1. Sagittal Balance

In an ideal sagittal balance, a vertical line can be drawn from the middle of the seventh cervical (C7) vertebra to the sacral promontory (a “plumb line”) if the cervical lordosis, thoracic kyphosis and lumbar lordosis, which collectively form the normal spine alignment in a standing individual, are in harmony. The sagittal balance of the spine is particularly affected by the degenerative changes that arise with the aging of the spine. The emergence of degenerative disc disease, stenosis in the lumbar spine or degenerative spondylolisthesis can arise from flaws in the sagittal balance of the spine. Similarly, the inability to preserve the sagittal balance or its disturbance may arise during surgical intervention. When the causes of “failed back,” such as pseudarthrosis or screw-rod breakage, are investigated in patient groups who did not benefit from surgery, the sagittal balance is impaired in the majority of the cases.

The center of mass of the human body is located anterior to the thoracic spine and close to the lumbar region. A motionless individual can stand straight by deriving support from the location where his/her feet touch the ground. The line drawn straight down from the center of mass, which is known as the “gravity line,” passes through the second sacral vertebra and the bone of the femoral head, follows the legs and reaches the ground together with the feet, which are the support points (Figure 1). The center of mass, and consequently the gravity line, changes position naturally with the movements an individual performs in his/her daily life. The plumb line and the gravity line are in harmony when a person is balanced when standing. When disturbances arise in the sagittal balance, the individual attempts to avoid perturbing the relationship between the gravity line and the plumb line to ensure balance. This relationship underlies compensation mechanisms. The establishment of a new balance state is attempted by developing compensation mechanisms to counteract the changes that occur in the spine in conjunction with the disruption of a systemic or functional unit. However, balance is impaired in thoracic kyphosis because change is more difficult due to the fixed structure of the spine as it begins to tilt forward as a result of the degenerative disc disease that develops in the lumbar area with old age (“flat back deformity”) (1,2) (Figure 2). Because the spine changes shape with respect to the pelvis, several compensatory changes take place in the pelvis in an attempt to reestablish the sagittal balance, and the changes that occur in the spine are evaluated by means of pelvic parameters.

How should an impairment that involves lumbar lordosis or pelvic rotation be defined, and from where does the pathology arise? The answers to these questions are important for determining the balance state of the spine, which is obtained by demonstrating the relationship between the pelvis and the spine. In the following section, the methods by which this relationship can be expressed are examined.

One of the most widely used measurements is the “pelvic radius technique,” which was defined by Jackson and colleagues (3). In this technique, four measurements are used to determine whether the spine is in balance. The first is a quantity called the “pelvic radius,” in which a line is drawn from the...
middle point of the line that connects the centers of the bones of the femoral heads through the back top edge of the sacrum. If the femoral heads are perfectly aligned with each other, the beginning of this line will be the center of the circle that forms the femoral head.

Subsequently, a line is drawn from the sacral plateau, and the angle that this line produces on the sacrum upon intersecting with the pelvic radius is called the “pelvic lordosis angle” or the “PR-S1 angle” (Figure 3). The value of this angle is given as 30 +/- 10 degrees. The second measurement is the lumbar lordosis angle, which is formed by the intersection of the line that passes through the sacral plateau and the line that passes through the upper plateau of the first lumbar (L1) vertebra. The normal value of this angle is accepted to be 60 +/- 15 degrees.

The third measurement is the angle formed by the intersection of the pelvic radius and the line that comes from the twelfth thoracic (T12) and L1 vertebrae, which form the lordosis angle. This third angle is called the “lumbopelvic lordosis angle” or the “PRT12 angle.” The normal value of this angle is considered to be 90 +/- 10 degrees.

The fourth angle is known as the “pelvis angulation angle” or the “sacropelvic angle” and is formed by the intersection of the pelvic radius and the line that runs tangentially from the center of the femur...
head to the front face of the spine. This angle increases or decreases depending on the state of the disturbance of the balance in the spine. Its normal value is considered to be 17.5 +/- 5.5 degrees. Thus, as the PR-S1 angle decreases, the lordosis angle increases; in other words, the lordosis angle increases and the pelvis angulation increases. As the PR-S1 angle increases, the lordosis angle decreases; that is, the lordosis angle and the pelvis angulation decrease (Figure 3). However, these parameters may not always reflect the physiological conditions. For example, in a lumbar spine with advanced flat back deformity, the PR-S1 angle is small, and therefore, the lumbar lordosis angle is expected to be large; however, the latter value can be small. In addition, this method of measurement does not show the entire spine balance, which also comprises the thoracic region and even the cervical region, and this omission may cause measurement errors.

Another important method for defining the pelvic parameters has been described by Duval-Beaupere. Although the method of pelvic incidence does not show the entire spine balance, this method provides a clearer understanding of the concordant movement of the pelvis and the spine and the relative states of their deformation. A line drawn connecting the femur head and the middle of the sacral plateau provides the width of the pelvis.

This technique will at least aid in the determination of the type of pelvis being examined. If a perpendicular line is dropped into the center of the sacral plateau, the angle that it forms with the line reaching to this point from the femur head, which also provides the width of the pelvis, is called the “sacral incidence.”

The sacral incidence equals the sum of two angles: the “pelvic tilt,” which indicates the state of the pelvis, and the “sacral slope,” which is the angle that indicates the slope of the sacrum. The pelvic tilt angle shows the position of the pelvis and is the angle that is formed by the vertical line that passes through the femur head and the line that passes through the center of the sacral plateau. The sacral slope, in contrast, is the angle between the line that passes tangential to the sacral plateau and the vertical line that passes through the middle of the sacral plateau (Figure 4). As a result, the sacral incidence is an important parameter that provides information...
about the state of the pelvis in space. A pelvic incidence of 40 degrees reveals the presence of a narrow pelvis, and an incidence of 70 degrees reveals a wide pelvis. To adjust the balance of the spine on the pelvis, anteversion or retroversion can be introduced. Retroversion is the more restricted of the two and can achieve a compensation of 10 degrees together with the deflexion of the hip joint.

The normal pelvic incidence is 52.6 +/- 10.4 degrees, the pelvic tilt is 13 +/- 6.8 degrees and the sacral slope is 39.6 +/- 7.9 degrees. As a result, for a normal balance of the spine, the pelvic tilt must be smaller than half of the pelvic incidence, and the sacral slope must be larger than half of the pelvic incidence.

In 2006, Roussouly (1) reported that the gravity line and the plumb line might not be in agreement in a standing individual in a balanced state. For a balanced spine, the plumb line or standard sagittal balance is the downward extension of the vertical line that passes tangential to C7 behind the back point of the sacral plateau (Figure 1). Roussouly stated that there are different variations in the shape of the spine in the majority of the population and stressed that it is important to have a posture (stance) in which harmony is obtained between the pelvis and the spine. The normal sagittal balance that shows that the spine and the pelvis are in harmony is the alignment of the spine that expends the least energy upon standing.

The plumb line is “ideal” as defined, and the sacral incidence is approximately 50 degrees. The angle of the lumbar lordosis has been investigated, and the contribution of the L1-L2 segment to the lumbar lordosis is 3%, that of the L2-L3 segment is 12%, that of the L3-L4 segment is 18%, that of the L4-L5 segment is 27% and that of the L5-S1 segment is 48%. The conclusion from these observations is that the lumbar lordosis is primarily supplied by the lower two segments. The practical conclusion is that in the event that these two segments are not given the appropriate lordosis during surgery, a flat back deformity will be caused surgically.

Vialle and colleagues (5) reported that the normal thoracic kyphosis is a T4-T12 angle of 40 +/- 10 and the lumbar lordosis is an L1-L5 angle of 41 degrees in males and 46 +/- 11 degrees in females.

Roussouly (1) developed a new method to evaluate the sagittal balance of the spine by determining the shape and angles of the spine in 709 asymptomatic volunteers. This analysis led to the classification of four main shape types and their rates: Type I spine shape (5%), Type II (23%), Type III (47%) and Type IV (25%) (6) (Figure 5). The lumbar lordosis in these different types arises due to the sacral slope. From this classification, the tangent circle technique is used to evaluate the lumbar lordosis by lateral graphy (Figure 6). The inner circle is the small circle with a radius defined as the intersection point of the sacral

**Figure 4:** The Duval-Beaupeure technique using the pelvic incidence (SS = sacral slope, PI = pelvic incidence, PT = pelvic tilt)
Sagittal and Coronal Balance in the Spine

Without harmony in the spine
Harmonious, but a flat spine
Harmonious spine
Harmonious, but a lordotic spine

Figure 5: Spine classification according to Roussouly: a) Type I: a spine that lacks harmony; b) Type II: a spine with harmony but with a flat back; c) Type III: a spine with harmony; d) Type IV: a spine with harmony but that is excessively lordotic.

slope line and the lumbar apex line. The outer circle is the large circle with a radius defined as the straight line drawn to the lumbar apex line from the inflexion point (the point at which the lumbar lordosis becomes kyphosis). The measurements showed that the inferior arch angle (the sacral slope angle found in the small circle) was variable; however, the superior arch angle (the angle found in the large circle) was fixed (Figure 6). In Type I spines, the lumbar apex is in the middle of L5, the sacral slope (SS) is < 35 degrees and the superior arch angle is 17-18 degrees; in Type II spines, the lumbar apex is inferior to L4, the SS < 35 and the superior arch angle is 17 degrees; in Type III spines, the lumbar apex is in the middle of L4, 35 < SS < 45 degrees and the superior arch angle is 17-18 degrees; and in Type IV spines, the lumbar apex is at the base of L3, SS > 45 degrees and the superior arch angle is 18 degrees (Figures 7 and 8).

With this new method, it is possible to record all the measurements of the entire spine on the sagittal plane. The angle between the horizontal line that passes through the apex and the line that passes through the sacral plateau is the lower angle, which is variable and comprises 70% of the total lumbar lordosis. As stated previously, the line between the inflexion point and the horizontal line that passes through the apex is fixed at 17-18 degrees and constitutes the inferior arch angle that determines the state of the lumbar lordosis. The knowledge of the shape and position of the pelvis and the morphology of the lumbar lordosis forms the basis for the treatment of back pain. Given the fact that the lumbar lordosis is determined by the last three levels and that 80% of back pain is the result of disc degeneration in the L4-L5 and L5-S1 vertebrae, the importance of these measurements while treating the patient becomes clear. If the necessary lumbar lordosis
Figure 6: Roussouly used the tangential circle method in lateral graphy. The inner circle is the small circle with a radius defined as the intersection point of the sacral slope line and the lumbar apex line. The outer circle is the large circle with a radius defined as the straight line drawn to the lumbar apex line from the inflexion point. With this method, the superior arch angle stays fixed at 17-18 degrees, and the inferior arch angle, which gives the sacral slope, changes based on the state of the sacrum.

is not provided to stabilize the patient during surgery, then a breakage of the screw, pseudarthrosis or a flat back state will result due to the forward tilt of the body, and back pain will be inevitable. It has been shown that the inferior arch angle constitutes 70% of the total lordosis angle and, consequently, that the lumbar lordosis is established primarily by the three lower levels.

Clinical applications are consistent with measurements taken in patients and with the data obtained in this study. By using the aforementioned study as a foundation, the type of discomfort that can develop in each type of spine can be predicted. For example, Roussouly described the Type I spine as a “spine that lacks harmony.” In this type of spine, high pressure is applied to the posterior members in the lumbar region, and contact among the spinous processes can be observed. These changes increase the risk of developing spondylolisthesis due to hyperextension; in addition, the risk developing thoracolumbar discopathy is high in the Type I spine. The Type II spine has a harmonious alignment, but the individual has a flat back. In this type of spine, high pressure is applied to the discs, and the risk of early degeneration and disc herniation is high. The Type III spine has the most harmonious alignment. However, the disc tissue collapses, and the shape of the spine changes with age. Over time, the Type III spine can convert into a Type I or Type II spine. The Type IV spine also has a harmonious alignment, but it has excessive lordotic alignment. In this spinal type, weight transmission primarily occurs through the facet joints, thereby allowing the observation of early facet

Figure 7: The angles of pelvic incidence (PI), lumbar lordosis (LL) and sacral slope (SS) are shown according to the Roussouly classification.
arthropathies. The risk of developing lumbar stenosis and spondylolisthesis is higher in Type IV spines than in the other spinal types.

The state of the pelvis with respect to the spine can easily be determined by the adaptation of Duval-Beaupere’s pelvic incidence method to this system. First, because of the flat back deformity that develops due to degenerative disc disease, the angle slowly increases toward the back in the pelvis; at the same time, the pelvic tilt increases, the pelvic incidence decreases and the sacral slope angle increases (Figure 9). When Roussouly’s method is followed, the relationship between the pelvic parameters with the thoracic and lumbar spine and whole-body posture can be shown. If C7 is at the right location, the thoracic kyphosis and lumbar lordosis follow the cervical lordosis, resulting in normal pelvic parameters (Figure 10). The relationship between the pelvis and the spine is determined by the spinosacral angle and the pelvic tilt. The “spinosacral angle” is the angle between the line that connects the middle of C7 to the middle of the line that passes through the sacral plateau. Its normal value is 134.7 +/- 8.1 degrees. The angle that shows the spinal tilt is the angle between this line and the line that passes through the middle of the sacral plateau (Figure 11).

The global assessment of the thoracic and lumbar spine is conducted using the spinosacral angle. This angle describes the whole spine and is closely related to the sacral slope. When the spine bends forward with age, the pelvis tilts backward in compensation; when the spinosacral angle decreases,
Figure 9: a) The PI is large, and the plumb line is behind the gravity line and inside the gravity area. The spinal compensation mechanism is in balance. b) The PI is small, and as a result, the plumb line cannot be protected in the gravity area, so the compensation mechanism is inadequate, and the sagittal balance is impaired. A fixed sagittal balance develops.

Figure 10: If C7 is at an appropriate position, cervical lordosis is followed by thoracic lordosis and lumbar lordosis, which are followed by normal pelvic parameters.

Figure 11: The angle between the plumb line and the sacral plateau, known as the spinosacral angle, determines the relationship between the pelvis and the spine. The global evaluation of the thoracic and lumbar spine is performed using this angle.
the SS angle also decreases, but the pelvic tilt increases. Maintaining the pelvic parameters within the normal limits is preferred. The knee joints may undergo flexion in an attempt to keep the spine straight.

However, together with the flat back that develops due to the degeneration in the lumbar region, the thoracic region begins to bend forward; consequently, C7 moves forward, and when the compensation mechanisms are inadequate, the plumb line moves in front of the gravity line and causes sagittal imbalance (Figure 12). The patient can stand up and walk without support, but the head and the body are bent forward (Figure 12).

Ultimately, the C7 parameters are important in spinal balance, the gravity line is effective in the entire balance, the sacral slope angle affects the lumbar lordosis and, in a holistic evaluation of the spinosacral slant (SSS) angle, the sagittal balance is an important parameter.
2. Coronal Balance

Normally, the position of the spine is perpendicular to the coronal plane. In an upright posterior-anterior radiogram, the vertical line that is drawn from the top of the dens reaches the ground by almost dividing the vertebrae into two, including the sacrum that is underneath. This line is called the “central sacral vertical line” (CSVL) (Figure 13). Although deviations to the right and left of this line are accepted as the normal variation if they are within 10 degrees of the “Cobb measurement,” slopes with larger angles are called “scoliotic deformities.” The deformity can develop to the left or to the right, but if its beginning and end are on the CSVL, then the spine is accepted as being balanced. If the spine is to the right or the left of the CSVL, it is imbalanced (Figure 14).

Scoliotic deformity has many causes. It can manifest as adolescent idiopathic scoliosis (AIS), the cause of which has not yet been conclusively shown and that is the most common deformity in the adolescent population. Alternatively, it is encountered as adult degenerative scoliosis or “scoliosis de novo,” which is caused by older age and degenerative factors. Although the frequency of AIS encountered in the general population is 2-4%, its frequency in female children is four times higher.

The progression of the slope is directly associated with the development of the skeleton. The complete development in children can be monitored by the degree of closure of the ends of the epiphysis on the iliac crest, which is called “Risser’s sign” (Figure 15). Risser 1 is the beginning of the ossification process and begins with the onset of adolescence; in contrast, Risser 4 indicates that the epiphysis line is completely closed. In Risser 1, if the iliac crests point to the epiphysis line and with a concurrent detection of a slope in the spine, the deformity may progress and close follow-up is necessary. Risser 4 indicates that the slope will not progress any further. Therefore, because people with an immature skeletal system and a wide slope have a higher risk of an increase in the slope, deformities with a double slope are under a higher risk than deformities with a single slope. In addition, there is a higher risk of lung problems with deformities that are under increased risk and that progress with a loss of thoracic kyphosis (6).
In the evaluation of AIS, the presentation of the apical spine is very important. The apical spine is the top of the normal spine or the one that is closest to normal. King and Moe (7) were the first authors to categorize the deformities that occur in the coronal plane. They divided the deformities into four major types: thoracic, lumbar, thoracolumbar and double major. They further subdivided thoracic deformities into five sections: the main lumbar secondary slope, the main thoracic and secondary lumbar slope, the thoracic slope only, and, around the T10 apex, the long thoracic slope that extends to L4 and the double thoracic slope (7) (Table 1). This classification scheme was devised before modern diagnosis tools were available, and it evaluates the slope only in one plane. For this reason, evaluations before or during the surgery were not very reliable. Later, Lenke and colleagues (8) introduced the modern classification system that is currently used. This classification scheme is a reliable system that enables the evaluation of the spine in both the coronal and the sagittal planes (Table 2).

The structural evaluation of the slope is as follows: in graphs taken by bending to the side (lateral bending), if the slope still persists as 25 degrees or more, this slope is accepted as the main “structural” slope. The other slopes are “nonstructural” slopes that develop as a result of compensatory mechanisms to keep the spine stable.

In this classification, the thoracic spine is evaluated with respect to six main slopes. It is recorded in the table as A, B and C after being modified based on the characteristics of the lumbar slope and according to the presence or absence of thoracic kyphosis as --, N or +. The relevant points are as follows:

- In the detection of the modification of the lumbar slope, the apical lumbar vertebra first intersected by the central sacral vertical line (CSVL) is defined as the main one.
- The stable vertebra is the lowest thoracic or uppermost lumbar vertebra that is passed by CSVL in the center (Figure 16).
- In graphs taken while the structural slope is bent to the side, a Cobb angle of 25 degrees or above is accepted as a structural slope.

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In this classification, if the patient is classified as 1B+, for example, this patient is characterized as having “one structural thoracic slope and one that is hyperkyphotic, with the CSVL only touching the vertebra body.”

In addition to Lenke, many other researchers have classified spine deformities; however, they are not superior to Lenke’s classification.

The evaluation of a patient who routinely has coronal deformities should be conducted by taking upright anteroposterior graphies that contain the cervical region and the pelvis.

The “Cobb Method” is used to measure the deformities \(\text{(9)}\). In this method, an angle results between the lines that are drawn perpendicular to the lines tangential to the upper plateau of the vertebra with the highest slope and the lines tangential to the lower plateau of the last vertebra with a slope \(\text{Figure 17}\). If a deviation lower than 10 degrees is obtained, this state is evaluated as “spinal asymmetry” and does not have clinical significance. If this deviation is found to be more than 10 degrees, it is evaluated as “scoliotic deformity,” and the patient should be taken under clinical observation. The treatment options can be briefly classified as observation, bracing and surgery. In AIS, the treatment algorithm is general, as shown in Table 3.
References


