Clinical and Radiographic Evaluation of Sagittal Imbalance: A New Radiographic Assessment

Hossein Elgafy, MD, MCh, FRCS Ed, FRCSC, Rick Bransford, MD, Hassan Semaan, MD, and Theodore Wagner, MD

Abstract

In this article, we describe a case series study involving a new radiologic evaluation of sagittal imbalance. We review the current radiologic assessment of sagittal imbalance and introduce a new radiologic evaluation that helps in ruling out hip flexion contracture as the primary cause of sagittal imbalance and the type and level of spinal osteotomy required to regain sagittal balance.

Sagittal imbalance is important in spinal deformity assessment. Studies have confirmed that overall clinical outcomes and patient satisfaction with surgery were best in cases that resulted in an increase in lumbar lordosis.

For this study, radiologic assessment of sagittal imbalance was conducted on a long, 14×51-inch upright lateral plain radiograph that included the proximal femur and the entire spine. The radiograph was taken with the arms at 45° forward flexion and the hips and knees fully extended. The femoral axis line was drawn and extended cephalad. The C7 offset, the perpendicular distance between the femoral axis line and the center of C7, represented the degree of sagittal imbalance. The angle between the femoral axis line and a line extending from the center of C7 to the vertebra at the level of the proposed osteotomy—the Seattle angle—predicted how much correction was required to bring the C7 plumb in line with the femoral axis and to decrease the C7 offset, thus regaining sagittal balance. The proposed method was used to evaluate 10 consecutive patients who required spinal osteotomies to regain sagittal balance. Preoperative and postoperative plain radiographs were assessed twice, at a 6-week interval, by an independent spine surgeon and a musculoskeletal radiologist. Cohen κ correlation coefficients were used to calculate intraobserver and interobserver reliability.

The 2 reviewers' intraobserver reliability was excellent (κs = 0.98, 0.93). Interobserver reliability was lower but good (κ = 0.76).

Inclusion of the proximal femur on the long upright lateral plain radiograph of the entire spine and identification of the relation between the femoral axis line and the center of C7 are important in evaluating sagittal imbalance. Excellent intraobserver reliability, coupled with good interobserver reliability, suggest that this new radiologic assessment method can be helpful in preoperative assessment of sagittal imbalance.

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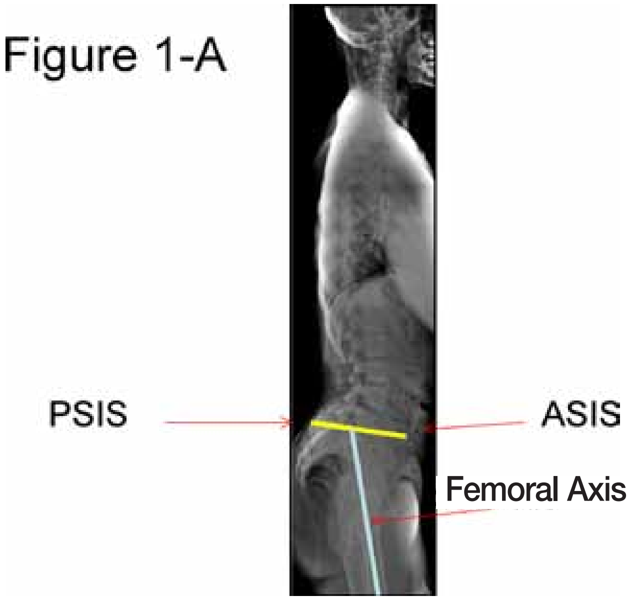
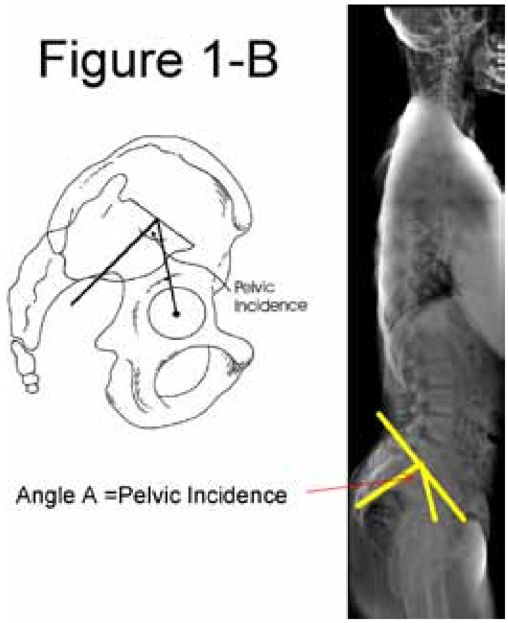
Spinal deformities, such as increased thoracic kyphosis and loss of lumbar lordosis, result in sagittal imbalance. These deformities can be functionally and psychologically disabling. Sagittal imbalance of the spine is becoming one of the most important factors in assessing degree of spinal deformity. Recent literature has shown that patients' satisfaction after lumbar spine surgery correlates with restoration of sagittal balance.[1,2]

Anteroposterior surgery was the most common procedure for adults with fixed deformity. Recent advances in techniques, however, have led to more frequent use of purely posterior approaches. The posterior approach allows for more correction because of 2 major advances in surgical method: osteotomy techniques and thoracolumbar spine pedicle screw instrumentation, which produces more curve correction with fewer levels of fixation. The 2 most common osteotomies for correcting sagittal imbalance are Smith-Petersen and pedicle subtraction.

The Smith-Petersen osteotomy can produce approximately 10° of correction in the sagittal plane at each spinal level at which it is performed. This osteotomy is beneficial for patients with a degenerative imbalance in the sagittal plane. The pedicle subtraction osteotomy can produce approximately 30° of correction in the sagittal plane. This is the preferred osteotomy for patients who have ankylosing spondylitis and an imbalance of the spine in the sagittal plane.[3,4]

Preoperative decisions should be made regarding surgical approach, surgery timing, and location of osteotomy and end of construct.





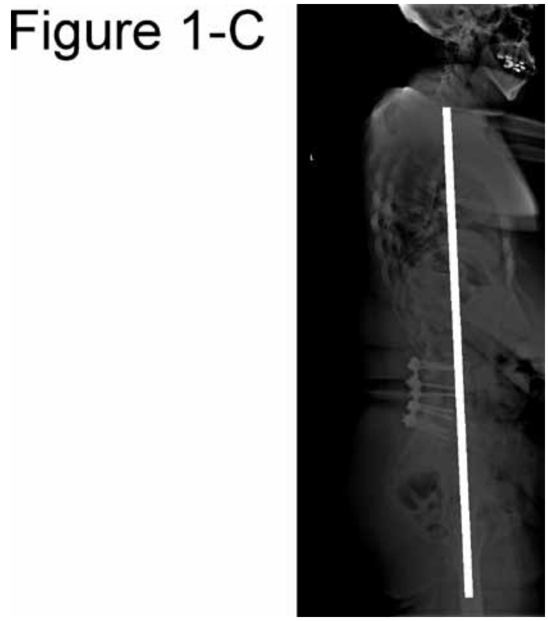


Figure 1. (A) For assessment of hip flexion, a line is drawn between the ASIS (anterior superior iliac spine) and the PSIS (posterior superior iliac spine. The relation between this line and the femoral axis represents hip flexion. (B) Angle A is the pelvic incidence angle. A line is drawn across the sacral endplate. Next, a perpendicular line is constructed from the midpoint of the sacral endplate line distally. A line is then drawn from the midpoint of the femoral head to the midpoint of the sacral endplate. (C) In a patient with normal sagittal balance, the C7 plumb line (sagittal vertical axis) is extended from the center of the C7 body down to the middle of the L2 vertebral body, the posterosuperior aspect of the sacrum at the L5–S1 disks, and the longitudinal axis of the femur.

In this article, we review the radiologic assessment of sagittal imbalance and describe a new radiologic evaluation that helps in ruling out hip flexion contracture as the primary cause of sagittal imbalance and the type and level of spinal osteotomy required to regain sagittal balance.

Patients and Methods

Proposed New Radiographic Assessment

We propose to include the proximal femur in addition to the entire spine in the long, 14×51-inch lateral plain radiograph. The radiograph was taken with the centering point at the midthoracic spine (T7 level), and the exposure was 80 to 85 kilovolts and 25 to 50 milliampere second. The radiograph was obtained with the arms at 45° forward flexion and the hips and knees fully extended. The femoral axis was identified as the midline of the femur shaft. For assessment of hip flexion, a line was drawn between the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS). The relation between this line and the femoral axis represented hip flexion (Figure 1A). The pelvic incidence angle was measured to assess the pelvic tilt. A line was drawn across the sacral endplate. Next, a perpendicular line was constructed from the midpoint of the sacral endplate line distally. A line was then drawn from the midpoint of the femoral head to the midpoint of the sacral endplate. This angle defined the pelvic incidence. Mean (SD) normal pelvic incidence is 53.2° (7°) in men and 48.7° (7°) in women (Figure 1B).[5]

In a patient with normal sagittal balance, the center of the C7 vertebral body is in line with the posterior superior corner of S1 and the longitudinal axis of the femur. This normal relation is demonstrated by the C7 plumb line, also known as the sagittal vertical axis (SVA), which is extended from the center of the C7 body down to the posterosuperior aspect of the sacrum at the L5–S1 disks, and the longitudinal axis of femur (Figure 1C). In patients with positive sagittal imbalance, the C7 center is shifted forward in relation to the femoral axis line. This C7 offset from the femoral axis line represents the positive sagittal imbalance, the perpendicular dis-

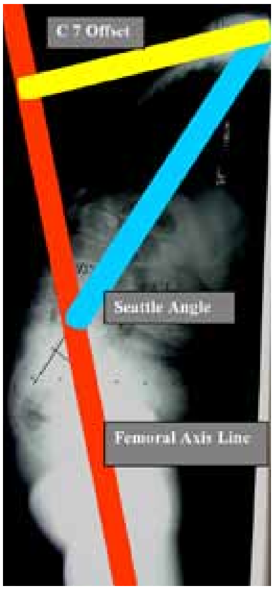


Figure 2. C7 offset, measured as the perpendicular distance between the femoral axis line and the center of the C7 vertebral body, represents positive sagittal imbalance. Seattle angle is measured between the femoral axis line and a line extending from the center of the C7 vertebral body down to the vertebra where the proposed osteotomy is to be performed.

tance between the femoral axis line and the center of C7 (Figure 2).

The Seattle angle, measured between the femoral axis and a line extending from the center of C7 to the vertebra at the level of the proposed osteotomy, predicted how much correction was required to bring the C7 plumb in line with the femoral axis and to decrease the C7 offset, thus regaining sagittal balance (Figure 2).

Many patients with symptomatic fixed flatback syndrome and ankylosing spondylitis require surgical management in the form of spine osteotomy, such as pedicle subtraction osteotomy or multiple Smith-Petersen (chevron-type) osteotomies. Measuring the Seattle angle at different segments determines the necessary degree of correction to bring the C7 plumb in line with the femoral axis and deceases the C7 offset to regain sagittal balance. Dr. Wagner has used this radiologic evaluation to assess sagittal imbalance and to decide on type and level of spine osteotomy required to regain sagittal balance (Figure 3).

The proposed method was used to evaluate 10 consecutive patients who required spinal osteotomies to regain sagittal balance. Inclusion criteria were presentation with back pain secondary to positive sagittal imbalance with failure of conservative management for a minimum of 6 months.

Preoperative plain radiographs obtained at the final clinic visit before surgery and immediate postoperative plain radiographs were assessed twice, at a 6-week interval, by an independent spine surgeon and a musculoskeletal radiologist. C7 offset, Seattle angle, and pelvic incidence angle were measured. Cohen κ correlation coefficients were used to calculate intraobserver and interobserver reliability.

Results

Mean age of the 10 patients was 54.2 years (range, 38-70 years). There were 6 women and 4 men. Mean symptom duration was 18.4 months (range, 6-36 months). Eight patients had lumbar flatback syndrome secondary to previous multilevel spine fusion. Two patients had ankylosing spondylitis and presented with loss of forward gaze and back pain. None of the 10 patients had hip problems identified by history and clinical examination, and none of the patients had hip flexion deformity identified by clinical examination and radiographic assessment.

Mean preoperative pelvic incidence was 48° (range, 45°-54°). Mean preoperative Seattle angle at the third lumbar vertebra was 40° (range, 32°-56°). Mean preoperative C7 offset was 7 cm (range, 5-9 cm), which improved to a mean postoperative offset of 2 cm (range, 1.5-3 cm).

The 2 reviewers' intraobserver reliability was excellent (κs = 0.98, 0.93). Interobserver reliability was lower but good (κ = 0.76). The lower interobserver reliability, as

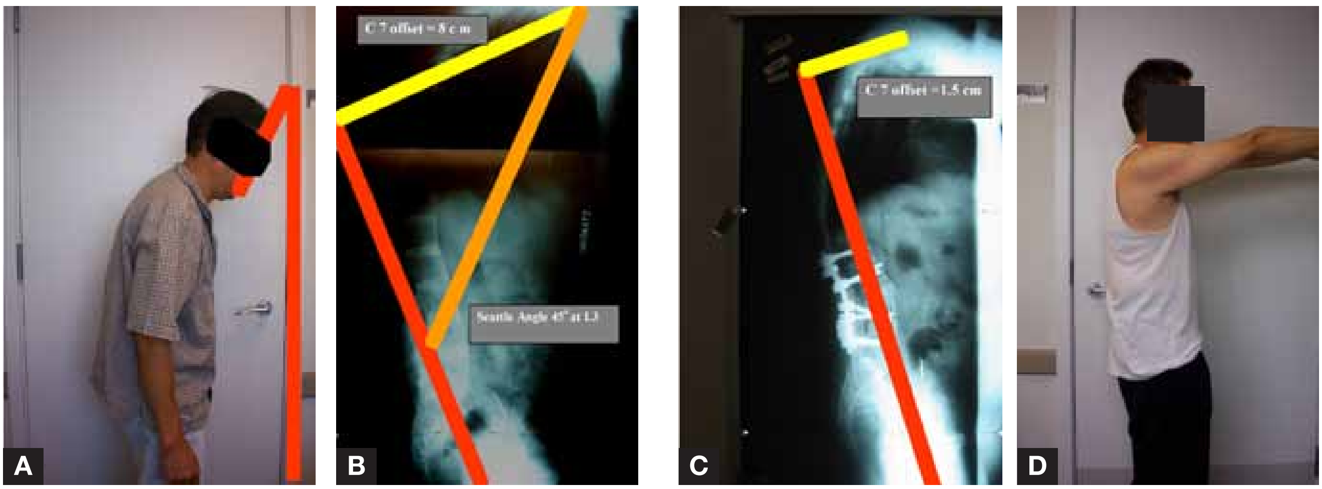


Figure 3. **(A) This patient with ankylosing spondylitis presented with progressive loss of forward gaze. Physical examination revealed a chin–brow vertical angle of 30°. (B) Preoperative upright lateral radiograph shows C7 offset of 8 cm and Seattle angle of 45° at L3. The patient's sagittal imbalance was managed with L3 pedicle subtraction osteotomy. (C) Postoperative upright lateral radiograph shows C7 offset improved to 1.5 cm. (D) Follow-up photograph shows improvement in sagittal imbalance.**

compared with the intraobserver reliability, was related to difficulty in identifying the C7 center on some of the old plain radiographs. Identification of the C7 center was clearer on the new digital radiographs.

Discussion

Sagittal imbalance, seen as forward displacement of C2 in relation to the pelvis, may be caused by deformity in cervical, thoracic, lumbar, lumbosacral spine, or fixed hip flexion. Flatback syndrome "fixed sagittal imbalance" is a postural disorder caused by loss of normal lumbar lordosis. It constitutes forward inclination of the trunk and inability to stand erect without knee flexion and neck hyperextension. Young patients can compensate, but adults older than age 40 lose the ability to compensate, and they present with fatigue-like pain and stooped posture.

Clinical evaluation of sagittal imbalance starts with an examination that has the patient standing with knee fully extended to eliminate any compensatory knee flexion that may mask a severe deformity. The patient is then examined sitting. When the trunk appears to have good balance in relation to the pelvis, then hip flexion contracture may be the cause, and this can be demonstrated with the Thomas test. When forward displacement of C2 in relation to the pelvis remains with the patient sitting, the patient is then assessed in the supine position. When the deformity is localized to the lumbar spine, the patient is able to lie down with shoulders on the table. When the head and upper thoracic spine remain elevated from the table, a fixed deformity in the cervical and/or thoracic spine is likely.

Recently published literature has shown that sagittal balance of the spine is one of the most important factors in patients' satisfaction after lumbar spine surgery. Berven and colleagues[1] reviewed 25 consecutive patients with fixed sagittal imbalance treated with combined anterior and posterior spinal arthrodesis. They concluded that overall clinical outcomes and patient satisfaction with surgery were best in cases that resulted in increased lumbar lordosis. Furthermore, the subset of patients with preoperative regional hypolordosis of the lumbar spine had better outcomes than patients with preoperative lumbar lordosis in the physiologic range. Booth and colleagues[2] reviewed 28 consecutive cases of flatback deformity treated with Smith-Petersen or pedicle subtraction spinal osteotomies to define factors that contribute to outcome results. They found that undercorrection of sagittal balance is one of the major factors that affect patient satisfaction.

Proper radiographic evaluation is essential in assessing segmental, regional, and global sagittal imbalance. Plain radiographs include upright anteroposterior and lateral lumbosacral views, using a long, 17×36-inch cassette of the entire spine, taken with the shoulders at 45° forward flexion and the hips and knees fully extended. Hip and knee full extension is important to eliminate any compensatory flexion that may mask a severe deformity. The radiographic method most often used to assess sagittal imbalance involves using a standing lateral radiograph and measuring the horizontal distance between a C7 plumb line (SVA) and the posterosuperior aspect of the sacrum at the L5–S1 disks. Positive sagittal imbalance is defined as an anterior deviation of the C7 plumb line.[6]

Marks and colleagues[7] studied 15 healthy female adolescents to examine the validity and reliability of SVA measurements during a variety of standing positions commonly used while obtaining lateral thoracolumbar spine radiographs. The mean SVA measurements were positive (C7 anterior to S1) for the functional positions (relaxed standing, 0.9 [2] cm; mean [SD] throughout gait, 4.5 [2] cm), whereas mean [SD] shoulder flexion resulted in a negative SVA (–4.6 [3.2]). Adding knee flexion resulted in a slight relative shift in SVA anteriorly. They concluded that 45° shoulder flexion alone was the best position for a lateral radiograph because of minimal compromise to repeatability of SVA measurement.

Van Royen and colleagues[8] conducted a study to investigate the effect of postural change on shifts in SVA and to evaluate whether SVA, as measured on a standing full-length lateral radiograph, can be used as an accurate measurement of spinal balance in clinical practice. Sagittal imbalance was analyzed in a patient with ankylosis of the entire spine caused by ankylosing spondylitis to eliminate segmental movement of the spine. The results of the study showed that small changes in hip, knee, and ankle joint angles affected SVA significantly and led to the horizontal distance between SVA and the anterior superior corner of the sacrum varying from –4.5 cm to 14.9 cm. They concluded that sagittal imbalance in ankylosing spondylitis cannot be measured from the SVA on a standing lateral full-length radiograph of the spine unless strict procedures are developed to control for the angle of the hip, knee, and ankle joints. Therefore, the accuracy of SVA as a measurement of sagittal spinal balance in other spinal deformities, with possible additional segmental movements, remains questionable.

We propose to include the proximal femur in addition to the entire spine in the long, 14×51-inch lateral plain radiograph. The radiograph was taken with the arms at 45° forward flexion and the hips and knees fully extended. The advantages of this new radiographic global assessment include ruling out hip contractures as the cause of the positive sagittal imbalance by including the proximal femur and the pelvis in the upright lateral plain radiograph. The relation between the ASIS–PSIS line and the femoral axis represented hip flexion. The pelvic incidence angle was measured to assess the pelvic tilt. As stated, the mean (SD) normal pelvic incidence is 53.2° (7°) in men and 48.7° (7°) in women.[5] A low pelvic incidence value implies low values of sacral slope and pelvic tilting, and as a result, creates a flattened lumbar lordosis with resultant low shear stress at the lumbosacral junction.

Inversely, a high pelvic incidence value implies a more sagittally tilted pelvis and increased lumbar lordosis, with increased verticality and increased shear.[9]

This method also helps in planning type and level of spinal osteotomy required to regain sagittal balance. Cho and colleagues[6] showed that mean correction of the kyphotic angle at the osteotomy sites for the Smith-Petersen osteotomy was 10.7° per segment. For cases of 3- level Smith-Petersen osteotomies, mean (SD) total correction was 33° (9.2°). Mean (SD) correction of 1-level pedicle subtraction osteotomy was 31.7° (9°). This means that the correction gained by 3-level Smith-Petersen osteotomies is similar to the correction gained by 1-level pedicle subtraction osteotomy. The most common level for pedicle subtraction osteotomy is L3. The second most common level is L4. Measuring the Seattle angle at different segments determines the necessary degree of correction to bring the C7 plumb in line with the femoral axis, which decreases C7 offset and regains sagittal balance. From the study by Cho and colleagues,[6] one expects a mean of 30° of correction that can be gained from 1-level pedicle subtraction osteotomy versus 10° from 1-level Smith-Petersen osteotomy. From preoperative measurement of the Seattle angle at the level of the proposed osteotomy, one can determine if a 1-level pedicle subtraction osteotomy performed at L3 or L4 will correct sagittal balance or if additional Smith-Petersen osteotomy and transforaminal interbody fusion with cages or allograft spacer are necessary. In a patient with a preoperative Seattle angle of less than 30°, one can expect correction of sagittal imbalance with Smith-Petersen osteotomy, whereas in a patient with a preoperative Seattle angle of 30° to 40°, a 1-level pedicle subtraction osteotomy may be used to regain sagittal balance. In a patient with an angle of 50° or more, one may consider 1-level pedicle subtraction osteotomy in addition to 1-level Smith-Petersen osteotomy.

Conclusion

Inclusion of the proximal femur on the long upright lateral plain radiograph of the entire spine and identification of the relation between the femoral axis line and the center of C7 are important in evaluating sagittal imbalance. Excellent intraobserver reliability, coupled with good interobserver reliability, suggest that this new radiologic assessment method can be helpful in preoperative assessment of sagittal imbalance.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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