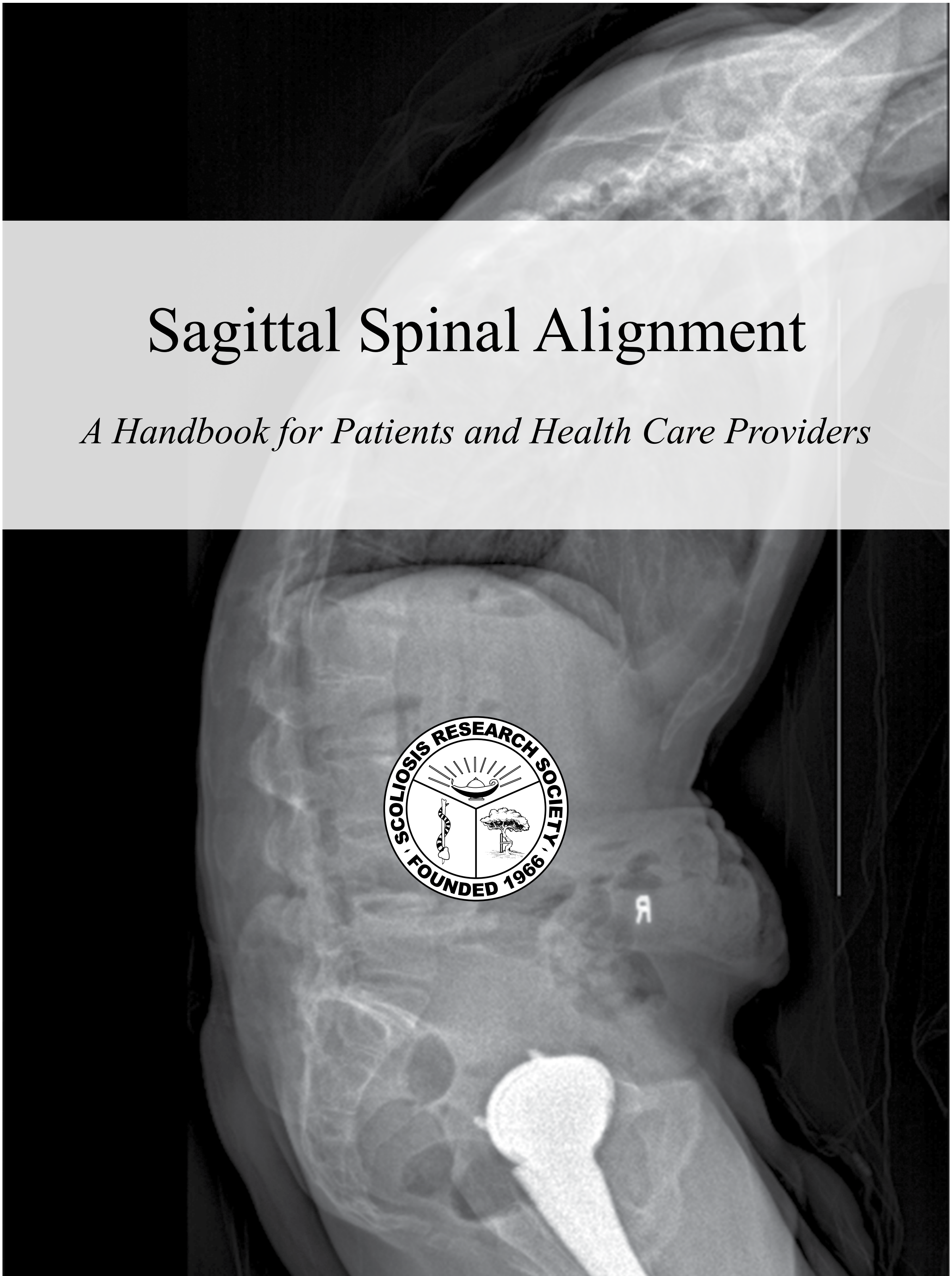
Sagittal Spinal Alignment

A Handbook for Patients and Health Care Providers



SCOLIOSIS RESEARCH SOCIETY
FOUNDED 1966

Scoliosis Research Society
Dedicated to Education, Research and Treatment of Spinal Deformity
555 East Wells Street, Suite 1100
Milwaukee, WI 53202
Phone: (414) 289-9107 | Fax: (414) 276-3349
Email: info@srs.org

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A Note from the Scoliosis Research Society

Surgery for adult spinal deformity (ASD) has become increasingly prevalent. The significant disability associated with the condition, as a result of chronic back pain, secondary nerve compression, and deformity has necessitated innovative surgical procedures. With advancements in medical care, as well as improvements in implant technology and surgical techniques, corrections and procedures deemed impossible in the past are now performed on a regular basis around the world.

As with all procedures, the balance between risks and benefits should be carefully considered prior to undergoing these surgeries. New procedures lead to improvements in outcomes, but they can also be associated with different complications, and thus we must improve our understanding of the resultant impact of these factors on the overall success of these procedures.

In this regard, the significance of sagittal alignment (global postural alignment) of the spine has been found to be a key factor associated with the outcome of spinal deformity surgery. Sagittal alignment is the side profile. Through research, many factors have been found to contribute to a person's upright posture. The angle that is formed between a person's spine and the pelvis, the pelvic incidence (PI), is a major contributor to the amount of sway (lordosis) that is required in the lower back (lumbar spine) as well as to how much roundness (kyphosis) is required in the upper back (thoracic spine). Based on the PI, a patient will adjust their lumbar lordosis and thoracic kyphosis to find a posture that is associated with the most energy efficient way to stand upright.

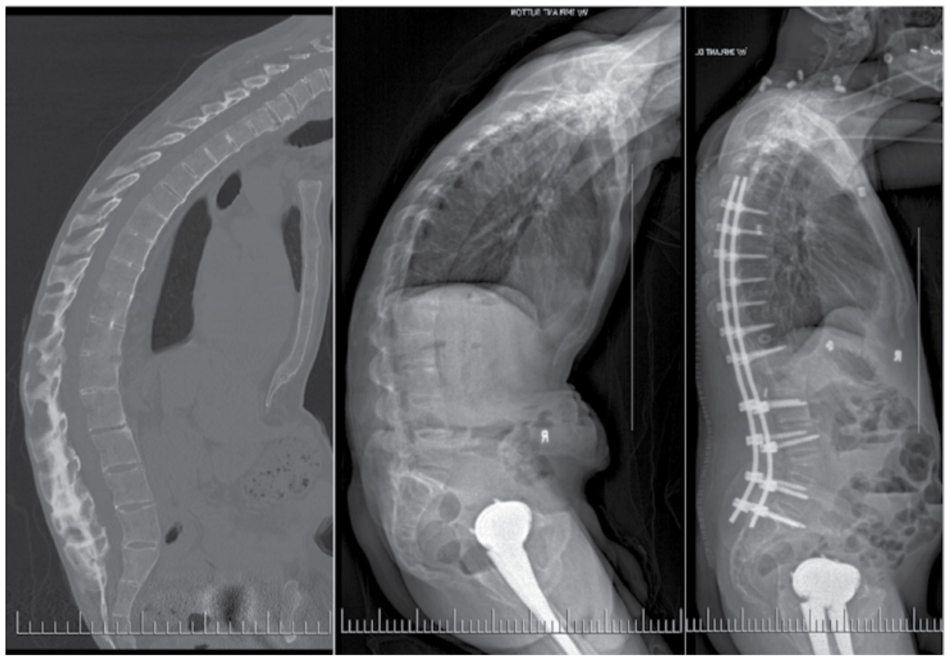
When pathological conditions affect the spine, either globally or regionally, the balance between the lumbar lordosis and thoracic kyphosis can become disrupted, interfering with the ability to maintain an efficient upright posture. Through this handbook, we will describe the normal alignment, describe pathologies associated with misalignment, compensatory mechanisms at play, how and when to manage the pathology, and what treatment options are available to manage and restore the natural balance.

On behalf of the Adult Deformity Committee of the Scoliosis Research Society, we have undertaken this handbook to provide our patients and health care providers with a better understanding of their spinal condition, what treatment options are available, and to supplement the information and options provided to you by your treating medical professionals. The SRS website provides other useful links and information on this and other related topics.

—The Scoliosis Research Society's Adult Spinal Deformity Committee

Table of Contents

Chapter 1: Adult Spinal Deformity



Anatomy of the Spine

Before entering into the details of spinal deformity and other diseases of the spine, it is important to understand the normal anatomy, or the components that make up the spine. The spine is the main element of the axial skeleton (trunk portion) and plays important roles.

- *Support:* It acts as a truss, supporting the trunk and making the connection with the head and the appendicular skeleton (upper and lower limbs). Together with the paraspinal muscles, it supports the body for upright posture.
- *Protection:* The spinal column provides protection to the spinal cord and nerves.
- *Mobility:* The spine is flexible allowing complex movements that include flexion/extension, rotation, and side bending.

To accomplish these goals, we have to appreciate the structure of the spine which is made by the stacking of bones (vertebrae), connected to each other and stabilized by muscles, ligaments and discs. *(Figure 1)*

fig.1

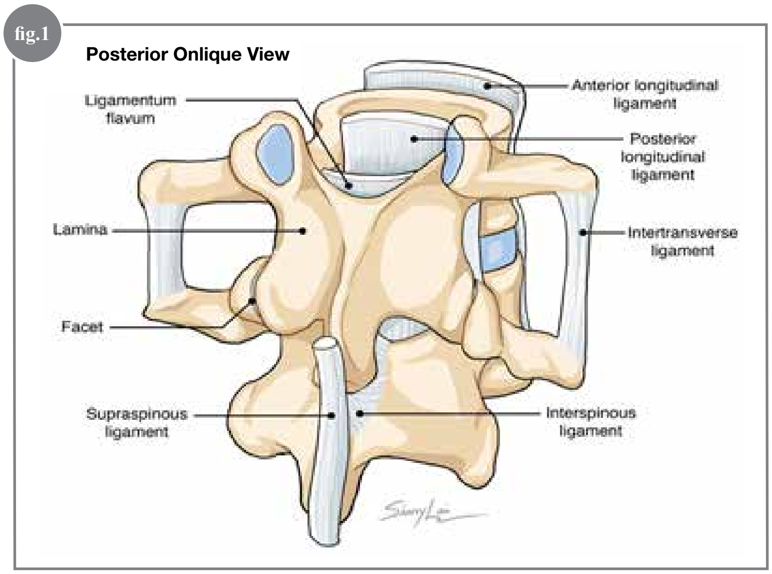


Figure 1:
A view from the back side of the lumbar spine depicting the bony and ligamentous structures.

Joints of the Spine

- *Intervertebral Discs:* This is a fibrous structure sitting in between two vertebral bodies that acts as a shock absorber. It is made of two parts: the annulus (surrounding, outer tissue) and the nucleus pulposus (inner core). Discs are central structures that are located in the front (anterior) part of the spine and are most loaded with flexion (bending forward) movements.
- *Facets Joints:* These are paired joints (right and left) that are located in the back (posterior) part of the spine. They are oriented in different directions at each level of the spine to direct the preferred motion of that particular motion segment (a combination of rotation, flexion/extension, and side bending). The facet joints that link vertebrae together may degenerate, just as other arthritic joints like the knees or the knuckle joints in fingers do. As part of the arthritic process, the facet joints can enlarge and take up space in the spinal canal, putting pressure on the nerves that run through and exit the spinal canal.

Ligaments, Muscles and Nerves

- *Ligaments:* Ligaments stabilize the spine by acting as tension bands. The main ligaments are the ligamentum flavum, the anterior and posterior longitudinal ligaments and the inter-spinous ligaments.
- *Muscles:* Responsible for movements of the spine and play a major role in the maintenance of its natural shape.
- *Nerves:* Run through the spinal canal giving off nerves that exit at each spinal level. Each nerve provides innervation to specific muscles which it powers as well as provide sensation to a specific region.

Bone

The spine is formed by the stacking of 24 vertebrae that are positioned on the sacrum and pelvis. The vertebral bodies increase in size as we go from the head to the pelvis to accommodate the increasing weight which is supported. The spine is divided into four sections: *(Figure 2)*

- *Cervical Spine:* Comprised of 7 cervical vertebrae (C1 to C7), highly mobile that is integrally related to the movements of the head
- *Thoracic Spine:* Comprised of 12 thoracic vertebrae (T1 to T12) that form a very rigid area. The region is intimately connected to the chest wall with each thoracic vertebra connected to a pair of ribs.
- *Lumbar Spine:* Comprised typically of 5 lumbar vertebrae (L1 to L5) forming a relatively mobile area, responsible for the majority of the motion through the trunk.
- *Sacrum/Coccyx and Pelvis:* The sacrum is formed by five vertebrae fused to each other, which are fused to the four coccyx bones that are attached at its lower end. Together this combination of nine bones form the tail bone. The sacrum is articulated to the lumbar spine on its upper surface and to the iliac bones on each of its sides through the sacro-iliac joints (SI Joints). This is the pedestal of the spine and the connection between the trunk and the lower limbs.

fig.2

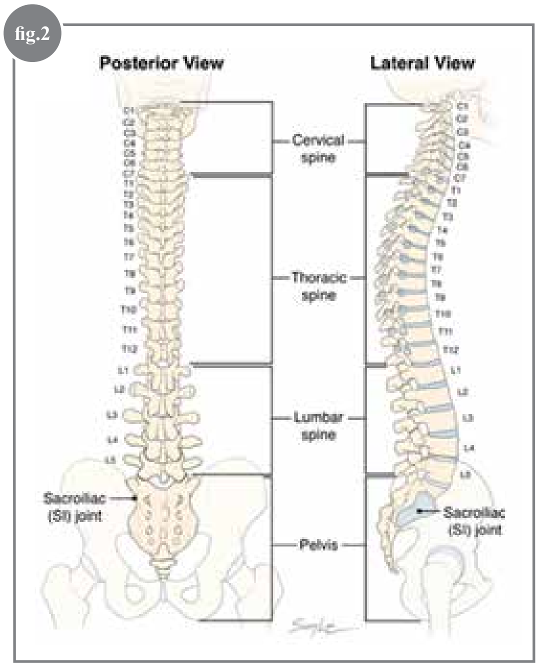


Figure 2:
Figure demonstrating the posterior and lateral views of the bony elements and normal alignment of the 7 cervical, 12 thoracic, and 5 lumbar vertebrae as they are related to the sacrum and pelvis below and the occiput above.

Spinal Alignment

The spine is generally viewed in two planes: coronal and sagittal. The coronal plane is the spine viewed from the front (anteroposterior) or back (posteroanterior). The sagittal plane is the spine viewed from the side. Rotational plane is not part of the normal spinal alignment, but represents an important plane in pathological conditions such as scoliosis.

Coronal Alignment:

When viewed from the front or back, (the coronal plane), the normal shape of the spine is close to a straight line with the head centered over the middle of the pelvis. Small deviations to the right or left from this normal are relatively common. Scoliosis is the main condition associated with coronal deviations of the spine, but maybe also seen as a result of non-spinal conditions such as leg length discrepancy.

Sagittal Alignment:

When viewed from the side (sagittal plane or lateral view), the spine has 3 main curvatures: a cervical lordosis (anterior convexity or swayback), a thoracic kyphosis (posterior convexity or roundback) and a lumbar lordosis (anterior convexity or swayback) shown in *figure 3*. Lordosis stems from the Greek root lordos, meaning “bent backward” whereas kyphosis stems from the root kyphos, meaning “hunched”. While they may be unfamiliar terms, kyphosis and lordosis are of crucial importance to the normal function of the spine. The curves relate to one another to enable the head to rest over the pelvis. These curvatures exist because, from a biomechanical point of view, it allows an optimal functioning of the muscles.

fig.3

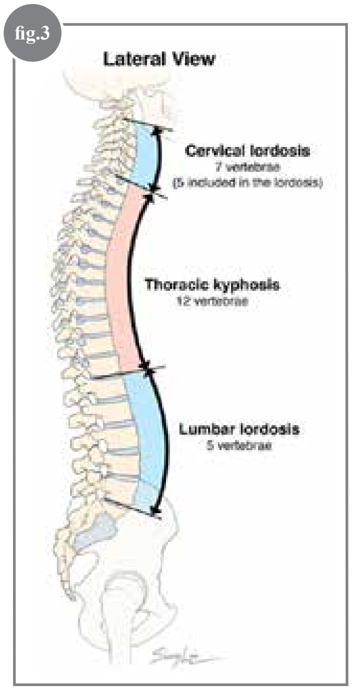


Figure 3:

Depiction of the normal contours of the cervical, thoracic, and lumbar spines with upright posture

Upright Posture and Alignment:

Each person finds their most efficient way to stand upright, determining the right amount of thoracic kyphosis and lumbar lordosis for their posture. This is greatly influenced by the angle formed between the spine and the pelvis, the pelvic incidence (PI). People with a high sagittal angle of the base (PI) of the spine will require a greater amount of lumbar lordosis and thoracic kyphosis to maintain an upright posture. Conversely, patients with low PI, require smaller amounts of lumbar lordosis and thoracic kyphosis. It is important to note that there is no normal mean value of what the PI should be; each individual has his/her own value and will adapt the shape of the spine to the PI value. The surgeon has to evaluate this factor pre-operatively.

What is Adult Spinal Deformity?

Adult Spinal Deformity is a broad term used when the shape of the spine differs from the previously described “normal” shape. This 3-dimensional deformity can be described in its deviation from normal when looking at the patient’s spine from the front, from the side, or both. A spine can be deformed in the coronal plane (i.e. scoliosis -associated with rotational deformity), in the sagittal plane (i.e. kyphosis), or in the translational plane (i.e. slipped vertebra, known as spondylolisthesis). Since most symptoms are associated with the severity of the deformity in the sagittal plane, this handbook focuses primarily on sagittal deformities or malalignment.

What is Sagittal Malalignment?

Sagittal malalignment occurs when a structural abnormality of the spine interferes with a person’s ability to stand upright. Sagittal malalignment can be **compensated**, i.e. other parts of the spine or pelvis make necessary adjustments to maintain the upright posture, or **imbalanced**, when either the magnitude of the deformity is too great or the ability of the non-deformed segments to compensate are insufficient to maintain an upright posture.

Causes of Sagittal Malalignment:

There are multiple causes that contribute to sagittal malalignment.

- Degenerative: Over time, natural wear and degeneration occurs in the discs and the facet joints that cause the spine to lose some of its lordosis and assume a more kyphotic posture with the trunk tilting anteriorly *(Figure 4, Figure 5 G, H)*
- Osteoporosis: Severe osteoporosis can be associated with vertebral fractures and secondary kyphosis.
- Trauma: Fractures of the spine cause a loss of the height of the front of the vertebral body. This creates a focal segment of kyphosis.
- Spondylolisthesis, Slip Vertebra: Can be associated with severe kyphosis at the L5-S1 level *(Figure 5 A, B)*.
- Deformity Conditions: Spinal deformities can disrupt the normal sagittal alignment of the spine. Scoliosis can be associated with either a loss or an excess of the normal thoracic kyphosis. Scheuermann’s, kyphosis *(Figure 5 C, D)*, a condition that occurs during adolescence, is associated with an excessive amount of thoracic kyphosis.
- Infection: Infections in the spine are rare, but when they occur, significant destruction of the disc space occurs, occasionally affecting the adjacent vertebral bodies leading to a focal segment of kyphosis.
- Tumors: Tumors affecting the spinal column can cause significant destruction of the vertebral elements leading to a kyphotic deformity.
- Congenital: Malformations of the vertebrae, either failure to develop or failure to separate can lead to fixed kyphotic deformities of the spine *(Figure 5 E, F)*.

fig.4

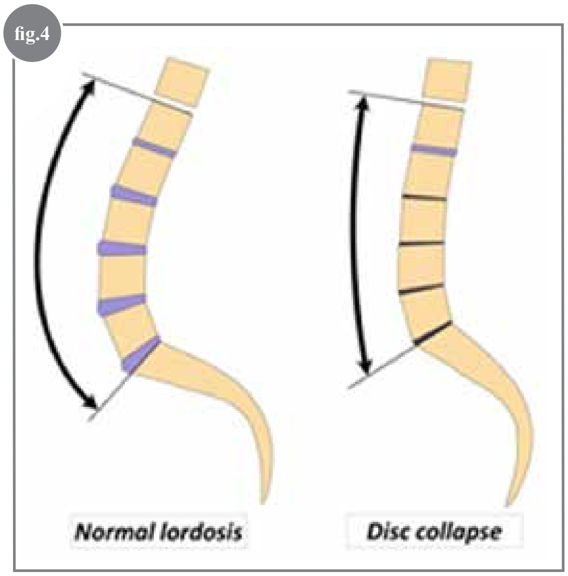


Figure 4:
Depiction of the normal contours of the cervical, thoracic, and lumbar spines with upright posture

fig.5

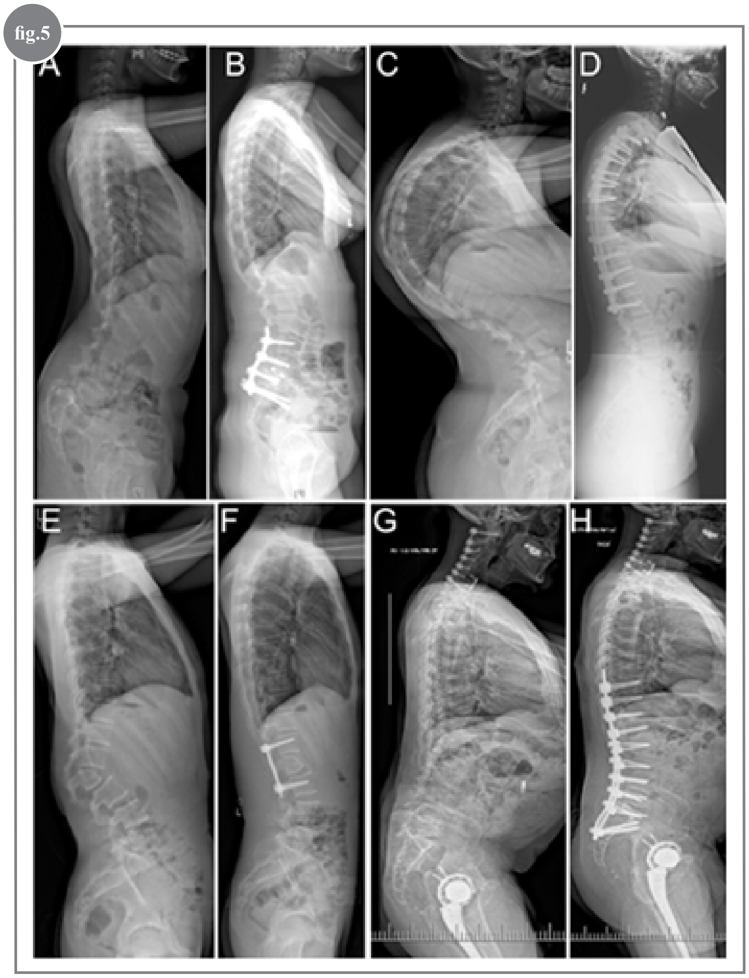


Figure 5:

Examples of conditions leading to sagittal malalignment are depicted in this figure. Figure A demonstrates a high-grade spondylolisthesis at L5-S1 causing a kyphotic deformity at this level. The remaining spine lordosis to compensate and requires retroversion of the pelvis to maintain an upright posture. Following surgical fusion of the region with reduction of the deformity at L5-S1 (B), the remaining spine and pelvis are able to return to their normal postures. Figure C depicts a severe thoracic deformity secondary to Scheuermann's kyphosis. Significant hyperextension of the lower lumbar levels and pelvis are required to compensate for the deformity. Following osteotomies (cutting through the bone) of the thoracic spine and stabilization of the spine from T2 to L2 (D), the lumbar spine assumes a more physiological position. Similar compensatory mechanisms are illustrated in Figure E secondary to congenital (present at birth) malformation of the L2 vertebra, which reverse with a short fusion (F), and in Figure G, secondary to lumbar degenerative kyphosis, that required a more extensive reconstruction (H), to restore sagittal balance.

- Previous Spinal Fusions: With the more recent understanding of the importance of the sagittal profile, many remote surgeries were performed without properly realigning the spine. Harrington rods, in particular, failed to restore the desired thoracic kyphosis and lumbar lordosis leading to the 'flat back' phenomenon, associated with late degeneration of the adjacent mobile segments. Even with modern instrumentation, sagittal malalignment could result through failure to restore the desired sagittal alignment with prior surgery, or as a result of other adjacent levels to the surgery breaking down or degenerating.
- Neuromuscular Conditions: Diseases such as Parkinson's or stroke/brain injury can result in spinal deformities leading to significant sagittal malalignment.
- Inflammatory Conditions: Ankylosing spondylitis is a condition associated with ossification of the ligaments of the spine and is associated with rigid kyphotic deformities and sagittal malalignment.

Compensation Mechanisms in Response to Sagittal Malalignment

The spine develops natural compensatory mechanisms to overcome spinal deformities to maintain an upright posture with the torso "as vertical as possible". For conditions with excessive thoracic kyphosis *(depicted in red in figures 6),* a mobile lumbar spine will compensate by increasing the lumbar lordosis through the discs and facets. For conditions associated with kyphosis at the junction of the thoracic and lumbar spine (i.e. the thoracolumbar junction), both the remaining mobile thoracic and lumbar spines compensate by increasing lordosis. For conditions causing lumbar kyphosis, the thoracic spine will compensate by increasing lordosis (straighten) as much as possible.

If the amount of compensation is inadequate to restore an upright posture, the body will recruit other regions to compensate. The first of these is the pelvis. The pelvis will retrovert (tilt backwards) to help restore the upright posture. Generally, the pelvic contribution is sufficient, but if the deformity is too severe, extension of the hips combined with flexion of the knees can provide the last bit of help. If the deformity is too great or if the pelvis/hips become too stiff to compensate, the patient will assume a forward stooped posture.

fig.6

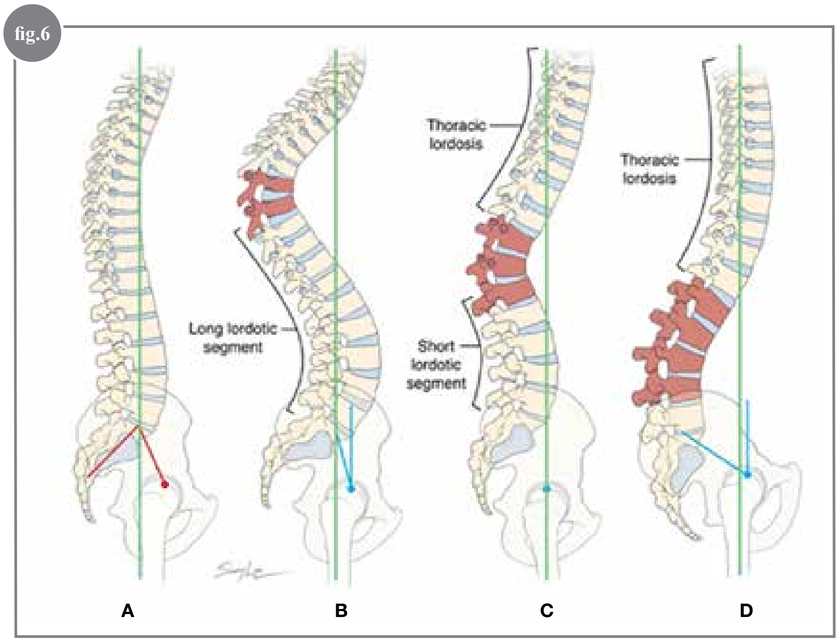


Figure 6:

Compensation for deformities occurs in the regions of the spine that are not affected by the condition causing the deformity, and are therefore able to make adjustments to maintain an upright posture. The pathological region affected by the structural deformity is depicted in red in the figures. The illustration on the left (A) demonstrates a normal spine. For conditions leading to excessive kyphosis in the midthoracic region (B), the normal lumbar spine compensates by increasing the lordosis. For deformities in the lower thoracic/upper lumbar region (C), compensation occurs by increasing the lordosis in the thoracic and lumbar spines. For deformities in the lumbar region (D), the thoracic spine tries to compensate through increasing lordosis. This in general is insufficient and the pelvis has to help out to maintain an upright posture by tilting back (retroverting).

Why is Sagittal Malalignment Important?

As stated previously, people will stand in the most economic position possible to maintain an upright posture. However, if a structural deformity exists, compensatory mechanisms in the spine, pelvis, or limbs will help out to maintain this posture. This will require more effort and energy to both stand and walk. This inefficiency and extra work greatly impact the standing tolerance and comfortable walking distance a patient can achieve and may increase back muscle fatigue leading to back pain. This is analogous to swimming when not floating. Excess energy is expended to maintain flotation at the expense of propelling the body forward.

An additional consideration is that compensatory mechanisms may have negative impact on the wear of other joints such as the hips and knees. The extra effort required of the joints of the lower extremities are relied upon to overcome the spinal deformity.

From a medical standpoint, sagittal malalignment has been recognized as a highly important factor in affecting a patient's quality of life and function. Individuals with sagittal malalignment will have a far lower level of function than unaffected people in their age groups and they can experience more health problems as they relate to other organ systems (heart, lungs etc.). Furthermore, their general overall function has been shown to be even worse than patients suffering from coronary artery disease, diabetes, and liver failure. Sagittal malalignment can be considered a problem of general health since it affects not only the spine, but the overall physical and mental well-being of the individual.

fig.7

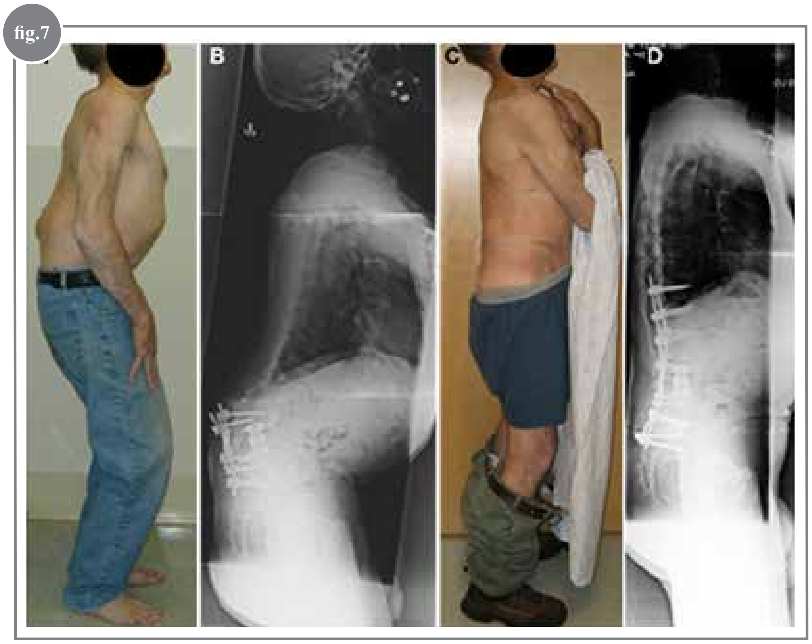


Figure 7:

Individual with severe lumbar kyphosis (A, B) following surgery for a traumatic injury to L4. Note the hyperextended posture of his thoracic spine, the tilting back of his pelvis and flexion of his hips and knees to maintain an upright posture. This posture requires significantly more energy to walk distances leading to decrease in overall function with a negative impact on health. Restoring the alignment can have a very positive impact on the patient's quality of life (C, D).

Signs, Symptoms and Evolution

Sagittal Malalignment

Individuals affected with sagittal malalignment rarely have rapid deterioration (within less than one year) based on x-rays alone. It is recommended that a physician with understanding of this disease entity monitor those affected by this problem. It is more common to see individuals with slowly progressive symptoms. Most people can cope with a mild amount of sagittal deformity; however, as this postural problem progresses, individuals find that they have less energy available to perform their activities of daily living. Furthermore, patients will complain of increasing back pain, difficulty walking or standing, and will likely not participate in social events for lack of energy, excessive pain, inability to stand for long periods, or the embarrassment of being seen in public with a stooped forward posture.

Sagittal malalignment can result in a variety of clinical signs and symptoms. Individuals may experience one or more of the following:

- Unexpected tiredness with walking and fatigue in the thighs/legs
- Feeling/being stooped forward
- Difficulty in climbing slopes/stairs
- Inability to stand for prolonged periods of time
- Bending the knees and tucking the tailbone to maintain an upright posture
- Feeling tired earlier in the day than usual
- Significant low back pain
- Needing to lean on objects to relieve pressure on the lower back (ex: shopping carts, walls, counters, etc.)
- Radiating nerve pain down the back of the thigh and sometimes into the calf and foot

In advanced cases, as the degree of the deformity increases, patients may experience more severe symptoms which may range from loss of appetite and further fatigue to chest pain and rib fractures from repetitive contact of the ribs against the pelvis. Patients with a severe deformity may also experience a worsening of other medical conditions.

Scoliosis

Scoliosis is a coronal and rotational deformity of the spine. It can often be associated with sagittal malalignment, as well. In adults, scoliosis can be a slow progression of a condition arising in childhood or can present as a new condition. The deformity can lead to accelerated wear of the discs and facets and cause compression of the nerves from the degeneration, most often on the concave side of the curve. Symptoms experienced with scoliosis can range from locaized back pain, deformity, and radicular pain, generally worse with standing and walking.

Diagnosis of Adult Spinal Deformity

Diagnosis of adult spinal deformity is based both on a physical exam and radiologic tests such as x-ray, MRI, and CT-Scans.

Radiographic Evaluation of Sagittal Malalignment

Sagittal malalignment means abnormal curvatures of the spine seen from the side. A thorough radiographic evaluation of the patient should include the curvature of the spine, the overall posture of the patient, and the compensatory mechanisms recruited by the patient.

Standing long radiographs of the entire spine (3 foot spine x-rays) are performed in the coronal plane (from the front) and sagittal planes (from the side- lateral). The AP x-ray shows whether there is an associated scoliosis, to assess the balance of the head over the pelvis, and to assess balance of the shoulders. The lateral x-ray is examined for the following:

1. The overall sagittal balance of the patient standing. This is measured from a line drawn downward from the middle of the 7th cervical vertebral body (SVA – sagittal vertical axis). That line should fall within 5 centimeters from the back of the L5-S1 disc space. If that line is in front of that point, the patient is considered to have positive global sagittal malalignment. If the patient is able to compensate through the mobile segments of the spine and pelvis, maintaining their overall alignment in the normal range, they are considered to have a compensated deformity. If the patient is unable to compensate, even with the help of the hips and knees, the SVA will be greater than 5 cm *(Figure 8)*.
2. The amount of thoracic kyphosis, lumbar lordosis, and cervical lordosis. Normal thoracic kyphosis is generally between 30 and 45°. Normal lumbar lordosis is related to the PI and should be specific to each patient.
3. Pelvic Parameters: Measurements are made of the patient's pelvic incidence (PI) and its components that include the sacral slope (SS) and the pelvic tilt (PT) *(Figure 8)*.
4. Compensatory Mechanisms: Patients with sagittal malalignment will attempt to compensate for their deformity when standing. This will manifest itself by increasing the lordosis of the thoracic and lumbar levels not involved in the deformity. If that compensation is insufficient, the patients will tilt their pelvis back.

fig.8

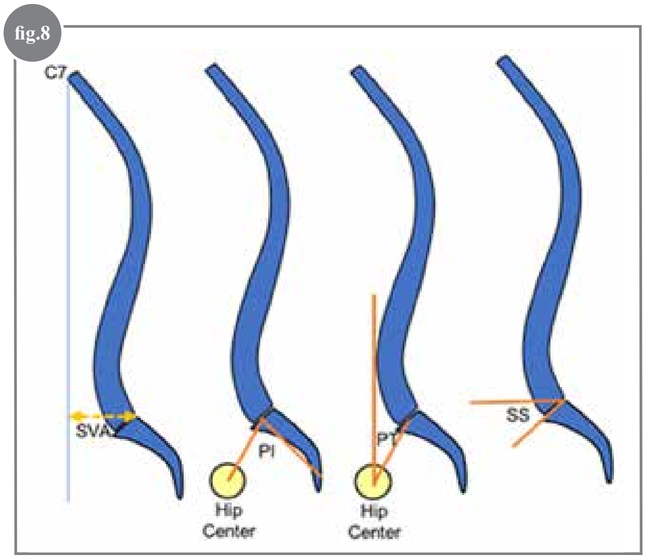


Figure 8:
Illustrations of sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS).

Other Imaging Techniques

In addition to the radiographic evaluation, MRI *(Figure 9)* and/or CT-scan of the spine provide useful information both for planning and diagnosing the condition. Nerve compression, degeneration of the discs, and fat infiltration in the muscles are clearly identified on the MRI scan. The bony anatomy, bone spurs, vertebral fusion and planning for possible instrumentation of the spine like pedicle screws, are best identified on the CT scan. Together with the full spine and bending or traction x-rays, the surgeon will have a clear understanding of your condition and is in the best position to plan surgery if it is required.

fig.9

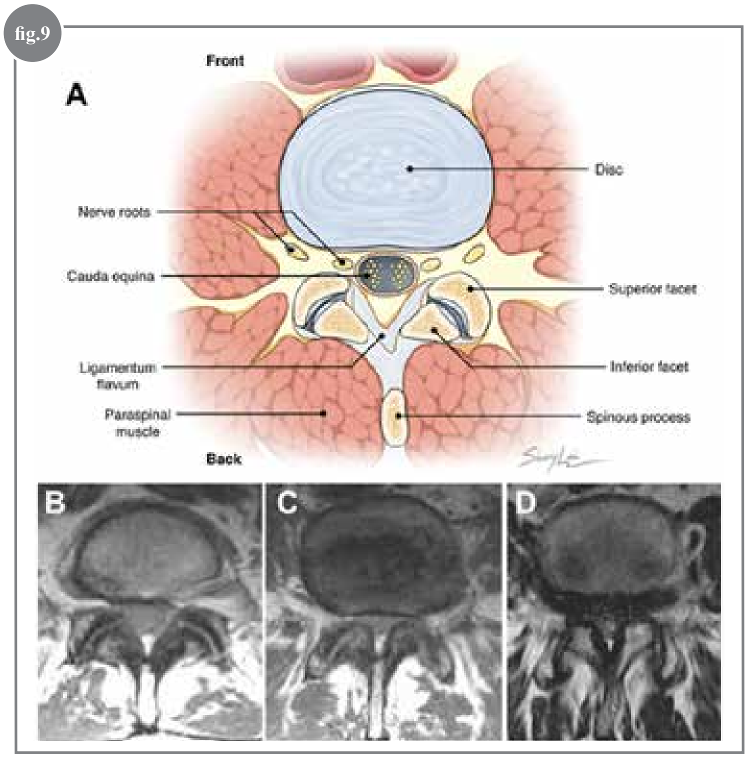


Figure 9:

Schematic (A) illustrates the cross-sectional anatomy visualized on an MRI of the lumbar spine. Narrowing of the spinal canal from a combination of disc bulge, thickening of the ligamentum flavum, and arthritic changes of the facet joints leads to varying degrees of spinal stenosis. Figure B represents a fairly normal spinal canal, with C demonstrating moderate spinal stenosis and D showing severe spinal stenosis.

Chapter 2: Treatment Options

Non-Surgical Management

The goals of non-surgical management include decreasing pain and improving function. The strategy for non-surgical care involves a combination of treatments including:

- Prevention
- Activity modification
- Therapeutic interventions
- Medications
- Bracing or other supports

The elements of **prevention** consist in the practice of a regular physical activity with dissociation of the scapular and pelvic belts and the adaptation of the sitting position with anterior flexion of the trunk while maintaining lumbar lordosis

Activity modification includes paying attention to and identifying the various activities that provoke pain. Keeping track with a journal can help identify these activities. Once the activities are identified, simply avoiding them where possible can result in a reduction of pain. It is not uncommon for an activity to precede the pain by 24-48 hours.

Therapeutic interventions include physical therapy (more specifically Physiotherapy Scoliosis Specific Exercises), chiropractic care, acupuncture and other non-supervised exercise programs such as Pilates and yoga. It is recommended that if pain and dysfunction exist, these therapies be supervised or be under the direction of a physician accustomed to treating sagittal malalignment.

Medication can also be used to help with pain from sagittal balance issues. Inflammation is the result of activity aggravating the spine and the use of anti-inflammatory medication can be beneficial. Opioid medications have been used in the past; however, they should be used as sparingly as possible and reassessed frequently.

Attention to proper diet and bone health are extremely important in maintaining bone mass and preventing osteoporotic fractures that could further exacerbate sagittal malalignment. It is important to work with your doctor to ensure that bone density testing is up to date and that appropriate treatments, if required, are instituted *(Figure 10)*.

fig.10

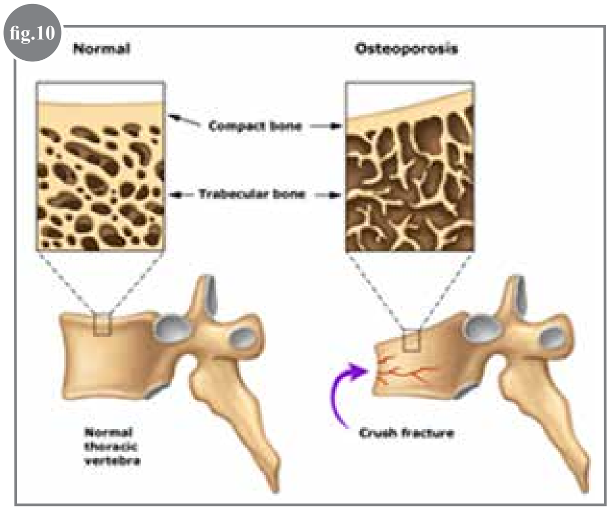


Figure 10:

Schematic comparison of normal and osteoporotic bone showing thinning of the trabecular leading to kyphotic collapse of the vertebra

Bracing, when done with soft braces, has not been found to be effective in improving sagittal malalignment; however, it may be used on a temporary basis to improve low back pain. Patients should not rely on a brace for an extended period of time as ultimately it may cause further weakening of the spinal muscles.

Sagittal malalignment is often associated with spinal stenosis *(nerve compression, see Figure 9)* that is generally worse with activities that involve spinal extension such as standing and walking. Use of a wheeled walker can assist patients by allowing them to bend forward while walking, therefore taking the pressure off the nerves. A cane can be used as well but is not as effective in alleviating the nerve compression as the walker.

Injections *(Figure 11)* can be effective in alleviating some of the back pain or nerve pain. Injecting local anesthetic and cortisone around the facet joints and/or nerve roots can provide temporary relief of the symptoms. These can be given as single shots or a series of three injections. These injections can be repeated if they are effective in managing the symptoms.

fig.11

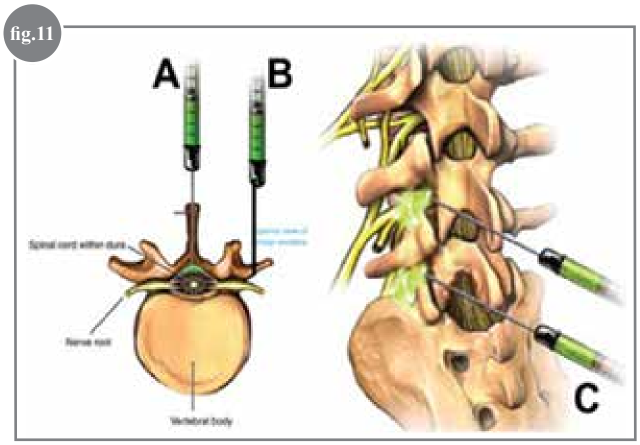


Figure 11:
Schematic of an epidural (A) injection, selective nerve root (B) injection done for patients with predominantly leg pain. For patients suffering from back pain, facet blocks (C) can provide relief.

Ultimately, it is important to note that there have been no scientific studies that have shown that non-surgical management of sagittal imbalance is effective for long term management of pain and functional difficulties. For patients with severe dysfunction, surgical treatment may be recommended to address both the alignment and nerve decompression *(Figure 12)*.

fig.12

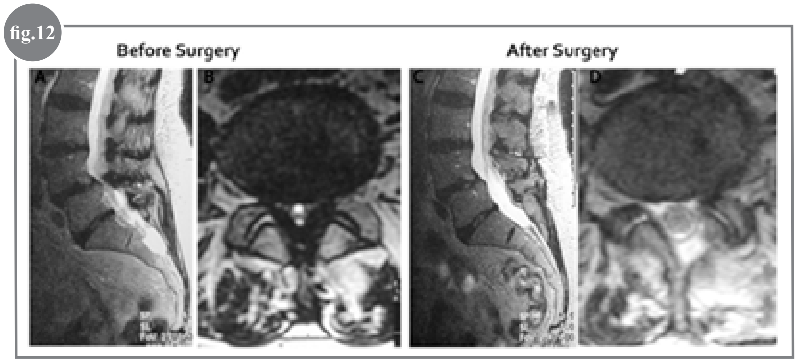


Figure 12:
MRI sagittal and axial (left 2 images) imaging of a patient with moderate to severe spinal stenosis. A decompression was performed (right 2 images) demonstrating removal of the ligamentum flavum with successful reopening of the spinal canal.

Surgical Management

Goals of the Surgery

Surgical management of Adult Spinal Deformity is reserved for those individuals with worsening function or activity levels, a decline in quality of life, and/or pain that is no longer controlled with non-surgical modalities. The goals of surgery include:

- Halt progression of the deformity
- Decrease pain
- Restore spinal alignment
- Improve quality of life

The overarching theme of surgery is to correct the deformity and fuse the appropriate number of vertebrae together to ensure a sustainable alignment. This fusion is a bony bridge that spans from one vertebra to another, and may range from encompassing 2 vertebrae to 25 vertebrae.

The Procedure

- The technique used to treat adult spinal deformity is dependent on several factors and ultimately is determined by your surgeon's experience, and preference of technique. The most common surgical treatment involves a fusion of the posterior (back part) of the spine. The fusion and reconstruction of the spine is accomplished by inserting implants into the spine. The implants can be a combination of screws, hooks and wires that are used as anchors in the spine. The anchors can be placed in the front of the spine (anterior spinal fusion with an incision on the lower abdomen or on the side) or in the back (posterior spinal fusion).

fig.13

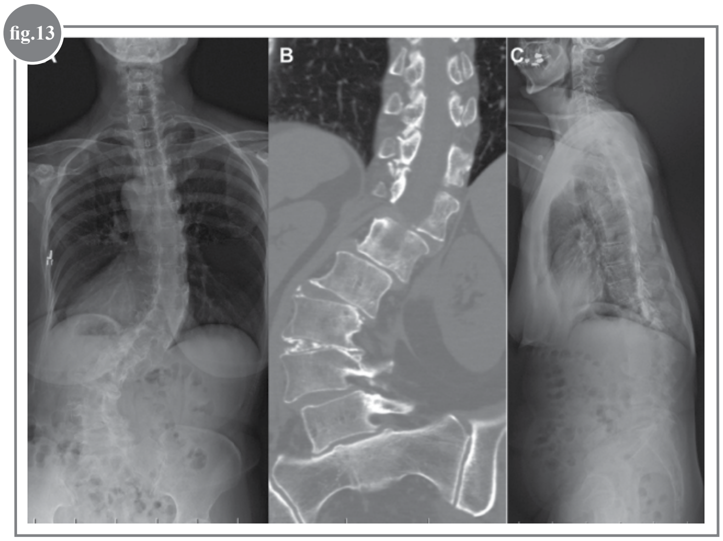


Figure 13:

Frontal view (A) of a 62 yo woman with a scoliosis deformity with shift of her trunk to the right. A CT scan (B) was performed and demonstrates finer details of the bone anatomy. Side view (C) demonstrates kyphosis through the upper lumbar spine resulting in compensatory changes in the thoracic spine and pelvis. Despite the compensation, the patient is unable to maintain a balanced posture.

- The basic components of the surgical procedure include a procedure from the back (posterior) of the spine but can include procedures from the front (anterior) or side (lateral) as well. Based on the pre-operative imaging studies, the surgeon will determine how flexible the deformity is and what procedures would be needed to reestablish a balanced, upright posture. If spinal stenosis is present in conjunction with the deformity, a spinal decompression (laminectomy) can be added to the procedure at the needed levels.

- Flexible Deformities: For patients with sagittal malalignment with flexible deformities, posterior procedures with screws and rods may be sufficient to achieve a balanced spine. Posterior procedures involve fusing the facet joints. If it is determined that fusion of the disc would be needed to supplement the fusion, an interbody procedure (removal of the disc and placement of a spacer) would be added to the procedure *(Figure 14)*. The interbody procedure can be performed from the back (PLIF- posterior lumbar interbody, TLIF- transformational lumbar interbody), from the front (ALIF- anterior lumbar interbody fusion) or from the side (OLIF- oblique lumbar interbody fusion, DLIF- direct lateral interbody fusion, also known as XLIF, extreme lateral). These grafts help to maintain and even restore the sagittal plane at these levels as well as to provide for fusion of the anterior column of the spine.

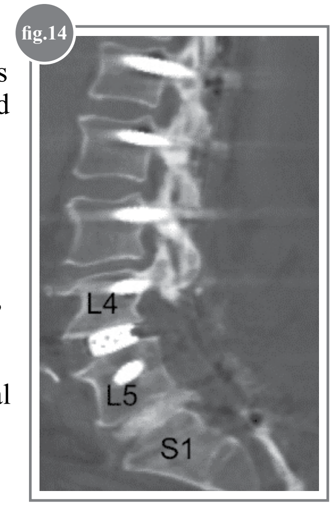


Figure 14:
Intradiscal fusion achieved with the help of a PLIF cage between L4 and L5 and with impacted bone graft between L5 and S1.

- Rigid Deformities: If the deformity is stiffer, the spine may have to be released to achieve the desired correction. Releases of the spine can be performed from the front of the spine, where the discs or vertebra are removed or released, or from posterior (back of the spine), where a release or removal of the facet joints and ligaments are performed. Osteotomy of the spine is the term used for these releases. Releases that involve removal of the facet joints and ligaments are termed Posterior Column Osteotomies *(PCO, #2 in Figure 15)*. Older terms for PCO include the Ponte osteotomy and the Smith Petersen Osteotomy (SPO). If PCO are not sufficient to provide the needed flexibility, more release would be required which would include the resection of part of the vertebral body, also known as pedicle subtraction osteotomy *(PSO, #3 in Figure 15)*, or resection of the complete vertebral body, also termed Vertebral Column Resection *(VCR, #5 in Figure 15)*. Osteotomies can be combined, so that some levels are released with PCO and others with PSO. Once the releases are completed, the rods can be placed and used to manipulate the spinal column into the desired alignment.

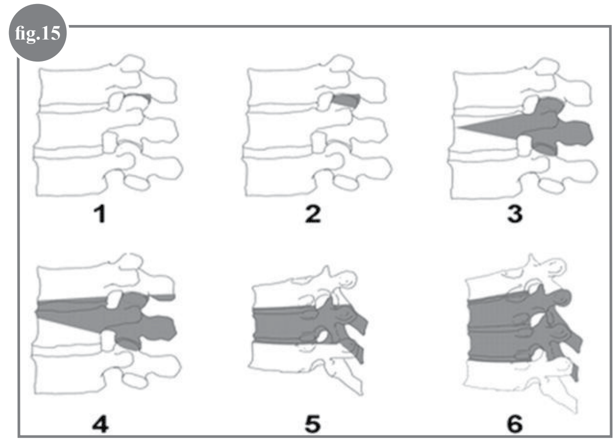


Figure 15:
Depiction of the different types of spinal osteotomies (Schwab classification). The areas in dark depict the bone that is resected in the particular type of osteotomy.

- Following the final placement of the rod, fusion of the vertebrae together is needed for the long-term success of the construct. The fusion is accomplished by creating a surface on the bones of your spine that will allow the selected vertebrae to fuse to each other. Fusion is enhanced by harvesting some bone from the exposed areas of the spine *(local bone or autograft, Figure 16)*, sometimes by taking some bone from the pelvis or ribs (usually accomplished through the same incision), or using donor bone (allograft) and/or synthetic bone substitutes, fusion extenders, and natural proteins that enhance bone formation.

fig.16

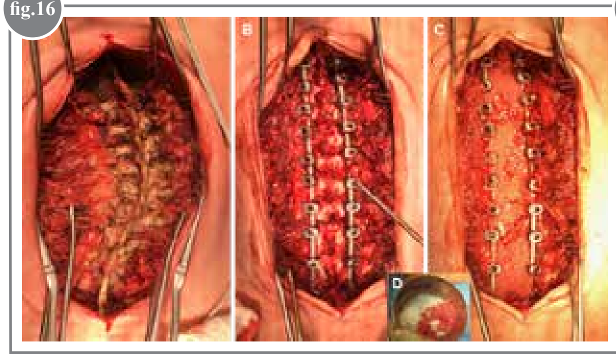


Figure 16:

Example of a deformity (A) correction with pedicle screws, type 2 osteotomies, and rods (B). Bone graft taken from the spine (D) is prepared then placed back to promote fusion (C).

fig.17

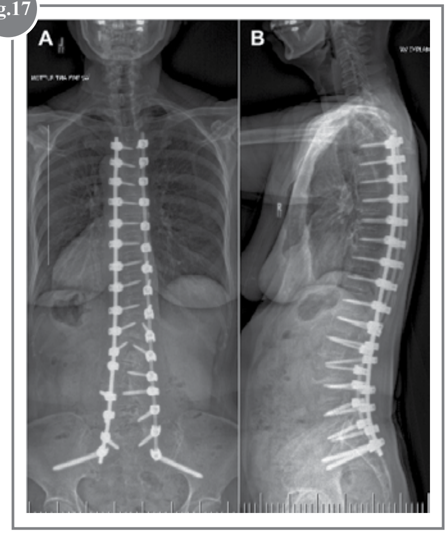


Figure 17:

Frontal (A) and side (B) radiographs of the patient shown in Figure 13. A T4 to pelvis instrumentation and fusion was carried out. Four Type 2 (Figure15) osteotomies were required to achieve the desired correction.

The Hospital Stay

Patients undergoing reconstructive procedures for spinal deformity *(Figure 17, 18)* must be prepared for a prolonged period of recovery and convalescence. Patients in the US may be hospitalized ranging from a few days to over a week after surgery depending on the type and complexity of their procedure. Other countries/other health care systems may differ in postoperative routines. During the hospital stay the patient will learn to get in and out of bed safely and walk with assistance. Activities of daily living such as bathing and dressing are adapted as needed to maintain any postoperative restrictions based on the surgeon's recommendations. Family members/friends are encouraged to get involved in assisting the patient so they are more comfortable doing so at home.

fig.18

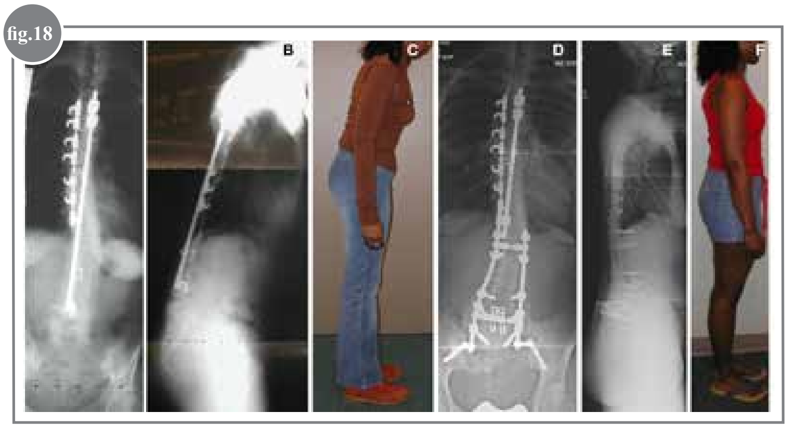


Figure 18:

Standing frontal (A) and side (B) view of a 36 yo lady treated with a Harrington rod for scoliosis. Clinical photograph C) demonstrates her best attempt at standing upright, known as a post-Harrington flat back deformity. Following a type 2 osteotomy at L3-4 and interbody fusions at L4-5 and L5-S1, frontal (D) and side (E) radiographs demonstrate restoration of her lumbar lordosis and regaining of her sagittal alignment (F).

What to Expect After Surgery

Recovery

(Please note that these are general guidelines and every patient is different. Depending on the type and amount of surgery done, recovery times may be faster or slower. Always follow the advice of your surgeon if you have questions.)

The 1st month: Some patients recovering from spinal deformity surgery will be discharged home after their hospital stay. However, for those who do not have help or are deconditioned a transfer to an inpatient rehabilitation or skilled nursing facility, for increased assistance during early recovery, is possible. For patients discharged directly home it is important to have someone in the home to assist them for at least the first 2-3 weeks. This month is challenging, as the patient continues to work on walking and moving with a reconstructed spine and a much-improved upright posture. Typically pain is still present from surgery but controlled with oral pain medication. Specific precautions with regards to bending, lifting and twisting may be recommended by your surgeon during the initial recovery period.

2-3 months: During this time frame, patients are beginning to walk with more confidence and endurance. The muscles are now recovering more from surgery. The patient is adapting to a new spinal shape and outpatient physical therapy may be arranged to improve function and help conditioning for daily activities.

3-6 months after surgery: During these three months patients find themselves actively re-engaging in their lives. Return to work is usually possible in this timeframe. Outpatient physical therapy may still be used to treat residual muscular pain, improve balance, and work on exercise tolerance and endurance. Patients generally no longer require opioid pain medication.

>6 months: During this final phase of recovery, -patients will continue to see gradual improvement in daily function. The lack of energy that was felt during the first 4-6 months of recovery will continue to slowly improve; while daily tolerance of activities also improves back strengthening exercises are allowed if deemed necessary and approved by the surgeon.

Complications

Complications can be common after complex spinal deformity surgeries even in the hands of the most skilled surgeons. The complications can be minor or major. Minor complications include issues such as urinary tract infections, superficial wound problems, or need for blood transfusions. Major complications can be divided into surgical and medical complications. Early surgical complications include substantial blood loss, reoperation within the first 30 days, infection, spinal fluid leak, implant failure, fracture at the top of the fusion, and temporary or permanent injury to nerve roots or to the spinal cord which can result in partial or complete paralysis.

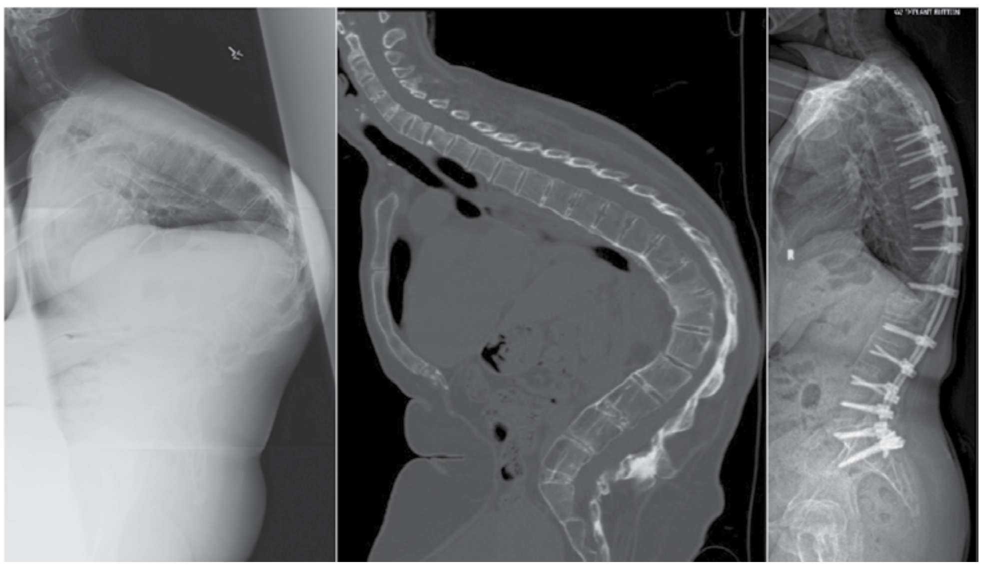
A later complication is the spine failing to fuse (pseudarthrosis) which can cause pain, rod breakage, and the need for additional surgery. Smoking and anti-inflammatory medication can interfere with the ability of the spinal fusion to take. Patients are strongly encouraged to refrain from these prior to surgery and for a minimum of 3 months following the fusion procedure. Medical complications up to and including death can include blood clots in the legs that may travel to the heart or lungs, heart attack, respiratory failure, stroke, blindness, or deep wound infection.

These complications are not listed to scare you but more to inform you of possibilities so that you and your family are well-informed and better able to deal with anything that may occur. This list is also not comprehensive. Most of these complications are treatable or improve over time on their own. Your doctor will review the risk of complications as they pertain to your particular case, based on your particular medical and surgical history.

Diet

It is critical to maintain a well-balanced diet with adequate protein intake. After a major surgery our bodies needs a lot of energy in order to heal and if your protein intake is not adequate you will lose muscle volume and strength. Maintaining a balanced diet with adequate protein should be part of your preparation for the surgery.

Chapter 3: Appendix



FAQs

Adult Spinal Deformity FAQs

Does Sagittal Malalignment ever get better on its own?

If your stooped forward posture is from a structural problem (previous surgery, spinal degeneration into an abnormal posture, etc.) then it is not likely to correct itself. If the cause is pain from muscular spasms, disc herniation, or spinal stenosis, then it is possible that your posture will improve with either non-surgical treatment or a smaller surgical procedure aimed at addressing any of these underlying conditions.

Is there anything I can do to keep this from getting worse?

Staying physically and mentally active is paramount to a good outcome regardless of the treatment that you end up requiring. Trying to maintain a good upright posture and avoiding stooping can help. Unfortunately, if the cause of the sagittal malalignment is structural in nature then there is not much that you can do outside of taking good care of your body, including both physical activity and a balanced diet.

If I do nothing, will I end-up in a wheelchair?

This is common concern but unlikely to happen unless the spinal stenosis progresses and compresses the nerves to the point of creating damage. Also if the pain becomes severe, some patients opt to use a wheelchair from time to time to relieve the pain associated with walking and standing

Surgery Related FAQs

Will you use bone from my pelvis or from someone else?

Ultimately this will be a discussion for you and your surgeon. Recently, surgeons have begun to avoid using bone from your pelvis and, instead, attempt to harvest bone from nearby segments of your spine. In addition to this your surgeon may choose to use bone from a cadaver (termed an allograft) as well as synthetic bone substitutes.

Will I need a blood transfusion?

Blood transfusions are very common for this type of operation. Most surgeons will use additional blood salvaging techniques such as cell saver, which involves collecting the blood through sterile suctioning in surgery and giving it back to you at the time of the operation. Ultimately, you need to be comfortable with the risk of blood transfusions, as they may be necessary to make the surgery as safe as possible.

Should I donate my own blood ahead of time?

This is completely up to you and your surgeon; however, this should be discussed more than a month in advance so that the necessary arrangements can be made with your local blood bank and hospital.

How do I know if my bones are strong enough to accept the spinal implants?

Most surgeons will perform a thorough history to see if you are at risk for having weak bone (age, menopause, history of cancer requiring chemotherapy, etc.). If you have risk factors, your surgeon may request that you have a bone density scan (frequently referred to as a DEXA scan) performed. Depending on the results of this study your surgeon may request that you start on medicine to improve the quality of your bone prior to scheduling your surgery. It would not be uncommon to delay the surgery for 3-6 months to ensure that your bone does not fail after fusion surgery.

Will I have a catheter in my bladder?

Yes, it is often necessary to measure your bladder function and will allow you to get the rest you need for the first 24-48 hours after surgery

Are there any minimally invasive surgeries that can be performed to help me?

There are many different techniques utilized to accomplish the goals listed above. The techniques used are largely dependent on the training your surgeon received and continues to seek out. The use of minimally invasive techniques has shown promise in the realm of adult spinal deformity. Their application in sagittal imbalance surgery is still fairly new and the overall benefit has not been clearly established.

Can I become paralyzed during the surgery?

This can happen but is **extremely** rare since your nerves will be monitored continuously during the surgery by a neuro-physiologist. If you wake up with weakness in one or both legs, the injury can be temporary or permanent, and could involve a combination of numbness, weakness and/or pain. Recovery of the nerve injury can improve over time. Generally the majority of the recovery occurs in the first 6 months after surgery, but improvement can be seen up to 2 years from surgery. If a nerve injury occurs with the surgery, the overall recovery period will likely be more prolonged to reach the desired milestones.

Who is involved in my surgery?

In addition to your primary surgeon, the surgery can involve a co-surgeon, a clinical fellow and/or residents. Other specialists include the anesthesiologist, neuro-physiologists, and sometimes a plastic surgeon.

After the Surgery FAQs

Will I be able to wear high heels after surgery?

Shoe wear is a difficult topic. While you are allowed to wear high heels, you should be cautious of how much time you spend in them. If the fusion was extended to your pelvis or if the fusion involved more than 4 vertebrae, you can expect to have an alteration in the way you walk. You may feel more unsteady in high heels than you did prior to surgery.

When can I resume driving and/or working?

Return to work varies from patient to patient and depends on your type of surgery and type of work. As a general guideline, it takes at least 4 to 6 weeks or longer for bigger surgeries. You may be able to resume driving about 4-6 weeks after the surgery, again dependent on the magnitude of your surgery and the extent of opioid usage.

When can I resume my workout routine?

Your surgeon should always be the one to clear you to resume activities as he/she will know if there were any specific circumstances around your surgery that may prompt a longer period of convalescence.

- In general, the first three months you will have unrestricted walking and be allowed to engage in low-impact cardio work on a stationary bike and treadmill. Light weight (<10 lbs.) upper extremity exercises are allowed as long the back remains fully supported.
- After 3 months from the time of surgery the weight restriction may be increased to 25 lbs. and more aggressive cardio training is allowed. Clear this with your surgeon first.
- After 6 months from surgery you may resume full activities as long as the activity does not result in significant discomfort or prolonged recovery.

Some surgeons will allow you to go back to full activities sooner, depending on the type of surgery that was done and your overall condition. Always check if you have questions.

Will I set the metal detectors off at the airport?

This depends on how sensitive the detector is, but it typically does not happen. A letter from your doctor explaining your implants or a picture of your x-ray may be helpful to have on hand. You may also need to show the healed incision on your back in the rare event that the detector goes off. For more information on this topic please visit: http://tsa.gov/travelerinformation/metal-implants.

Will I need to use a Bone Stimulator?

This is completely up to your surgeon and depends on your overall bone health. Some data has shown that this may help with the bone formation provided it is worn for 3 to 6 months after surgery. Most patients do not need to use a bone stimulator.

Glossary

Anterior Spinal Fusion - A surgical technique which involves removal of the intervertebral disc and replacement with bone graft. Additional structural supports may be placed in the disc space to maintain good spinal alignment, (hard (cortical) bone grafts, metal or synthetic spacers.)

Autologous Blood - Blood collected from a person for later transfusion to that same person. This technique is often used prior to elective surgery if blood loss is expected to occur. This may avoid the use of bank blood from unknown donors.

Autotransfusion - The practice and technique of transfusing previously drawn autologous blood back to the same patient.

Bone Graft - Human bone, which is harvested from one location in an individual and placed in another individual (allograft bone, usually from a cadaver) or in a different location in the same individual (autograft bone). A common place to take autogenous bone graft from is the spine itself as the surgeon is removing parts of the vertebrae while exposing the spine. Occasionally, the anterior and posterior iliac crests (the pelvic bones) may be used, although this is not as common anymore. Allograft can also be obtained from synthetic or man-made products.

Cervical Spine - Seven spinal segments (C1-C7) between the base of the skull (occiput) and the thoracic spine. The normal cervical spine alignment is lordosis.

Compensatory Curve - In spinal deformity, a secondary curve located above or below the structural curvature, which develops in order to maintain normal body alignment.

Decompensation - In scoliosis, this refers to loss of spinal balance when the spine is not centered over the pelvis.

Fusion - The uniting of two or more bony segments.

Idiopathic Scoliosis - A structural spinal curvature for which the cause has not been established. There is no evidence of underlying physical or radiographic pathology. This is the most common type of scoliosis.

Iliac Bone - A part of the pelvic bone that is above the hip joint and from which autogenous bone grafts may be obtained.

Kyphoscoliosis - A structural scoliosis associated with increased kyphosis (roundback).

Kyphosis - The normal forward curvature of the thoracic spine. A posterior angulation of the spine as evaluated from the side (roundback). Opposite of lordosis.

Lordoscoliosis - A lateral curvature of the spine associated with increased lordosis (swayback).

Lordosis - The normal mild anterior angulation (swayback) of the lumbar spine as evaluated from the side. Opposite of kyphosis.

Lumbar Spine - Five mobile segments of the lower back (L1 to L5). These are the largest of the vertebral segments and provide most of the bending and turning ability of the back, in addition to bearing most of the weight of the body. The normal alignment of the lumbar spine is lordosis.

Lumbosacral - Pertaining to the lumbar and sacral regions of the back.

Osteotomy - The surgical removal of a wedge or piece of vertebral bone to alter the alignment of the spine; may also be used in previously fused vertebrae to enable the surgeon to move them.

Pedicle - The part of each side of the neural arch of a vertebra which projects backward from the vertebral body. It connects the lamina with the vertebral body.

Pseudarthrosis - An area of the spinal fusion where the bone did not heal (fuse). Often found with broken instrumentation and, in some instances increased pain, although not always.

Sacral Spine - (Sacrum) - The curved triangular bone at the base of the spine, consisting of five fused segments of the lower spine that have four foramen on each side. The sacrum articulates (connects) with the last lumbar vertebra and laterally with the pelvic bones.

Scoliosis - Lateral deviation of the normal vertical line of the spine which, when measured by x-ray, is greater than ten degrees. Scoliosis consists of a lateral curvature of the spine with rotation of the vertebrae within the curve. Rotation of the vertebrae also occurs which produces the rib cage and flank muscle asymmetry.

Spinal Canal - The long canal between the vertebral bodies anteriorly and the lamina and spinous processes posteriorly through which the spinal cord passes. The spinal cord and nerve roots extend to the level of the second lumbar segment in adults. Below this level are numerous nerve roots from the spinal cord that resemble a horse's tail and is referred to as such (cauda equina). The thick outer covering of the spinal cord is called the dura.

Spinal Fusion - A surgical technique which involves roughening or removing the hard bony surfaces (decortication) of the lamina(e), spinous processes, and facet joints, to stimulate two or more spinal bones (vertebrae) to heal together (fusion). Bone grafting with autogenous and/ or allograft bone is used to enhance the fusion process. Instrumentation (implants) may also be used.

Spinal Instrumentation - Metal implants fixed to the spine to improve spinal deformity while the fusion solidifies (becomes solid bone). This includes a wide variety of rods, hooks, wires, and screws used in various combinations.

Thoracic (Dorsal) Spine - Twelve spinal segments (T1-T12) incorporating the 12 ribs of the thorax. Other than a slight increase in size from top to bottom, they are fairly uniform in appearance. The normal alignment of the thoracic spine is kyphosis.

Vertebra - One of the 33 bones of the spinal column. A cervical, thoracic, or lumbar vertebra has a cylindrically shaped body anteriorly and a neural arch posteriorly (composed primarily of the laminae and pedicles as well as the other structures in the posterior aspect of the vertebra) that protect the spinal cord. The plural of vertebra is vertebrae.

Vertebral Column - The flexible supporting column of vertebrae separated by discs and bound together by ligaments.

Your Support Can Change the Lives of Others with Spinal Deformities

Please consider a donation to SRS.

100 percent of all contributions and donations to the Scoliosis Research Society's (SRS) Research, Education Outreach (REO) Fund are used entirely for research, outreach programs, and educational scholarships and fellowships seeking improved treatments, the causes and possible prevention of spinal deformities. Operating funds for SRS come from membership dues, educational meetings and courses, publication sales and other sources.

With your support, SRS can continue to support and offer necessary educational opportunities, beneficial research grants and maintain effective advocacy efforts that will change the lives of those living with spinal deformities.

If you would like to make a donation to the Scoliosis Research Society, please fill out the form below and mail it to:

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YES! I would like to donate to the Scoliosis Research Society (SRS) to help continue in fulfilling its mission to improve the lives of patients with spinal deformities!

Enclosed is my gift of: ☐ $10, ☐ $20, ☐ $35, ☐ $50, ☐ $100, ☐ $150, ☐ Other ____________

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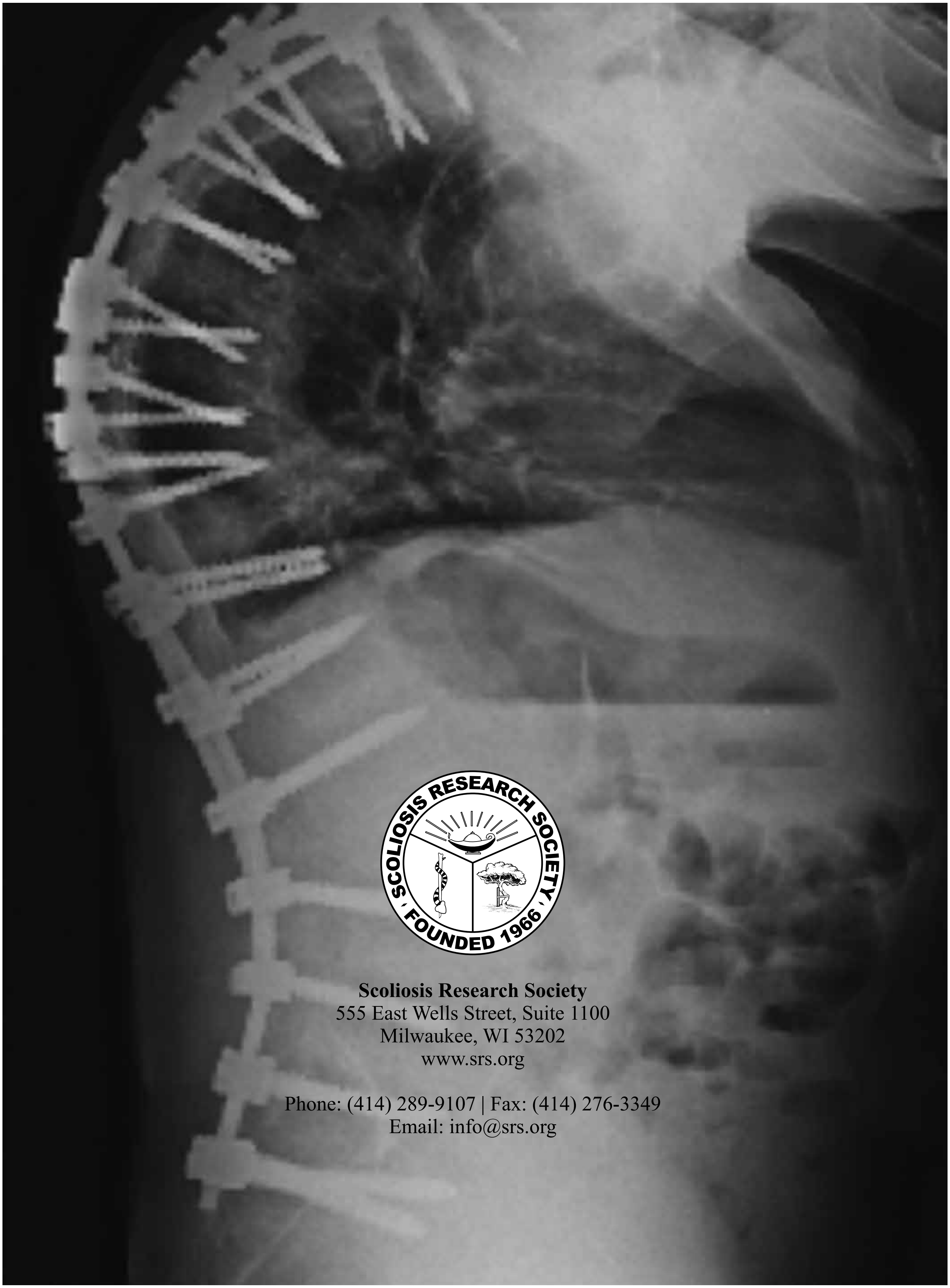

Scoliosis Research Society
555 East Wells Street, Suite 1100
Milwaukee, WI 53202
www.srs.org

Phone: (414) 289-9107 | Fax: (414) 276-3349
Email: info@srs.org