Measurement Possibilities of Thoracic (C7-T12) and Lumbar (L1-L5) Curvature

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Abstract. Spinal cord provides the support to withstand the weight of the human body. The lumbar and thoracic curves mostly represent the spine curvature of human. They are also used to determine the normality of the human spine. If the normality doesn’t exist these data are helpful in treating the human. Low back ache arises even if any of the curves shows abnormality. This study revolves around the available techniques or instruments in measuring those mentioned curvatures and the standard of the instruments. Around the world, many countries have started collecting spine curvature data for more than five decades; however, India lacks in this field. Every instrument faces its own difficulties and providing its own advantages. Construction of one new machine which will be providing only the advantages is a hectic task. For collection of spine curvature data countries have developed various instruments such as (X-ray), Inclinometer, Arcometer, Goniometer, Flexicurve, Laser scanner, Fibre optic sensor, electromagnetic sensors, spinal mouse, etc.; some might not be accessible to Indian markets. Today, there is a die-hard need in developing of machine or instrument or technique which will overcome all the limitations that were provided by the above mentioned instruments.

1. Introduction
The structure of the Spinal cord is strong and it is multi-functional. There are 32 to 34 individual vertebrae which supports the body between head and pelvis. The minimum distance between any two consecutive vertebral gaps is known as Inter-Vertebral distance. Human Spine consists of three segments, the c-shaped curves in the cervical area and the lumbar area are known as Lordosis and the reversed c-shaped curve in the thoracic area is known as kyphosis. [1] The Cervical spine consists of seven vertebrae ranges from (C1-C7). The Thoracic spine consists of twelve vertebrae ranges from (T1-T12). The Lumbar spine consists of five vertebrae ranges from (L1-L5). The Sacrum spine consists of five vertebrae ranges from (S1-S5). The Coccyx spine consists of three to five vertebrae. Hunchback and Swayback are the two types of abnormal curvatures can be found on thoracic and lumbar spine respectively. Scoliosis is another type of spine deformity, which makes S or C-shaped curvature when it is viewed from back.

1.1. Necessity of the Development
Doctors and Physiotherapists decide their medical treatments based on Spine curvature data only. The treatment may totally go wrong if there is any change in the curvature, so it is required to get the spine curvature data before treating a person. One of the easiest forms of measurement among the whole body is the Spine. The core strength to the body as well as the spine comes from the curvature. If a
person sits for too much of period, more amount of stress been developed on spinal cord and surrounding muscles. Therefore it is a dire requirement to invent customized cushion for chairs or ergonomic chairs etc. which is shown in fig 1. The children aged below 15 years related to spine issues can be treated and cured if the treatment were given at right time. This need shows the requirement of spine curvature instrument for early diagnosis in kids. These above mentioned reasons ignite many ways for many scholars in finding the spine curvature measuring instrument. But each way shows drawback as well as advantages of it. Some methods show the risk in getting the spine curvature data while some shows how expensive it is to get the data. Hence there is a dire requirement in developing the instrument for getting the spine curvature which is safe, precise and cost-effective so as every person can afford it.

Figure 1. Applications of spine curvature data. Picture credit [2] [4].

2. Literature survey
The numerous amounts of work which is done previously and the number of published journals, papers, and patents helped in understanding the importance of spine curvature measurement.

Figure 2. Flowchart for selection of articles.
Getting the spine measurement seems to be an easy process but it involves lot of hidden works and once the curvature has been got, it can be useful for the following purposes such as Medical, Physiotherapy, Customised Cushions, Chairs, and Ergonomics etc. The works which were done by many of the researchers in this field consist of providing results in either a costly manner nor in a numerical manner later it needs to be converted into curvature format, which requires an additional work to be done by trained person. So, still there is a need in developing a type of instrument which supports economical way of getting a spine curvature data as well as without the help of any trained person so that a normal person can able to get it. The following are the methods to get a spine curve which are currently in use. The steps involved in selection of methods are shown in fig.2.

3. Measurement methods
The flowchart represents the basis of selection process on which the measuring methods are taken into discussion. On analysing all the filtered methods from the flowchart, the discussion leads to two basic divisions. The devices which have a direct skin contact on spine comes under the category of contact type mechanism and the other one which does not have a direct contact and uses ultrasound or infrared imaging to get the spine curvature data are comes under the category of non-contact type of mechanism. Under these two sections the numerous amount of work done to measure the spine curvature remains. In this paper, working methods of each available spine curvature measuring systems were explained clearly and in addition to that it proves that no system will give the complete solution in measuring the curve instead each method faces its own difficulty as well as its own advantages.

3.1 Contact type measurement methods
The following systems will have direct contact to the spine while measuring its curvature and they are as follows, Goniometer, Arcometer, Flexicurve, Spinal mouse, Wireless sensors method, Smartphone method and finally Posture parameter determining instrument.

3.1.1 Goniometer. Spinal flexion, Extension, and Lateral flexion can be measured by Goniometer shown in fig.3 the angle between the vertical plane and tangent to any point on the spine gives the respective values. This instrument is reliable for measuring Trunk extension, Lumbar spine flexion, and Lateral flexion. Whereas it cannot be reliable for measuring Trunk rotation. The major disadvantages of Goniometers are they are not supposed to measure spinal or pelvic motion [11]. It is due to the differences in leg length and arm length among the individuals and it cannot be used to make comparisons between the subjects. Goniometers are also interfaced with computers to control the range of motion through control signals. The Goniometers are prone to repeatability errors [10] which are in the range of 2 to 5% when it is measured by same examiner and 5 to 10% by different examiner. So, there is a need in developing a goniometer which has reduced repeatability errors and meters which are self-aligned to the centre of spinal cord.

![Figure 3. Goniometer. Picture credit [10].](image-url)
3.1.2. Arcometer. Arcometer shows good results only when it is used in adults. However, it does not provide usage in children ages ranging below 10 years. They have used around 40 persons to validate the repeatability, intra and inter reproducibility and concurrent validity of Arcometer, which results lumbar lordosis and thoracic kyphosis angles. Two trained evaluators worked on two different days to evaluate the results. For statistical analysis, paired t test, Spearman’s rho test, Wilcoxon’s test, Pearson’s product moment correlation, Intraclass correlation coefficients were used ($\alpha = .05$). It consists of three rods shown in fig.4 namely upper rod (FA), central rod (f), and lower rod (FB) was positioned on spine of human being [12]. Chaise et al discovered the method of calculating the angles in the sagittal plane using the method of trigonometry. Cobb angle is one of the commonly used methods to find the lumbar and thoracic curves using two line methods. The obtained results from Cobb angle method is used to assess the concurrent validity of both lumbar and thoracic curves. The differences between the measurements can be verified using Wilcoxon and paired t test.

3.1.3. Flexicurve. Flexicurve replicates the shape of spine when it gets stick to the spinal cord and is approximately 60 cm in length. It is a malleable band of flexible metal ruler which has given a plastic layer coating [19]. The curvature is measured under different isolated levels using this instrument. The ruler can able to retain the bent shape as long as the measurement can be made. Once the measurements were taken it can be able to bend back the normal position which is shown in fig.5 they have instructed the subjects to stand still and straight as possible and the ruler is then placed on the subject’s spine (C7 – T12). The bent ruler is then placed on the paper to get the spinal curvature of the human. Length of the thoracic kyphosis can be evaluated by drawing a straight line from the ruler position. Height of the thoracic kyphosis can be evaluated by drawing a perpendicular line to the highest point in the thoracic kyphosis curve.

3.1.4. Spinal Mouse. Spinal Mouse is a compact and electromechanical device which measures spine and it needs the use of a computer for operation. This device can be rolled over the midline of spine
shown in fig.6 starting from the top (cervical) and ends in the bottom (lumbar) and the curvature can be made visible in the computer screen. It consists of two rollers which follow the shape of the spine when rolled and the distance and angles between them is measured. It is then communicated to a base station which is interfaced with a personal computer [17]. For every 1.3mm the data is collected and has its sample frequency of 150Hz. The relative position of the Vertebral bodies such as lumbar, thoracic, sacrum can be calculated with the help of the above information and intelligent, recursive algorithm. They conducted the test by adopting three different positions; they are standing upright, maximal flexion, maximal extension.

![Figure 6. Spinal mouse. Picture credit [17].](image)

3.1.5. Smartphone. George et al. invented spine measuring technique with the help of smartphones shown in fig.7 which works with android operating system. They invented gravity based inclinometric application named as “iHandy level” is used as tool to measure spine curvature. This application shows a numeric level angle measurement which has a display like digital inclinometer. In this study [14] they established the reliability level of sagittal lumbosacral in standing posture. They also validated the normative database in establishing the difference in methods between the male and female subjects. They first calibrated the application by placing a smartphone on a stable surface. This calibration procedure was carried out for each participant before measuring process. The upper vertical side of the smartphone is placed between T12-L1 and S1-S2 to obtain the angular measurements. The value of sacral slope is corresponded to the S1-S2 reading. The value of lumbar slope is corresponded to sum of the T12-L1 and S1-S2 absolute readings. This technique follows the double inclinometric method by Waddell et al. by placing the electronic goniometer in the above mentioned positions such as upright standing and end-range spinal movements. It is also similar to flexible curve ruler technique where the curvature is measured by tangential calculation.

![Figure 7. Smartphone method. Picture credit [14].](image)
3.1.6. **Wireless Sensors.** One of the progressive diseases in spine in which it slowly stiffens and turns out to a state where it cannot be bend is known as Ankylosing spondylitis (AS). It is a difficult process in diagnosing a human being below 10 years [21]. They designed and developed an intelligent system shown in fig.8 which is wearable that can be used to detect the spine displacement and gives feedback signals with continuous posture monitoring of the subject. It gives the data about abnormality of the posture with the help of accelerometer and gyroscopic sensors. This wearable system helps in preventing the development of lower back and neck pain due to the incorrect posture. With the help of the shimmer sensors placed, it can able to out shape the spine curvature and provides relevant information on exercises to avoid back pain.

![Wireless sensors](image)

**Figure 8.** Wireless sensors. Picture credit [21].

3.1.7. **Posture parameter determining instrument.** Ernst Moeckl, et al. invented an instrument which was patented later to measure the parameters of the human spinal cord. It consist of five sliders shown in fig.9 with feelers attached to a single upright column where it is connected with the base. The base has a heel stop so as a person can stand on it. These five feelers help in determining the parameters of the spine’s posture. The feeler present on the top slider is used to measure the height of the person. The second highest slider consist of two feeler which will make three contact points in the human body around the cervical or neck region. These two feelers are allowed to tilt and swing in a freely manner. The third one will inspect and measure the kyphosis position. While the lordosis of the spine was measured by the fourth slider which consist of two feeler and it is also tiltable like second one. To determine the attitude and width of the pelvis the last slider was made displaceable and tiltable which also has two feelers to have a contact with the spine. In the second slider an ancillary feeler plate is attached with horizontally shiftable member to support the feeler heads. It is made so as to establish the reference position for shoulder measurements.
3.2 Non-contact type measurement method

These measurement devices do not impose any of the direct physical contact on the human being, instead it uses various types of sensors and X-Ray imaging technique to measure the spine profile. The devices are as follows such as, Biplanar electromagnetic device, Tergoskop, 3-D Ultrasound technique, X-Ray imaging method, Laser triangulation system.

3.2.1. Biplanar Electromagnetic Device. Electromagnetic device is used to measure the spine curvature which works under a frequency sample of 120Hz with 0.76mm of static accuracy position for X, Y as well as Z. This handheld device shown in fig.10 consists of electromagnetic sensor in it which is allowed to slide over the spine of a human from top to bottom [18]. Number of digitised points was created along the spine when it is travelled. These points are then transformed to a curvature with the help of the algorithm created in the MATLAB software. Participants were instructed to stand in an upright position, arms parallel to the body and should be a 25cm gap between their feet. Gonzalez et al made two different agreements in performing the experiments, they are as follows. One of which is they have connected the spine with four digitised points placed on the various points.
positions and then they got a trace with the help of MATLAB software. Another agreement they made was they established the local system using the reference points of posterior superior iliac spines (PSIS) and T₈. The origin of the system is situated at midpoint between the two iliac spines. The curves can be adjusted by the fifth order polynomial equation and can be determined by their derivatives.

3.2.2. Tergoskop. Tergoskop was exclusively made for Scoliosis patients to categorize analyse, follow-up, and relapse check them. It is very similar to the X-Ray method shown in fig.11 but the radiation emitted from the system is comparatively very minimum. This system also serves its purpose in diagnosing pelvic and scapula obliquity and further detects and evaluates difference in leg length. It is exclusively built [13] to evaluate and measure the effectiveness of orthopaedic appliances and supplies. It also combines the use of centre of gravity analysis with spine measurement technique in child healthcare. It well serves its purposes in physiotherapy by reducing the muscular dysfunctions by giving target oriented training and repeated training.

3.2.3. 3-D Ultrasound. Ultrasound volume projection uses prior knowledge on vertebral anatomical structures of spine to obtain its curvature data. This free-hand ultrasound imaging technique shown in fig.12 is best used for scoliosis asessment. The process of obtaining the curvature consist of four stage process such as preprocessing with phase congruency, segmenting bony feature, identifying spine profile and detecting spine curve. Two fold thresholding [24] strategy extracts bony features from volume projected images which has the information of asymmetric and symmetric measures from phase congruency. The bony regions are segmented to detect the spine profile and hence it can be used to obtain curve representing spine profile. It automatically generates the spine curve with the help of inflected points on the curve. This method is then validated with the Gold standard X-Ray imaging.
technique and it results better measurement which confirms it is more reliable. Thus the proposed
method by the author promises better results in screening and diagnosing of scoliosis.

![3D Ultrasound technique](image)

**Figure 12.** 3-D Ultrasound technique. Picture credit [24].

3.2.4. X-Ray Method. Ming et al. proposed the method of measuring spinal curvature through X-Ray imaging technique [22]. The principle used in this technique is explained through the flowchart as follows. They proposed and automated a system which includes four stages shown in fig.13 of measuring techniques they are as follows. The region of interest of spine is decided by isolating the spine region. They first reduced the size of the spinal view to its quarter. This stage focuses on the region between lumbar and the thoracic vertebrae. The next stage is vertebral detection where the edges are detected by the help of intensity and gradient. There are three sub phases are included in this phase they are, central line segment detection, spine boundary detection and finally vertebrae detection. In this stage they have segmented around 17 vertebrae through spine region of interest method. The intensity of the vertebrae varies considerably in images shown in fig.14. In general, lumbar vertebrae has higher intensity when compared with cervical vertebrae. This inconsistency in intensity makes it complex for the segmenting process, therefore Convolutional Neural Network (CNN) comes into play to overcome the above difficulty. The widely used Cobb angle method is applied to quantify the spine curvature. The Cobb angle method can be defined as the angle between borders of the upper and lower vertebra. The angle can be find by drawing parallel lines manually to the upper and lower vertebra.

![Flowchart for X-Ray method](image)

**Figure 13.** Flowchart for X-Ray method. Picture credit [22].
3.2.5. Laser Triangulation System. Researchers from University of Ljubljana developed a portable and compact profilometer shown in fig.15 which can able to swing about a perpendicular axis and it has a laser source in it. They developed this device to evaluate the accurate measurement of wounds [25]. Later this device also served its purpose in spine curvature measurements too. Dusan et al applied this laser triangulation technique in measuring the spine curvature [26]. The device is based on laser-line triangulation principle which is shown in fig.16 The range of the device is 150x150x200 mm and it is rotated around the surface to get the 3D shape of the curve with added colors too. The components of the system includes laser projector (5mW, 670nm), camera, stepper motor, rotary mechanism with housing and swing arm. The working principle of this system is explained by the following step by step procedure and can be referred with the following fig.17 A laser projector which acts as the light source >1<. A beam of light >2< is emitted from the source. The back of the surface >3< is illuminated. The visible bright red line >4< shows the profile of the curve. The camera used >5< here will acquire the profile. One out of the total profile has 640 points as a result that shows the intersection between >4< emitted and illuminated light. The translational motion of the sytem required to measure the total height of the curve is denoted as >7<. The system works at a speed of 70 mm/sec and it has an operational frequency of 80 profiles per second.
4. Summary

The gold standard method of defining the spine curvature is the X-Ray technique which in turn emits the harmful radiations that affects the human being it is frequently used. It also requires skilled labour to operate and the total setup requires the much cost. CMM is an electronic and mechanical device which has a sensor used for measurement purposes. Number of points can be measured from the spine precisely and needs to be plotted in separate software to obtain the curvature. The cost for measurement purposes does not allow an individual to use it extensively. The setup cost for this equipment will be higher than that of compared to the X-Ray and in turn also requires skilled labour to operate it. These above mentioned methods are well suited for validation purposes and not for the common use. Goniometer and Inclinometer are the olden ages of instruments in measuring the spine curvature data but they have their own limitations such as there is a chance of human error in measuring the curvature as it is directly handled by the human. The obtained results are also in the form numerical values and converting them into curves is another tedious process. The probability of getting good results using a Flexicurve is based on the person who operates it. Since it has flexible ruler slight changes in the action of ruler results drastic differences in taking the measurement. It is the very cheapest form of obtaining the spine curvature while compared with all the techniques. Arcometer is one of the oldest forms of spine measuring technique consist of three rods for measuring process. Since the entire curve is based only on three points, the accuracy of the curve is comparatively lesser than that of their alternatives. Spinal mouse is a compact and handheld device and looks like a computer mouse. The curvature data can be straight away obtained if it is travelled across the human spine. The one who takes the measurement needs to be very careful during the process, since the slight changes of hand position results in drastic changes in taking the measurement. The working procedure for Biplanar electromagnetic device is almost same as that of spinal mouse but it looks way different. There are some devices in market which are completely different in doing their purposes. Instead of getting the spine curvature these device shows us how the spine reacts or responds to a load, normality of the spine, and treatment or medication requirement for the spine. Some of the above mentioned devices are Wireless sensors, Tergoskop etc., India is still in a developmental stage to measure the spine curvature. New development for measuring the spine curvature with serving the purposes like user friendly, harmless, precise, and cheap etc., will be an appreciated one and many of the researchers tend to acquire this problem to serve the nation.

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