Design and development of an instrument to measure coordinates of spine curvature

Shreyansh Gharde, Debojit Talukdar, M R Asif, Dinesh Shanmugam and Murali Subramaniyam
Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India
E-mail: murali.subramaniyam@gmail.com

Abstract. Human spine curvature data are required to detect spinal deformity/diagnose irregular spine curvature. The shape of the spine assisting for the flexibility and weight distribution of the body. Around the world, many countries have started collecting spine curvature data for more than five decades; however, India lacks in this field. Few countries have also developed various instruments to gather spine curvature data; on the other hand, they still seem inaccessible to Indian markets. A device which can collect the data is very much required as it has application in vast fields like product development on ergonomics principles. This study developed an instrument (simple and low cost) to measure coordinates of spine curvature. A wooden specimen (resembles human spine shape) was designed with various angles to validate the measurement accuracy of the developed instrument. The selected curves of the template were measured using three machines, including CMM machine, FARO arm machine, and developed device. T-Test confirms that there was no significant difference in the measured curvature data among instruments. The error percentage was 2.57 % (maximum).

1. Introduction
Human Spine is a multi-functional and robust structure. It is to protect the spinal cord. The complete Vertebral column divided into five different parts, namely, Cervical, Thoracic, Lumbar, Sacrum and Coccyx [1]. The normal curvature of the spine, when viewed from the side, has four curves, namely, Cervical Curve, Thoracic Curve, Lumbar Curve and Sacral Curve. For a healthy normal spine, the thoracic spine should have a natural Kyphosis angle of 20° -45° [2], whereas, the normal Lordosis angle should be around 39° -53° . The published literature confirms that most of the medical practitioner, including doctors and physic otherapists, decide their medication technique, especially related to the spine; based on the spine curvatures [4,5,6]. Hence, even a small deviation in the curvature measured from any instrument can lead to drastic changes, and the whole medication can go wrong [7,8]. Therefore, it was required to make a system which can give accurate results and also remain cheap to facilitate even an ordinary physiotherapist to afford it [9,10]. Measuring the curvature of the spine is the easiest among all the body parts, and hence several instruments (not available in India), are available [11] and each one has its pros and cons. For example, an inclinometer is cheap and affordable, but not accurate. However, a Photogrammetry is accurate but costly. Therefore, there is a need to develop an instrument which is reliable and affordable [12,13,14].

The curvature of the spine is an important parameter. The researcher observed that mostly the dysfunctioning of the upper body part of the body is closely linked with the postural deformity [15]. It is also found that the human spends most of the time sitting. While sitting he distorts the most of the curvature, thereby introducing more loads on the surrounding muscles and vertebrae. Hence, there is a
As we have seen in elders, as they grow older, there is a fall in the upper back. Survey has determined that this fall of the upper back is recurrent every year. Fall of the upper back leads to changes in the center of pressure, which affect the balance. The researchers have linked this fall of the upper back to the improper postural control by the individuals [28]. Hence the study of the different spine curvature is necessary to determine the back shape or posture that causes the unbalance. So that the elders can be put through proper treatment with strengthening or balance exercises to improve balance and posture and hence reduce the risk of the fall of the back.

In recent times, technological advancement reduced the physical work/activity of an individual, which leads to an increased sitting posture and increased load on the spine. As a result, the number of people fighting with back pain is growing significantly. And also the back pains can be due to many reasons like slouching while sitting, due to lifting heavy weights, twisting unconfortably and overstretching [29]. Surveys show that 5-10% of the sick cases are related to the back problem, and these stats show the economic expenses involved in this issue [30]. After considering the above reasons to study the spinal curvature, scholars worked out some sophisticated methods to study the spinal curvature. One such way is the radiographic assessment which is very expensive and highly skilled labour is required to operate the machine. But above that, the major drawback of this machine is the radiation emitted from the device which can cause other health issues to the individual under repeated study [31]. So even though we can study the spine curvature but this can be only at some risk. Hence, we have developed a method which can get us the values as accurate as of the values from the radiography assessment. So we need to explore ways which can be operated either manually or mechanically with the ease of usability and also should be easily accessible. So after carefully reading many papers and after studying about different methods and getting ideas from these developed methods, we interfused and constructed our concept to develop a design which satisfied our objective.

2. Design and Fabrication
The proposed model (Fig. 1) (Spine Curvature Measuring Machine- SCMM) is the basic model has the constraint of measuring spine curvature only and not the spine deformity. The model consists of an L-shaped structure with a slot on the vertical portion. The model also has a hollow cover with holes of 10mm diameter on it at a regular distance of 30mm. The measuring rods constructed to measure the vertebrae distance from the reference goes through the hole. The outer cover is fixed with the rigid structure using the Aluminum rods. Hence, this design provides three variable height adjustments to cover the persons of varying height ranges.
Figure 1. Dimensions of the proposed SCMM.

Figure 2. Basic model with rods fixed to Mannequin.
The major parts of this model consist of Main structure, wooden cover with holes, measuring rods and aluminium restricting pieces. The working of this model comprises of making the person stand on the wooden platform upright and straight. The outer cover is then adjusted according to the height of the person. After that, the rods are inserted in the holes throughout the length of the spine. The rods are then pushed outwards to touch the Vertebrae (Fig 2). The distance travelled by each rod is then calculated by noting down the number of slots moved from the reference plane. The coordinates point hence obtained are used to form the curve on any of the designing software. The advantages of this model include a simple and cost-effective design which is very easy to manufacture. The model has very less moving parts and doesn’t require any external power source to operate. The operation is effortless and doesn’t require any expert supervision. The disadvantage of this machine is its low precision. Its accuracy in the horizontal direction is 5mm and in vertical is 30mm, which may or may not touch the Vertebra.

3. Results and Discussion
The proposed model required to get it first validated. For the validation, a template/specimen was prepared, which precisely depicts the human spine curve (Fig 3). It had two curves on opposite directions through the length which closely resembled the Kyphosis and Lordosis curvatures of the human spine. The template was rigidly fixed with the base platform using clamps to restrict its motion while measuring as these minute deviations could affect the overall curve adversely. When observed closely, it was found that the two sides were not exactly parallel to each other and hence the angles on both the sides were different. Therefore, the measurement for both the sides were taken separately and compared with the standard machines. The curvature data of the template compared with the same data obtained from the Coordinate Measuring Machine (CMM) and Faro Arm 3D laser scanning (Fig 6 and Fig 7). For both, these processes markers were attached to the sides of the template.
Figure 4. Template curvature measured at CMM (Markers attached on the template measuring side).

A. Template being scanned using Faro Arm.  
B. Scanned model of Template.

Figure 5. Template scanned using Faro Arm (Markers attached on the model measuring side).
Figure 6. Comparison of angles obtained from the three instruments for side 1.

Figure 7. Comparison of angles obtained from the three instruments for side 2.
Table 1. SCMM error percentage for side 1.

|                      | Compared to CMM | Compared to Faro Arm |
|----------------------|-----------------|----------------------|
| Kyphosis Angle       | 0.68° 0.415     | 1.21° 0.733          |
| Lordosis Angle       | 0.97° 0.577     | 2.04° 1.22           |

Table 2. SCMM error percentage for side 2.

|                      | Compared to CMM | Compared to Faro Arm |
|----------------------|-----------------|----------------------|
| Kyphosis Angle       | 2.2° 1.33       | 2.34° 1.44           |
| Lordosis Angle       | 4.25° 2.57      | 0.6° 0.35            |

After comparing the measurements of SCMM from CMM and Faro Arm, it was found that the data obtained were more or less the same. The values got had a negligible difference, with 0.60° being the smallest error and 4.25° the most significant difference in the angle. The error percentage varied from 0.35% to 2.57% (Table 1 and Table 2). After analyzing the data, it was inferred that the produced instrument is accurate in the given constraints with measurements at par with the devices worth lakhs. The template being compared and evaluated gave the satisfaction of achievement of the aim; hence it was found fit to be used on human subjects. To cross-check the model by performing the statistical analysis of data obtained from the SCMM and other machines. T-Test concluded that there is no significant difference among measurements from SCMM, CMM and Faro Arm, and this instrument is ready to be used for human subjects as the aim was to develop a device which is simple, manually operable, and accessible. But still, the instrument has some limitations like the measuring process is very tedious and time-taking, as the measuring rods have to be moved manually with exceptional care every time, which makes the model inconvenient for measurements in large numbers.

4. References

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