Chapter 3

Scoliosis – An Overview

3.1 Introduction

All spines have curves, but occasionally the spine twists and develops curves in the wrong direction - sideways. It is a condition known as scoliosis. Scoliosis occurs relatively frequently in the general population, and its frequency depends upon the magnitude of the curve being described. Scoliosis of greater than 25 degrees has been reported in about 3-5/1000 persons in the United States [1]. If scoliosis is neglected, the curves may progress dramatically, creating significant physical deformity and even cardiopulmonary problems. Generally, scoliosis is treated by orthopedic surgeons with special training in spinal problems. Since a part of the work is to construct a system for measurement and analysis of scoliosis, a brief introduction to the pathology is presented here. Important literature related to spine localization and scoliosis measurement is reviewed in this chapter.

3.2 Human Spine Anatomy

The human spine consists of number of small bones (vertebrae) and joints (intervertebral disks) together to form a flexible spinal column. A normal adult spine contains 33 vertebrae, and 23 intervertebral disks. A vertebra is composed of a ventrally placed body and a dorsal arch. The dimensions of the vertebral body and disk gradually increase from cervical to lumbar spine. The vertebral body is responsible for carrying weight and protecting the spinal cord and the
nerve roots. They are attached firmly to each other by intervertebral disks.

Classically the vertebral column is divided into several regions. Seven vertebrae starting from the top of the spine belong to the Cervical spine (C1-C7); twelve vertebrae after cervical spines are called the Thoracic spine (T1-T12); five (or six) bottom ones belong to the Lumbar spine (L1-L5); five (fused) vertebrae form the Sacrum spine (S1-S5); and the last three belong to the Coccyx spine. A normal adult spine also has cervical, thoracic, lumbar and sacral curves along the vertebral column as we can see in Figure 3.1.

The lumbar spine's shape has a lordotic curve. The lordotic shape is like a backward "C". If you think of the spine as having an "S"-like shape, the lumbar region would be the bottom of the "S". The vertebrae in the lumbar spine area are the largest of the entire spine.
The vertebrae of thoracic spine connect to the ribs and form part of the back wall of the thorax (the ribcage area between the neck and the diaphragm). Very narrow and thin intervertebral discs present at this part of the spine allow only much less movement between these vertebrae than in the lumbar or cervical spine. The thoracic spine's curve is called kyphotic because of its shape, which is a regular "C" curve with the opening of the C in the front.

The cervical spine starts just below the skull and ends just above the thoracic spine. The cervical spine has a lordotic curve (a backward C-shape) - just like the lumbar spine. The cervical spine is much more mobile than both of the other spinal regions. Two vertebrae in the cervical spine, the atlas and the axis, differ from the other vertebrae because they are designed specifically for rotation.

### 3.3 X-ray Imaging of Spine

X-ray imaging is a painless method of using radioactive materials to capture images of bone. During X-ray imaging, patient will be asked to hold certain still positions in a standing or lying posture, while pictures of spine are taken.

The three axis of human spine is shown in Figure 3.2. They are coronal plane, sagittal plane and axial plane. In X-ray imaging, common views taken are

- Anteroposterior (AP) view: front-back view of spine (coronal plane)
- Posteroanterior (PA) view: back-front view of spine (coronal plane)

![Figure 3.2 Different axis of human spine](image-url)
• Lateral view: side-to-side view of spine (sagittal plane)

### 3.4 Scoliosis

Scoliosis is lateral curvature of the spine. The normal spine is straight in the coronal plane and has ‘S’ shaped curvature in the sagittal plane. But in the case of scoliosis, the spine is curved in the coronal plane as shown in Figure 3.3. The following are a few typical physical features/symptoms of scoliosis:

- Asymmetry in the shoulders, trunk, scapula, and waistline - one shoulder or hip will be higher than the other
- A prominent shoulder blade - one is higher than the other and sticks out further
- Symptoms are most noticeable when bending over
- Rib hump - which occurs when scoliosis causes the chest to twist and throws off the alignment of the shoulder blade; this causes a hump on the back at the ribs or near the waist when the patient bends
- One arm hangs longer than the other because of a tilt in the torso

Scoliosis is a complicated deformity that is characterized by both lateral curvature and vertebral rotation. As the disease progresses, the vertebrae and spinous processes in the area of the major curve rotate toward the concavity of the curve. On the concave side of the curve, the ribs are close together. On the convex side, they are widely separated. Vertebral canal is narrower on the concave side. Physiological changes include: 1) Decrease in lung vital capacity due to a compressed intrathoracic cavity on the convex side and 2) With left scoliosis, the heart is displaced downward; and in conjunction with intrapulmonary obstruction, this can result in

![Figure 3.3 A case of scoliosis](image)
3.4 Scoliosis

right cardiac hypertrophy.

3.4.1 Diagnosis

X-ray images are the most important evidence of scoliosis. For diagnosing scoliosis the following images will be taken:

- Three-foot standing AP or PA
- Three-foot standing lateral
- Lateral bend (sideways view while bending forward at the waist)
- Traction films - traction is when your spine is pulled and held in a particular position; these films are only occasionally taken

3.5 Types of Scoliosis

The scoliosis curves are broadly classified into two: structural or nonstructural. Structural curves are those in which lateral bending of the spine is asymmetric or the involved vertebrae are fixed in a rotated position or both. These are the curves the patient cannot correct by lateral bending. Nonstructural curves, in contrast, are those in which intrinsic changes in the spine or its supporting structures are absent. In these curves, lateral bending is symmetric and the involved vertebrae are not fixed in the rotated position. Generally a nonstructural curve requires no treatment or any treatment is directed toward its cause, which is not located in the spine itself.

The structural scoliosis can be further classified into idiopathic, congenital, and paralytic [2]. When the scoliosis does not have a known cause, the condition is called idiopathic scoliosis. Idiopathic genetic scoliosis accounts for about 80% of all cases of the disorder, and has a strong female predilection (7:1). It can be subclassified into infantile (< 3 years), juvenile (between 4 and 10 years) and adolescent types (> 10 years), depending upon the age of onset. Idiopathic scoliosis in adolescents is called adolescent idiopathic scoliosis (AIS). Scoliosis can result from congenital vertebral anomalies. Discovery of these anomalies should prompt a workup for other associated cardiac, genitourinary or vertebral anomalies. Paralytic scoliosis is generally caused by neuromuscular diseases, neurfibrmatosis or spinal cord tumors. Scoliosis also occurs due to trauma.
3.6 Basic Definitions

Basic definitions of the standard terminology used in scoliosis measurement are given below. The defined terms are marked in an AP view scoliosis image in Figure 3.4.

3.6.1 Central Sacral Line (CSL)

CSL is called the spinal axis. It is the line passing through the centroid of the sacrum and perpendicular to the line joining the top points of iliac crests. In normal cases the pelvis is aligned parallel to the horizontal axis and CSL is a vertical line passing through the centroid of sacrum. This CSL is called central sacral vertical line (CSVL). This is based on the assumption that the leg lengths are equal.
3.6 Basic Definitions

3.6.2 Pelvic Inclination

The inclination of the line joining the top – mid points of the iliac crests to horizontal axis is called pelvic inclination.

3.6.3 Apical Vertebra (AV)

It is the center vertebra of each of the curve, also called curve apex. The curve apex could be a vertebra or a disk between the vertebrae, if two vertebrae are located in the curve center. By definition, AV has the following properties: most horizontal vertebra with respect to the horizontal axis, maximally rotated vertebra, most wedged vertebra, and maximally displaced vertebra from CSL.

3.6.4 Apical Distance

Apical distance is the perpendicular distance from centroid of AV to the CSL.

3.6.5 End Vertebrae

They are the vertebra in the upper and lower limit of the curve and with maximum endplate tilt angle. The vertebra at the upper limit of the curve is called upper end vertebra (UEV) and at the lower limit is lower end vertebra (LEV). They are also called superior end vertebra and inferior end vertebra. The disc above the UEV and below the LEV will have maximum parallel end plates.

3.6.6 Spinal Balance (Coronal Balance)

Spinal balance is the horizontal distance between sagittal C7 plumbline (a vertical line passing through the centroid of C7) and CSL. This is an indication of the amount of shoulder elevation due to scoliosis.

3.6.7 Tilt Angle of a vertebra

The angle made by the inferior end plate of a vertebra with the horizontal axis.
3.7 Radiographic Assessment of the Scoliosis

3.7.1 Measurement of Curve

The radiographic assessment of the scoliosis begins with erect anteroposterior (AP) and lateral views of the entire spine (occiput to sacrum). A lateral view of the lumbar spine is also taken to look for the presence of spondylolysis or spondylolisthesis (prevalence in the general population is about 5%). The scoliotic curve is then measured from the AP view. The Cobb method [3, 4] is the most commonly used method (used by the Scoliosis Research Society) for scoliosis measurement [2]. The Cobb method has several advantages over other methods, including the fact that it is more consistent while measured by several different examiners.

3.7.1.1 Cobb Method

Cobb angle is the most important parameter in scoliosis diagnosis and is reported along with the location of the curve. This method consists of three steps: (1) locating the superior end vertebra (upper limit of curve), (2) locating the inferior end vertebra (lower limit of curve), and (3) drawing intersecting perpendiculatrs from the superior surface of the superior end vertebra and from the inferior surface of the inferior end vertebra as shown in Figure 3.5. The angle of deviation of these perpendiculatrs from a straight line is the angle of the curve. The end vertebrae of the curve are the ones that tilt the most into the concavity of the curve being measured. If the endplates cannot be easily seen, these lines can be drawn along the top or bottom or the pedicles. Generally, as one moves away from the apex of the curve being measured, the next intervertebral space inferior to the inferior end vertebra or superior to the superior end vertebra is wider on the concave side of the curve being measured. Within the curve being measured the intervertebral spaces are usually wider on convex side and narrower on the concave side. When significantly wedged, the vertebrae themselves rather than the intervertebral spaces may be wider on the convex side of the curve and narrower on the concave side. Appelgren and Willner modified the Cobb method by dividing the Cobb angle into two parts, as the sum of the angles between each end vertebra and the horizontal plane [5]. Usually, the original Cobb technique is used for measurements.
3.7.1.2 Other Techniques

Other similar measurement techniques are: 1) Anterior Vertebral body technique; where scoliosis is measured in terms of the intersecting angle of the lines paralleling the anterior aspect of each of the vertebral bodies, 2) Posterior Vertebral body Technique; where the intersecting angle of the lines paralleling the posterior aspect of each of the vertebral bodies, 3) Cobb-Posterior Vertebral Technique; where the intersecting angle of the lines drawn along the superior end plate of the superior vertebral body and along the posterior aspect of the inferior vertebral body is measured [6]. In Risser-Ferguson method, straight lines are drawn from the middle of the end vertebra to the middle of the vertebrae at the apex of the curve [7]. This method is not frequently used. A technique useful when evaluating minimal curvatures, which are often difficult to measure with the currently accepted methods, was introduced in 1978 by Adam Greenspan and is more accurate in measuring the deviation of each involved vertebra [8]. This technique, called the "scoliotic index," measures the deviation of each involved vertebra.
from the vertical spinal line, as determined by a point at the center of the vertebra immediately above the upper end-vertebra of the curve, and the center of the vertebra immediately below the lower end-vertebra.

The accuracy and precision of the Cobb method compared to other techniques in measuring coronal plane abnormalities have been well documented [9, 10].

3.7.2 Measurement of Vertebral Rotation

The position of the pedicles on the x-ray image indicates the degree of vertebral rotation, which Nash and Moe divided into five grades as shown in Figure 3.6. If the pedicles are equidistant from the sides of the vertebral bodies, there is no vertebral rotation (grade 0). The grade then increase up to grade 4 rotation, which indicates that the pedicle is past the center of the vertebral body [2].

Figure 3.6 Nash and Moe method of determining vertebral rotation

3.8 Classification Schemes

In idiopathic scoliosis most of the characteristic features of the primary curve or curves are present at the onset of deformity and they rarely change. As the primary curve increases, one or two vertebrae may be added to it, but its apex, location and the direction of rotation of the included vertebrae remain unchanged. A curve classification scheme is useful in predicting the natural history based on the grouping and also in assignment of therapeutic strategies. Classification is usually taken as a factor in deciding the extent of spinal arthrodesis. Usually curves are identified in the medical community by their curve pattern type and are an integral part in scoliosis description. Many curve pattern classification schemes are in use today and new schemes are frequently proposed. Most important schemes are

- Ponsetty and Friedman scheme [11]
• King et. al. classification [12]
• Lenke et. al. classification [13]
• Peking Union Medical College (PUMC) method [14]
• SRS classification [15]

The Ponsetty and Friedman scheme is used in this thesis and hence its brief review is provided here.

3.8.1 Ponsetti and Friedman Scheme

Ponsetty and Friedman found that spinal curves form five main patterns that behaved differently. Also, a sixth pattern was described by Moe.

3.8.1.1 Single Major Lumbar Curve

This was described as the most benign and least deforming of all curves. It can however cause marked distortion of the waistline. It usually contained five vertebrae, T11 to L3, with apex at L1 or L2.

3.8.1.2 Single Major Thoracolumbar Curve

It usually included six to eight vertebrae, and extended from T6 or T7 to L1 or L2. Its apex was at T11 or T12. Curves of this type produce more cosmetically objectionable deformities than thoracic or lumbar curves of the same magnitude, especially when the curves are long.

3.8.1.3 Combined Thoracic and Lumbar Curve (Double Major Curve)

In these patients, the two curves being present from the onset and essentially equal. The thoracic curve is usually to the right and includes five or six vertebrae from T5 or T6 to T10 or T11. Its apex is at T7 or T8. The lumbar curve is usually to the left and includes five or six vertebrae from T10 or T11 to L3 or L4. Its apex is at L2 or L2. Often a neutral or unrotated vertebra was common to the adjacent ends of the curves. The prognosis as to cosmetics is good. Deformity of the back and decrease in the vital capacity is less severe than in single thoracic curve.
3.8.1.4 Single Major Thoracic Curve

Its onset is earlier than any other type of curve. It usually includes six vertebrae from T5 or T6 to T11 or T12 and has its apex at T8 or T9. Because of the thoracic location of this curve, marked rotation of the involved vertebrae is present. The curve produces prominence of the ribs on its convex sides and depression of the ribs on its concave side and elevation of one shoulder, resulting in an unpleasant deformity.

3.8.1.5 Cervicothoracic Curve

Although this type of curves never seemed to become large, the deformity is unsightly because of the elevated shoulder. The deformed thorax could be poorly disguised by clothing. The apex is usually at T3 with the curve extending from C7 or T1 to T4 or T5.

3.8.1.6 Double Major Thoracic Curves

This pattern was described by Moe. It consists of a short upper thoracic curve often extending from T1 to T5 or T6 with considerable rotation of the vertebrae and other structural changes in combination with a lower thoracic curve extending from T6 to T12 or L1. The upper curve is usually to the left and lower curve is usually to the right. The appearance of patients with this curve is usually better than with a single thoracic curve, but asymmetry in neckline is evident.

3.9 Related Pathologies

This section briefly introduces other pathologies related to scoliosis: kyphosis and lordosis. They are also deformities due to the curvature of spine.

3.9.1 Kyphosis

As introduced in Section 3.2 the thoracic spine has a curvature in the sagittal plane. Normal thoracic kyphosis is in the range of 20° to 50° [16]. But, if the curve in a person's thoracic spine is more than 50 degrees, it is considered abnormal and the spinal deformity is called kyphosis.
Sometimes this deformity is described as "round back posture" or "hunchback". The kyphosis is measured using Cobb technique in lateral x-rays of the spine.

3.9.2 Lordosis

The cervical spine (neck) and lumbar spine (lower back) have lordotic curves (like a backward "C") in sagittal plane. The direction of this curve is opposite to that of kyphosis. Hardacker suggests that the normal range of cervical lordosis is 40° (+/-) 9.7° [17]. Lumbar lordosis ranges from 31° to 79° in normal situations depending from where you chose to measure it [18]. The lordosis is measured using Cobb technique in lateral x-rays of the spine. A value exceeding normal limits is a spinal deformity called lordosis.

3.10 Literature Review

This section reviews important literature related to spine localization and scoliosis measurement of digitized spine x-ray images.

3.10.1 Spine Localization

Spine localization refers to estimation of location and position of spine in digitized x-ray images. The methods proposed can be divided into two categories: semi-automated and fully-automated. Semi-automated techniques demands human intervention at some point during segmentation, while fully-automated techniques do not involve human intervention.

3.10.1.1 Semi-automated Techniques

In the literature, some human assisted methods are reported for the segmentation of the vertebrae by using Active Contour Segmentation (ACS) technique [19]. A fundamental and comprehensive treatment of the whole field of active shape modeling (ASM), which has given technical direction to a number of research efforts was provided by cootes et. al. [20]. A semi-automated method has been proposed for the segmentation of lumbar spine dual x-ray absorptiometry (DEXA) images [21]. The user manually identifies two “anchor points” for placing a template. The template then deforms by ASM, maintaining invariance of the anchor
points, which are placed at the top and bottom of a column of vertebrae. Another ASM based technique uses manually selected boundary points of the vertebra to form the shape model and gray-scale model created by sampling the gray-scale profile (or gray-scale difference profile) along normal to each of these points [22]. In a test set of 40 cervical spine images, for 16 of the cases, the results showed a mean point-to-point error of less than 1/10 inch. Strong sensitivity of convergence to initial template positioning was observed in some cases [23].

3.10.1.2 Fully-automated Techniques

The fully automated methods proposed in the literature can be broadly classified into two groups. 1) based on landmark points like skull, shoulder etc to determine the characteristic curves assumed to lie in the spine region [24-26] and 2) a template matching based method for spine pose estimation [27, 28]. The first category includes a method proposed by Zamora et. al. which determines the approximate spine axis location, based on line integrals of image grayscale [29]. He reported an orientation error in his algorithm of less than 15 degrees, for 34 of the cases in a test set of 40 cervical spine images. Also, Dynamic programming methods are proposed for spine axis localization in the region of interest computed from basic landmark points [30]. The algorithm was tested in a test set of 48 images and the landmark points and spine axis could be successfully computed for 46 cases. In the template matching method, a customized implementation of the Generalized Hough Transform (GHT) is used for the object localization [27]. A template, which represents the shape of the object of interest (spine), is matched to a target image for different values of position, orientation, and scale. The output of GHT is the pose of the object within the image. For the cervical images, the GHT template represents the interior endplate of C2 and C3 through C6, and for the lumbar images, the template represents L1 through L5.

Another solution to the problem of vertebrae segmentation in digitized x-ray images is a hierarchical approach that combines three different methodologies [25, 26]. The first module is a customized Generalized Hough Transform (GHT) algorithm that is used to find an estimate of vertebral pose within target images. The second module is a customized version of Active Shape Models (ASM) that is used to combine gray-level values and edge information in order to find vertebral boundaries. ASM is a technique that captures the variability of shape and local gray-level values from the training set of images and builds two models, one for shape (SM) and
3.10 Literature Review

for gray-level values (GLM). Segmentation with ASM is achieved by iteratively deforming the SM towards the boundaries of the objects of interest as guided by GLM. It requires GLM to be a good representative of the gray-level values of the images around the shapes of interest and the deformation of SM does not allow for local deformations of shape at key parts of the objects. The third module is a customized DM (Deformable Model) approach based on the minimization of external and internal energies, that allow the capture of fine details such as vertebral corners [26]. The local deformation shortcoming of ASM is addressed by building a number of DMs along the local shapes of interest, such as vertebral corners, and deforming them according to an energy minimization approach. Thus, the ASM module needs to be correctly initialized with the location and orientation of the spine for accurate segmentation.

3.10.2 Scoliosis Measurement

The scoliosis is evaluated by measuring the Cobb angle of the curve. Accuracy and reliability in Cobb angle measurement is an important issue. The poor reproducibility of Cobb angle measurement commonly raises uncertainty about the validity of identified changes or progression in curvature [9, 31]. A 5° increase in Cobb angle measurements between two follow-up visits can suggest a curvature progression, and this may lead to changes in the treatment plan [32]. There are manual and computer-assisted techniques in use for scoliosis measurement. A number of publications are available in the literature reporting the measurement error and inter and intra observer reliability.

Manual measurement of the Cobb angle between involved vertebrae on spinal radiographs is done using simple protractors or other devices [33]. Numerous studies have focused on the error inherent in manual measurements of spinal alignment using plain film radiographs [9, 10, 34-37]. Carman et. al [9] reported an average difference of 3.8° (95% of differences less than 8.0°) in repeated measurements by 5 readers on 8 radiographs. They inferred from analysis of variance components that the overall standard deviation was 2.97°. Average intraobserver standard deviation (SD) has been reported as 3.5° and interobserver SD range from 2.8° to 7.2° [10, 38]. Cumulative errors ranging from 5° to 10° have been reported for successive measurements [39]. Oda et al reported that 5 surgeons, measuring 50 radiographs, had an average error of 9° (calculated as twice the standard deviation) and that the main error source was in identifying end vertebrae [40]. High levels of variability have also been reported when
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the end vertebrae of the curve are pre-selected. Morrissy et al.[10] reported an intra-subject variability of 2.8 ° and an inter-subject variability of 6.3 ° under conditions of pre-selection. These findings indicated that a change in a Cobb angle measurement of less than 10° cannot be interpreted with confidence as a real change [38]. Goldberg et al [41] showed interobserver variability of 2.5° and intraobserver reliability of 1.9° in a study by 4 evaluators of the primary curve identified in 30 radiographs. They also reported that the interclass correlation coefficient for the Cobb angle was 0.98. The interobserver standard deviation was 2.8° and the intraobserver standard deviation was 1.8° in a study by Yliko&ki and Tallroth [42] in consecutive measurements of Cobb angle of 30 untreated patients having a mean Cobb angle of 24.4° by 2 readers using a specially designed angle-measuring instrument (“Plurimeter”).

Computer-assisted methods have enabled the evaluation of spinal curves with greater accuracy and lower measurement error compared to manual techniques [43]. Shea et al. reports that for manual measurements the intraobserver error was 3.3 ° and for computer-assisted measurement 2.6 ° [43].

Nachiappan et al. [44] proposed a system in which the vertebral column is subdivided into a number of segments and the observer marks the lateral and medial intersecting points. The maximum angle is taken as the Cobb angle. Recently, Stokes et al. proposed a new system in which the user marks standard landmark points and the computer logic automatically measures the Cobb angle and classifies the curve [38, 45]. In that study of patients with larger (preoperative) scoliosis, the average sample standard deviations of the Cobb angle were (intraobserver) 2.0 ° for upper and lower curves, and (interobserver) 2.5 ° and 2.6 ° for upper and lower curves, respectively.

References:


