar Lordosis by Tactile and Non Tactile Methods: A Revisit

Physiotherapy Section

ANUSHREE RAI[1], ZUBIA VEQAR[2]

ABSTRACT

Lumbar lordosis alteration results in various disabilities and common problems like low back pain, among others which severely impacts the quality of life of a person. This paper focuses on postural evaluation used to identify this alteration, which till date has received little attention even though it is an important outcome measure in various experimental studies. This review focuses on both quantitative and qualitative postural evaluation methods. Conventional methods range from visual observation method to the gold standard method, namely, radiography and various other non invasive methods like photogrammetric, flexicurve, spinal mouse, and inclinometer. However, recent research suggests some 3 Dimensional (3D) analysis methods like 3D radiographs, inertial sensors and posturometer. There is a lack of consensus on the most suitable method for this evaluation, hence, the selection is difficult for clinical as well as research purposes. Although there are few reviews available, none of them have attempted to establish the pros and cons of all these methods. This review provides a comprehensive overview of different 2D, 3D, tactile and non tactile methods or tools that have been developed to measure posture or shape of lumbar spine. This review will also provide practical recommendations to researchers as well as clinicians about the tool selection for lumbar lordosis assessment.

Keywords: Cobb's angle, Inclinometer, Lumbar spine, Photogrammetry, Posture, Posturometer

INTRODUCTION

Lumbar lordosis is the anterior convexity in the mid-sagittal plane. It compensates for the inclined sacrum and to avoid anterior inclination. It gives lumbar spine toughness and ability to resist compressive forces. Any alteration in the lumbar lordosis due to congenital condition, trauma, degenerative and inflammatory conditions, compressive forces are transferred to the intervertebral disc through vertebral bodies and can cause low back pain and disabilities. Hence, assessment using reliable methods is used for measuring this alteration of curve and for adequate restoration of lumbar lordosis [1,2].

A variety of postural assessment methods have been used for clinical and research purposes. Some are conventional (non tactile or tactile methods), while some are advanced (non tactile or tactile methods).

In light of the recognition that lumbar lordosis assessment plays an important role in the prevention and management of low backache and its associated problems, its assessment needs to be given due importance. The primary aim of this review was to provide the readers with a comprehensive information regarding different tools and instruments used for assessing it. It further aimed at finding the most appropriate method among many on the basis of cost, availability, portability, reliability, validity, and ease of use. This information will help researchers as well as clinicians to decide about the most suitable tool/method which can be used on their subjects/patients for the lumbar lordosis assessment.

TWO-DIMENSIONAL ANALYSIS OF POSTURE

Methods of Measurement

Visual observation method: It is one of the oldest, easiest and most commonly used methods for assessment of posture in clinical practice as it doesn't require any tool. The main disadvantage of this method is its inability to do a quantitative assessment which leads to variability. It also fails to diagnose minor postural alterations [3].

A study was done by Fedorak C et al., for evaluation of reliability of visual assessment for lumbar lordosis [4]. It was reported poor ($k<0.40$) inter-rater and fair ($k=0.50$) intra-rater reliability. Another study conducted by Iunes DH et al., compared the inter-rater reliability between visual and photogrammetry method in 21 volunteers aged between 22 to 26 years [3]. Inter-rater reliability for lumbar lordosis measurement by visual method was 28.6%. The result of both studies concluded that it has poor inter-rater agreement. With this method of postural assessment, reliable results cannot be obtained so more accurate methods should be used in clinical practice.

Radiographic method: Radiography, considered as the gold standard method of postural assessment allows the quantification of the anteroposterior curvature of spine, which is important for structural stability, protection of spinal cord and spinal segment mobility [5]. Assessment of lumbar lordosis by lateral radiograph is done routinely and Cobb's method is the most commonly used technique. Cobb's angle is measured through the intersection of line drawn from endplate of one vertebra to the endplate of another vertebra [1,6] and usually superior endplate of L1 segment and superior endplate of S1-segment is used for this assessment [1,7,8]. Hicks GE et al., determined the inter-rater reliability (0.98), Minimum Detectable Change (MDC) (3.90) and Standard Error of Measurement (SEM) (1.99 degree) of 4-line Cobb method for measuring lumbar lordosis and Intraclass Correlation Coefficient (ICC) value after two years (0.81) [9]. Chung NS et al., determined the validity and reliability of spinopelvic and lumbar lordosis measurement by lateral lumbar radiograph and compared it with lateral whole radiograph [10]. They reported similar correlation coefficient 0.93-0.95 and intra and inter observer ICC values as >0.75 for both. Even though the reliability of both the measurements were similar; lateral lumbar radiograph has certain advantages over lateral whole-spine radiograph like special film is nonessential, radiograph is easy to obtain and radiation exposure is lesser. Although studies concluded excellent reliability of radiographic method but the radiation exposure is an important health concern along with its cost [11].

Photogrammetric method: Photogrammetry is a non invasive method used by healthcare professionals and researchers, as it allows precise evaluation by recording the postural changes over multiple frames. It is helpful for giving information in sagittal and frontal planes [12].

Drzal-Grabiec J et al., evaluated the validity of this method with radiographic method for measuring Cobb's angle and size of anteroposterior curvature of spine among participants (n=50) aged between 35 to 65 years. A significant correlation was reported between these methods for length of lordosis (r=0.88; p<0.001) and Cobb's angle (r=0.30; p<0.001) [13]. Other validity studies reported no significant difference for lumbar lordosis angle (p=0.817) for photogrammetric and inclinometer in healthy elderly women [14]. The validity of prediction equation from skin surface is (r>0.85) for T10-S2 level [5]. Apart from validity, its reliability was also examined well in the literature with its ICC values ranging from (0.98-0.99) and (0.97-0.99) for inter and intra-rater reliability respectively [5].

Numerous studies have reported the use of photogrammetric method for postural evaluation as it is:

(i) Non invasive tool which provides precise qualitative postural evaluation
(ii) Good agreement with radiograph
(iii) Repeatability
(iv) Reduces exposure to radiation during radiographic evaluation

The main limitation associated with this method is the possibility of error while marking the points and their positioning on the computer screen and it is indistinct how photogrammetric technique is utilised to screen postural treatment or to record posture in observational studies [12,13].

Tactile Methods of Measurement

Flexicurve: This method is used in healthy and patient population from children [15] to adolescents, and adults to analyse spinal curvature [16]. It has a malleable ruler which is moulded to the back to trace the shape of the spine onto paper, which is followed by calculation of angle of curvature of spine [17].

The reliability studies conducted in the literature among healthy population reported ICC value for lumbar length and width ranging from (0.72-0.74) and (0.56-0.58) for intrarater and inter-rater reliability respectively [16]. Furthermore, de Oliveira TS et al., reported excellent inter and intra rater reliability with ICC values 0.83 and 0.78 respectively [18]. The results of both studies showed that flexicurve is a reliable tool to assess the lumbar curvature in sagittal plane.

Validity is not very extensively studied, however, a study conducted by de Oliveira TS et al., demonstrated strong correlation between radiographic measurement and flexicurve (r=0.60). The limitations associated with flexicurve measurements are the following [15,16,18]:

- Firstly, difficulty in moulding the flexicurve in the lumbar spine which causes greatest variability in the measurements
- Secondly, difficulty in palpation of anatomical landmarks in the lumbar region
- Thirdly, high chances of measurement errors due to patient and examiner variability during data collection and angle measurement, also lack in the concurrent validation to ensure its diagnostic capacity

Spinal mouse: It is a hand-held, non invasive device with inbuilt accelerometers and small wheels that roll along the length of the spine to record the distance and alteration of inclination with respect to the plumb line as well as spinal angle and shape in frontal and sagittal plane, regional kyphosis and lordosis, mobility of the thoracic and lumbar spine, mobility and posture of single vertebral segments, hypomobility and hypermobility of a particular segment, postural competence, posture and mobility of the sacrum/pelvis, posture of the upper body in space [19,20].

Various reliability studies were conducted to measure the spinal curvature in sagittal and frontal plane among healthy participants. The ICC value for lumbar lordosis ranges from (0.90-0.99) and (0.87-0.99) for intrarater and inter-rater reliability respectively [19,21]. Miyazaki J et al., reported ICCs of 0.94 and 0.89 over skin and clothing respectively [22]. Russell BS et al., reported high reliability with ICC values >0.99 of Spinal Mouse unit in measuring lumbar lordosis by use of wooden spine model among 50 participants with or without high- heeled shoes [23]. The result of the above-mentioned studies showed that Spinal Mouse is a reliable skin-surface device to measure lumbar lordosis in sagittal and frontal planes [22,23].

Validity of Spinal Mouse in sagittal plane measurement has not been established yet [23]. There has been difference in the lumbar lordosis measurements using Spinal Mouse as reported by various authors. Liberg EM et al., reported a mean lordosis of 15°; Keller S et al., reported about 27°; Takihara Y et al., below 20°; and Miyazaki J et al., 19° and 20° over skin and clothing respectively [24-26]. Spinal Mouse measurements are not correlated with radiographic measurement as:

(i) Measurement using skin surface device follow line of posterior elements while X-ray measurements use vertebral bodies
(ii) Distribution of subcutaneous tissue mainly in the lumbar region [19,21], but comparable with other skin surface devices

Majority of the studies mentioned above were conducted among healthy asymptomatic participants; there are chances that the use of Spinal Mouse may be more difficult for symptomatic patients.

Inclinometer: Inclinometer is a reliable, handy, affordable, and non-invasive device which is used to assess the anteroposterior curvature of the spine and helps the clinician to diagnose or to record patient progress efficiently [14,27]. The baseline digital inclinometer offers the speed and ease of use of a digital display. It can be used in conjunction with a second unit for neck and back measurements. Baseline gravity inclinometer and Bubble inclinometer also provides accurate range of motion measurements which can be read directly from the dial. They are used for diagnosis in hospitals, clinics and tracking the progress of therapy [28].

Various authors reported the reliability of inclinometer in measuring lumbar range of motion and lumbar lordosis. Good to excellent intrarater reliability has been reported with ICC values ranging between (0.90-0.95) for lumbar lordosis measurement using inclinometer among healthy subjects [27,29]. Ng JK et al., [29] measured lumbar lordosis with inclinometer at T12-L1 and L5-S1 level. Van Blommestein AS et al. [27] calculated the lumbar lordosis at T12-L1 and S2-S3 using Isomed Inclinometer (Isomed, 975 Sandy Blvd., Portland, OR 97214) which consists of a protractor with a freely swinging pointer and two feet that project from its base. Czaprowski D et al. [30] measured the lumbar lordosis using Saunders Digital Inclinometer (Baseline Digital Inclinometer, The Saunders Group Inc, Chaska, MN, USA) in healthy subjects by setting the inclinometer at lumbosacral junction. It was found to have good intrarater reliability with Cronbach's alpha coefficient (0.87), but significant difference was reported between inter-rater measurements (p=0.02). Inclinometer is a reliable tool to assess posture in both asymptomatic and symptomatic individuals. MacIntyre NJ et al., reported the interrater (0.64), intrarater (0.94) reliability of Saunders Digital Inclinometer in measuring spinal curvature of postmenopausal women with osteoporosis [31]. MacIntyre NJ et al., determined the interdevice reliability with ICC value (0.97) and SEM (1.33°) using IONmed mobile phone application and digital inclinometer in individuals with osteoporosis and osteopenia [32]. Inclinometer is a reliable tool in assessing posture, classification of women with postmenopausal osteoporosis and increased risk of fracture, monitoring progression and response to intervention aimed to improve abnormal posture [31,32].

Limitations include [33,34]:

- Measurement in single plane (sagittal)
- Higher Body Mass Index (BMI) can make the palpation of landmarks difficult

- Error in the measurement can be due to inability to maintain constant pressure during movement
- Misplacement of device or holding the inclinometer slightly off plumb

Reliability studies of iHandy smartphone application: Smartphones have become our new friends. A free software has been developed to evaluate the posture called as iHandy®. It is available on phones that use android™ operating system as well as iPhone®. This smartphone application can be used as an alternative to inclinometer from accessibility perspective. It provides the capacity to convert the phone into an inclinometer using a built-in tilt sensitive system. The reliability of iHandy smartphone application has been found with ICCs value 0.96 and 0.81 for inter and intrarater reliability respectively using iPhone® model 4 with iHandy® level application (iPhone® is a trademark of Apple Inc, Cupertino, CA). It has a build-in accelerometer and digital display to show angle [34]. Concurrent validity for iHandy and bubble inclinometer was comparable with r=0.86 [34]. Similarly, Koumantaki GA et al., established the intrarater reliability (0.93,0.96) for male and female respectively, SEM (2.13), MDC (5.9) using iHandy level smartphone among healthy adults [33].

Although inclinometer is a reliable instrument but it may not be available in every clinical setting. Studies confirm that mobile phone application offers a quick, convenient, easily accessible and alternative method for assessing sagittal plane spine curvature in clinical settings. Both studies were conducted in young population, so the result cannot be generalised to older population; more studies should be done in older, symptomatic group to increase generalisability [32-34].

THREE-DIMENSIONAL ANALYSIS OF POSTURE

Method of Measurement

3D radiographic imaging: Biplanar radiographic or open magnetic resonance imaging (MRI) are used to assess 3D spinal and pelvic alignment, vertebral and intervertebral orientation. Gangnet N et al., and Janssen MMA et al., conducted studies to assess spinopelvic alignment using Biplanar radiographic technique, which provides high-definition digital radiograph which further uses 8-10 times lesser radiation dose than conventional imaging among asymptomatic subjects [35,36]. It was found that Pearson's correlations exist between pelvic incidence, L1-S1 lordosis (R=-0.40, p=0.02); pelvic radius-S1 angle, pelvic radius-L4 lordosis (R=0.72, p<0.0001); sacral slope, L1-S1 lordosis (R=-0.64, p<0.0001); and T12-S1 lordosis, T1-T12 kyphosis (R=-0.60, p=0.005) [35]. The inter-rater and intra-rater reliability ranges from (0.97-1.00), (0.95-1.00) respectively among asymptomatic subjects [36,37].

The advantage of 3D imaging techniques are:

- It allows better understanding of 3D aspects of posture [35]
- Higher reproducibility and quicker processing once the user is familiar [37]

Inertial sensors: Inertial sensors are objective measurement tools, used to measure spinal motion or evaluation of spinal shapes [38]. Vision-based Inertial sensor system consist of high-speed cameras, reflective markers or 3D cameras. Vicon is one of the most commonly used marker-based vision sensor system in research and clinical setting [39]. It is an advanced 3D motion analysis system for measurement. Surface markers positioned on the body and infrared cameras are used to detect the movement of markers precisely [40].

The Cartesian Optoelectronic Dynamic Anthropometric (CODA) motion analysis system is a 3D kinematic analysis instrument. It is a highly reliable and valid tool for measuring cervical range of motion [41] and upper extremity kinematics [42]. O'Sullivan K et al., reported the intra (0.75-0.97) and inter-rater (0.57-0.95) reliability of upper and lower lumbar spine using CODA motion analysis system [43].

This marker-based vision system has certain disadvantages:

- Firstly, it requires large laboratory setup with expensive equipment
- Secondly, installation of setup is time consuming and requires technical expertise
- Thirdly, soft tissue artefacts due to incorrect marker positioning may affect the measurement accuracy [39]

Other portable, non invasive wearable sensors used in the posture assessment are E-textile, wearable spine monitoring system and Epionics Spine. Electronic textile (E-textile) has electronic components or sensors such as Inertial Measurement units (IMUs), LEDs, capacitive, resistive or inductive sensors embedded within the fabric. The advantage of E-textiles is that it is lightweight, small-sized fabric that allow unassuming monitoring [44]. A study was done by Sardine E et al., to detect the posture with wearable T- shirt, an inductive sensor was integrated in the T-shirt. It measures the deformation applied on the T-shirt due to lengthening or straightening of the posture which will generate change in impedance [45].

Another wearable sensor used by Voinea GD et al., was "Wearable Monitoring System" to generate the shape of spine [38]. It has the following components: A shirt on which sensors are embedded to detect movement and a controller, used to record data from sensors which is then transmitted to a smartphone, so that the individual can visualise the posture. It has five sensors evenly distributed on the entire spine to detect curvature.

Epionics spine system is an advancement of former SpineDMS system and is used for assessment of thoraco-lumbar posture and motion using strain-gauge technology [46]. Inbuilt accelerometer allows the additional detection of orientation of the upper body relative to the earth's gravitational field. The system is portable and lightweight. It is advantageous because it assesses the lumbar spine during activities of daily living. Consmuller T et al., investigated the intra-rater reliability and compared normative data in healthy subjects using Epionics spine. Significant correlation was exhibited with ICC value 0.85. The lordosis angle during standing measured with Epionics spine was 32.4±9.7 degree [47]. The device is also capable of detecting movements out of sagittal plane but certain limitations have also been reported like difficulty in determining a curvature in subjects with short height as the same sensor strip size is used for all heights, slippage of sensor strips, also this device measures the shape of the back and not shape of the spine, so the measurements of subjects with higher BMI can differ considerably. A brief summary of existing sensing systems for measurement of lumbar lordosis is given in [Table/Fig-1].

Tactile Method of Measurement

Posturometer-S: Posturometer-S is a non invasive device designed to analyse body posture. It consists of three coupled systems:

- Mechanical-uses a pointing stick to indicate position of measured point
- Electronic-calculate the position of marked points
- Informatique-used to analyse the results

Its setup includes measuring device, platform for subjects, seat and computer set [48,49]. It also helps in determining parameters of angular and linear in the planes [50]. Posturometer is used to measure angle of lumbar lordosis among children with different body type, children with hearing impairment, which will help in early correction of posture [48,50]. The main limitation reported by the authors in the studies was that the posturometer-S was not user-friendly, consumes area and requires an intensive understanding of the instrumentation along with training before it can be used [51].

Type of sensors	Components	Measurement
ViMove sensors	• Two sensors with integrated accelerometer, magnetometer and gyroscope • Radiofrequency device	• Lumbar angle: angle of upper sensor and lower sensor relative to Line of Gravity (LOG)
Vicon system	• Surface markers • Myon accelerometer • 8 MX-T20 (2 megapixel), 8 MX-T40 (4 megapixel) and 2 Bonita digital high-speed cameras (1 megapixel)	• Lumbar angle: angle between two segments
Cartesian Optoelectronic Dynamic Anthropometric (CODA) motion analysis system	• CODA markers • CODAmpx30 cameras	• Total Range of Motion (ROM) • Upper lumbar angle • Lower lumbar angle • Pelvic angles
Electronic textiles (E-textiles)	• Inductive sensors embedded within fabrics	• Monitor trunk movement
Wireless wearable T-shirt	• Inductive sensor • Circuit board • Piezoelectric actuator	• Monitor posture
Wearable monitoring system	• Shirt with inertial sensors • Collector • Smartphone	• Shape of spine using mathematical model
Epionics spine system	• Two sensor strips with accelerometer • Storage unit	• Angle of lordosis • Range of motion

[Table/Fig-1]: Summary of components and measurement of lumbar lordosis using different sensors [38,40,43-45,47].

DISCUSSION

The present article has reviewed a number of methods used for lumbar lordosis assessment, including visual observation, radiography and various other non invasive methods like photogrammetric, flexicurve, Spinal Mouse, Inclinometer and some 3D analysis methods like 3D radiographs, Inertial sensors and posturometer, and their possible clinical application as well as advantages and disadvantages. Each method/tool reviewed here comes with its own set of strengths and limitations. The most common method which is used to assess posture in clinical practice is the visual observation method, but it is unable to provide the assessor with a reliable and valid quantitative tool. With this method, quantitative data cannot be obtained as well as there is difficulty in assessing minor posture alteration and possesses poor inter-rater reliability. Hence, it's usage should be discouraged in research as well as clinical settings.

Radiography is considered as the gold standard method for postural assessment. But its risk of exposure to radiation and cost limits its use in clinical settings and this further encourages the use of non invasive methods like photogrammetry, flexicurve, spinal mouse, inclinometer. Photogrammetry is capable of giving information in sagittal and frontal planes [12]. This method has been compared with visual, and radiographic methods. Flexicurve also has good reliability, but limited number of validity studies are available for this method and also has limited availability. It also has high chances of measurement error during data collection and angle measurement which limits its use in clinics [15,16,18]. Spinal Mouse, Inclinometer are some other non invasive reliable devices but may not be available in every clinical setting. As a result, convenient, easy, accessible, reliable smartphone application such as "iHandy" can be used as an alternative method for posture analysis [14,27].

Some of the 3D methods are also used for posture assessment like 3D radiographic imaging, inertial sensors, raster stereography, and posturometer. These methods and tools can give information about the posture in transverse, sagittal and frontal plane, but they have certain limitations like being expensive, not user friendly, and also require large laboratory settings to measure posture.

CONCLUSION(S)

The evidence reviewed support the conclusion that photogrammetry and iHandy smartphone application are reliable, quick, convenient, non invasive methods which can be used to measure posture of lumbar spine. The use of these methods is recommended for future studies in different populations to increase the generalisability of these methods.

REFERENCES

[1] Okpala FO. Comparison of four radiographic angular measures of lumbar lordosis. J Neurosci Rural Pract. 2018;9(3):298-304.
[2] Lee CS, Chung SS, Park SJ, Kim DM, Shin SK. Simple prediction method of lumbar lordosis for planning of lumbar corrective surgery: Radiological analysis in a Korean population. Eur Spine J. 2014;23(1):192-97.
[3] Iunes DH, Bevilaqua-Grossi D, Oliveira AS, Castro FA, Salgado HS. Comparative analysis between visual and computerized photogrammetry postural assessment. Rev Bras Fisioter. 2009;13(4):308-15.
[4] Fedorak C, Ashworth N, Marshall J, Paull H. Reliability of the visual assessment of cervical and lumbar lordosis: How good are we? Spine. 2003;28(16):1857-59.
[5] Furlanetto TS, de Oliveira EBC, Candotti CT, Vieira A, de Mesquita PV, Navarro IJ, et al. Development and validation of prediction equations for spinal curve angles based on skin surface measurements. J Manipulative Physiol Ther. 2017;40(9):692-99. Available from: https://doi.org/10.1016/j.jmpt.2017.06.015.
[6] Harrison DE, Harrison DD, Cailliet R, Janik TJ, Holland B. Radiographic analysis of lumbar lordosis: Centroid, Cobb, TRALL, and Harrison posterior tangent methods. Spine. 2001;26(11):e235-42.
[7] De Carvalho DE, Soave D, Ross K, Callaghan JP. Lumbar spine and pelvic posture between standing and sitting: A radiologic investigation including reliability and repeatability of the lumbar lordosis measure. J Manipulative Physiol Ther. 2010;33(11):48-55. Available from: http://dx.doi.org/10.1016/j.jmpt.2009.11.008.
[8] Lee ES, Ko CW, Suh SW, Kumar S, Kang IK, Yang JH. The effect of age on sagittal plane profile of the lumbar spine according to standing, supine, and various sitting positions. J Orthop Surg Res. 2014;9(1):01-10.
[9] Hicks GE, George SZ, Nevitt MA, Cauley JA, Vogt MT. Measurement of lumbar lordosis: Inter-rater reliability, minimum detectable change and longitudinal variation. J Spinal Disord Tech. 2006;19(7):501-06.
[10] Chung NS, Jeon CH, Lee HD, Won SH. Measurement of spinopelvic parameters on standing lateral lumbar radiographs: Validity and reliability. Clin Spine Surg. 2017;30(2):E119-23.
[11] Navarro MV, Leite HJ, Alexandrino JD, Costa EA. Control of health risks in radiodiagnosis: A historic approach. História, Ciências, Saúde-Manguinhos. 2008;15(4):1039-47.
[12] Furlanetto TS, Sedrez JA, Candotti CT, Loss JF. Photogrammetry as a tool for the postural evaluation of the spine: A systematic review. World J Orthop. 2016;7(2):136-48.
[13] Drzał-Grabiec J, Truszczyńska A, Tarnowski A, Płaszewski M. Comparison of parameters characterizing lumbar lordosis in radiograph and photogrammetric examination of adults. J Manipulative Physiol Ther. 2015;38(3):225-31.
[14] Walicka-Cupryś K, Wyszyńska J, Podgórska-Bednarz J, Drzał-Grabiec J. Concurrent validity of photogrammetric and inclinometric techniques based on assessment of anteroposterior spinal curvatures. Eur Spine J. 2018;27(2):497-507. Available from: https://doi.org/10.1007/s00586-017-5409-8.
[15] Sedrez JA, Candotti CT, Rosa MI, Medeiros FS, Marques MT, Loss JF. Test-retest, inter-and intra-rater reliability of the flexicurve for evaluation of the spine in children. Braz J Phys Ther. 2016;20(2):142-47.
[16] Dunleavy K, Mariano H, Wiater T, Goldberg A. Reliability and minimal detectable change of spinal length and width measurements using the Flexicurve for usual standing posture in healthy young adults. J Back Musculoskelet Rehabil. 2010;23(4):209-14.
[17] Raupp EG, Candotti CT, Marchetti BV, Vieira A, Medeiros FS, Loss JF. The validity and reproducibility of the Flexicurve in the evaluation of cervical spine lordosis. J Manipulative Physiol Ther. 2017;40(7):501-10.
[18] de Oliveira TS, Candotti CT, La Torre M, Pelinson PP, Furlanetto TS, Kutchak FM, et al. Validity and reproducibility of the measurements obtained using the flexicurve instrument to evaluate the angles of thoracic and lumbar curvatures of the spine in the sagittal plane. Rehabil Res Pract. 2012;2012:01-09.
[19] Mannion AF, Knecht K, Balaban G, Dvorak J, Grob D. A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. Eur Spine J. 2004;13(2):122-36.
[20] Biotechindia. Spinal Assessment Device- Spinal Mouse. [Internet]. Mumbai: Biotech; Available from: http:// www.biotechindia.net/physiotherapy-rehabilitation/product/spinal-mouse.html.
[21] Ripani M, Di Cesare A, Giombini A, Agnello L, Fagnani F, Pigozzi F. Spinal curvature: Comparison of frontal measurements with the spinal mouse and radiographic assessment. J Sports Med Phys Fitness. 2008;48(4):488-94.
[22] Miyazaki J, Murata S, Arakawa C, Suzuki S. Reproducibility of spinal curve angle measurements using spinal mouse. Rigakuryoho Kagaku. 2010;25(2):223-26.
[23] Russell BS, Muhlenkamp KA, Hoiriis KT, DeSimone CM. Measurement of lumbar lordosis in static standing posture with and without high-heeled shoes. J Chiropr Med. 2012;11(3):145-53. Available from: http://dx.doi.org/10.1016/j.jcm.2012.02.002.
[24] Liebig EM, Kothe R, Mannion AF, Grob D. The clinical significance of the lumbar lordosis: Relationship between lumbar spinal curvature and low back pain. Eur Spine J. 2000:286.

[25] Keller S, Mannion A, Grob D. Reliability of new measuring device spinal mouse in recording sagital profile of the back. Eur Spine J. 2000;9(4):303. Available from: https://www.sid.ir/en/journal/ViewPaper.aspx?ID=279970.
[26] Takihara Y, Urabe Y, Nishiwaki GA, Tanaka K, Miyashita K. How back-muscle fatigue influences lumbar curvature. J Sport Rehabil. 2009;18(2):327-36. Available from: https://journals.humankinetics.com/view/journals/jsr/18/2/article-p327.xml.
[27] van Blommestein AS, Lewis JS, Morrissey MC, MaCrae S. Reliability of measuring thoracic kyphosis angle, lumbar lordosis angle and straight leg raise with an inclinometer. Open Spine J. 2012;4(1):10-15.
[28] Quickmedical. Inclinometer. [Internet]. England: Quickmedical; Available from: https://www.quickmedical.com/inclinometer.html.
[29] Ng JK, Kippers V, Richardson CA, Parnianpour M. Range of motion and lordosis of the lumbar spine: Reliability of measurement and normative values. Spine. 2001;26(1):53-60.
[30] Czaprowski D, Pawłowska P, Gębicka A, Sitarski D, Kotwicki T. Intra-and interobserver repeatability of the assessment of anteroposterior curvatures of the spine using Saunders digital inclinometer. Ortop Traumatol Rehabil. 2012;14(2):145-53.
[31] MacIntyre NJ, Bennett L, Bonnyman AM, Stratford PW. Optimizing reliability of digital inclinometer and flexicurve ruler measures of spine curvatures in postmenopausal women with osteoporosis of the spine: An Illustration of the use of generalizability theory. ISRN Rheumatol. 2011;2011:01-08.
[32] MacIntyre NJ, Recknor CP, Recknor JC. Spine curve measures taken in individuals with osteoporosis and osteopenia using the ionmed mobile phone application are highly consistent with digital inclinometer measures. ISRN Rehabil. 2014;2014:01-06.
[33] Koumantakis GA, Nikoloudaki M, Thacheth S, Zagli K, Bitrou K, Nigritinos A, et al. Reliability and validity measurement of sagittal lumbosacral quiet standing posture with a smartphone application in a mixed population of 183 college students and personnel. Adv Orthop. 2016;2016:01-09.
[34] Salamh PA, Kolber M. The reliability, minimal detectable change and concurrent validity of a gravity-based bubble inclinometer and iphone application for measuring standing lumbar lordosis. Physiother Theory Pract. 2014;30(1):62-67.
[35] Gangnet N, Dumas R, Pomero V, Mitulescu A, Skalli W, Vital JM. Three-dimensional spinal and pelvic alignment in an asymptomatic population. Spine. 2006;31(15):507-12.
[36] Janssen MMA, Drevelle X, Humbert L, Skalli W, Castelein RM. Differences in male and female spino-pelvic alignment in asymptomatic young adults: A three-dimensional analysis using upright low-dose digital biplanar X-rays. Spine. 2009;34(23): E826-32.
[37] Okamoto M, Jabour F, Sakai K, Hatsushikano S, Le Huec JC, Hasegawa K. Sagittal balance measures are more reproducible when measured in 3D vs in 2D using full-body EOS® images. Eur Radiol. 2018;28(11):4570-77.
[38] Voinea GD, Butnariu S, Mogan G. Measurement and geometric modelling of human spine posture for medical rehabilitation purposes using a wearable monitoring system based on inertial sensors. Sensors. 2017;17(1):03.
[39] Zhang Y, Haghighi PD, Burstein F, Yap LW, Cheng W, Yao L, Cicuttini F. Electronic skin wearable sensors for detecting lumbar–pelvic movements. Sensors. 2020;20(5):1510.
[40] Mjøsund HL, Boyle E, Kjaer P, Mieritz RM, Skallgård T, Kent P. Clinically acceptable agreement between the ViMove wireless motion sensor system and the Vicon motion capture system when measuring lumbar region inclination motion in the sagittal and coronal planes. BMC Musculoskelet Disord. 2017;18(1):01-09.
[41] Gao Z, Song H, Ren F, Li Y, Wang D, He X. Reliability and validity of CODA motion analysis system for measuring cervical range of motion in patients with cervical spondylosis and anterior cervical fusion. Exp Ther Med. 2017;14(6):5371-78.
[42] Levanon Y, Gefen A, Lerman Y, Givon U, Ratzon NZ. Validity and reliability of upper extremity three-dimensional kinematics during a typing task. Gait Posture. 2010;32(4):469-74.
[43] O'Sullivan K, Clifford A, Hughes L. The reliability of the CODA motion analysis system for lumbar spine analysis: A pilot study. Physiother Pract Res. 2010;31(1):16-22.
[44] García Patiño A, Khoshnam M, Menon C. Wearable device to monitor back movements using an inductive textile sensor. Sensors. 2020;20(3):905.
[45] Sardini E, Serpelloni M, Pasqui V. Wireless wearable T-shirt for posture monitoring during rehabilitation exercises. IEEE Trans Instrum Meas. 2014;64(2):439-48.
[46] Taylor WR, Consmüller T, Rohlmann A. A novel system for the dynamic assessment of back shape. Med Eng Phys. 2010;32(9):1080-3.
[47] Consmüller T, Rohlmann A, Weinland D, Druschel C, Duda GN, Taylor WR. Comparative evaluation of a novel measurement tool to assess lumbar spine posture and range of motion. Eur Spine J. 2012;21(11):2170-80.
[48] Stachoń A, Burdukiewicz A, Andrzejewska J, Pietraszewska J. The imaging and evaluation of body posture defects in hearing impaired children. Bio-Algorithms Med-Syst. 2012;8(2):221-36.
[49] Mieszała W, Demczuk-Włodarczyk E, Chromik K, Hawrylak A, Małachowska-Sobieska M. Examining relationships of the anterior pelvic tilt angle with the anterior-posterior curvatures and elongation of the spine. Acta Bioeng Biomech. 2019;21(1):37-44.
[50] Kuligowski T, Cieślik B, Radziszewski Ł, Czerwiński B, Pióro A. Body somatic type influence on the spinal curvatures in early age school children: Preliminary report. Dev Period Med. 2015;19(3):362-66.
[51] Kandasamy G, Bettany-Saltikov J, van Schaik P. Posture and back shape measurement tools: A narrative literature review. In: Spinal Deformities in Adolescents, Adults and Older Adults. 2020. Available from: http://dx.doi.org/10.5772/intechopen.91803.

PARTICULARS OF CONTRIBUTORS:

1. Assistant Professor, Faculty of Physiotherapy, SGT University, Gurugram, Haryana, India.
2. Associate Professor, Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia, New Delhi, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Zubia Veqar,
Associate Professor, Centre for Physiotherapy and Rehabilitation Sciences,
Jamia Millia Islamia, New Delhi, India.
E-mail: veqar.zubia@gmail.com

PLAGIARISM CHECKING METHODS: [Jain H et al.]

- Plagiarism X-checker: Jan 22, 2022
- Manual Googling: Feb 24, 2022
- iThenticate Software: May 11, 2022 (27%)

ETYMOLOGY: Author Origin

AUTHOR DECLARATION:

- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? NA
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Jan 21, 2022**
Date of Peer Review: **Feb 24, 2022**
Date of Acceptance: **Mar 04, 2022**
Date of Publishing: **Jun 01, 2022**