Chapter 2

Background

2.1 Spine Anatomy

The spinal column (ref Figure 2.1) is one of the most vital parts of the human body, supporting our trunks and making all of our movements possible. The human spinal column provides flexibility for movement, support for bearing weight and protection of nerve fibers. The spinal column surrounds and protects the spinal cord, which is the main pathway of communication between the brain and the rest of the body [32]. Humans are born with 33 separate vertebrae, by adulthood, most have only 24, due to the fusion of the vertebrae in certain parts of the spine during normal development. The spinal column also protects the nerve roots and part of the autonomic nervous system. The anatomy of the spinal column is extremely well designed to serve many functions. All of the elements of the spinal column and vertebrae serve the purpose of protecting the spinal cord, mobility and sensation in the body through the complex interaction of bones, ligaments and muscle structures of the back and the nerves that surround it. The back also supports our trunk and make all the movements of our head, arms and legs possible [33]. Table 2.1 describes the position, the total number of vertebra and abbreviation for the vertebral column.
Figure 2.1: Complete Spine (Courtesy: Oxford University)
Table 2.1: Vertebral Information

<table>
<thead>
<tr>
<th>Term</th>
<th>No of Vertebrae</th>
<th>Body Area</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>7</td>
<td>Neck</td>
<td>C1 - C7</td>
</tr>
<tr>
<td>Thoracic</td>
<td>12</td>
<td>Chest</td>
<td>T1 - T12</td>
</tr>
<tr>
<td>Lumbar</td>
<td>5 or 6</td>
<td>Low Back</td>
<td>L1 - L5</td>
</tr>
<tr>
<td>Sacrum</td>
<td>5 (fused)</td>
<td>Pelvis</td>
<td>S1 - S5</td>
</tr>
<tr>
<td>Coccyx</td>
<td>3</td>
<td>Tailbone</td>
<td>None</td>
</tr>
</tbody>
</table>

Cervical Vertebra:

The main function of the cervical spine is to support the weight of the head which is approximately 10-12 pounds. The upper portion of the spine, called the cervical spine (neck), is made up of bony vertebrae along with ligaments to provide stability [34] (Ref. Figure 2.2). While supporting the weight of the head the neck allows a significant amount of motion for the head: rotating up, down, left, right, and sideways. The bones of the cervical spine are separated by a gel-like cartilage pad known as an inter-vertebral disc. These discs allow the neck to bend and can act like shock absorbers during physical activity. Spinal nerves that branch at each vertebra (bone) allow sensation to reach the neck and the rest of the spine. The ligament’s and muscle’s job is to support and protect the spinal cord and nerves which runs like a long tube up and down the spine.

The cervical spine has the greatest range of motion in part because of two specialized vertebra that move with the skull. Cervical vertebrae are the smallest of the vertebrae. The first cervical vertebra is called the atlas as shown in Figure 2.2 and is significantly different from the other vertebrae. It is ring-like in shape with two large protrusions on the sides to support the weight of the head. The second cervical vertebra is called the axis as shown in Figure 2.2. The axis is also unique because it has a bony peg-like protrusion,
Injuries to the neck can be caused by accidental trauma, age, or normal wear and tear. Usually pain occurs when inter-vertebral discs bulge or rupture suddenly or slowly over time. When a disc ruptures, the pain a patient experiences may be a direct result of the spinal nerves being compressed. Numbness, instability and discomfort in the neck could be associated with this type of nerve compression.

![Axial view of cervical vertebrae](image)

**Figure 2.2: Axial view of cervical vertebrae**

**Thoracic Vertebra:**

The middle region of the back is called the thoracic spine as shown in Figure 2.1. The thoracic spine is located in the chest area and contains 12 vertebrae. The ribs connect to the thoracic spine and protect many vital organs. The section of the spine found in the upper back is called the thoracic spine. It goes from the base of the neck to the bottom of the rib cage.

The main function of the thoracic spine is to protect the organs of the chest,
especially the heart and lungs. There are 12 thoracic vertebrae (Ref Figure 2.3) with one rib attached on each side, to create a thoracic cage, which protects the internal organs of the chest. The thoracic spine has a normal kyphosis, or "C" curve. The thoracic spine is less mobile than the cervical and lumbar spine because of the thoracic cage.

Lumbar Vertebra:

The third major region of the spine is part of the lower back. This area of the back is most frequently involved in back pain because these vertebrae carry the most amount of body weight and are subject to the most stress along the spine. Each vertebra is stacked on top of the other with a gel-like cushion, called an inter-vertebral disc, in between. The discs help to absorb pressure, distribute stress, and keep the vertebrae from grinding against each other. The lumbar spine has five lumbar vertebrae, which are the largest vertebrae as shown Figure 2.4. These vertebrae are also aligned in a reverse "C" like the cervical spine, creating a normal lumbar lordosis. The five lumbar vertebral bodies are the weight-bearing portion of the spine and are the largest in diameter compared to the thoracic and cervical vertebral bodies. There are usually no identifiable disc spaces between the sacral segments. At the end of the spinal column is the coccyx or tailbone. Most people have 33 vertebrae in total, although there may be 32 or 34. Variations are usually found in the lumbar or sacral regions.

2.1.1 Vertebra

Each vertebra (Ref. Figure 2.5) is composed of several parts that act as a whole to surround and protect the spinal cord and nerves, provide structure to the body and enable to fluid movement in many planes. It bears about 80% of the load while standing and provides an attachment for the discs between
Figure 2.3: Thoracic vertebra from T1 to T12

Figure 2.4: Lumbar vertebra
Figure 2.5: Detailed views of a vertebra and vertebral segment

the vertebrae. The front or anterior section of the vertebral body protects the spinal cord and nerve roots. Both the vertebral body and the discs increase in size from the head to the sacrum.

Pedicles:

Figure 2.6: Pedicle: Axial view(left) and Lateral view(right)

Each vertebra has two cylinder-shaped projections (pedicles) of hard bone
that stick out from the back part of the vertebral body, providing side protection for the spinal cord and nerves as shown in Figure 2.6. The pedicles also serve as a bridge, joining the front and back parts of the vertebra.

**Laminae:**

![Figure 2.7: Laminae: Axial view (left) and Lateral view (right)](image)

The laminae (Ref. Figure 2.7) are two flattened plates of bone extending medially from the pedicles to form the posterior wall of the vertebral foramen. The pars inter-articularis is a special region of the lamina between the superior and inferior articular processes. The lamina is the roof of the spinal canal that provides support and protection for the backside of the spinal cord.

**Spinous Process:**

The long rearward projection from the arch of a vertebra provides a point of attachment for muscles and ligaments. The bumps that can be felt down the back are the spinous processes (Ref. Figure 2.8). They are bony projections that arise at right angles (perpendicular) to the midline of the lamina. Each spinous process is attached to the spinous process above and below it by ligaments.
The spinal canal (Ref. Figure 2.9) is a bony tunnel surrounding the spinal cord. It is made up of the front (anterior) of the vertebral body, the pedicles on the sides of the vertebral body and the lamina in the back. In the lower back it not only contains the spinal cord, it also contains the nerve roots of the lower spine.
Facet Joints:

Facet joints (Ref. Figure 2.10) occur in pairs at the back of each vertebra. The facet joints link the vertebrae directly above and below to form a working unit that permits movement of the spine. The structure of the facet joint is identical to other joints in the body, such as knees and hips. The bone surfaces of the facet joints are covered with a specialized tissue called articular cartilage. The joint is lined by a membrane called the synovium and enclosed with fibrous. A thick liquid (synovial fluid) surrounds the joint, allowing the bones to move without friction. Facet joint syndrome refers to pain that occurs in the facet joints. This syndrome most often affects the lower back and neck. Facet syndrome in the neck might cause headaches or shoulder pain. Each vertebra has a paired joint on its right side and a second paired joint on its left side, allowing a connection with the vertebrae above and below it. The pair that faces upward is the superior articular facet. The pair that faces downward is the inferior articular facet. The facet complex is surrounded by a watertight synovial capsule, much like the small joints in the fingers that allow for smooth movements.
2.1.2 Inter-vertebral discs

The inter-vertebral discs make up one fourth of the spinal column’s length. The inter-vertebral discs are fibro cartilaginous cushions serving as the spine’s shock absorbing system, which protect the vertebrae, brain, and other structures (i.e. nerves). There are no discs between the Atlas (C1), Axis (C2), and Coccyx. Discs are not vascular and therefore depend on the endplates to diffuse needed nutrients. The cartilaginous layers of the endplates anchor the discs in place. The discs allow some vertebral motion: extension and flexion. Individual disc movement is very limited. However, considerable motion is possible when several discs combine forces [35].

Inter-vertebral discs are composed of an annulus fibrosis and a nucleus pulposus (Ref. Figure 2.11). The annulus fibrosis is a strong radial tire-like structure made up of lamellae; concentric sheets of collagen fibers connected to the vertebral endplates. The sheets are orientated at various angles. The annulus fibrosis encloses the nucleus pulposus. Although both the annulus fibrosis and nucleus pulposus are composed of water, collagen, and proteoglycans (PGs), the amount of fluid (water and PGs) is greatest in the nucleus pulposus. PG molecules are important because they attract and retain water. The nucleus pulposus contains a hydrated gel-like matter that resists compression. The amount of water in the nucleus varies throughout the day depending on activity.

2.1.3 Nervous system

The nervous system (Ref. Figure 2.12) is essentially a biological information highway, and is responsible for controlling all the biological processes and movement in the body, and can also receive information and interpret it via electrical signals which are used in this nervous system. Nerves control the body’s functions including the vital organs, sensation and movement. The
nervous system receives information and initiates an appropriate response. It is affected by internal and external factors (i.e. stimulus). Nerves follow tracts and cross over junctions called Synapses. Simplified, it is a complex communicative process between nerves conducted by chemical and/or electrical changes.
2.1.4 Ligaments

Ligaments (Ref. Figure 2.13) are fibrous bands or sheets of connective tissue linking two or more bones, cartilages, or structures together. One or more ligaments provide stability to a joint during rest and movement. Excessive movements such as hyper-extension or hyper-flexion may be restricted by ligaments. Further, some ligaments prevent movement in certain directions. Three important ligaments in the spine are the Ligament Flavum, Anterior Longitudinal Ligament and the Posterior Longitudinal Ligament.

- The Ligament Flavum forms a cover over the dura mater: a layer of tissue that protects the spinal cord. This ligament connects under the facet joints to create a small curtain over the posterior openings between the vertebrae.

- The Anterior Longitudinal Ligament attaches to the front (anterior) of each vertebra. This ligament runs up and down the spine (vertical or longitudinal).

- The Posterior Longitudinal Ligament runs up and down behind (posterior) the spine and inside the spinal canal.

2.1.5 Anatomical Planes

1) Sagittal Plane - divides body in right and left parts (Median sagittal Plane-divides body into right and left halves). 2) Coronal Plane - divides body into front and back parts. 3) Horizontal Plane - transverse plane - cross section-divides body into top and bottom parts perpendicular to long axis of body (Ref. Figure 2.14).
Figure 2.13: Ligament Structure

Figure 2.14: Anatomical Planes

Figure 2.15: Movements of vertebral column
2.1.6 The Movements of vertebral column

Rotation: Rotation should be equal and about $70^\circ - 90^\circ$ to each side (Ref. Figure 2.15). The neck should be straight without either flexion or extension and patient should asked to look as far as possible to one side and to the other side.

Flexion and Extension: Full forward bend (Flexion)is present when the chain touches the chest (Ref. Figure 2.15). Full extension of at least $30^\circ$ degree beyond the horizontal should be possible, and is usually greater in younger people.

2.2 Spinal Disorder

2.2.1 Scoliosis

Everyone’s spine has curves and these curves produce the normal rounding of the shoulder and the sway of the lower back. A spine with scoliosis has abnormal curves with a rotational deformity as shown in Figure 2.16. This means that the spine turns on its axis like a corkscrew.

Scoliosis is the medical term for curvature of the spine. Scoliosis occurs in approximately 2% of women and less than 0.5% of men. It usually starts in the early teens or pre-teens and may gradually progress as growth occurs. Once rapid growth (puberty) is over then mild curves often do not change while severe curves nearly always progress. Curves are measured in degrees and persons with curves measuring less than $30^\circ$ entering adulthood are considered having a mild curve while those over $60^\circ$ are considered severe. However, when curves in excess of $30^\circ$ were evaluated, it was found that, females are more frequently affected by a ratio of approximately 8-10:1. The cause of the most common form of scoliosis – idiopathic scoliosis – is unknown, but there are certainly hereditary factors that are present. Scoliosis causes shoulder,
Figure 2.16: Scoliotic spine (Courtesy: KMC, Manipal)
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trunk and waistline asymmetry. In mild forms, the condition may be barely noticed; whereas in severe forms there is significant disfigurement, back pain and postural fatigue, and it may be associated with heart failure. Fortunately, the majority of scoliosis cases need only close follow-up to watch for worsening of the curve. Some cases require more aggressive treatment which could include surgery. Orthopedic surgeons are best qualified to evaluate and treat deforming spinal conditions like scoliosis.

Severe scoliosis does indeed require treatment. Scoliosis occurs mainly in the thoracic and thoracic-lumbar regions. There are two basic types of scoliosis, structural and functional. In the structural scoliosis the mechanics of the curve are such that rotation of the vertebrae occurs in combination with lateral curvature, and this usually produces a protuberance of one side of the rib cage, seen best when a person bends forward. This is the worst type of scoliosis, and it can be progressive. In the functional scoliosis, fixed rotation does not occur, and the curvature is usually non-progressive. This type of scoliosis is categorized as postural, which disappears while bending forward, and compensatory, which is most commonly due to a short leg.

There are many causes of a structural scoliosis, but by far the most common (80 to 90 per cent) is the unknown, or idiopathic. This idiopathic scoliosis develops usually as the spine is growing rapidly. The earliest form, or infantile form, occurs in the first three years of life, and it usually resolves with time. The juvenile form occurs up to the age of nine, and has a high familial relationship. It can often be a progressive scoliosis. The adolescent form is the most common, and occurs from nine to fourteen years, and the most severe cases involve females. It appears that genetic inheritance is a major contributor to a scoliosis. It is often difficult for the untrained eye to detect a developing scoliosis when standing from behind, even though the bones may be twisted to a considerable degree the spine can appear straight because the spinous processes (the parts of the spine that project backwards and can be
felt under the skin) can remain in a fairly straight line, while the front of the vertebrae rotate to a large extent. A better guide to the extent of a scoliosis can often be obtained by looking at a person from the front. In this view, the asymmetry of the body can be more readily detectable. This view may detect an abnormally shaped chest, or protuberance of some of the ribs on one side. The best way to look for a scoliosis is to look at the back from behind as the person bends forward. It is then easy to see the curve as one side of the rib cage will project more than the other. If there is any suggestion of a scoliosis medical opinion should be sought. Plain PA radiographs of the spine may be ordered. These radiographs can easily detect the extent of a scoliosis.

Types of Scoliosis

Nonstructural Scoliosis

1. Postural Scoliosis: Usually noted in later years of first decade. Curves are always slight and disappear on lying down

2. Compensatory Scoliosis: Usually a result of leg length discrepancy. Pelvis dips down on the short side

Transient Structural Scoliosis

1. Sciatic Scoliosis: Not true scoliosis; an irritative form caused by pressure on nerve roots from a herniated disc

2. Hysterical Scoliosis: Rare, usually requires psychiatric treatment

3. Inflammatory Scoliosis: Seen with perinephric abscess or similar infection
Structural Scoliosis

Idiopathic (Genetic) Scoliosis

About 70% of all cases of scoliosis. Classified by age of onset

1. Infantile—before 3 years of age
2. Juvenile—age 3 to onset of puberty, usually age 10
3. Adolescent—from age 10 until maturity

Congenital Scoliosis

1. Vertebral
   - Open—with posterior spinal defect
     - with neurologic deficit (e.g., myelomeningocele)
     - without neurologic deficit (e.g., spina bifida occulta)
   - Closed—no posterior element defect
     - with neurologic deficit (e.g., diastematomyelia with spina bifida)
     - without neurologic deficit (e.g., hemivertebra, unilateral unsegmented bar)

2. Extrvertebral (e.g., congenital rib fusions)

Neuropathic forms

- Lower motor neuron disease (e.g., poliomyelitis)
- Upper motor neuron disease (e.g., cerebral palsy)
- Others (e.g., syringomyelia)
- Progressive (e.g., muscular dystrophy)
Background

- Static (e.g., amyotonia congenital)

- Others (e.g., Friedreich’s ataxia, unilateral amelia)

Mesenchymal Disorders

1. Congenital (e.g., Marfan’s syndrome, Morquio’s disease, amyoplasia congenita, various types of dwarfism)

2. Acquired (e.g., rheumatoid arthritis, Still’s disease)

3. Others (e.g., Scheuermann’s disease, osteogenesis imperfecta)

Trauma

1. Vertebral (e.g., fracture, irradiation, surgery)

2. Extravertebral (e.g., burns, thoracic surgery)

Scoliosis based on age:

Infantile

Infantile scoliosis is classically defined as scoliosis that is first diagnosed in a child between birth and 3 years of age. Congenital spinal anomalies (i.e., missshapen and connected vertebrae) are also often diagnosed during this period, but are not included in the infantile category. Many infantile curves will resolve without treatment. Those that do not resolve can be very difficult to manage. The pediatric spine surgeon may suggest a MRI study in a case of not resolving infantile idiopathic scoliosis to determine if there are any abnormalities of the spinal cord or spinal column that are causing the deformity. The decision to get an MRI in an infant is not a simple one. Generally sedation, or even anesthesia, with their associated risks, is necessary to relax the child so that good images can be taken. Most infantile idiopathic scoliosis curves are left sided curves in the thoracic (chest) area. It is more common in boys
than girls. In some patients, there is an increased association with hip dysplasia, mental retardation, and congenital heart disease. Many other infants are healthy and normal and simply have a small curvature of the spine.

**Juvenile**

Juvenile idiopathic scoliosis is classically defined as scoliosis that is first diagnosed between the ages of 4 and 10. This category comprises about 10% to 15% of all idiopathic scoliosis in children. At the younger age of the spectrum, boys are affected slightly more than girls and the curve is often left-sided. Towards the upper end of the age spectrum, the condition is more adolescent idiopathic scoliosis, with a predominance of girls and right-sided curves.

**Adolescents**

Scoliosis in patients between 10 and 18 years of age is termed adolescent scoliosis and can be due to many causes. These include an underlying neuromuscular condition such as cerebral palsy or muscular dystrophy, or can be associated with genetic disorders or can be congenital where part of the spine has not developed normally. By far the most common type of scoliosis in the adolescent period is one in which the cause is not known and is called idiopathic or adolescent idiopathic scoliosis (AIS). Although significant ongoing research continues in this area, including the genetic basis for AIS, there are no identifiable causes for this condition today.

**Diagnosis of scoliosis**

**Examination and diagnostic testing**

The different types of examinations and different types of diagnostic testing are listed in Table 2.2 and Table 2.3.
### Table 2.2: Different types of scoliosis examination

<table>
<thead>
<tr>
<th>Examination</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical assessment</td>
<td>The physician looks for asymmetry of the trunk such as uneven shoulders or hips, humpback, or listing to one side</td>
</tr>
<tr>
<td>Cardiopulmonary</td>
<td>Testing of the function of the heart and lungs</td>
</tr>
<tr>
<td>Adam’s Forward Bending Test</td>
<td>The patient bends forward at the waist, with arms extended forward. The physician looks for asymmetry thoracic prominence (such as a shoulder blade), or a lumbar prominence</td>
</tr>
<tr>
<td>Leg length</td>
<td>Both legs are measured to determine if they are of equal length</td>
</tr>
<tr>
<td>Plumb line</td>
<td>A plumb line is dropped from the C7 vertebra (in the neck) and is allowed to hang below the buttocks. In scoliosis the line does not hang between the buttocks</td>
</tr>
<tr>
<td>Range of motion</td>
<td>The physician measures the patient’s ability to perform flexion, extension, bending, and rotation movement’s</td>
</tr>
<tr>
<td>Palpation</td>
<td>The physician feels for abnormalities. Perhaps the ribs are more prominent on one side</td>
</tr>
<tr>
<td>Neurological assessment</td>
<td>In addition to testing reflexes, the physician want to know if the patient’s symptoms include pain, numbness, tingling, extremity weakness or sensation, muscle spasm, and bowel/bladder changes</td>
</tr>
</tbody>
</table>
Table 2.3: Different types of diagnostic testing

<table>
<thead>
<tr>
<th>Diagnostic Test</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoliometer</td>
<td>A scoliometer is used to measure a rib hump while the patient is bent at the waist</td>
</tr>
<tr>
<td>X-rays (radiographs)</td>
<td>X-rays may include an upright lateral view of the spine and side bending</td>
</tr>
<tr>
<td>Cobb Angle Measurement [36]</td>
<td>This test uses a full-length posteroanterior X-ray to calculate the angle of the curve(s)</td>
</tr>
<tr>
<td>Risser Sign</td>
<td>An x-ray to provide information about skeletal maturation. The Risser Sign looks at the iliac crest growth plate, a fan-shaped part of the pelvis. The crest fuses with the pelvis at maturity</td>
</tr>
<tr>
<td>Nash-Moe [2]</td>
<td>A technique used to measure vertebral rotation. The rotation of the vertebral pedicle is measured by dividing the vertebral body into segments</td>
</tr>
<tr>
<td>Classification [4] [3]</td>
<td>Doctors primarily use one of two classification schemes: King or Lenke. The System helps surgeons to determine what levels of the spine to fuse and instrument</td>
</tr>
</tbody>
</table>
Radiographic technique

1. Cobb Angle Measurement
2. Nash-Moe technique
3. King classification

Management of scoliosis

The management of a scoliosis is determined by the extent of the scoliosis. A number of methods are used to decide upon the most appropriate treatment. In most instances a mild scoliosis requires no specific treatment. Advice in regard to posture and exercises may be offered. If the scoliosis is more severe it must be treated. The options are:

Bracing

Although a definite inconvenience, bracing is sometimes necessary, and may prevent the need for surgery. A recent study has shown that bracing is effective in stopping the progression of the curve in about 80% of patients, until the age of 16. However, those children who have been braced generally still have curves within the acceptable range, which should not carry any particular disadvantage into adulthood.

Physiotherapy

Surface electrical stimulation has now been discredited as a treatment, and studies have shown that the children treated in this way do no better than those left untreated. Treatment such as manipulation has no place in the management of the mechanical defect in scoliosis, although manipulation and physical therapies can help any low back pain that occurs in association with a scoliosis. In the majority of functional scoliosis, Physiotherapists will give
advice regarding posture, strengthening of muscles and correction of muscle imbalance, strapping, ergonomics and exercise.

Exercises can be prescribed, but they will probably not affect the progression of a curve. If a brace is required, an exercise program will also be prescribed, but if not required, instruction regarding review of the scoliosis and exercises will be provided.

**Surgery**

In the rare cases where the scoliosis reaches the point of no return, surgery may be required. In thoracic scoliosis it entails the insertion of metal rods - called Cotrel-Dubousset Instrumentation - along the spine. These rods act as braces to straighten the spine and prevent further deterioration of the scoliosis. These rods are usually left in the spine throughout life. These operations are performed by Orthopedic Surgeons, who are specialized in the area of Pediatric Orthopedics. This type of surgery does not require the patient to wear a plaster jacket after the operation. The stay in hospital is about 7 to 9 days, and return to school is about 1 month. Life after surgery returns to near normal by about 9 months, except that body contact sports are not permitted. Lumbar scoliosis is treated with other operations including fusion, and the underarm brace is required for up to 6 months after surgery.

### 2.2.2 Spondylolysis

Spondylolysis (Ref. Figure 2.17) is a Latin term meaning improper forward movement of a vertebra over the vertebra below it. Most often, this forward slip of the vertebra occurs in the lumbar area of the spine. This slippage and herniation (deformity) of the disc places pressure on the nerve roots associated with the affected vertebrae, causing pain and dysfunction. While the herniation of the disk causes pain, discectomy alone is unable to provide relief. The
reduction in disk space height and abnormal amount of movement allowed by the joint also causes pressure on the nerves. This inter-vertebral space must be restored in order to provide adequate space for the nerves. This most frequently occurs in the fifth vertebra. As a result, nerves can be pinched, causing pain. For most patients, the pain is mild and can be treated by pain medications. Avoiding of lifting of heavy objects and doing exercises to strengthen back muscles may also help.

2.2.3 Kyphosis

A normal spine, when viewed from behind appears straight (Ref. Figure 2.18). However, a spine affected by kyphosis shows evidence of a forward curvature of the back bones (vertebrae) in the upper back area, giving back humpback appearance. The normal spine has only 20° to 45° degrees of curvature in the upper back area. Kyphosis is a type of spinal deformity and should not be confused with poor posture [2].
2.3 Modalities used for diagnosis

2.3.1 X-Ray

Plain X-rays are the simplest and often most important in a basic and gross screening of spinal complaints. Proper radiographs are preferably performed in the standing position, which will help to determine the effects of gravity on the overall alignment of the spine. In essence, misalignment of the spine is associated with muscle spasm or deformity and can be seen in congenital conditions, idiopathic scoliosis, or trauma related issues. These are best visualized on full length standing spinal X-rays. In addition, bending X-rays (forwards, backwards, side bending) are also useful in determining if there is any instability of the spine. This can help the physician to formulate the best treatment plan for the patient.

2.3.2 Magnetic Resonance Imaging

MRI’s are commonly performed on patients with chronic back pain, neck symptoms or individuals with a neurological deficit. It uses magnetic energy to visualize internal structures based on the degree of water or fat content in tis-

Figure 2.18: Kyphosis (Courtesy: American Vinivyoga Institute)
sues. This is non-radiation energy and shows very detailed information about the soft tissue structures (such as nerves and tendons) and the relationship between the soft tissue and bone.

Certain limitations do exist with MRI’s. When previous surgery has been performed and metallic implants have been placed, the image quality of the MRI is highly degraded due to a phenomenon called metal artifact. In addition, the time required to obtain the MRI is relatively lengthy and the artifact related to patient movement (motion artifact) can also distort the images. High quality images are quite valuable in identifying subtle spinal pathology. These are generally obtained on closed MRI units of 1.5 Tesla or higher. Although the open MRI scanners are more tolerable for a claustrophobic or an obese patient, the image quality is compromised and not as detailed as the closed unit. There are certain incidences where MRI scan is contradictory. This usually happens to patients with pacemakers or other forms of non-MRI compatible implants, such as pain pumps, dorsal column stimulators, and older metallic stents or clips.

2.3.3 Computed Tomography

CT scan is another tool in a physician’s armamentarium with regards of diagnostic tools. CT scans utilize gamma radiation and can be seen using X-ray technology. The information obtained through a CT scan is processed digitally with a computer, which yields a three dimensional picture of the local anatomy. CT scans are generally less beneficial in demonstrating soft tissue detail yet yield very high quality details of bone structures. Fine bone details (small cracks in the bone), as seen in Spondylolysis, or areas of arthritis with facet arthritis are best visualized with CT scans. A CT scan may be used for a better evaluation of the degree of healing that can be expected after a spinal fusion. Plain X-rays in combination with CT scans will help to deter-
mine whether or not a spinal fusion has healed based on bony growth from one vertebra to the next. Additionally, for a patient who cannot undergo MRI scans (in the event of pacemaker or other metallic implants, which preclude obtaining an MRI scan), CT scans are invaluable in visualization of the spinal canal.

2.4 Scoliosis Analysis

The extent of scoliosis need to be known before going for any treatment and also required to observe progress of treatment. There are various parameters available like spine curvature, rotation of vertebral body, classification, etc..

2.4.1 Spinal Curvature Estimation

Quantitative evaluation of spinal curvature is necessary for the determination of normal and pathological conditions and for understanding the mechanisms of the progression of spinal deformities. In the following section we have discussed various methods to estimate the spinal curvature.

Ferguson Method:

One of the earliest methods for estimating spinal curvature was proposed by Ferguson [37]. The method evaluates the deformity by the angle between the two straight lines that connect the centers of the end vertebrae with the center of the apical vertebra as shown in Figure 2.19.

The vertebra at each end of the curve is the inferior and superior vertebrae. Next the apex vertebra is located, which is the most rotated one at the peak of the curve. In each of these three vertebrae, the center of the outline of the body is marked with a dot. Lines are drawn from the apex to each end of the vertebra. The angle of the curve is the divergence of these two lines from $180^\circ$.
Figure 2.19: Ferguson method of spinal curvature measurement

Disadvantage of this method is it can measure deformity, which is less than $50^\circ$ and beyond that it may not be accurate.

**Greenspan Index Method:**

In Greenspan index method [38] deformity is measured at individual vertebrae and is therefore valuable for measuring short-segment or small spinal curvatures [3]. The centers of the end vertebrae are connected to form the spinal line, orthogonally to which additional lines are drawn from the center of each vertebra in the spine curve as shown in Figure 2.20. The sum of the lengths of these additional lines divided by the length of the spinal line represents the index of the deformity. The index should be zero for normal spine.

**Diab method:**

Diab developed a new method for measuring coronal curvature in radiographs and compared it to the Cobb and Ferguson method [39]. The new method consisted of identifying the four vertebral body corners of the apical and end vertebrae [3] as shown in Figure 2.21. In contrast to the Ferguson method, the centers of vertebral bodies were found at the intersection of lines orthogonal to the superior and inferior endplates. The centers of both end vertebrae were
then connected with the center of the apical vertebra, forming two intersecting lines that defined the angle of the deformity.

**Centroid method:**

It is proposed by Chen and in this method center of the vertebral body (i.e. centroids) is obtained by connecting the opposite corners of two vertebral bodies at both ends of the measured spine curve [40]. The spinal curvature is the angle between the straight lines drawn through the two top and through the two bottom vertebral centroids as shown in Figure 2.22. The analysis of the
measurements in digitized radiographs showed that the centroid angle revealed smaller curvatures and was strongly correlated with the Cobb angle. However, as it resulted in equal intra- and inter-observer variability, the authors suggested that the centroid method, although originally developed for evaluating sagittal spinal curvatures, may represent an alternative in assessing scoliosis for clinical diagnosis and treatment decision.

Figure 2.22: Centroid method

Cobb’s method:

Figure 2.23: Spinal curvature using Cobb’s technique
Figure 2.23 shows the quantitative evaluation of spinal curvature by Cobb’s technique [36]. This assessment needs distinctly visible endplates for estimation of spinal curvature. Deformity is measured by the angle between the two straight lines that are tangent to the superior and inferior endplates. In S-shaped scoliosis where there are two continuous curves the lower end vertebra of the upper curve will represent the upper end vertebra of the lower curve. The significance of the Cobb angle is depicted in Table - 2.4. Cobb method is preferred because of its better reproducibility, easier application and measurement of larger angles for more severe spinal curvatures.

<table>
<thead>
<tr>
<th>Cobb Angle</th>
<th>Remark or measures to be taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 10^0$</td>
<td>Not considered to be scoliosis</td>
</tr>
<tr>
<td>$10^0to25^0$</td>
<td>Regularly monitored until skeletal maturity progression starts</td>
</tr>
<tr>
<td>$25^0to45^0$</td>
<td>Brace treatment is suggested</td>
</tr>
<tr>
<td>$&gt; 45^0$</td>
<td>Surgery is recommended</td>
</tr>
</tbody>
</table>

In 1966 Cobb’s procedure was adopted by the Scoliosis Research Society (SRS) [36] as the standard method for quantification of scoliotic deformities. As the Cobb method has been standardized, a number of studies tested its reproducibility and reliability in measurement of idiopathic and congenital scoliosis. In order to improve the reliability and accuracy of the Cobb angle measurements, many computer algorithms were developed.

### 2.4.2 Grading of Vertebral Rotation

Quantitative evaluation of axial vertebral rotation is essential for the determination of reference values in normal and pathological conditions and for understanding the mechanisms of the progression of spinal deformities.
Cobb Method:

One of the first methods for the measurement of axial vertebral rotation in radiographic images was presented by Cobb [36]. The rotation was determined according to the position of the vertebral spinous process relative to the vertebral body. Based on the position of the tip of the spinous process in relation to the underlying vertebral body, Cobb described a method for measurement of vertebral rotation.

![Cobb's method of determining vertebral rotation](image)

Values ranged from 0 to +++++, but not made to correlate these grades with the degree of rotation. Figure 2.24 shows the Cobb’s method of determining vertebral rotation, in which vertebral body is divided into six equal segments and identifying the segment that contains the spinous process. If spinous process lies in the center of the body i.e. at a, then there is no rotation. If spinous process lies at b, then the rotation is +. If spinous process lies at c, then the rotation is ++’. If spinous process lies at d, then the rotation is +++’. If the spinous process crosses beyond d then the rotation is +++’.

Disadvantage: One weakness of Cobb’s method is its ability to provide an approximation of vertebral rotation [41]. The grading scheme is limited to five grades and does not allow quantification of the angle of axial rotation. Surgical techniques often alter the spinous process; the visibility of spinous process will be faint after operation.
Fait and Janovec Method:

In Fait [42] and Janovec Method the outer edge of the pedicle at the convex side was used rather than its center as shown in Figure 2.25. Moreover, the measurements resulted in a pedicle offset ratio that was converted to degrees of rotation by using a pre-defined look-up table.

Nash-Moe Method:

It divides the vertebral body into six equal segments and identifies the segment containing the pedicles. The five grades of axial vertebral rotation were determined as shown in Figure 2.26. As the vertebral body rotates in an evolving curve, the pedicle outline on the convex side moves on the vertebral outline, while that of its concave counterpart becomes less evident, finally disappearing in severe curves. The grades of rotation were also translated to degrees of rotation [2]. Table 2.5 shows the rotation of vertebra in terms of grading depending on the position of the pedicle.
Figure 2.26: Pedicle method of determining vertebral rotation

Table 2.5: Nash-Moe method of determining vertebral rotation [2]

<table>
<thead>
<tr>
<th>Grade</th>
<th>Convex</th>
<th>Concave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade: Normal</td>
<td>No asymmetry</td>
<td>No asymmetry</td>
</tr>
<tr>
<td>Grade: +1</td>
<td>Migrates within first segment</td>
<td>May start disappearing</td>
</tr>
<tr>
<td></td>
<td>Early distortion</td>
<td>Early distortion</td>
</tr>
<tr>
<td>Grade: +2</td>
<td>Migrates to second segment</td>
<td>Gradually disappears</td>
</tr>
<tr>
<td>Grade: +3</td>
<td>Migrates to middle segment</td>
<td>Not visible</td>
</tr>
<tr>
<td>Grade: +4</td>
<td>Migrates past mid-line to concave side of vertebral body</td>
<td>Not Visible</td>
</tr>
</tbody>
</table>
2.4.3 Scoliosis Classification

Classification of patient according to their clinical presentation is used to assist in planning their management. Grouping of patient according to classification scheme provides guidelines as to the appropriateness of different treatment interventions. To be effective a classification should be exhaustive and mutually exclusive patient should be assigned. Therefore, classifications must fulfill two important criteria viz., reproducibility and reliability. Reproducibility: The structure of the classification system should ensure that the same examiner would arrive at the same assessment by repeating the examination at any other time. This criterion is also known as intra-observer reliability. Reliability: This criterion measures the level of dependability with which a classification system ensures that all examiners using it would arrive at the same result when examining the same case. This is also known as inter-observer reliability.

Depending on the classification used, the evaluation of scoliosis includes a PA radiographic assessment and the quality of the image is important. A poorly centered picture does not allow for a reliable evaluation because the correct determination of the measuring points (upper and lower neutral vertebra, apex vertebra, terminal vertebra) is absolutely essential to the accurate evaluation of the scoliosis angle. The more complex a classification system is, the greater the number of parameters required for the exact assignment to a class and the greater the error rate will be for inexperienced examiners.

Schulthess Classification

Wilhelm Schulthess defined classes of scoliosis according to location and curve form [10]. Five types of manifest scoliosis were defined viz., cervicothoracic type (at the cervical-to-thoracic spine transition), Thoracic type (in the thoracic spine), thoracolumbar type (at the thoracic-to-lumbar spine transition), Lumbar type (in the lumbar spine) and type with primary double curves in
the thoracic and lumbar spine.

**Lenke’s Classification**

Lenke adopted a rather rigorous form for the classification of the Scoliotic radiographs [3]. The curve type is determined by the localization, degree, and flexibility of the manifested curves. The curve apex is defined in various ways for localization purposes like upper thoracic localization (curve apex between T2 and T6), thoracic localization (curve apex between T6 and inter-vertebral disc T11/12), thoracolumbar localization (curve apex between T12 and L1) and lumbar localization (curve apex between inter-vertebral disc L1/2 and L4).

The flexibility is assessed either based on the residual curve in the bending radiograph or the extent of kyphosis. A curve is defined as structural if the bending Cobb angle exceeds $25^0$ or the kyphosis angle exceeds $20^0$. The 6 curve types can be defined as shown in Figure 2.27, based on these parameters viz., Type I (main thoracic, major curve thoracic only), Type II (double thoracic, 2 thoracic curves), Type III (double major, 2 major curves), Type IV (triple major, 3 major curves), Type V (primary thoracolumbar/lumbar, major curve thoracolumbar or lumbar only) and Type VI (primary thoracolumbar/lumbar, main thoracic).

**King’s Classification**

The scoliosis is classified into five types as per King’s definition [4] as shown in Figure 2.28 and explanation follows below.
Figure 2.27: Lenke classification [3]
2.5 Materials and Methods

PA radiograph’s of 250 patients with idiopathic scoliosis is used for study from KMC medical center Karnataka India. These radiographs are taken in a conventional standing posture at a fixed distance of 228cm from X-ray source with knees fully extended and upper limbs resting on two arm support. These PA radiographs includes thoracic, thoraco lumbar and lumbar scoliosis with all classes of scoliosis as defined by King. For the present study, JPEG compressed radiographic images of 256 gray levels with size 925 pixel height by 475 pixel wide are used.

The estimation of three quantitative parameters of scoliosis viz., Spinal Curvature, Vertebral Rotation and Classification involves various image processing and computer assisted technique. The specific methods used are discussed in the respective chapters in detail.

2.6 Literature Review

2.6.1 Spinal Curvature Estimation

Cobb angle, a measurement used for evaluation of curves in scoliosis on an PA radiographic projection of the spine. When assessing a curve the apical vertebra is first identified; this is the most likely displaced and rotated ver-
tebra with the least tilted endplate. The end/transitional vertebrae are then identified through the curve above and below. The end vertebrae are the most superior and inferior vertebra which are least displaced and rotated and have the maximally tilted endplate. A line is drawn along the superior endplate of the superior end vertebra and a second line drawn along the inferior endplate of the inferior end vertebra. If the endplates are indistinct the line may be drawn through the pedicles. The angle between these two lines (or lines drawn perpendicular to them) is measured as the Cobb angle. There were several attempts had been made to measure this angle as accurately as possible without any inter- and intra- observer error.

The Ferguson [37] and the Cobb methods [36] are the two commonly utilized techniques for measuring scoliosis. In 1979 Barry F Jefferies [43] stated that a change in curvature of $5^\circ$ may be due to variations in measurement rather than true improvement or worsening of the curve. To eliminate these deficiency in the scoliosis evaluation, they started with a computerized program to identify and accept spatial data regarding the locations of thoracic to lumbar vertebrae. Computerized measurement provides better evaluation of true shape of the curve with reference point were located on standard PA radiographs from first thoracic to iliac crests using sonic digitizer.

In 1982 Arthur et al., [44] studied the difference between the scoliotic angle measured on PA and anteroposteiror radiographs. Their study examined the association between the difference in measured angle and the various clinical and curve parameter. Their study concludes that PA has more variation error compared to AP error.

In 1990 T Morrissy [1] did the quantitative intrinsic error in measurement procedure where each measured on six separate occasions. In Set I measurement each observer selected end vertebra. In SetII , the end vertebra were preselected and constant. The result with Set I is $5^\circ$ variation and $3.8^\circ$ for SetII with same protractor.
G Capasso et al., listed all possible error during the measurement procedure that may be intrinsic or extrinsic error. Extrinsic part consists of identification error and technical error. Identification errors are due to anatomical deformities of the vertebrae [45].

In 1994 J E H Prujis, et al., [46] tried to determine a reliable system for Cobb angle measurement for Scoliosis. Their study ends with a standard deviation about 3.20° for the Cobb angle measurement and it should be taken into account when marking the decision in scoliosis management.

Leonard Berliner introduced faster and more reliable way of performing the scoliosis evaluation, which involves real time graphic feedback during stitching process. Using computerized techniques of image stitching and angle calculation, the task of scoliosis evaluation is more accurate, less time consuming and prone to fewer human error [47].

To develop a measurement with high resolution and accuracy, Chockalingam et al., [26] divided the vertebral column as a line that can be subdivided into number of segments. In which 16 points must be assigned manually to define the vertebral edges.

K M Diab, et al., proposed a new method of measurement for scoliotic curve [39]. They reported that the level of significance of inter- and intra- observer difference between new, Cobb and Ferguson methods were significantly higher in curve with Cobb method. In the new method, the end vertebra and apical vertebra and four corners of each vertebra were identified using manual decision and the midpoint of each line was determined with a ruler.

In 2002 John Chung, et al. started analysis [48] of scoliotic deformity by means of computerized digital analysis. This study was to determine the reliability of computerized measuring system. All the computerized methods are bounded with human intervention, either in deciding the endplates of vertebra or drawing the lines along those endplates.

Andrew V Linial et al., [49] proposed a direct method and apparatus for
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detection of Scoliosis. This innovative idea needs computer mouse to obtain continuous measurement of the human spine, hence ends with inter- and intra-observer error.

To determine the inter- and intra-observer reliability, Timothy done the analysis for adolescent idiopathic scoliosis to assess the three dimensional deformity. Their study concludes that reliability of digital radiographic measurement will have increasing importance as digital radiographic reading becomes more prevalent [50].

He continued his studies for comparison of manual and digital measurement for adolescent idiopathic scoliosis. As digital techniques becomes more advanced and affordable at higher volume of health care institutions. In addition to reducing the long term costs associated with the use of expensive and cumbersome radiograph film, digital imaging has many advantageous in terms of portability and ability to manage the radiographs with equal or potentially increased accuracy [51].

The role of preselection of end vertebrae are discussed by Brian in 2007 [52]. This comparison includes computer measurement of digitally acquired radiographs, manual measurement of hard copy and manual measurement of traditional films. To minimize previous identified errors manual measurement were performed with each examiner with same marking pencil. Examiners are allowed to alter brightness, contrast and magnifications of digital image to assist the measurement. To familiarize the examiner with software program each underwent an initial training period consisting of minimum 10 radiographs [52].

In 2007 Gstoettner et al., did the reliability assessment on the Cobb angle with manual versus digital measurement [53]. They used ICC for the reliability assessment. Digital radiography does not improve the measurement accuracy. For Cobb angle measurement, definition of the end vertebra introduces the main source of error [53].

Shannon et al., proposed a reliable Cobb angle measurement using ASM
in 2008 for idiopathic scoliosis [54]. They need a training set of radiographs representative of curves seen in scoliosis, to train the software to recognize the vertebrae and ASM cannot significantly deviate from variations and thus can only generate shapes similar to the training set. During the training set the boundary of the object is identified by manually digitizing N landmarks points around the perimeter of the object in an image.

In 2009 Hitesh Modi et al., [25] studied the reliability of Cobb angle between juvenile and adolescent idiopathic scoliosis. In their study two observers, independently measured the Cobb angle using computer based digital radiographs. Both the observer given predefined level of upper and lower endplates. Because of the pre-decision of the upper and lower end vertebrae, there was no significant difference in the Cobb angle measurement.

Satyen et al., studied statistical analysis on reliability of Cobb angle measurement between endplate versus pedicle. Vertebral endplates in younger children provides less distinct bony landmarks and pedicle may be more easily identifiable in children. This study has been done for child with less than 7 years [55].

Junhang et al., proposed an automated Cobb measurement using Fuzzy Hough transform with vertebral shape prior. This work incorporates the vertebral shape prior into the Fuzzy Hough transform to automatically detect the direction of end vertebrae. No training set is required but pre-selection of the end vertebrae are done using manual intervention [27].

Junhang continued his study for Cobb angle and vertebral rotation based on Hough transform and snake model. Both the algorithm were integrated with shape priors to improve the performance of evaluation. Since selection of end vertebrae was a possible source of error that had no relation to the technique involved in the Cobb measurement, end vertebrae were preselected in this study [56].

For the pediatric orthopedic [23], Eiten et al., did the reliability analysis for
the Cobb angle measurement using novel PACS computer software program. Their reliability relies on precise definition of bony landmarks for measurement angles, indexes and length of joints, limbs and spine. They concluded that most of the differences between specialist and non-specialist were insignificant. The correlation between the results according to the number of bony landmarks that needed to be identified was also insignificant.

Finally, technical report on Reliable Assessment of Cobb angle [57] using manual and digital methods says that Cobb angle in the PA view is an important parameter in the assessment of scoliosis, obtained from the radiographs. Technical advances allows increased use of digitized X-rays images in clinical practice. The computer assisted method is clinically advantageous and appropriate to assess the scoliotic curvature, but the end vertebrae selections are the unsolved problems.

### 2.6.2 Grading of Vertebral Rotation

Current research has provided a more comprehensive understanding of scoliosis as a three-dimensional spinal deformity, encompassing both lateral and rotational components. Apart from quantifying curve severity using the Cobb angle, vertebral rotation has become increasingly prominent in the study of scoliosis. The study reveals the efforts put by the researchers to accurately measure the vertebral rotation.

In 1948, Cobb [36] first proposed a method for assessing the angle of rotation of a vertebra based on the linear offset of the spinous process in relation to position of the vertebral body on PA radiographs. Nash-Moe [2] claimed that, as suggested by the Cobb method it is difficult to visualize the spinous process. He suggested in terms of displacement of pedicles instead of spinous process as quantifying parameter for vertebral deformity.

Drerup et al., [58, 59] improved the Nash-Moe method by modifying the
measurement of the position of anatomical landmark, which is the projection of vertebral pedicles. The accuracy of the measurement was affected by ignoring the facts such as increasing vertebral rotation; the radiographic projection of the vertebral body is not constant, resulting in inaccurate measurement of its properties (e.g. width of vertebra).

Benson et al., [60] explained calculation of rotation angle based on the pedicle position in radiographs images that likely resulted in errors: (1) significant changes in the shape of all vertebrae; (2) differences between actual pedicle and pedicle images; (3) inclination of vertebra on the sagittal plane. Stokes et al., [61] developed a procedure that separately marked six landmarks on both an anteroposterior-view and oblique radiographs to calculate vertebral rotation angles but it was the least accurate among all methods and had a very complex analytical system.

Instruments for measuring the vertebral rotation angle directly from the radiographic position of the inner edges of both the pedicles and from the center of the inner pedicle were designed by Perdriolle [62]. When such instrument was positioned on the radiograph so that it was lined with the lateral borders of the body of the measured vertebra, the line through the anatomical landmark on the inner pedicle shadow was used. Richards [62] et al., reported that precise measurement of vertebral rotation with the Perodriolle torsinometer should not be expected, especially due to obstruction of anatomical landmarks by metal implants, difficulties in precise marking of the pedicle and further variation caused by patient positioning. The accuracy of the above mentioned method depends highly on the ability to mark the anatomical landmarks on the radiographs.

In 2005 Kuklo et al., [63] studied reliability analysis for manual adolescent idiopathic scoliosis measurement. They reported that apical vertebral rotation assessed by the technique of Nash-Moe produced good intra observer reliability before surgery, but only fair reliability after surgery.
2.6.3 Scoliosis Classification

Classification procedure that rely on radiographic measure are used in surgical planning for patient with idiopathic scoliosis. The King classification relies on subjective identification and measurement of the radiographic features, including the apical and end vertebrae and vertebral endplates tilt. Errors in identifying these radiographic landmarks and using the resulting measurements in identifying the pattern of deformity provides numerous opportunities for both technical and judgmental errors, resulting in inter- and intra-observer error.

In 1998 Lawrence, et al., [3] has done a study to determine the reliability of the classification of thoracic adolescent idiopathic curves. They have a good team of 8 members from SRS. Each reviewer was provided with diagrammatic summary of the five types of the curves according to the classification. This study had two shortcomings, first they have an overall reviewer bias, as five of eight were members of a scoliosis study group and they have a different training background. Secondly, the curves were preselected by the lead author because they had a difficulty in classifying themselves. Finally, the mean inter observer reliability of the classification was only 64%, it is very poor.

In 2002 Ian, et al., [6] has done a study to reduce or eliminate the sources of errors. The measurement used in classification includes endpoints, range of lateral bending and parameters relating to spinal alignment and vertebral tilt. The purpose of their study is to report whether radiograph of a patient with idiopathic scoliosis could be reliably classified by the King’s method using unambiguous rules for classification encoded in computer program. There are two steps in the encoded computer method, first is to record the coordinates of the defined landmark on the radiographs, to assist objective determination of the parameters used to distinguish between group and second step is to apply the rule. This computerized algorithm works automatically only under the condition that required coordinates of the landmarks are clearly defined.
Defining the landmark on the noisy radiograph itself is a main source of error.

The most common problem in King’s classification is postoperative decomposition after selective thoracic fusion in King Type-II curves and comparative study among different institutes are eliminated because of its lower reliability and reproducibility. In 2005 Guixing, et al., [64] defined a new classification system, which categorizes idiopathic scoliosis into 3 different types according to the number of curves. As it is a new classification system, SRS adopted King’s as the standard method. Further study on the reliability and reproducibility of this system at other spinal centers are needed.

In 2006 Ian, et al., [30] continued their study on the reliability of the classification. In this study they want to check how much the above mentioned computer assisted algorithm is reliable. Their conclusion is that there is an influence of experience of the individual using computer assisted tool, magnitude of scoliosis and image quality.

In 2010 Manuel D Rigo, et al., [65] introduced a new classification system which will correlate with surgical treatment. They showed that proposed new classification has better inter- and intra- observer reliability with brace treatment. But their new system needs human intervention in identifying the position of the transition point between thoracic curve and caudal curve along with its CSL.

2.7 Statistical measures for inter- and intra-observer variability of the methods

A single quantitative measurement of a spine parameter depends on the unknown true value, the inability of the observer or method to repeat multiple measurements (i.e., repeatability, reproducibility or intra-observer variability), and the bias of the observer or method (i.e., reliability or inter-observer vari-
ability). Various statistical measures for inter- and intra-observer variability of the measurements are available. Some of them, which are used in this thesis are discussed below with its meaning and interpretation; wherever it is used in the subsequent chapters the reader is requested to refer this section.

Meaning of some terms used in following statistical equations:

- $N$ - number of measurements,
- $m_i, n_i$ measurement values,
- $\bar{m}, \bar{n}$ - mean measurement values,
- $r$ - the reliability coefficient that estimates the amount of consistency

**Root-Mean-Square Error (RMSE):**

It is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. It is a good measure of accuracy. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (m_i - \bar{m})^2} \quad (2.1)$$

Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable.

**Mean Absolute Difference (MAD):**

It is a measure of statistical dispersion equal to the average absolute difference of two independent values drawn from a probability distribution.

$$MAD = \frac{1}{N} \sum_{i=1}^{N} |m_i - \bar{m}| \quad (2.2)$$
The RMSE and the MAD can be used together to diagnose the variation in the errors in a set of forecasts. The RMSE will always be larger or equal to the MAD; the greater difference between them, the greater the variance in the individual errors in the sample. If the RMSE=MAD, then all the errors are of the same magnitude.

Both the RMSE and MAD can range from 0 to $\infty$. They are negatively-oriented scores and lower values are better.

**Standard Deviation (SD):**

It is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or dispersion there is from the average (mean, or expected value). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data are spread out over a large range of values.

Technically, the standard deviation of a statistical population, data set, or probability distribution is the square root of its variance. It is algebraically simpler though practically less robust than the average absolute deviation. A useful property of SD is that, unlike variance, it is expressed in the same units as the data.

$$SD = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (m_i - \bar{m})}$$  \hspace{0.5cm} (2.3)

Both the SD and the MAD dispersion—how spread out are the values of a population or the probabilities of a distribution. The mean difference is not defined in terms of a specific measure of central tendency, whereas the SD is defined in terms of the deviation from the arithmetic mean. Because the SD squares its differences, it tends to give more weight to larger differences and less weight to smaller differences compared to the mean difference. When the arithmetic mean is finite, the mean difference will also be finite, even when the standard deviation is infinite.
Correlation coefficient (R):

It measures the strength and the direction of a linear relationship between two variables. The linear correlation coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson.

\[
R = \frac{\sum_{i=1}^{N} (m_i - \bar{m})(n_i - \bar{n})}{\sqrt{\sum_{i=1}^{N} (m_i - \bar{m})^2 \sum_{i=1}^{N} (n_i - \bar{n})^2}} \tag{2.4}
\]

The value of R is such that \(-1 < R < +1\). The + and – signs are used for positive linear correlations and negative linear correlations, respectively.

Positive correlation: If \(m\) and \(n\) have a strong positive linear correlation, \(R\) is close to +1. An \(R\) value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between \(m\) and \(n\) variables such that as values for \(m\) increases, values for \(n\) also increase.

Negative correlation: If \(m\) and \(n\) have a strong negative linear correlation, \(R\) is close to −1. An \(R\) value of exactly −1 indicates a perfect negative fit. Negative values indicate a relationship between \(m\) and \(n\) such that as values for \(m\) increase, values for \(n\) decrease.

No correlation: If there is no linear correlation or a weak linear correlation, \(R\) is close to 0. A value near zero means that there is a random, nonlinear relationship between the two variables.

Note that \(R\) is a dimensionless quantity, which means that it does not depend on the units employed.

A perfect correlation of 1 occurs only when the data points all lie exactly on a straight line. If \(R = +1\), the slope of this line is positive. If \(R = -1\), the slope of this line is negative.

A correlation greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak. These values can vary based upon the type of data being examined. A study utilizing scientific data
Background

may require a stronger correlation than a study using social science data.

**Coefficient of Variation (CV):**

It is a normalized measure of dispersion of a probability distribution. It is also known as unitized risk or the variation coefficient.

\[ CV = \frac{SD}{\bar{m}} \]  \hspace{1cm} (2.5)

The coefficient of variation is useful because the SD of data must always be understood in the context of the mean of the data. The coefficient of variation is a dimension less number. So for comparison between data sets with different units or widely different means, one should use the coefficient of variation instead of the SD.

**Intra- or inter-class correlation coefficient (ICC):**

It is a descriptive statistic that can be used when quantitative measurements are made on units that are organized into groups. It describes how strongly units in the same group resemble each other. While it is viewed as a type of correlation, unlike most other correlation measures it operates on data structured as groups, rather than data structured as paired observations.

\[ ICC = \frac{SD_{(intra \ or \ inter)}}{SD_{intra}^2 + SD_{inter}^2} \]  \hspace{1cm} (2.6)

The ICC is commonly used to quantify the degree to which individuals with a fixed degree of relatedness resemble each other in terms of a quantitative trait.

**Standard Error of Measurement (SEM):**

It is an estimate of error to use in interpreting an individual’s test score. A test score is an estimate of a person’s true test performance. Using a reliability
coefficient \((r)\) and the test’s SD, one can calculate this value:

\[
SEM = SD\sqrt{1-r}
\]  \hspace{1cm} (2.7)

The higher a test’s reliability coefficient, the smaller the test’s SEM. The larger the SEM the less reliable the test is.

**Kappa**

Cohen’s kappa \((\kappa)\) measures the agreement between two raters who each classify \(N\) items into \(C\) mutually exclusive categories. The equation for \(\kappa\) is,

\[
\kappa = \frac{Pr(a) - Pr(e)}{1 - Pr(e)}
\]

where \(Pr(a)\) is the relative observed agreement among raters, and \(Pr(e)\) is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category. If the raters are in complete agreement then \(\kappa = 1\). If there is no agreement among the raters other than what would be expected by chance (as defined by \(Pr(e)\)), then \(\kappa = 0\).