J Orthop Spine Trauma. 2023 March; 9(1): 31-4. DOI: 10.18502/jost.v9i1.12568
Educational Corner

Sagittal Balance Concept and Spinopelvic Parameters

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Received: 09 April 2022; **Revised:** 17 June 2022; **Accepted:** 21 July 2022

Abstract

"Sagittal balance" is defined by the anatomic relationship between the pelvis and the spine in the sagittal plane to keep the center of gravity over the feet. It is important to calculate the anatomical parameters of cervical, thoracic, lumbar, and spinopelvic regions and how any static and dynamic changes could affect the sagittal balance to understand the conditions necessary for such a balance. One of the effective changes in sagittal balance is aging, which leads to changes in spine parameters and further activation of compensatory mechanisms. Understanding the relationships between these parameters, especially in pathological cases, helps correct spine sagittal imbalance.

Keywords: Spinal Curvatures; Lordosis; Kyphosis; Pelvis

Citation: Sadeghian M, Golbakhsh M, Rahimian A, Talebiyan P, Dehghani Firoozabadi MJ. **Sagittal Balance Concept and Spinopelvic Parameters.** *J Orthop Spine Trauma* 2023; 9(1): 31-4.

Background

"Sagittal balance" is defined by the anatomic relationship between the pelvis and the spine in the sagittal plane to keep the center of gravity over the feet. The concept of balance is a situation in which the forces present are equal (agonist and antagonist muscles) (1). The "cone of economy" was mentioned first time by Dr. Dubbouset in 1994, which means how small changes in spinopelvic balance bring about increasing muscles recruitment and energy expenditures. Bipedalism is an outstanding feature of the human species, which has the advantage of freeing the upper extremities for other tasks, but it needs anatomic structures that could maintain the whole-body balance (2).

To understand the conditions necessary for such a balance, it is important to calculate the anatomical parameters of cervical, thoracic, lumbar, and spinopelvic regions and how any static and dynamic changes could affect the sagittal balance.

Spinal Balance

When an individual is standing, a plumb line dropped from the top of the spine should consistently cross the centroid of his or her pelvis. This allows the muscles associated with posture and gait to function most efficiently.

In the coronal plane, a plumb line dropped from the dens typically falls near the S1 spinous process (within 1 cm). This plumb line is usually located posterior to the cervical spine, near the body of C7, anterior to the thoracic spine, posterior to the lumbar spine, and near the body of S1 (Figure 1).

As radiographs usually do not show the dens, the plumb line is often dropped from the middle of the C7 vertebral body, known as the sagittal vertical axis (SVA). The normal value of SVA is less than 5 cm, and it is one of the parameters that suggest the quality of life. Moreover, this parameter is age-dependent. While several "normal range" values for the SVA have been described, current adult spinal deformity literature suggests that SVA values greater than 5 cm are considered pathologic. Lafage et al. reported that an SVA larger than 4.7 cm was associated with severe disability by the Oswestry Disability Index (ODI) (3).

Sagittal Balance Elements of the Spine

Cervical: Fundamental parameters in this area should be considered about sagittal balance:

High Cervical Angle (0-C2): It is the angle between McGregor's line (4) and the inferior endplate of C2 (always lordotic, average: 15.81 ± 7.15°) (2) (Figure 1).

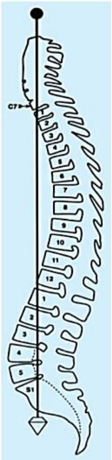

Figure 1. Sagittal vertical axis (SVA)

Low Cervical Angle (C2-C7): It is the angle between the C2 endplate and the lower C7 endplate (5). 0-C2 and C2–C7 angles work inversely: when one increases, the other decreases (average: 11.7 ± 10.0°) (2).

The C7 Slope: It is the angle between the upper endplate of C7 and the horizontal line. The average value is 20°. If the C7 slope is greater than 20, the cervical spine is lordotic (lordosis between C2 and C7), and if it is less than 20, the cervical spine is neutral or kyphotic (6).

The Spino-Cranial Angle (SCA): The angle is defined between the C7 slope and the line connecting the middle of the upper C7 plateau to the center of the sella turcica (83 ± 9°). It represents an idea of the head offset over C7-T1 (6).

The Vertical Cervical Offset: It is the horizontal distance of C2 and C7 plumb lines which is another parameter of the head offset (average value: less than 2 cm) (2) (Figure 2).

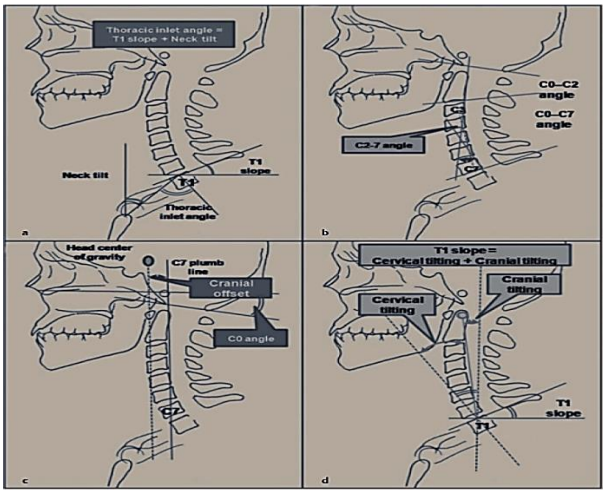

Figure 2. Cervical spine radiographic parameters

Thoracic

The main angles that should be measured in the thoracic spine are:

Thoracic Kyphosis (TK): It is measured between the upper T1 endplate and lower endplate of T12. Some investigators measure TK between T4 and T12 due to the poor quality of normal radiography. Research has shown that the theoretical value of TK is equal to 0.75 times the global lumbar lordosis (LL) angle (T1-T12 kyphosis = 0.75 × L1-S1 lordosis) (2).

T1 Pelvic Angle (TPA): It is the angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 superior end plate (7). In asymptomatic individuals, the average TPA is estimated at approximately 12°. This angle is one of the considerably important parameters that should be considered in patients with adult spinal deformity because it is not position-dependent and can be measured in supine, standing, and prone positions (1) (Figure 3).

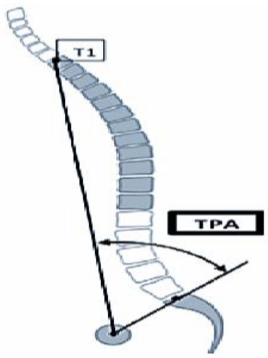

Figure 3. T1 pelvic angle (TPA)

Lumbar

LL: The angle is usually measured between the L1 and S1 (normal lordosis between 20° to 45°). However, according to Roussouly et al., this angle must be calculated between the inflection point and the superior endplate of S1 (8).

There is a direct correlation between TK and LL; that is, the larger the TK, the larger the LL, and vice versa (2).

The Point of Inflection: This point is determined when the TK turns to the LL (2) (Figure 4).

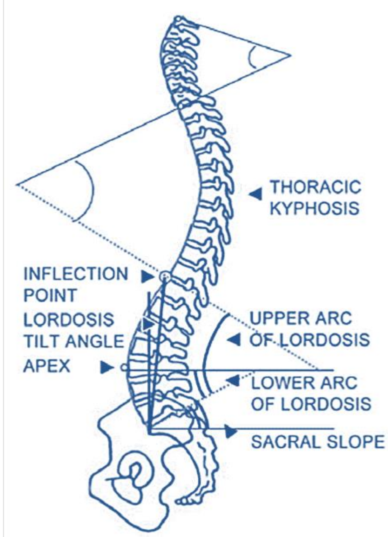

Figure 4. Thoracolumbar radiographic parameters

Spino-Pelvic Parameters

Three main parameters of pelvic alignment are pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) (Figure 5).

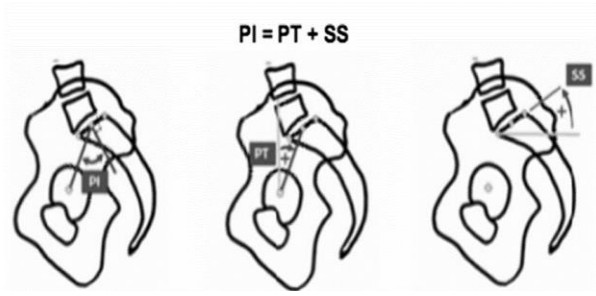

Figure 5. Spino-pelvic parameters

PI: PI is a morphologic parameter of spinopelvic alignment and is described by an angle between the perpendicular line of femoral heads and the midpoint of the sacrum. PI is a unique parameter because it does not change after skeletal maturity; therefore, unlike the SVA, PI will remain constant despite the compensatory mechanism (9).

PT: PT is the angle between the line drawn from the center of the femoral heads to the midpoint of the endplate of S1 and the vrtical line (1). The normal angle of PT is approximately 13° (10).

SS: SS is the angle between the S1 endplate and the horizontal plane. In contrast to PI, PT and SS are not constant after skeletal maturity and can change to compensate for a spinal deformity (1) (Figure 6).

Pelvic and Spinopelvic Sagittal Alignment: The spinopelvic alignment was first described by Jean Debousset as an essential predictor of the management of patients with spinal deformity (3).

Knowing about the normal variant of the asymptomatic population is essential to better understand the sagittal malalignment.

Spinopelvic balance is completely dependent on the shape of the pelvic (center of femoral heads and SS) and spinal column curvatures (LL and TK) (Figure 6).

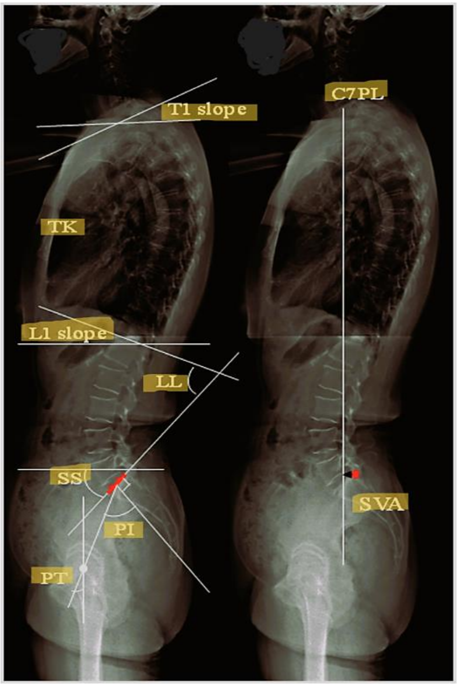

Figure 6. Spino-pelvic landmarks

A morphological factor determines the pelvic shape. The PI is one of the parameters that remain constant and stable through adulthood. However, two other parameters (SS and PT) may change according to the pelvic retroversion, which is associated with increasing PT or pelvic anteversion with decreasing PT based on geometrical relation: PI = PT + SS (10) (Table 1).

Considering spinopelvic inclination, Roussouly et al. created a classification of spinal sagittal alignment in the general population without any symptoms (8) (Figure 7).

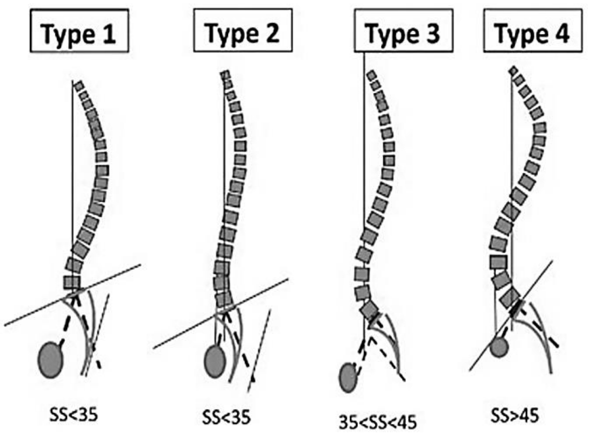

Figure 7. Roussouly classification of spinopelvic alignment (9)

Types 1 and 2 are categorized by a low SS (SS < 35°). Type 1 is characterized by small lordosis and high thoracolumbar kyphosis, which has a lower inflection point. Type 2 is characterized by a flattened lower arch ("flat" back). Type 3 has an average SS between 35° and 45° (35° < SS < 45°). This type is the most common type among the general population. The apex of lordosis is at the level of L4, which means the lordosis is balanced between two arches, proximal and distal lumbar spine lordosis. Type 3AP has been recently described by Roussouly et al. that is presented in 16% of the normal population (8). This new type has shown important characteristics of type 3 (35° < SS < 45°, and long LL) despite a low-grade PI which is the characteristic of types 1 and 2 (2). Type 4 is considered by an SS of more than 45° with a lordotic apex at the anterior-inferior corner of L3 (20% of normal population). Unlike types 1 and 2, the inflection point is upper than other types, which is associated with shorter TK.

Compensatory Mechanism in Sagittal Imbalance

Several mechanisms are used to keep sagittal balance, such as pelvic retroversion, thoracic hyperkyphosis, lumbar hyperlordosis, and knee flexion. Any disruptions in sagittal balance lead to unconsciously activating the compensatory mechanisms which try to keep the center of gravity over the feet. The pelvis acts as a link between the spinal column and lower extremity, whose unique anatomical position has the main role in compensation by rotating the pelvic backward (pelvic retroversion). Retroversion of the pelvis has been described as a first compensatory mechanism and has shown to be an important source of pain in patients with spinal deformity.

On the other hand, patients with hip problems such as flexion contracture or neurodegenerative disorders may not be able to use this compensatory mechanism efficiently to tilt the pelvis. Therefore, they are prone to severe spinal deformity, pain, and disability.

Among all pelvic parameters, PI is an important factor in determining the amount of pelvic retroversion that can be achieved. Patients with low PI have a slight capacity to rotate the pelvic backward, and other compensatory mechanisms should be applied to maintain sagittal balance, comprising thoracic hyperkyphosis and lower extremity compensation. In contrast, patients with high PI have a greater ability to retrovert the pelvis (1).

The clinical importance of PI is strongly based on its relationship to LL. PI correlates significantly with LL in asymptomatic patients and helps describe pathologic changes in LL, such as those seen in flatback deformity. Bess et al. have described a PI-LL greater than or equal to 11 degrees to be associated with severe deformity based on the ODI (11).

Spinal Compensation: In general, TK and LL have a mutual correlation and tend to counteract one another. For instance, any decrease in LL in patients with the lumbar flat back syndrome compensates with decreasing TK to keep sagittal balance. This compensatory mechanism requires the flexible thoracic spine to maintain hyperkyphosis. Conversely, increasing thoracic or thoracolumbar junctional kyphosis leads to increased LL to restore sagittal balance (1).

Recent studies have shown that there is a correlation among TK, LL, and PI (12). Therefore, it has been suggested that the PI, a static parameter of spinal alignment, can be utilized to calculate the optimal LL (LL = PI + 10 for PI ≤40 degrees, LL = PI for PI between 40 and 70 degrees, and LL = PI -10 for PI ≥70 degrees) (3).

Table 1. Normal population pelvic morphology

	SS (°)	%	PI (°)	PT (°)	Global LL (°)	LTA (°)	Number of vertebra LL	C7 ratio (%)
Type 1	29.0 ± 4.0	12	39.0 ± 5.0	10.0 ± 5.0	51.0 ± 6.0	-8.0 ± 4.0	3.0 ± 0.5	-10
Type 2	30.0 ± 4.0	22	41.0 ± 6.0	10.0 ± 5.0	48.0 ± 5.0	-6.0 ± 3.0	4.0 ± 0.5	18
Type 3 AP	44.0 ± 6.0	16	48.0 ± 6.0	4.0 ± 3.0	64.0 ± 7.0	-6.0 ± 4.0	5.0 ± 1.0	5
Type 3	39.0 ± 3.0	30	53.0 ± 7.0	13.0 ± 7.0	58.0 ± 10.0	-4.0 ± 4.0	4.5 ± 1.0	30
Type 4	49.0 ± 4.0	20	62.0 ± 8.0	12.0 ± 7.0	69.0 ± 6.0	-2.0 ± 4.0	5.5 ± 1.0	46

SS: Sacral slope; PI: Pelvic incidence; PT: Pelvic tilt; LL: Lumbar lordosis; LTA: Lower thoracic arch; AP: Anteverted pelvis

Lafage et al. have also suggested that LL can be measured from the relationship between LL, TK, and PI [LL = 2(PI + TK)] (3). Thus, the relationship between TK, LL, and PI can be applied to distinguish primary deformity from spinal compensation and plan optimal surgical correction.

Lower Extremity Alignment: The importance of the lower extremity as a compensatory mechanism in spinal deformity has been recently considered. All the large lower extremity joints, hip, knee, and ankle play a vital role in sagittal alignment in patients with spinal deformity. Pelvic retroversion is the first compensatory mechanism in these patients. However, when this mechanism becomes exhausted and is unable to maintain sagittal balance, the lower extremity will try to overcome imbalance by knee or ankle flexion to return the center of gravity to the proper position.

In patients with positive sagittal imbalance, knee flexion may occur to compensate as quadriceps muscles are recruited in the anterior thigh to maintain standing alignment and gait. Moreover, ankle flexion may also occur to maintain the cone of economy and minimize energy expenditures, although it appears to be less vital in maintaining sagittal balance than knee flexion (1).

Conclusion

It has been established that understanding these sagittal values allows for comprehensive surgical planning that improves operative outcomes, and it is fundamental for the spine, hip, and knee surgeons to consider these parameters as important measures.

Conflict of Interest

The authors declare no conflict of interest in this study.

Acknowledgements

None.

References

1. Bridwell KH. Bridwell and DeWald's textbook of spinal surgery. Philadelphia, PA: Lippincott Williams & Wilkins; 2019.
2. Le Huec JC, Thompson W, Mohsinaly Y, Barrey C, Faundez A. Sagittal balance of the spine. *Eur Spine J*. 2019;28(9):1889-905. doi: 10.1007/s00586-019-06083-1. [PubMed: 31332569].
3. Lafage V, Schwab F, Vira S, Patel A, Ungar B, Farcy JP. Spino-pelvic parameters after surgery can be predicted: A preliminary formula and validation of standing alignment. *Spine (Phila Pa 1976)*. 2011;36(13):1037-45. doi: 10.1097/BRS.0b013e3181eb9469. [PubMed: 21217459].
4. Pavithra AS, Premavathy D. Estimation of McRae line, McGregor line, and Chamberlain line in South Indian dry skull. *Drug Invention Today*. 2019;12(4):848-50.
5. Xing R, Liu W, Li X, Jiang L, Yishakea M, Dong J. Characteristics of cervical sagittal parameters in healthy cervical spine adults and patients with cervical disc degeneration. *BMC Musculoskelet Disord*. 2018;19(1):37. doi: 10.1186/s12891-018-1951-8. [PubMed: 29390994]. [PubMed Central: PMC5795794].
6. Ling FP, Chevillotte T, Leglise A, Thompson W, Bouthors C, Le Huec JC. Which parameters are relevant in sagittal balance analysis of the cervical spine? A literature review. *Eur Spine J*. 2018;27(Suppl 1):8-15. doi: 10.1007/s00586-018-5462-y. [PubMed: 29332239].
7. Takasawa E, Kawamura N, Iizuka Y, Ohya J, Onishi Y, Kunogi J, et al. The standing T1-L1 pelvic angle: A useful radiographic predictor of proximal junctional kyphosis in adult spinal deformity. *J Neurosurg Spine*. 2022;36(4):609-15. doi: 10.3171/2021.7.SPINE21571. [PubMed: 34740179].
8. 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(3):346-53. doi: 10.1097/01.brs.0000152379.54463.65. [PubMed: 15682018].
9. Laouissat F, Sebaaly A, Gehrchen M, Roussouly P. Classification of normal sagittal spine alignment: refounding the Roussouly classification. *Eur Spine J*. 2018;27(8):2002-11. doi: 10.1007/s00586-017-5111-x. [PubMed: 28455623].
10. Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: A fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J*. 1998;7(2):99-103. doi: 10.1007/s005860050038. [PubMed: 9629932]. [PubMed Central: PMC3611230].
11. Bess S, Schwab F, Lafage V, Shaffrey CI, Ames CP. Classifications for adult spinal deformity and use of the Scoliosis Research Society-Schwab Adult Spinal Deformity Classification. *Neurosurg Clin N Am*. 2013;24(2):185-93. doi: 10.1016/j.nec.2012.12.008. [PubMed: 23561557].
12. Vialle R, Ilharreborde B, Dauzac C, Lenoir T, Rillardon L, Guigui P. Is there a sagittal imbalance of the spine in isthmic spondylolisthesis? A correlation study. *Eur Spine J*. 2007;16(10):1641-9. doi: 10.1007/s00586-007-0348-4. [PubMed: 17437136]. [PubMed Central: PMC2078287].