Literature Survey on Human Spinal Deformities using 3D Reconstruction Techniques

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Abstract: The spine is a very complex anatomical structure, the pathological deformations of which have traditionally been evaluated in 2D using posteroanterior (PA) and/or lateral (LAT) view X-rays. The importances of 3D concepts in clinical studies, as well as personalized biomechanical finite element models and specific morphometric studies of the human spine have created a need for a precise geometric reconstruction method. 3D reconstruction of the spine from PA and LAT radiographs is extremely challenging. An approach based on epipolar geometry is proposed for 3D spine reconstruction. A jacket with embedded steel beads of known coordinates is used for calibration.

Key Words: Scoliosis, Scoliotic spine, Spinal kyphosis, Vertebrae.

INTRODUCTION:

Spine and its deformities: Scoliosis is a complex three-dimensional (3-D) deformation of the trunk that requires orthopedic treatment in 5 out of 1000 persons [1]. It is described as a lateral deviation of the spine (Fig. 1), combined with asymmetric deformation and axial rotation of the vertebrae, deformation of the rib cage and possibly of the pelvis.

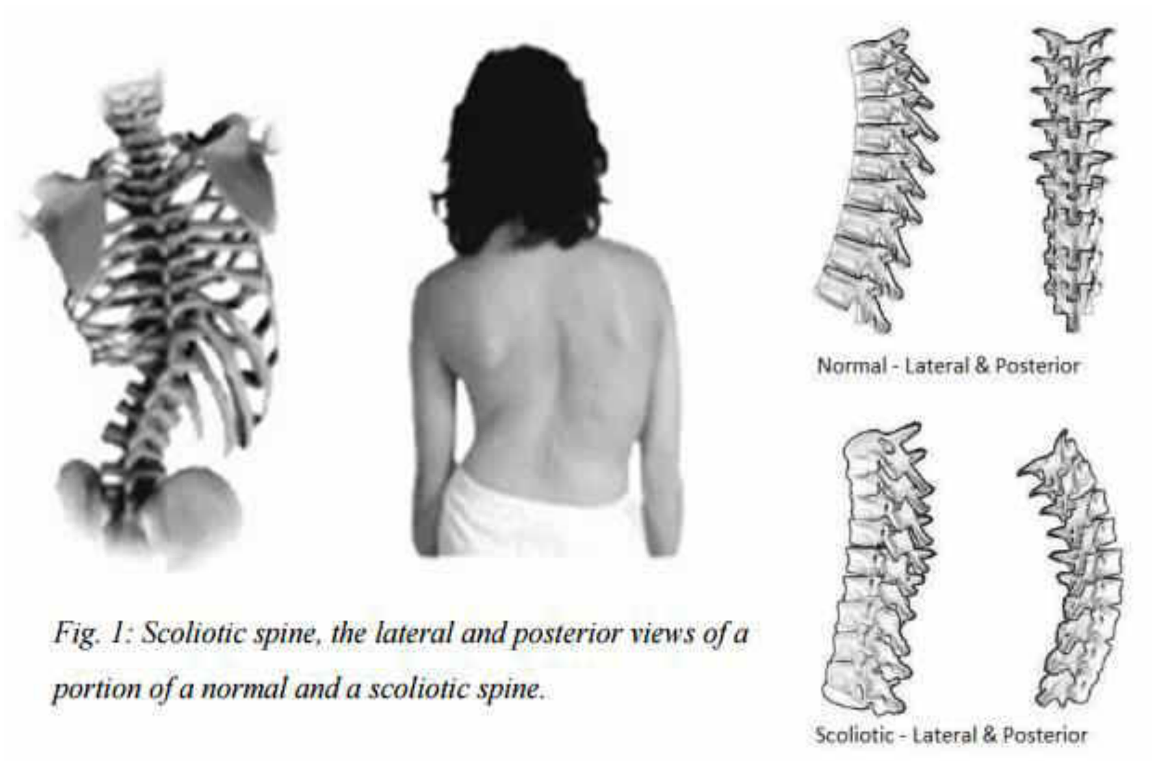

Fig. 1: Scoliotic spine, the lateral and posterior views of a portion of a normal and a scoliotic spine.

The human spine is divided into cervical (7 vertebrae C1 - C7), thoracic (12 vertebrae Tl - T12), and lumbar (5 vertebrae L1 - L5) sections above a fused sacrum (Fig. 2). While the spine normally has no lateral curvature, there are normal side-view curves including lumbar lordosis, thoracic kyphosis and cervical lordosis. Scoliotic curves are considered thoracic when the apex lies between T2 and T11, thoracolumbar at T12-L1, and lumbar from L2-L5. Each vertebra consists of an anterior weight-bearing vertebral body and posterior elements that protect the spinal cord and enable muscular and ligamentous attachments (Fig. 3). Particularly in severe scoliotic curves, asymmetric loads on the vertebrae encourage asymmetric growth of the vertebral elements, with one result being that despite a substantial underlying spinal curve the spinous processes may deform to produce a relatively straight line on the back surface. The spine, composed of vertebrae connected by fluid-filled intervertebral discs, is a loose and unstable tower which would collapse without the dynamic support of a network of ligaments and muscles. The balancing forces generated by the neuromuscular control system that allow the human spine to be stable, strong and flexible in a vast range of loading conditions are astonishingly complex.

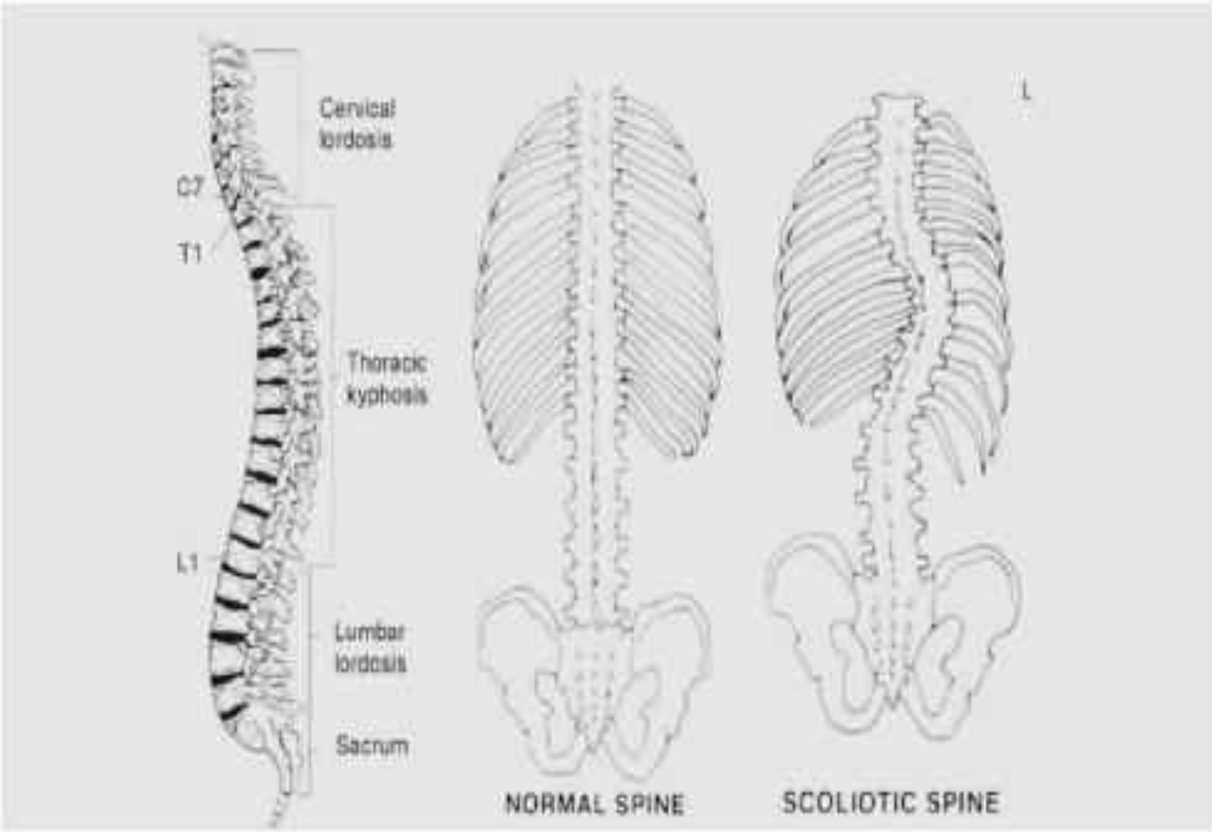

Fig. 2: Spinal kyphosis, lordosis and PA view of normal and scoliotic spine

The neuromuscular disorders, for example polio, cerebral palsy or muscular dystrophy, can lead to scoliosis. Scoliosis is classified as congenital (onset at age < 3 years, 10 years). Severity of scoliosis, generally measured by the Cobb angle of lateral curvature [16], ranges from mild asymmetry barely noticeable on X-ray (Cobb angle < 10°) to severe spine and rib cage deformity requiring surgery (Cobb angle > 50°).

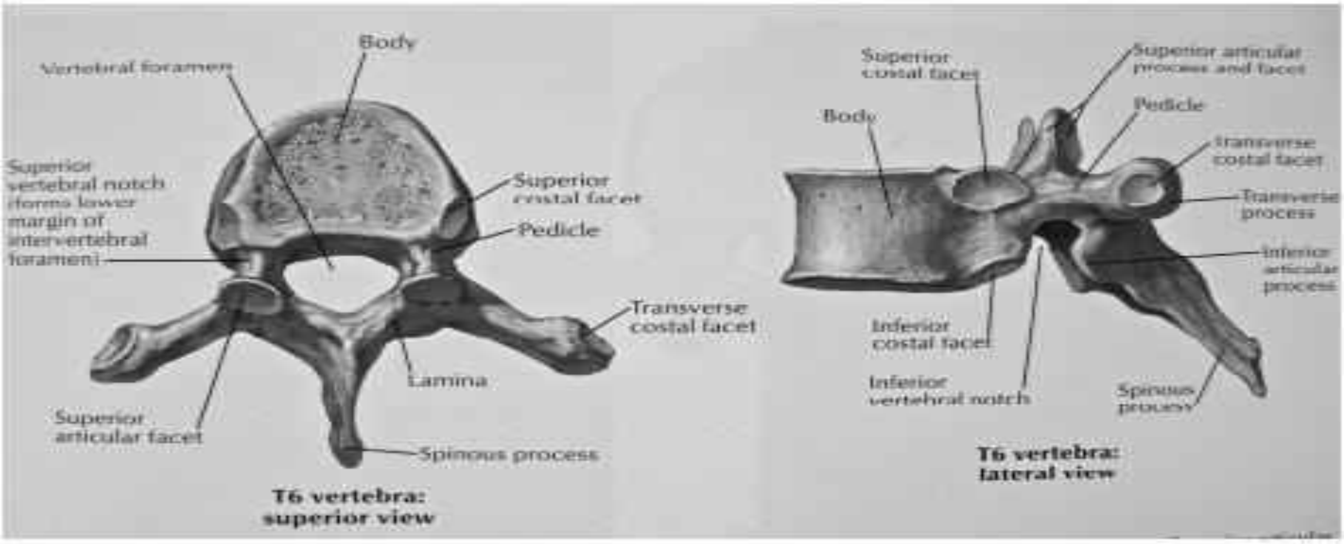

Fig. 3: Vertebra

The most frequent type of scoliosis, idiopathic scoliosis, has no specific identifiable cause. It is most commonly a condition of adolescence that progresses during the growth spurt. In the absence of treatment, it may lead to postural problems and even cardiac or pulmonary complications. Conservative treatment of scoliosis generally consists in the wear of a thoraco-lumbosacral orthosis (brace) during bone growth to apply corrective forces on the spine via the trunk soft tissues, rib cage, and pelvis. Surgical treatment usually involves correction of the scoliotic curves with pre-shaped metal rods anchored in the vertebrae with screws or hooks, and arthrodesis (bone fusion) of the inter-vertebral articulations of the instrumented segment of the spine.

Scoliosis is clinically visible from asymmetry of the spinous processes, ribs and scapulae, imbalance between the top and bottom of the spine, and left-right asymmetry on forward bending. Numerous tools beyond the eyes and measuring tape of the physician aid in scoliosis diagnosis and monitoring. Scoliosis patients are monitored by X-rays directly visualizing the entire spine, taken annually or semi-annually during rapid adolescent growth. The standard radiographic index of scoliosis severity is the Cobb angle, formed in the frontal plane between perpendiculars to the endplates of the endvertebrae of the scoliotic curve (Fig. 4).

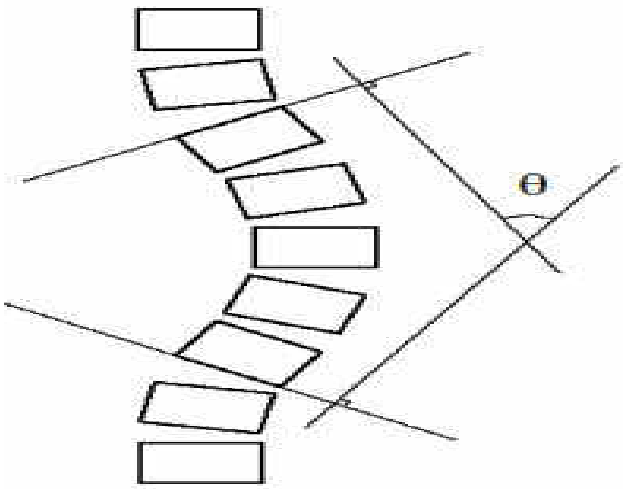

Fig. 4: Cobb angle

LITERATURE SURVEY:

The spine is a very complex anatomical structure, the pathological deformations of which have traditionally been evaluated in 2D using posteroanterior (PA) and/or lateral (LAT) view X-rays [1]. The importances of 3D concepts in clinical studies, as well as personalized biomechanical finite element models and specific morphometric studies of the human spine have created a need for a precise geometric reconstruction method. The advanced 3D imaging techniques like CT and MRI fail in the diagnosis of spinal deformities as they are obtained on a patient in supine position. Also they have restricted usage [2]. Hence stereo photogrammetry is the only technique available for 3D reconstruction.

Initially Direct Linear Transformation (DLT) is used as an algorithm for 3D reconstruction of the human spine [15]. The study is performed on a skeleton using a calibration object. When this method is applied to stereo radiographic reconstruction of bones, difficulties occur when attempting to identify the corresponding landmarks in two images. There is a need for more landmarks to obtain a better description of all the vertebrae [16]. The method is validated using an X-ray phantom with number of steel beds embedded in it for calibration purpose [17].

The development of the non-stereo corresponding point (NSCP) algorithm is an advance in the 3D vertebra reconstruction [12]. The principle of this method is the deformation of an elastic generic object (deformable mesh) that respects stereo corresponding and non-stereo corresponding observations available in different projections. Deformable models, which are commonly used in medical imaging for tasks such as segmentation (active contour model), have also been used to solve ill-posed tomographic reconstruction problems. This method is called the non-stereo corresponding point method [10], [11].

Performance / 3D Reconstruction Method	Cost	Imaging position	Radiation risk	Usage	Accuracy	Recons-truction error	Subject
Computed Tomography(CT) [3],[7],[13]	High	Supine	High	Any time	High	Low	Human
Magnetic Resonance Imaging (MRI) [1],[8],[14]	High	Supine	Low	Except after surgery	High	Low	Human
Direct linear transformation (DLT) on biplanar X-rays [15],[16],[17]	Low	Upright	Moderate	Any time	Moderate	4-8mm	Steel beads embedded in skeleton
Non Stereo Corresponding Points (NSCP) on biplanar X-rays [10],[11],[12]	Low	Upright	Moderate	Any time	Moderate	3-6mm	Cadaveric vertebrae
Epipolar geometry [4],[5]	Low	Upright	Moderate	Any time	Moderate	2-4mm	Cadaveric vertebrae
Statistical [2],[6],[9]	Low	Upright	Moderate	Any time	Moderate	Low	Human

Table 1: Comparison of existing 3D reconstruction methods

An approach based on epipolar geometry is also used for 3D spine reconstruction. It first detects the stereo corresponding points (SCPs) in biplanar radiographs and estimates the 3D positions of these landmarks based on epipolar geometry [4]. Then 3D reconstruction of the landmark positions is done with the non-stereo corresponding points (NSCPs) under the constraints of both epipolar geometry and spinal topology. For the NSCP reconstruction, the 3D distances between any two landmarks measured from anatomical primitives were used to define the vertebral topological constraint. The cost of the reconstruction is defined as the sum of the differences between the primitive distances and the reconstructed distances. Since the 3D position of a NSCP is restricted to an epipolar line under the constraint of epipolar geometry, the 3D positions of NSCP are found by searching on the epipolar lines to minimize the reconstruction cost. With the 3D landmarks (including SCPs and NSCPs) reconstructed as control points, the anatomical primitives are deformed to obtain the personalized vertebral models by using the Kriging algorithm. The point-to-surface distances between the biplanar radiographic and CT-scan reconstructions are calculated for two vertebrae (T4 and L2) to validate the method [5]. This approach uses cadaveric vertebrae placed in a calibration object for 3D reconstruction. These approaches are summarized in Table 1.

CONCLUSION:

The methods discussed so far are limited to the reconstruction of either cadaveric vertebrae or the skeleton. For clinically useful 3D reconstruction, more number of landmarks has to be identified on the vertebrae and to be performed on the living individual. An efficient algorithm that reconstructs and quantifies a scoliotic spine of an individual with only biplanar radiographs is not available till date. The description of the 3D scoliotic deformity by 2D X-rays is incomplete and equivocal; there are currently no accurate means of predicting which curves will progress and which will remain stable. 3D CT-scan analysis provides accurate local diagnoses for pathologies such as congenital scoliosis or for surgical planning. Nevertheless a global analysis of the whole spine morphology would require a number of slices leading to a considerable radiation dose for the patient. Moreover the study of patients in supine position underestimates scoliotic curves and thus biases the morphological analysis of scoliosis. Surgical implants in the spine do not allow the use of MRI imaging. The acquisition time and cost of these imaging modalities are also very high. Therefore there is a need to develop a 3D reconstruction method from biplanar X-rays which will provide 3D subject-specific models of the whole spine of patients in standing position with a low radiation dose and at lower cost. Diagnosing scoliotic patients is still a subjective process since doctors still measure the angles manually and they deal with 2D images while the deformation is three-dimensional. So errors in measurement as well as errors in visualizing the patient's spine frequently occur or in the simplest case, inaccuracy is there. This makes 3D modeling of the spine an aid to doctors, for better view of the patient's situation. Using 3-D model of the spine, 3-D clinical parameters are computed and used for diagnosis.

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