3

Radiographic Parameters of Adult Lumbar Scoliosis

Patrick Reid, Jeffrey Varghese, and Virginie Lafage

Introduction

Radiographic evaluation is essential in the management of scoliosis. X-rays provide objective insight into a patient's structural deformity, often validating a proper yet subjective history and physical. Radiographic measurements from posteroanterior and lateral standing films provide the language we use to communicate about patients and compare results. Since the advent of the Risser sign and the Cobb angle, through the evaluation of spinopelvic alignment and the sagittal plane, radiographic measurements have provided reliable, objective measurements for the diagnosis and treatment of scoliosis.

The radiographic analysis of scoliosis in the twentieth century concentrated primarily on coronal deformities; coronal alignment continues to occupy a position of primacy in the evaluation and treatment of childhood scoliosis. In the management of adult deformity, however, emphasis has shifted toward the correction of sagittal malalignment. Analyzing the sagittal plane is more complex than analyzing the coronal or axial planes, owing to the natural kyphosis and lordosis of the spine. This complexity has driven the development of parameters to simplify and guide the management of adult deformity. The work of Roussouly and others have characterized the normal curvatures of the spine and, importantly, its relationship to the pelvis [1, 2, 10, 12, 15, 16, 18, 25, 38]. Building upon this, parameters defining pathological alignment in the sagittal plane were evaluated using patient-reported outcome studies, leading to the development of the SRS-Schwab classification system for adult scoliosis [7, 28–30, 32].

History of Radiographic Parameters in Scoliosis

X-ray measurements have been a keystone in the evaluation of scoliosis since the advent of the Risser and Cobb measurements in the 1950s. The Risser sign, a measurement of iliac ossification, has been used to evaluate skeletal maturity and has persisted in the study of adolescent idiopathic scoliosis. Likewise, John Cobb's end plate-to-end plate angular measurement still serves as the primary radiographic finding in coronal deformity and is used to diagnose, discuss, classify, and treat these curves. The Cobb measurement, in particular, has been used in multiple classification systems designed to predict the natural history and surgical outcome from the angle and location of coronal curves. Ponseti and Friedman; James, Collis, and Ponseti; and Harrington combined Cobb angles with other factors, e.g., curve location, rotation, progression, and length, as

P. Reid, MD • J. Varghese, BS • V. Lafage, PhD (✉)
Hospital for Special Surgery,
535 E 70th St, New York, NY 10021, USA
e-mail: reidp@hss.edu; varghesej@hss.edu;
lafagev@hss.edu, virginie.lafage@gmail.com

E.O. Klineberg (ed.), *Adult Lumbar Scoliosis*, DOI 10.1007/978-3-319-47709-1_3

well as patient maturity, to form distinct classification systems intended to guide management [9, 21].

In 1983, King published a classification system based entirely on posteroanterior upright and bending x-rays of the thoracolumbar spine, combining Cobb angle measurements with curve patterns, locations, relative flexibilities, and vertebral axial rotations [13]. It also required more than just the Cobb angle, codifying many of the terms used in deformity evaluation today, e.g., the center sacral line, stable and neutral vertebrae, and a “flexibility index” derived from comparing lateral bending in thoracic and lumbar curves. This system was designed to guide selection of fusion levels in adolescent idiopathic scoliosis and was the first classification system to be widely adopted.

The widespread adoption of the King classification offered an excellent opportunity to study a large population of deformity patients. Systematic examination ultimately exposed the weaknesses in the classification; more significant than its reliability pitfall was its lack of consideration for the sagittal plane [36]. Several subsequent AIS classification schemes improved on the King system, adopting its attention to the coronal curve but adding parameters to characterize pathologic sagittal alignment. The Lenke classification accounted for the chief shortcomings of the King system, improving reproducibility and adding a modifier for lordosis as measured on lateral films [17]. The Lenke Classification for AIS served as a starting point for the radiographic examination and classification of adult deformity, although the disease processes and important measures for each would prove very different.

Adult Deformity and the Cone of Economy

The study of adult deformity, separate from its juvenile counterpart, has grown rapidly over the past few decades. The application of key radiographic parameters and classification systems used in AIS and other juvenile scoliotic diseases has proved largely ineffective [7]. Emphasis has shifted away from coronal realignment—frequently the primary goal of juvenile scoliosis surgery—toward alignment correction in the sagittal plane.

Spinal alignment is more complicated in the sagittal plane than it is in the coronal or axial planes. Whereas the goal of coronal and axial correction is to straighten and de-rotate, correction in the sagittal plane must account for the natural spinal lordosis and kyphosis. Appropriate alignment in the sagittal plane has been shown to improve outcomes in the adult scoliotic population [14, 32]. As such, the parameters that constitute pathologic sagittal malalignment, including compensatory measures outside the thoracolumbar spine, have been the subject of increasing study [19, 20, 22, 24, 26, 33, 34].

The “cone of economy” as published by Dubousset in 1994 describes the range of standing postures in which the body can remain balanced without support and with minimum energy expenditure [3]. Those unable to maintain a standing posture in the center of the cone demand the muscles and joints of the spine and legs to compensate, which can result in fatigue, pain, and disability. Many of these patients require external aids such as walkers or canes to stand. Studies on flatback syndrome have noted the clinical sequela of iatrogenic sagittal malalignment since the 1970s. That, with the quantification of normal and pathologic spinal curvatures, has driven the development of many radiographic parameters [5].

Multiple studies have attempted to characterize radiographic alignment in the sagittal plane. Stagnara, in 1982, proposed normal reference values for thoracolumbar lordosis and kyphosis, as well as for sacral slope [35]. His findings—that there were wide and irregular variations between healthy subjects for both values, belying the idea of a “normal” lumbar lordosis or thoracic kyphosis—have been born out in subsequent studies. The study did note the intra-patient relationships between lordosis, kyphosis, and sacral slope, which would also be a theme of sagittal analysis going forward.

Quantitative Radiographic Evaluation for Sagittal Plane

A landmark study by Jackson et al. in 1994 compared healthy adult volunteers with patients reporting low back pain, noting a wide but largely similar range of values for lordosis ad kyphosis in healthy patients, as well as similar C7 plumbline values, between the two groups [11]. However, they noted a critical proximal shift in segmental lordosis and a decrease in sacral inclination in back pain patients, representing possible compensatory mechanisms for any loss of lordosis at the lower lumbar levels in these patients.

An emphasis on sagittal alignment led to widespread use of the sagittal vertical axis (SVA), determined by measuring the AP translation relative to S1 of a cephalad vertebrae. Gelb et al. examined the horizontal distance between a plumbline dropped from the middle of the C7 vertebral body to the anterior superior corner of the sacrum on a standing lateral x-ray, noting the tendency for SVA to move anteriorly in older subjects, while sagittal alignment remained neutral in asymptomatic patients [6]. Van Royen et al. examined the horizontal distance between a plumbline dropped from the tip of the C7 spinous process to the anterior superior S1 vertebral body in a single patient with an ankylosed spine to isolate the relationship between posture and SVA (Fig. 3.1) [37]. They pointed out that small angular adjustments in the lower extremities resulted in significant changes to SVA measurements, implying that SVA ought to be considered in the context of compensatory postural mechanisms. Further studies pointed out inadequacies in SVA measurements: a dependence on arm position, a lack of correlation to "functional" standing position, and a poor correlation between a cervical plumbline and the true center of gravity. Still, poor clinical outcomes have been shown to correlate linearly with increasing sagittal malalignment as measured with a C7 plumbline, indicating SVA as an important parameter for health-related quality of life.

The incorporation of pelvic parameters led to a fuller understanding of sagittal alignment and its contribution to quality of life outcomes. In 1998, Legaye and Duval-Beaupere et al. proposed pelvic incidence (PI), a measure quantifying the interface between the spine and the pelvis [4, 16]. Defined as the angle between the line from the femoral head axis to the midpoint of the superior S1 end plate and the line perpendicular to the S1 end plate, PI is morphologically unique to each individual and is independent of postural changes. PI, a fixed value, correlated well with LL; patients with a high PI were also likely to have a high LL. They postulated that a chain of interdependence existed between the pelvic and spinal parameters. Other parameters proposed by

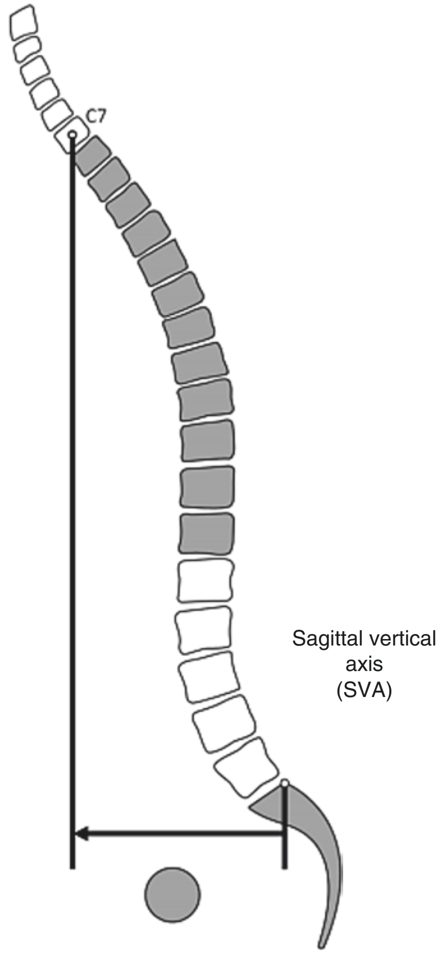

Fig. 3.1 Schematic diagram for sagittal vertical axis (SVA)

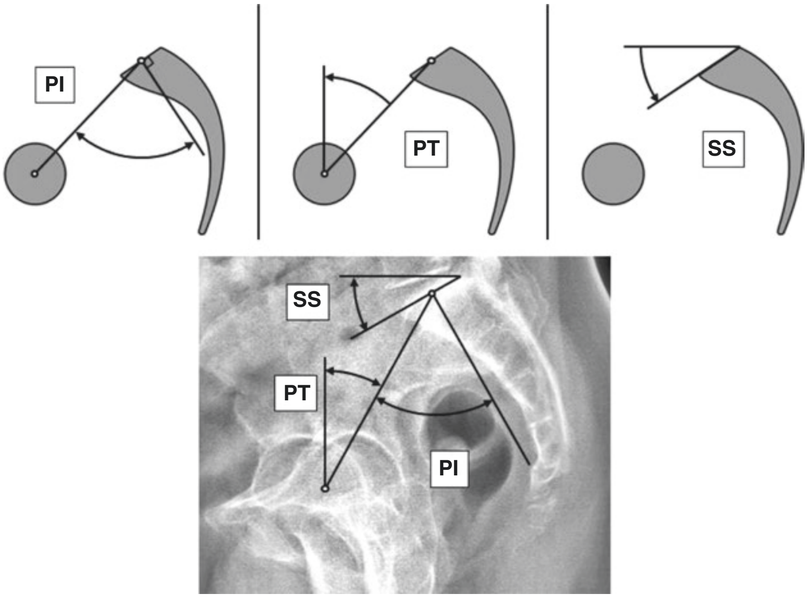

Fig. 3.2 Schematic diagrams for pelvic parameters

Legaye include sacral slope (SS), defined as the angle between the S1 end plate and the horizontal on a lateral standing x-ray, and pelvic tilt (PT), defined as the angle between the line from the mid-axis of the femoral heads to the midpoint of the superior S1 end plate and the vertical on a lateral standing x-ray (Fig. 3.2).

Attention to the pelvic parameters revealed the importance of pelvic compensation for sagittal malalignment. Earlier papers had characterized the effect of small, angular changes in posture around the hip axis on the SVA, but in the late 1990s and early 2000s, efforts were made to quantify this compensation [1, 12].

Pelvic Parameters and the Sagittal Plane

The high degree of patient-to-patient variability in spinal sagittal alignment complicates the study of pathologic malalignment. Roussouly et al., in 2005, published a classification system describing categories of lumbar lordosis in relation to curve apices and spinopelvic relationships in 160 normal subjects [25]. In addition to describing an association between PI and LL, they found a reciprocal relationship between the sacral slope and pelvic tilt and established the equation: SS + PT = PI. Relating spinal sagittal curves to pelvic parameters lends meaning to these measurements that otherwise vary so wildly as to make radiographic identification of pathology, in many cases, difficult if not impossible.

Spinopelvic alignment criteria have been shown to correlate with patient-reported outcomes. Previous studies sought to delineate, without success, a relationship between coronal deformity and clinical outcomes. However in the sagittal plane, Glassman et al. demonstrated that positive sagittal malalignment is predictive of poor clinical health status; their two studies revealed that symptom severity increased linearly with worsening positive sagittal malalignment and that restoring normal sagittal alignment improved clinical symptoms [7, 8].

The identification of sagittal alignment as a primary driver in adult scoliosis patient satisfaction, both pre- and post-op, set the stage for the establishment of the SRS-Schwab classification system, which has undergone several iterations since the early 2000s. Based originally on a prospective analysis of 95 patients, the initial study in 2002 identified L3 and L4 end plate obliquity in the frontal plane, lateral olisthesis, lumbar lordosis, and thoracolumbar kyphosis as radiographic parameters that correlated with increased pain [29]. This led to the first SRS-Schwab classification system, which grouped patients into three categories based on lumbar lordosis and L3 coronal obliquity. The system was then expanded; the curves were further characterized by their coronal deformity apex, degree of lordosis, and intervertebral subluxation. Coronal curve categories were prescriptive—different curve types demanded tailored surgical approaches—while the lordosis and subluxation modifiers stratified patients into clinical groups, with higher grades indicating worsening HRQOL.

The work of Glassman et al. led to the inclusion of a global sagittal balance modifier in later iterations [8]. Ultimately, outcome-driven criteria led to refining the SRS-Schwab classification system to include a coronal curve modifier and three sagittal alignment modifiers: PI-LL, SVA, and pelvic tilt (Fig. 3.3). The coronal modifier describes the coronal curve type: T for thoracic only, L for thoracolumbar or lumbar only curves, D for double curves (T and TL/L curves both >30°), and N for no coronal curves>30°. The three sagittal modifiers, stratifying patients by clinical symptomatology, were established based on HRQOL studies:

PI-LL, calculated by subtracting the lumbar lordosis from pelvic incidence: 0 (non-pathologic) for PI-LL < 10°, + (moderate deformity) for PI-LL between 10° and 20°, and ++ (marked deformity) for PI-LL>20°

Global alignment, assessed by measuring the translational distance from the posterior superior S1 body to a plumbline dropped from the middle of the C7 vertebral body: 0 (non-pathologic) for SVA< 4 cm, + (moderate deformity) for SVA between 4 and 9.5 cm, and ++ (marked deformity) for SVA<9.5 cm

Pelvic tilt, measured as the angle between the line from the mid-axis of the femoral heads to the midpoint of the S1 plate and a vertical line: 0 (non-pathologic) < 20°, + (mild deformity) between 20° and 30°, and ++ (marked deformity) > 30°

The SRS-Schwab classification provides a framework for interpreting radiographic parameters by incorporating the current base of knowledge regarding sagittal alignment, spinopelvic parameters, and compensatory measures [27]. The classification has been validated using patient-reported outcomes for both operative and nonoperative patients [30, 31]. When combined with clinical judgment, the SRS-Schwab classification can guide treatment in adult scoliosis patients. Prospective studies have validated the

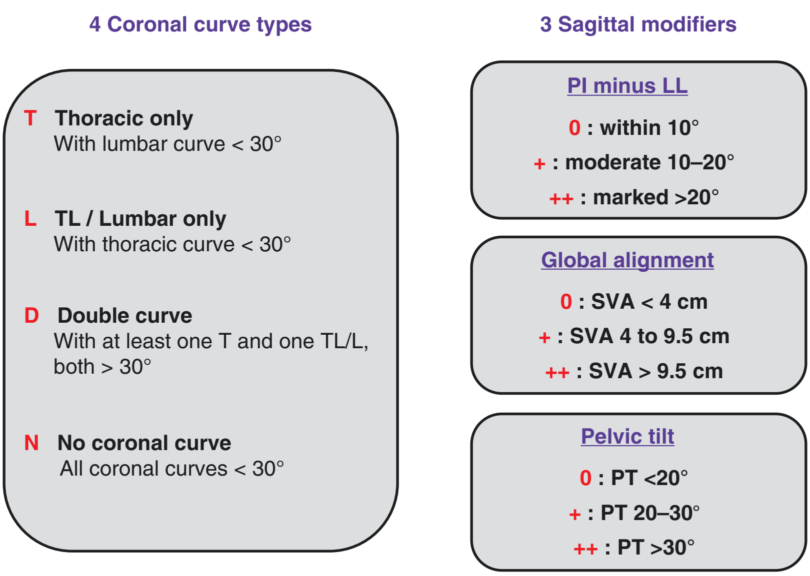

Fig. 3.3 SRS-Schwab classification for adult spinal deformity

classification in follow-up studies, relating improvement in SRS-Schwab classification with higher HRQOL scores [32].

Future Directions

Sagittal alignment and spinopelvic parameters have allowed surgeons to pursue evidence-based radiographic goals anchored in patient-reported outcomes. Still, complications persist, and outcomes are not perfect. Several parameters show promise with regard to predicting complications and patient dissatisfaction beyond those described by the SRS-Schwab classification. Patients with severe sagittal malalignment, unsurprisingly, have poorer outcomes than those with mild or moderate deformities. High preoperative PT and SVA have been specifically shown to increase the risk of poor surgical outcomes. Poor postoperative alignment is a common cause of patient dissatisfaction and low HRQOLs; careful and adequate planning is critical in providing the proper degree of sagittal correction tailored to each individual patient. Postsurgical reciprocal changes, e.g., alterations in TK after lumber realignment surgery, have been observed. Surgical planning will need to account for these changes, although they are currently still difficult to predict.

Staying true to the global nature of malalignment, concomitant cervical deformity is also not uncommon in adult thoracolumbar disease. 53% of thoracolumbar deformity patients have cervical deformity, either as a compensatory mechanism or as a primary disease process [33]. New cervical deformity has also been found in 48% of post-op patients, as has improvements in preoperative cervical deformity following thoracolumbar realignment [19, 20, 22, 34]. This is a logical extension of the chain of interdependence connecting the pelvis and thoracolumbar spine. Radiographic parameters to quantify and predict cervical deformity are currently being studied, including T1 angle, T1 spinopelvic inclination, C2-T1 SVA, and cervical lordosis. T1 spinopelvic inclination also correlates with HRQOL outcome scores in adult scoliosis patients [23, 26]. Caudal to the spinopelvic axis, studies are being directed at knee flexion, another compensatory mechanism with similar biomechanics to pelvic tilt.

Predicting outcomes from adult scoliosis surgery has proven difficult. Patients on either end of the disease spectrum tend to improve after surgery; it is those who fall between the extremes—the majority of patients—that have mixed results. Poor outcomes occur even after a successful sagittal realignment. This emphasizes the need for further studies to determine if there are radiographic parameters that can be further optimized to increase chances of obtaining good clinical results.

Conclusion

Radiographic parameters, clinically backed with patient-reported outcomes, are both useful in the baseline evaluation of and the treatment selection for adult spinal deformity patients. With the spinopelvic parameters and the SRS-Schwab classification in mind, a framework has been established to deliver a more personalized surgical approach, resulting in better clinical outcomes and greater patient satisfaction.

References

1. Berthonnaud E, Dimnet J, Roussouly P, Labelle H. Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. J Spinal Disord Tech. 2005;18:40–7. Available: http://www.ncbi.nlm.nih.gov/pubmed/15687851.
2. Boulay C, Tardieu C, Hecquet J, Benaim C, Mouilleseaux B, Marty C, et al. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. Eur Spine J. 2006;15:415–22. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3489325&tool=pmcentrez&rendertype=abstract. Accessed 18 Nov 2013.
3. Dubousset J. Three-dimensional analysis of the scoliotic deformity. In: Weinstien SL, editor. The pediatric spine: principles and practices, vol. 1994. New York: Raven Press; 1994. p. 479–96 .Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Three-Dimensional+Analysis+of+the+Scoliotic+Deformity#0. Accessed 5 Dec 2014.

4. Duval-Beaupère G, Schmidt C, Cosson P. A barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. Ann Biomed Eng. 1992;20:451–62. Available: http://www.ncbi.nlm.nih.gov/pubmed/1510296. Accessed 17 Nov 2014.
5. Farcy J-P, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. Spine (Phila Pa 1976). 1997;22:2452–7. Available: http://www.ncbi.nlm.nih.gov/pubmed/9355229.
6. Gelb DE, Lenke LG, Bridwell KH, Blanke K, McEnery KW. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. Spine (Phila Pa 1976). 1995;20:1351–8. Available: http://www.ncbi.nlm.nih.gov/pubmed/7676332. Accessed 23 Aug 2013.
7. Glassman SD, Berven S, Bridwell K, Horton W, Dimar JR. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. Spine (Phila Pa 1976). 2005;30:682–8. Available: http://www.ncbi.nlm.nih.gov/pubmed/15770185. Accessed 12 Aug 2013.
8. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab FJ. The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976). 2005;30:2024–9. Available: http://www.ncbi.nlm.nih.gov/pubmed/16166889. Accessed 17 Nov 2014.
9. Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. J Bone Joint Surg Am. 1962;44-A:591–610. Available: http://www.ncbi.nlm.nih.gov/pubmed/11861739. Accessed 28 July 2014.
10. Jackson RP, Kanemura T, Kawakami N, Hales C. Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. Spine (Phila Pa 1976). 2000;25:575–86. Available: http://www.ncbi.nlm.nih.gov/pubmed/10749634.
11. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. a prospective controlled clinical study. Spine (Phila Pa 1976). 1994;19:1611–8. Available: http://www.ncbi.nlm.nih.gov/pubmed/7939998. Accessed 23 Aug 2013.
12. Jackson RP, Peterson MD, McManus AC, Chris H, Hales C. Compensatory spinopelvic balance over the hip axis and better reliability in measuring lordosis to the pelvic radius on standing lateral radiographs of adult volunteers and patients. Spine (Phila Pa 1976). 1998;23:1750–67. Available: http://www.ncbi.nlm.nih.gov/pubmed/9728376. Accessed 12 Aug 2013.
13. King HA, Moe JH, Bradford DS, Winter RB. The selection of fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg Am. 1983;65:1302–13. Available: http://www.ncbi.nlm.nih.gov/pubmed/6654943. Accessed 23 Aug 2013.
14. Koller H, Pfanz C, Meier O, Hitzl W, Mayer M, Bullmann V, et al. Factors influencing radiographic and clinical outcomes in adult scoliosis surgery: a study of 448 European patients. Eur Spine J. 2015. Available: http://www.ncbi.nlm.nih.gov/pubmed/25917822. Accessed 30 Apr 2015.
15. Lafage V, Schwab FJ, Patel A, Hawkinson N, Farcy J-P. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. Spine (Phila Pa 1976). 2009;34:E599–606. Available: http://www.ncbi.nlm.nih.gov/pubmed/19644319. Accessed 26 Aug 2014.
16. Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J. 1998;7:99–103. Available: http://www.ncbi.nlm.nih.gov/pubmed/9629932. Accessed 18 Nov 2014.
17. Lenke LG, Betz RR, Harms J, Bridwell KH, Clements DH, Lowe TG, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am. 2001;83-A:1169–81. Available: http://www.ncbi.nlm.nih.gov/pubmed/11507125. Accessed 23 Aug 2013.
18. Mac-Thiong J-MM, Labelle H, Berthonnaud E, Betz RR, Roussouly P. Sagittal spinopelvic balance in normal children and adolescents. Eur Spine J. 2007;16:227–34. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2200687&tool=pmcentrez&rendertype=abstract. Accessed 23 Aug 2013.
19. Oh T, Scheer JK, Eastlack R, Smith JS, Lafage V, Protopsaltis TS, et al. Cervical compensatory alignment changes following correction of adult thoracic deformity: a multicenter experience in 57 patients with a 2-year follow-up. J Neurosurg Spine. 2015;22:1–8. Available: http://www.ncbi.nlm.nih.gov/pubmed/25793468. Accessed 3 May 2015.
20. Passias PG, Soroceanu A, Smith J, Boniello A, Yang S, Scheer JK, et al. Postoperative cervical deformity in 215 thoracolumbar patients with adult spinal deformity: prevalence, risk factors, and impact on patient-reported outcome and satisfaction at 2-year follow-up. Spine (Phila Pa 1976). 2015;40:283–91. Available: http://www.ncbi.nlm.nih.gov/pubmed/25901975. Accessed 5 May 2015.
21. Ponseti IV, Friedman B. Prognosis in idiopathic scoliosis. J Bone Joint Surg Am. 1950;32A:381–95. Available: http://www.ncbi.nlm.nih.gov/pubmed/15412180. Accessed 11 Aug 2014.
22. Protopsaltis TS, Scheer JK, Terran JS, Smith JS, Hamilton DK, Kim HJ, et al. How the neck affects the back: changes in regional cervical sagittal alignment correlate to HRQOL improvement in adult thoracolumbar deformity patients at 2-year follow-up. J Neurosurg Spine. 2015;23:153–8. Available: http://www.ncbi.nlm.nih.gov/pubmed/25978077.
23. Protopsaltis TS, Schwab FJ, Bronsard N, Smith JS, Klineberg E, Mundis G, et al. The t1 pelvic angle, a

novel radiographic measure of global sagittal deformity, accounts for both spinal inclination and pelvic tilt and correlates with health-related quality of life. J Bone Joint Surg Am. 2014;96:1631–40. Available:http://www.ncbi.nlm.nih.gov/pubmed/25274788. Accessed 7 Nov 2014.

24. Protopsaltis T, Schwab F, Smith JS, Klineberg E, Mundis G, Hostin R, et al. The T1 Pelvic Angle (TPA), a novel radiographic measure of sagittal deformity, accounts for both pelvic retroversion and truncal inclination and correlates strongly with HRQOL. Scoliosis Res Soc Lyon, Fr Sept 18–21:2013.
25. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. Spine (Phila Pa 1976). 2005;30:346–53. Available: http://www.ncbi.nlm.nih.gov/pubmed/15682018.
26. Ryan DJ, Protopsaltis TS, Ames CP, Hostin R, Klineberg E, Mundis GM, et al. T1 Pelvic Angle (TPA) Effectively Evaluates Sagittal Deformity and Assesses Radiographical Surgical Outcomes Longitudinally. Spine (Phila Pa 1976). 2014;39:1203–10. Available: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00007632-201407010-00012.
27. Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. Spine (Phila Pa 1976). 2013;38:E803–12. Available: http://www.ncbi.nlm.nih.gov/pubmed/23722572. Accessed 12 Aug 2013.
28. Schwab FJ, Lafage V, Farcy J-P, Bridwell KH, Glassman SD, Ondra S, et al. Surgical rates and operative outcome analysis in thoracolumbar and lumbar major adult scoliosis: application of the new adult deformity classification. Spine (Phila Pa 1976). 2007;32:2723–30. Available: http://www.ncbi.nlm.nih.gov/pubmed/18007252.
29. Schwab FJ, Smith VA, Biserni M, Gamez L, Farcy J-PC, Pagala M. Adult scoliosis: a quantitative radiographic and clinical analysis. Spine (Phila Pa 1976). 2002;27:387–92. Available: http://www.ncbi.nlm.nih.gov/pubmed/11840105. Accessed 3 Apr 2015.
30. Schwab FJ, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976). 2012;37:1077–82. Available: http://www.ncbi.nlm.nih.gov/pubmed/22045006. Accessed 12 Aug 2013.
31. Slobodyanyuk K, Poorman CE, Smith JS, Protopsaltis TS, Hostin R, Bess S, et al. Clinical improvement through nonoperative treatment of adult spinal deformity: who is likely to benefit? Neurosurg Focus. 2014;36:E2. Available: http://www.ncbi.nlm.nih.gov/pubmed/24785484.
32. Smith JS, Klineberg E, Schwab F, Shaffrey CI, Moal B, Ames CP, et al. Change in classification grade by the SRS-schwab adult spinal deformity classification predicts impact on health-related quality of life measures: prospective analysis of operative and non-operative treatment. Spine (Phila Pa 1976). 2013;38:1663–71. Available: http://www.ncbi.nlm.nih.gov/pubmed/23759814. Accessed 12 Aug 2013.
33. Smith JS, Lafage V, Schwab FJ, Shaffrey CI, Protopsaltis T, Klineberg E, et al. Prevalence and type of cervical deformity among 470 adults with throacolumbar deformity. Spine (Phila Pa 1976). 2014;39:1001–9. Available: http://www.ncbi.nlm.nih.gov/pubmed/24859571. Accessed 27 May 2014.
34. Smith JS, Shaffrey CI, Lafage V, Blondel B, Schwab FJ, Hostin R, et al. Spontaneous improvement of cervical alignment after correction of global sagittal balance following pedicle subtraction osteotomy. J Neurosurg Spine. 2012;17:300–7. Available: http://www.ncbi.nlm.nih.gov/pubmed/22860879.
35. Stagnara P, De Mauroy JC, Dran G, Gonon GP, Costanzo G, Dimnet J, et al. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis. Spine (Phila Pa 1976). 1982;7:335–42. Available: http://www.ncbi.nlm.nih.gov/pubmed/7135066. Accessed 12 Aug 2013.
36. Stokes IA, DD A. Identifying sources of variability in scoliosis classification using a rule-based automated algorithm. Spine (Phila Pa 1976). 2002;27:2801–5.
37. Van Royen BJ, Toussaint HM, Kingma I, Bot SD, Caspers M, Harlaar J, et al. Accuracy of the sagittal vertical axis in a standing lateral radiograph as a measurement of balance in spinal deformities. Eur Spine J. 1998;7:408–12. Available: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3611289&tool=pmcentrez&rendertype=abstract.
38. Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. Eur Spine J. 2002;11:80–7. Available: http://www.ncbi.nlm.nih.gov/pubmed/15614978. Accessed 8 Mar 2015.