Causes of Sagittal Spinal Imbalance and Assessment of the Extent of Needed Correction

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Abstract
Most patients with spinal sagittal imbalance have a fusion mass that is either kyphotic or hypolordotic, with segments above or below the fusion that have subsequently degenerated. The four most common presentations include a patient who had a long fusion for adolescent idiopathic scoliosis with subsequent degeneration distally; a patient with degenerative sagittal imbalance in whom fusions have initially been performed in the distal lumbar spine in a somewhat hypolordotic or kyphotic position with subsequent degeneration of segments above the fusion; a patient with posttraumatic kyphosis; and a patient with ankylosing spondylitis.

Sagittal Imbalance
Sagittal balance is most frequently defined by the position of the C7 plumb on a standing lateral radiograph. When a C7 plumb is dropped, neutral balance is suggested if the plumb falls through the lumbosacral disk. If the C7 plumb falls behind the lumbosacral disk, sagittal balance is defined as negative, whereas if it falls in front of the lumbosacral disk it is positive. The most commonly used specific reference point for the C7 plumb is the posterior aspect of the L5-S1 disk. Most investigators consider normal sagittal balance as the C7 plumb falling through the lumbosacral disk or 2 cm in front or behind it. It is known that the C7 plumb and the center of gravity are not identical. In most circumstances the center of gravity falls in front of the C7 plumb and slightly behind the hip joints (P Roussouly, MD, Lyon, France, personal communication, 2004).

There is a range of sagittal imbalance (Figure 1). Booth and associates1 refer to a type I imbalance as a segmental kyphosis, with global balance in which the C7 plumb falls over the lumbosacral disk on a standing long cassette lateral radiograph taken with the patient standing with knees fully extended in a natural, comfortable position. Most patients should have at least 10° to 20° more lumbar lordosis than thoracic kyphosis. Usually a Smith-Petersen osteotomy will achieve 10° of correction and a pedicle subtraction osteotomy will produce 30° to 35° of lordization of the spine.


Many factors contribute to fixed sagittal imbalance. A hypolordotic or hyperkyphotic fusion mass with subsequent disk degeneration above or below the fusion is common. Subsequent disk degeneration leads to loss of anterior column height and increased kyphosis. In most patients, both aging and iatrogenic factors contribute to fixed sagittal imbalance.

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There is a range of sagittal imbalance (Figure 1). Booth and associates1 refer to a type I imbalance as a segmental kyphosis, with global balance in which the C7 plumb (on a long cassette standing radiograph) falls over the lumbosacral disk. Patients with this type of imbalance frequently have to hyperextend segments above or below the kyphosis to maintain balance. It is believed that this compensatory mechanism predisposes the patient to accelerated disk degeneration. In a type II sagittal imbalance,
the C7 plumb is so far anterior to the lumbosacral disk that the patient is not able to compensate to maintain global balance. In this situation, there is usually substantial disk degeneration above or below an area of prior fusion or pathology that makes it impossible for the patient to hyperextend segments below the fusion because of moderate to severe degeneration of those segments; the C7 plumb falls a few centimeters anterior to the lumbosacral disk. In a patient with major sagittal imbalance (C), the spinal fusion is sufficiently kyphotic and the segments above and below have degenerated to the extent that the C7 plumb falls more than 10 cm in front of the lumbosacral disk.

Idiopathic Scoliosis
Idiopathic scoliosis usually results in a long hypolordotic fusion mass. In the past, this condition was associated with the use of Harrington distraction instrumentation (which reduces lumbar lordosis) that had been placed to L3, L4, or L5. If this hypolordotic fusion mass is combined with subsequent disk degeneration of segments below, then sagittal imbalance ensues. This condition also can occur with more modern segmental implants if the final result is that the patient loses lordosis within the fusion mass. Full-blown sagittal imbalance syndrome most commonly occurs in the fourth decade of life in a patient who had undergone fusion as a teenager.

The goal of surgical treatment of a sagittal imbalance that occurs after fusion for scoliosis is to normalize the patient’s sagittal plane within the fusion mass and extend the fusion down to the sacrum. A potential complication of this surgical strategy is that the sacral fixation points often loosen, pull out, or fail. If sacral fixation is lost, the patient will develop a pseudarthrosis at L5-S1. Most commonly this pseudarthrosis will have some degree of kyphosis and further contribute to the patient’s sagittal imbalance. Because of the possibility of pseudarthrosis, structural grafting at L5-S1 and protection of the sacral screws with iliac screws to reduce the likelihood of failure of the sacral screw implants is recommended.

Degenerative Sagittal Imbalance
Patients with degenerative sagittal imbalance are usually older than patients with idiopathic scoliosis. Most patients with degenerative sagittal imbalance have undergone fusions of the distal one, two, or three segments of the lumbar spine. Often these distal segments have been fused in a somewhat hypolordotic position. Disk degeneration leads to loss of anterior column height; therefore, most degenerative lumbar fusions tend to solidify in a position of hypolordosis. As the patient ages, segments above the fusion degenerate. When these proximal segments degenerate, kyphosis is exaggerated and the patient is no longer able to maintain sagittal balance. Some component of spinal extensor muscle denervation as well as ligamentous disruption and decompression that extends above the prior fusion mass also may be involved.

Posttraumatic Kyphosis
Posttraumatic kyphosis may occur in patients who have received either surgical or nonsurgical treatment. It is more common to see full-blown sagittal imbalance syndrome in a patient who has been treated surgically. Post-

| Figure 1 | In a type I deformity (A), the patient is able to maintain balance (the C7 plumb falls over the lumbosacral disk) by substantially hyperextending segments below a hypolordotic fusion mass as shown on this long cassette sagittal radiograph. In a mild to moderate type II deformity (B), the patient is not able to hyperextend the segments below the fusion because of moderate to severe degeneration of those segments; the C7 plumb falls a few centimeters anterior to the lumbosacral disk. In a patient with major sagittal imbalance (C), the spinal fusion is sufficiently kyphotic and the segments above and below have degenerated to the extent that the C7 plumb falls more than 10 cm in front of the lumbosacral disk. |
Possible presentation scenarios include patients who had prior anterior surgery, prior posterior surgery, or prior decompressions with or without pseudarthrosis. The longer the length of the prior fusion and the greater the degree of kyphosis with the prior fusion, the more likely there is to be a complication. Subsequently, segments degenerate above or below the kyphosis. These additional degenerative segments further contribute to sagittal imbalance as is the case in patients with degenerative sagittal imbalance and idiopathic scoliosis. Patients with posttraumatic kyphosis most commonly present with a type I imbalance, although this condition may progress to a type II imbalance. A change in the patient’s neurologic status will affect decisions concerning surgical treatment.

**Ankylosing Spondylitis**

The natural history of a patient with ankylosing spondylitis is characterized by a progressive fusion of spinal segments, atrophy of spinal extensor muscles, and progressive kyphosis. This condition may occur with a coexistent spondylodiskitis, which refers to a three-column fracture that often is initially unrecognized and presents in a manner similar to a neuropathic spine. Ankylosing spondylitis is usually characterized by a rounded kyphosis that occurs from the sacrum upward into the cervical spine and occiput. Some patients with ankylosing spondylitis present with more of a cervicothoracic kyphosis, subsequent to a fracture in the upper thoracic or lower cervical spine. Another presentation is characterized by reasonable cervical alignment and a long rounded kyphosis that affects the lumbar and thoracic spine and creates fixed sagittal imbalance. The amount of sagittal imbalance may be very dramatic.

**How Surgeons Can Impact the Natural History**

When performing a spinal fusion it has been recommended that the patient be positioned on a four- or six-poster frame with the hips relatively extended to maintain lordosis. Using instrumentation that does not distract the posterior column also prevents complications. The risk of sagittal imbalance increases to some extent as the fusion is increased in length; however, performing a fusion that is too short may predispose the patient to junctional kyphosis.

For a patient with degenerative sagittal imbalance, it is beneficial to attempt to perform distal lumbar fusion with the patient in a position of normal segmental lordosis. There are many strategies to potentially normalize the segmental sagittal plane when performing a lumbar fusion. Circumferential fusion seems to accelerate disk degeneration at levels above the fusion. Pedicle screw implants may violate the facet capsule of the segment above the fusion. Anterior threaded cage constructs have a tendency to settle and to lose some of the lordosis that was initially achieved. There are no precise remedies for the preservation and enhancement of distal lumbar lordosis in a patient with a degenerative spine.

For a patient with a fracture, the use of distraction instrumentation is now largely obsolete. Distraction instrumentation, with or without three-point fixation, may create an initial ligamentotaxis effect that is radiographically desirable. Unfortunately, the usual long-term outcome involves settling of the reduction and ultimate healing with segmental kyphosis. Other strategies such as anterior-only treatment or posterior pedicle screw constructs have evolved to accomplish ultimate physiologic segmental lordosis.

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**Assessment of Correction**

**Pelvic Incidence**

Duval-Beaupère and associates defined the term pelvic incidence and the term has been further popularized by Labelle and associates. Pelvic incidence measures a combination of pelvic tilt and sacral slope (Figure 2). The higher the pelvic incidence the more lumbar lordosis a patient needs to maintain balance. A higher pelvic incidence is associated with a more horizontal sacrum; the hip joints are situated more anterior to the L5-S1 disk. The measurement of pelvic incidence is made by...
Thoracic Kyphosis Relative to Lumbar Lordosis

There is a wide variation in the normal range of the measurements of thoracic kyphosis and lumbar lordosis.28 The middle of the bell-shaped curve is 30° to 35° of thoracic kyphosis measured from T5 to T12 and 55° to 60° of lumbar lordosis measured from T12 to the sacrum. Lumbar lordosis usually begins at T12-L1. Between two thirds and three fourths of lumbar lordosis is located in the distal two disks. However, there is substantial individual variation. If a patient has only 10° of thoracic lordosis, then lumbar lordosis is required to maintain balance. One guideline is that the measurement of lumbar lordosis from T12 to S1 should exceed the measurement of thoracic kyphosis from T5 to T12 by at least 10° to 20°.12,29

The C7 Plumb

The C7 plumb will be affected by the patient’s positioning. When a long cassette lateral radiograph is taken, the patient is usually asked to extend the shoulders and arms out in front of the trunk to allow the spine to be seen on the radiograph. This positioning may have a tendency to posteriorly displace the C7 plumb. The effect of arm position on the C7 plumb was studied and it was concluded that a position in which the shoulders are flexed approximately 30° and the fists are placed in the supraclavicular fossa was the most desirable position to allow for visualization of the anatomic landmarks (W Horton, MD, Atlanta, GA, personal communication, 2004). The upper thoracic spine is the area most difficult to see on radiographs because of the overlap with the shoulder girdle.

Patients with sagittal imbalance will frequently stand with their feet further apart and their knees flexed to better position their head over their feet. This posture will adversely affect the C7 plumb assessment. Therefore, it is preferable to ask the patient to stand with knees fully extended and feet no more than shoulder width apart. Also, there are limitations to the assessment of a C7 static plumb. As the patient ambulates, the hip extensors tend to fatigue; therefore, after walking a certain distance a patient’s posture will clinically be more pitched forward than it was at stance.30-32

The C7 plumb is the best assessment for sagittal balance, but it is not perfect because it does not always directly correlate with the center of gravity, which is the element that is actually being assessed. A patient’s center of gravity should always fall either through the hip joints or somewhat behind it. Usually the center of gravity is in front of the C7 plumb.

Expectations With Smith-Petersen Osteotomies

The extent of correction achieved with a Smith-Petersen osteotomy depends on the characteristics of the anterior column of the spine and the amount of bone that is resected posteriorly.18,33–38 In patients with ankylosing spondylitis, corrections up to 50° have been achieved with this osteotomy. However, for patients who do not have ankylosing spondylitis the amount of correction that is achieved per level is approximately 10°.30

Therefore, three Smith-Petersen osteotomies usually achieve the same amount of correction as one pedicle subtraction procedure. To close a Smith-Petersen osteotomy it is necessary to have a mobile anterior column. In the presence of an anterior fusion, it will not be possible to close a Smith-Petersen osteotomy without releasing the spine anteriorly. If there is an open visible disk space, then it usually is possible to close a Smith-Petersen osteotomy without an anterior operation (Figure 3).

A Smith-Petersen osteotomy shortens the posterior column and lengthens the anterior column. Therefore, if these osteotomies are done symmetrically at the apex of a residual scoliosis with residual rotation, there is potential to decompensate the patient’s spine in the coronal plane.1 With residual rotation the posterior column is on the concave side of the spine and the anterior column is on the convexity. Shortening the posterior column and lengthening the anterior column has a tendency to shorten the concavity, lengthen the convexity, and pitch the patient’s spinal alignment to the concavity (Figure 4). When performing multiple Smith-Petersen osteotomies through seg-
ments with residual rotation, care must be taken to avoid increasing coronal deformity.

Smith-Petersen osteotomies can be used to treat mild or moderate type II deformities if care is taken not to create a coronal imbalance. Figure 5 shows a patient who had severe spinal stenosis of distal segments and degeneration of two segments below the prior fusion mass. Rebalancing in the sagittal plane was achieved by extending the fusion down to the sacrum and pelvis and by performing Smith-Petersen osteotomies at the two distal levels of the prior fusion (L2-L3 and L3-L4). The Smith-Petersen osteotomy is discussed in greater detail in chapter 57. (DVD-56.1)

**Expectations With Pedicle Subtraction Osteotomies**

A pedicle subtraction procedure may achieve up to 50° to 60° of correction, depending on the size of the wedge that is resected and whether the disk above is also resected. However, a more typical correction is approximately 35°.39-41 Pedicle subtraction procedures can be performed through the apex of a deformity in the presence of substantial rotation. If the procedure is performed symmetrically on both sides, there does not appear to be a tendency to pitch the patient’s spinal alignment to the concavity as can occur in Smith-Petersen osteotomies. A pedicle subtraction procedure shortens the posterior column and hinges on the anterior column in contrast to the Smith-Petersen procedure, which lengthens the anterior column (Figure 6). One pedicle subtraction procedure accomplishes approximately as much correction as three Smith-Petersen osteotomies. A pedicle subtraction procedure is usually associated with more blood loss than three Smith-Petersen osteotomies.30

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**Figure 4**  
A, Composite long cassette radiographs of a patient who presented with good coronal balance, very positive sagittal balance, and pseudarthrosis of the lumbar spine are shown. The patient was treated with circumferential surgery in the lumbar spine and multiple Smith-Petersen osteotomies that were done symmetrically at several segments through areas of residual rotation. This treatment shortened the posterior column and lengthened the anterior column. Postoperative results at 9 years were satisfactory. Sagittal balance was excellent; however, in the coronal plane the patient decompensated to the right side. B, Clinical photographs of the same patient showing the correction of the sagittal deformity with somewhat worsened balance in the coronal plane. In the preoperative photographs the patient was asked to keep her knees extended, but otherwise to stand as erect as possible. In the postoperative photographs the patient was asked to stand naturally.
possible to perform a pedicle subtraction procedure somewhat asymmetrically if substantial coronal and sagittal deformities both exist. In such a circumstance, the surgeon would make a larger wedge on the convexity and would reach around to the front of the spine and resect more of the vertebral body on the convexity. In terms of correction of the C7 plumb, a pedicle subtraction procedure will usually accomplish between 12 and 15 cm of correction in the sagittal plane.39-41 (Figure 7). In the coronal plane, the potential correction is not as well established but appears to be in the range of 5 to 7 cm.21,22,42,43 An algorithm summarizing strategy for deciding when to perform Smith-Petersen osteotomies versus pedicle subtraction procedures for various types of sagittal imbalance is shown in Figure 8. The pedicle subtraction ostetomy is also discussed in chapter 58. (DVD-56.2)

Expectations With Adding Levels to an Existing Fusion
In patients with fixed sagittal imbalance, degenerated segments that develop either above or below a prior

Figure 6 A three-column pedicle subtraction osteotomy involves resection of bone through the posterior, middle, and anterior columns, hinging on the anterior column. This procedure shortens the middle and posterior columns. The hinge is located through the vertebral body, not the disk space, therefore, the mobility of the disks is not germane. Approximately 35° of correction is usually achieved.

Figure 5 A, Composite preoperative and 1-year postoperative long cassette radiographs of a patient with a prior Harrington fusion and instrumentation to L4. The patient presented with a kyphotic fusion mass, marked degeneration of the two segments below the fusion, and marked spinal stenosis of those segments. Her sagittal imbalance was moderate. Treatment involved appropriate decompressions at the lower two segments and subsequent correction of the sagittal deformity with two Smith-Petersen osteotomies in the mid lumbar spine. Some lordization of the segments at L4-L5 and L5-S1 was accomplished with intraoperative table positioning. B, Clinical photographs of the same patient showing substantial improvement in the deformity. In the preoperative photographs she was asked to keep her knees extended, but to stand as erect as possible. In the postoperatively photographs the patient was asked to stand naturally.
fusion are logically included in the revision surgical construct. It may be possible to achieve additional lordosis of the spine when adding those segments. Most commonly, if distal segments (for example, L4-L5 and L5-S1) are being added, those segments first will be structurally grafted anteriorly and then fixed posteriorly. The anterior structural grafting will open up the disk spaces and create a ligamentotaxis effect that both reduces subluxations and also provides additional lordosis. Also, in segments with severe degeneration, placing the patient in a prone position under anesthesia may open up disk spaces and provide more lordosis than was apparent when the patient was standing.

Figure 7  A, Composite preoperative and postoperative (2 years and 3 months) long cassette radiographs of a patient who presented with a kyphotic fusion mass after prior surgery (many years before) for idiopathic scoliosis and marked degeneration of the segments below. The C7 plumb was greater than 10 cm in front of the lumbosacral disk. Surgical treatment included pedicle subtraction osteotomy, structurally grafting the degenerated segments below, and performing instrumented fusion to the sacrum and pelvis. Most of the correction was accomplished with the pedicle subtraction procedure, although some correction was achieved with the structural grafting of segments below. B, Clinical photographs of the same patient. In the preoperative photograph the patient was asked to keep her knees extended, but to stand as erect as possible. In the postoperative photograph she was asked to stand naturally.

Figure 8  A treatment algorithm that provides guidelines for performing Smith-Petersen versus pedicle subtraction osteotomies based on the characteristics of the sagittal deformity and its anatomic location. SPO = Smith-Petersen osteotomy; PSO = pedicle subtraction osteotomy.
The amount of additional lordosis that can be achieved by adding segments above and below the prior fusion is quite variable. The additional amount of lordosis that can be achieved by adding segments is on average 5° per level.

**Summary**

There are multiple causes of sagittal spinal imbalance. Historically, distraction instrumentation (specifically, the posterior Harrington implant) was the principal cause of this condition. The most common causes of sagittal imbalance are degeneration at L3-L4, L4-L5, or L5-S1 distal to a fusion for idiopathic scoliosis; multiple fusions performed in the middle to distal lumbar spine with each level being fused in a somewhat hypolordotic position and subsequent degeneration of the segments above; post-traumatic kyphosis; and ankylosing spondylitis. When performing an instrumented fusion in the lumbar spine to treat a fracture it is important to always place the fused segment(s) in lordosis. When treating degenerative fusions, the fusing of a segment in a kyphotic position should be avoided. Although a one-level fusion in a slightly kyphotic position may be tolerated, the subsequent addition of more segments may make it impossible for the patient to compensate by hyperextending unfused segments and will contribute to sagittal imbalance syndrome.

For a patient with sagittal imbalance the most common radiographic measure used to characterize the imbalance is the C7 plumb relative to the posterior aspect of the L5-S1 disk. Because the C7 plumb does not always correlate with the center of gravity, studies are underway to investigate this parameter.

In most circumstances the patient should have 10° to 30° more lumbar lordosis than thoracic kyphosis to have ideal balance. Usually a Smith-Petersen osteotomy will accomplish approximately 10° of spinal lordosis. A pedicle subtraction procedure will accomplish approximately 30° of additional lordosis. Usually 30° to 35° of correction will displace the C7 plumb posteriorly between 12 and 15 cm in a patient with type II major sagittal imbalance. Many investigators believe that the more distal the osteotomy, more correction will be achieved in the C7 plumb. Some investigators find it useful to cut wedges from photocopies of the long cassette radiograph in an effort to assess the extent of correction in overall sagittal balance that will be achieved by performing various osteotomies at various locations. The reproducibility and reliability of such practices has not been documented in the peer-reviewed literature.

For the treatment of sagittal imbalance within a solid spinal fusion from T3 to the sacrum, osteotomies will achieve correction. This situation, however, is somewhat unusual. More commonly, the patient also has either multiple pseudarthroses or very degenerated segments that need to be added to the fusion. Correction may also be achieved by adding pseudarthrotic or degenerated segments to the prior fusion.

**References**

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