

Sagittal Alignment Concepts and Spinopelvic Parameters

Conceitos de alinhamento sagital e parâmetros espinopélvicos

Cristiano Magalhães Menezes^{1,2} Gabriel Carvalho Lacerda^{1,2} Santiago Lamarca^{1,2}

¹ Spinal Surgery Service, Hospital Ortopédico, Belo Horizonte, MG, Brazil

² Spinal Surgery Service, Hospital Vila da Serra, Belo Horizonte, MG, Brazil

Address for correspondence Cristiano Magalhães Menezes, MD, PhD, Columna Instituto, Rua Conde de Linhares, 278, Cidade Jardim, 30380-030, Belo Horizonte, MG, Brazil (e-mail: cristiano@columnainstituto.com).

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Abstract

Spinal surgery continues to expand its horizons to care for disabled patients presenting pain and deformities. Over the past decade, our knowledge of spinal alignment, from the skull to the pelvis, has increased considerably. Such knowledge must expand to reach general orthopedists and improve the care required for so many people. Global spinal alignment is a critical concept in understanding the impact of pathological conditions (degenerative diseases, traumas, deformities) and their treatment, including spinal instrumentation and arthrodesis. Therefore, the treatment of any spinal disease must include the knowledge of the complexity of the spinopelvic alignment.

At first, all parameters seem like pure mathematics, hardly applicable to the everyday life of the inattentive reader. However, it gradually becomes clear that, like everything else in orthopedics, biomechanics is an essential part of the knowledge of the musculoskeletal system, revealing the logic behind the physiology of movements.

The knowledge of the sagittal alignment concepts and spinopelvic parameters provide a better comprehension of the axial and appendicular skeletons, increasing the understanding of the physiological and adaptive spinal processes in the face of the degenerative process that increases throughout life.

Keywords

- ▶ spine/surgery
- ▶ spinopelvic parameters
- ▶ spinal fusion
- ▶ sagittal alignment

Resumo

A cirurgia da coluna continua a expandir seus horizontes para cuidar dos pacientes incapacitados com dor e deformidades. Desde a última década, nosso conhecimento sobre o alinhamento espinal, do crânio à pelve, aumentou consideravelmente. Portanto, faz-se necessária a expansão de tal conhecimento para o ortopedista geral, para que possamos proporcionar melhores cuidados para essa população.

O alinhamento espinal global é um conceito crítico no entendimento do impacto ocasionado pela condição patológica (doença degenerativa, trauma, deformidade) e

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Palavras-chave

- ▶ coluna vertebral/cirurgia
- ▶ parâmetros espinopélvicos
- ▶ fusão vertebral
- ▶ alinhamento sagital

mesmo do seu tratamento, como na instrumentação e artrodese da coluna. O tratamento de qualquer doença na coluna deve incluir o entendimento da complexidade do alinhamento espinopélvico.

A princípio, todos os parâmetros parecem puramente matemáticos e pouco aplicáveis à realidade do leitor mais desatento. Mas, aos poucos, fica claro que, como tudo em ortopedia, a biomecânica faz parte essencial do conhecimento do sistema musculoesquelético, tornando mais claras as lógicas da fisiologia do movimento.

O conhecimento dos conceitos de alinhamento sagital e dos parâmetros espinopélvicos proporcionam uma melhor compreensão dos esqueletos axial e apendicular, além de um melhor entendimento dos processos fisiológicos e adaptativos da coluna frente ao processo degenerativo crescente que ocorre ao longo da vida.

Introduction

The distinction between alignment and balance, which is virtually obvious to engineers, physiologists, and choreographers, is not so clear to orthopedic surgeons. Sagittal balance describes something dynamic, appreciating a person in motion. Optimal spinal alignment in the sagittal and coronal planes is mistakenly described as balance, for example, when we are interpreting panoramic radiographs of the spine. In the present article, we want to clarify the concept of *stability with movement*, a continuous process that defines balance.

These concepts have gained importance since the study by Schwab et al.¹ Before that, there were few works on the subject in the literature, but the number of publications has grown exponentially throughout the last decade.

In the sagittal plane, the normal spine has four curvatures (thoracic and sacral kyphoses, and cervical and lumbar lordoses) that correlate; this enables the correct body alignment to stand up and walk, with equal force distribution across the spine towards the lower limbs.

These curvatures present normal variations, but pathological processes and aging can change this sagittal alignment, modifying the distribution of these curves. This imbalance leads to a cascade of adaptation mechanisms, but with a high energy cost for the human body. These changes occur in the lower extremities and the pelvis, altering spinal alignment.¹

Regarding alignment in the sagittal plane, Hardacker et al.² propose the following parameters:

- Cervical lordosis: 30° to 50°. It is equally distributed over the cervical spine, with its apex at C4-C5.
 - Thoracic kyphosis: 20° to 50°. It increases with age, especially after 40 years; the greatest increase occurs in women.
 - Lumbar lordosis (LL): 30° to 80°. Two thirds of LL occur between L4 and S1.
- Changes in any of these sagittal alignment components result in compensatory changes in adjacent segments.

Sagittal Misalignment Cascade

A subject with a correctly-aligned spine needs a virtually-imperceptible basal energy expenditure to maintain an

upright position. On the other hand, a subject with an misaligned spine requires great effort to remain up, and may need crutches for better body weight distribution. Therefore, sustaining an upright position depends on three components: an aligned spine, good distribution of body weight, and adequate support provided by stabilizing muscles.

The defense mechanisms activated by sagittal malalignment include the use of stabilizing muscles (increasing energy expenditure), changes in sacral position (pelvic tilt, PT), and hip and knee flexion (► **Figs. 1a** and **1b**).

Young patients and subjects with good muscle tone can deal with this situation better, but not older people or those with worse tonus. Aging worsens spine alignment because the deformity depletes the muscular system and contributes to the acceleration of disc degenerative processes; in addition, older patients may develop knee and hip osteoarthritis, which significantly increases energy consumption and pain.³

Clinical presentations

In younger patients, sagittal spinal malalignment occurs in cases of deformities such as scoliosis (coronal and sagittal deviations), Scheuermann disease, and spondylolisthesis, especially of the dysplastic or traumatic types.

In adults, these presentations are a natural progression of the lack of treatment or incorrect management (iatrogenic lesions) of the aforementioned diseases, or the result of osteoporotic fractures.

Main sagittal alignment measurements

Panoramic spinal radiography is the “gold standard” study to correctly assess sagittal alignment. It enables complete observation of the spine and its position regarding the sacrum, the femoral heads, and the femoral orientation.⁴⁻⁶

The main virtue of this test is its objectivity in assessing spinal alignment; as such, it reveals the magnitude of the deformity and enables an accurate preoperative planning to restore alignment.⁷

A new technology introduced about 15 years ago for body imaging, called EOS (EOS imaging, Paris, France), enables a more comprehensive study, including the lower limbs, with a low dose of radiation.⁸

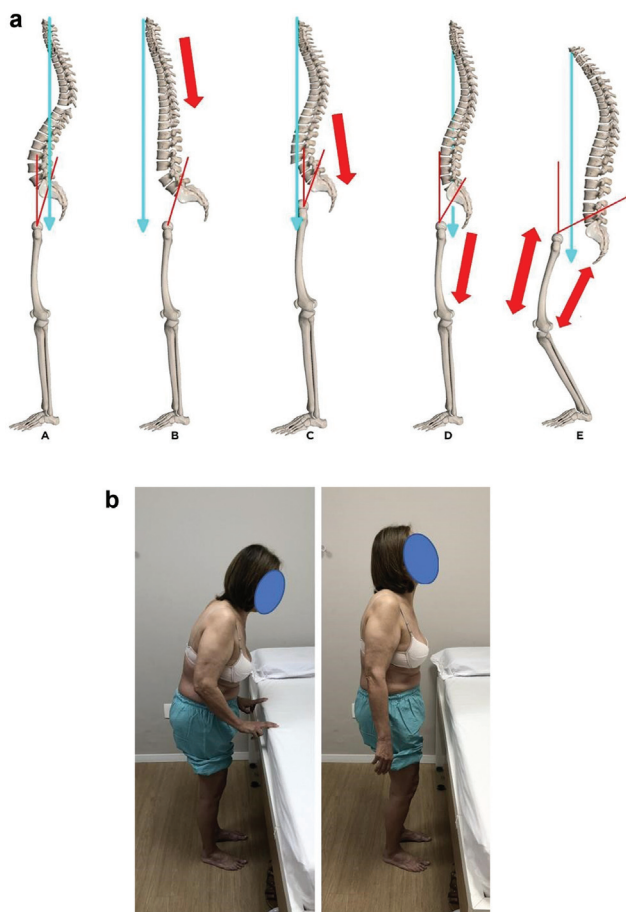


Fig. 1 (a) Compensatory mechanisms in patients with variable loss of lumbar lordosis or thoracic kyphosis. (A) A normal spine. (B) Active extension of the thoracic spine, resulting in hypokyphosis. (C) Active extension of adjacent lumbar segments, resulting in an atypical distribution of lumbar lordosis. (D) Pelvic retroversion with increased pelvic tilt. (E) Knee flexion results in a further increase in pelvic tilt and posterior trunk translation. (b) A patient presenting defense mechanisms against sagittal imbalance: pelvic retroversion and knee and hip flexion.

In addition, new software such as Surgimap (Nemaris, Inc., New York, NY, United States) and SagittalMeter enable the quick and efficient acquisition of the measurements presented below.

The main measurements evaluated on panoramic spinal radiography for the study of sagittal alignment include the following:

- **Sagittal vertical axis (SVA):** it is used to locate the position of the head concerning the normal center of gravity. It is a straight line that runs from the center of the vertebral body of C7 to the tip of the superior platform of the sacrum (► Fig. 2). The SVA can be positive (normal), negative or neutral, depending on where the line runs in relation to S1. A normal SVA measures < 5 cm, and it is associated to the health-related quality of life (HRQOL) index.^{1,7}
- **Sacral slope (SS):** it is the angle between the upper platform of S1 and a horizontal line that reaches the



Fig. 2 Sagittal vertical axis (SVA).

highest portion of the sacrum. The average SS is of 40° , ranging from 20° to 65° .⁵

- **Pelvic incidence (PI):** it is the angle between a line perpendicular to the center of the sacral platform and a line running from the same point to the center of the femoral head (► Fig. 3). It measures the inclination at which the sacrum articulates with the pelvis. The average PI is of 51° , ranging from 34° to 84° . The PI usually is fixed in adults, and it does not vary with changes in the patient's position.¹
- **Pelvic tilt (PT):** it is the angle between a vertical line starting at the center of the femoral head and a line from the same point to the center of the platform of S1. This angle describes the rotation of the pelvis regarding the femoral heads (► Fig. 4). The average PT is of 12° , ranging from 5° to 30° . It displays compensatory changes since it is a postural angle.⁵

The PT is directly related to the PI (► Fig. 5). A PI increase results in a PT increase, although not proportionally. There is a geometric relationship among all of these angles, and PI equal to the sum of PT and SS, that is, $PI = PT + SS$.¹

To minimize energy consumption, the pelvis tends to align itself with the sacrum that is, its angulation changes to achieve a vertical femoral-sacral line (► Fig. 5). However,

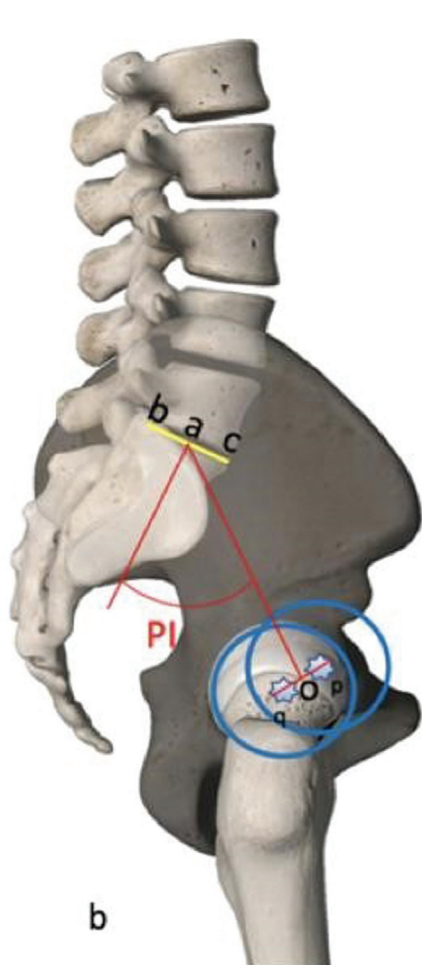


Fig. 3 Pelvic incidence (PI).

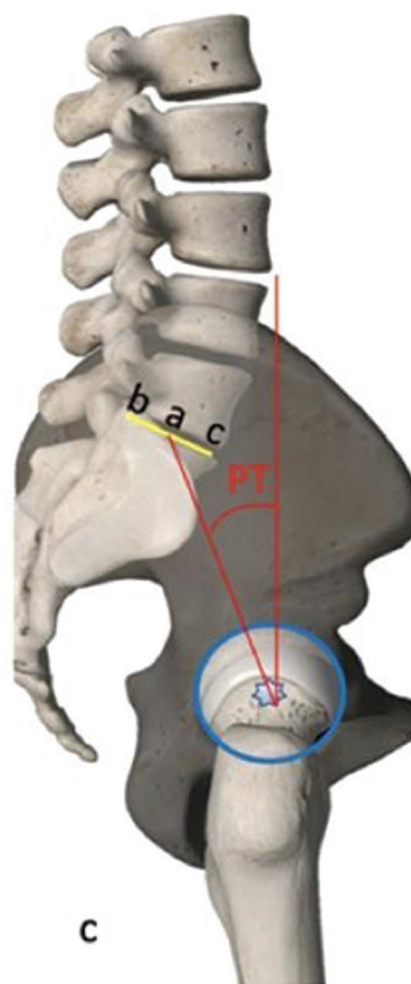


Fig. 4 Pelvic tilt (PT).

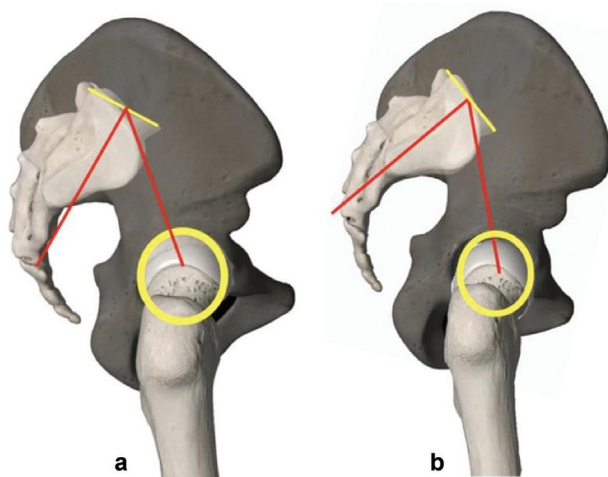


Fig. 5 (a) Low pelvic incidence due to the lower forward inclination of the sacrum in the pelvis. (b) There is a greater forward tilt of the sacrum within the pelvis, corresponding to a high pelvic incidence.²

when this line becomes horizontal, pelvic retroversion increases. At this point, the defense mechanisms become insufficient, leading to sagittal malalignment.

A PT increase results in increased pelvic torque, which is the torque of bodyweight mainly at the pelvis and sacrum,

and the ground reaction force, applied mainly at the pelvis and acetabulum (► Fig. 6). Therefore, a higher PT increases compensatory muscle effort to stabilize the pelvis and keep the subject standing straight. Spines with better alignment present smaller PT values (a more vertical femoral line and lower pelvic torque).³

- **Spinopelvic angle (SPA):** it is the angle between a line from the center of the vertebral body of C7 to the center of the superior sacral plate, and a line from that point to the center of the femoral head (► Fig. 7). The SPA defines the subject's position. Patients with hip flexion present increased SPA, for instance.
- **Spinosacral angle (SSA):** it is an angle between a line from the center of the vertebral body of C7 to the center of the superior sacral plateau, and a line running along the surface of the superior sacral plate (► Fig. 8). The SSA is directly related to the angle of inclination of the sacrum, and it does not vary (it is a fixed angle).¹

Lordosis distribution

Approximately two-thirds of LL occur between L4 and S1. When total lordosis is lost at the expense of the lower lumbar

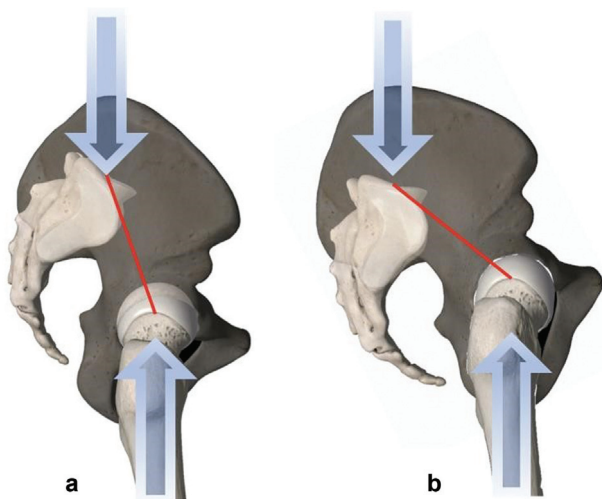


Fig. 6 (a) With a low pelvic tilt angle and a relatively vertical sacrofemoral line (“magic line”, in red), the axis of the trunk’s weight load on the sacrum and the ground reaction force on the hip joint are closer, resulting in low pelvic torque. (b) Increasing the pelvic tilt (relatively horizontal “magic line”, in red) increases the distance between forces, resulting in greater pelvic torque. The torque is increased approximately four-fold between these two designs.²



Fig. 7 Spinopelvic angle.

spine, the remaining levels try to compensate by increasing segmental lordosis, which leads to normal LL values. The compensatory defense mechanism leads to a significant pain response.

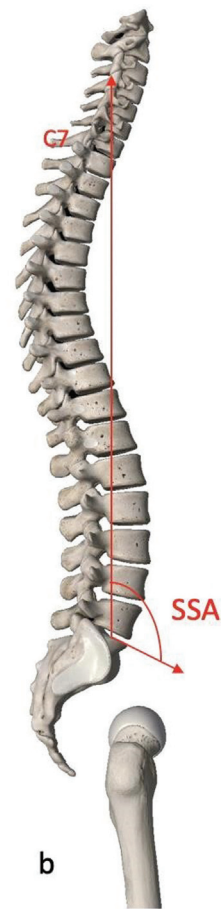


Fig. 8 Spinosacral angle.

Roussouly et al.³ defined four types of sagittal alignment and consequent lordosis distribution. This classification shows the variability and distribution of spinal curves in a subject. These categories help identify some morphological characteristics involved in the pathogenesis of back pain, deformities, and some surgical outcomes. In addition, they improve the understanding of the relationship between sagittal alignment and degenerative changes.³

• Sagittal profile variations

There is no single sagittal profile considered normal. In a study with 160 asymptomatic subjects using a three-dimensional model, Roussouly et al.³ defined four different types (→ Fig. 9):

- Type-1 lordosis: the transition point in which lordosis changes to kyphosis is at L3-L4, while the apex is at L5. The SS is lower than 35°, and the PI is small. Thoracic kyphosis is long, and lumbar lordosis is short. The ratio between thoracic and lumbar segments is of 80:20.
- Type-2 lordosis: the transition point is at L1-L2, and the apex is at the base of L4. The SS is lower than 35°, and the PI is small. Thoracic kyphosis is smaller, while lumbar lordosis is greater, with a 60:40 ratio.
- Type-3 lordosis: the transition is at T12-L1, the SS is between 35° and 45°, and the apex is at the center of

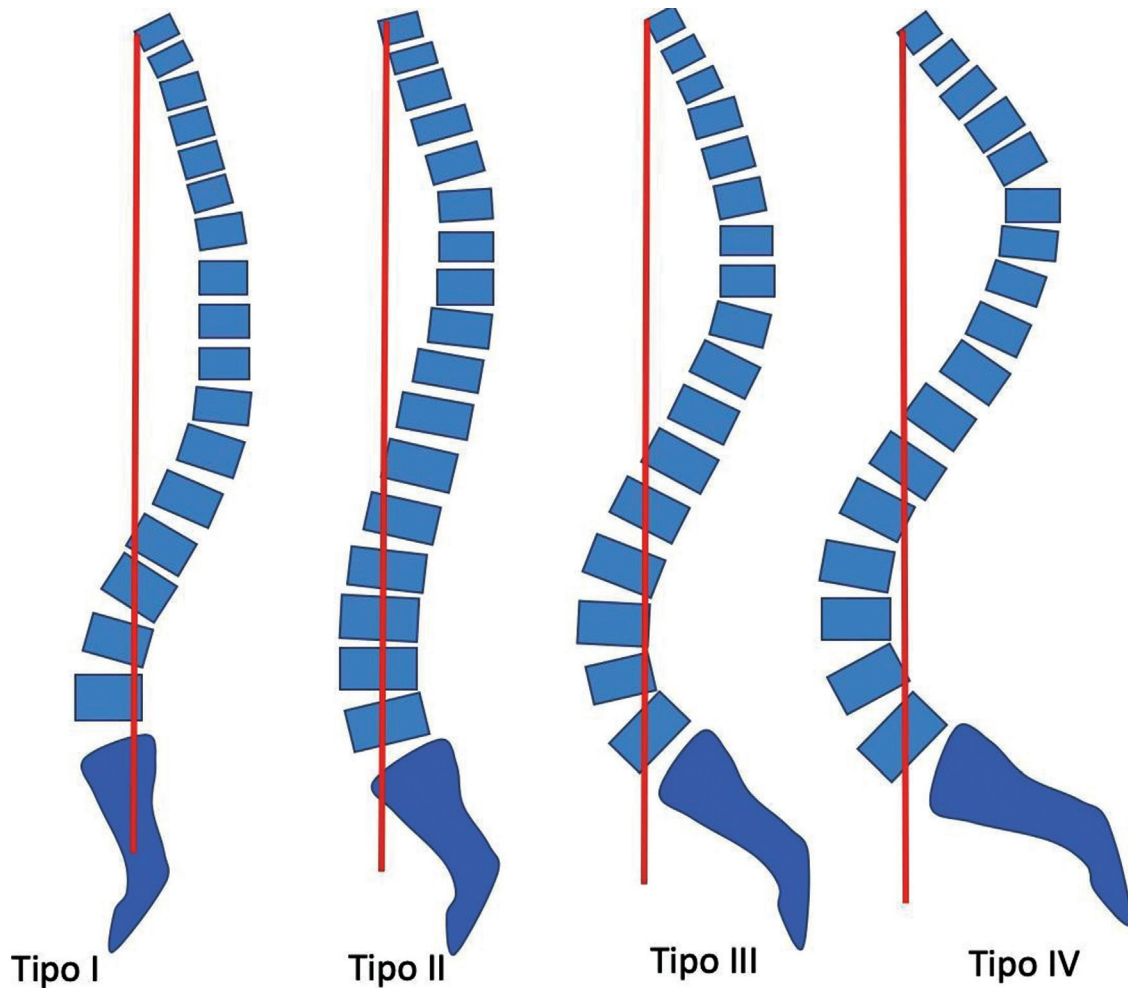


Fig. 9 Russouly et al.³ classification system.

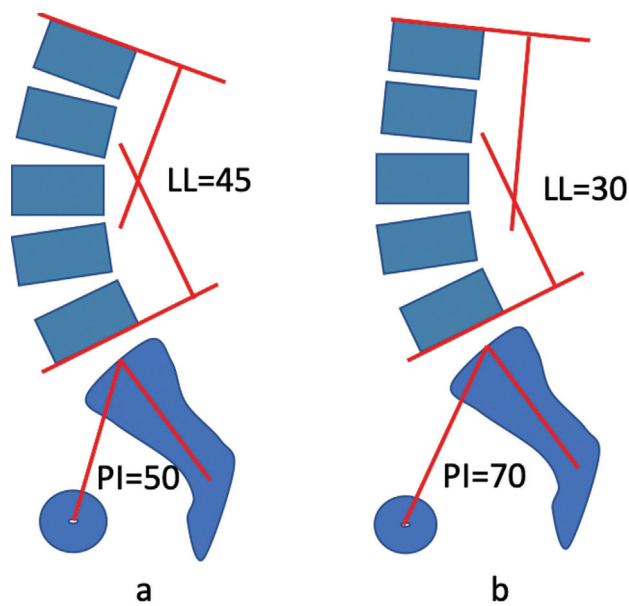


Fig. 10 (a) If pelvic incidence (PI) = 50° and lumbar lordosis (LL) = 45°, the difference between them is 5°; (b) on the other hand, if PI = 70° and LL = 30°, there is a 40° mismatch.

L4. The PI is high. The transition point is on the thoracolumbar segment. The kyphosis-to-lordosis ratio is of 50:50, which assumes that the spine is well aligned. It is the most frequent type.

- Type-4 lordosis: the transition point is at T9-T10. The SS is higher than 45°, the PI is high, and the apex is at the base of L3. Lordosis is greater than dorsal kyphosis, with a 20:80 ratio.

Pelvic Incidence and Lumbar Lordosis Mismatch

The difference between PI and LL is known as a mismatch. The PI and LL are directly related, and the normal difference between them (PI-LL) is $\leq 10^\circ$ (►Fig. 10). There is also a correlation between PI-LL imbalance and the SVA. Its correction is the main goal in the surgical treatment of sagittal malalignment for a harmonious, painless spinopelvic alignment, applicable in both long and short fusions.⁹

Treatment

- **Conservative treatment**

Patients with symptomatic sagittal imbalance respond poorly to the conservative treatment, showing temporary

improvement with braces, muscle strengthening due to physical therapy, and/or selective blocks. Although surgery may not be an initial indication, it is the therapeutic goal for these subjects.^{5,10}

• Surgical treatment

The indications include failure of the conservative treatment, curvature progression, back pain, progressive neurological deficit, loss of quality of life, and correction of the underlying disease (scoliosis, spondylolisthesis, Scheuermann disease).¹¹⁻¹³ The goals of surgery are to achieve solid fusion with an aligned spine in the sagittal and coronal planes, relieve pain, and achieve PI-LL < 10°, PT < 25°, and SVA < 5 cm.⁷ Several studies have shown that proper restoration of sagittal alignment significantly improves clinical outcomes and prevents adjacent disc disease and further pseudarthrosis.¹⁴ Glassman et al.¹⁵ demonstrated that restoring sagittal alignment as much as possible is the critical goal for any spinal reconstructive surgery.

Since surgeries to correct sagittal imbalance are major procedures, the patient must be carefully assessed preoperatively by a multidisciplinary team to reduce risks, such as those of pseudarthrosis, implant loosening, infection, neurological damage, and excessive bleeding.¹⁵⁻²⁰ Studies show a 24% prevalence of pseudarthrosis after long instrumentation with fusion up to S1.²⁰

The measurement of spinopelvic parameters is essential in preoperative planning. Bridwell et al.¹⁹ classified the deformities into three categories based on curve flexibility: fully flexible, partially flexible with movable segments, and fixed deformity with no correction in recumbency.

Spine flexibility must be evaluated radiologically due to the presence of mobile segments. Anteroposterior and lateral panoramic radiographs and lateral flexion and extension radiographs may demonstrate the flexibility of the deformity.¹⁸

It is suggested that flexible deformities can be corrected both anteriorly and posteriorly with no need for three-column osteotomies, such as pedicle subtraction osteotomy (PSO) or vertebral column resection (VCR).¹⁹ The improvement in sagittal alignment is due to correction and elongation of the anterior column, through a structural allograft, a structural autograft, or interbody cages.

Rigid deformities are corrected by anterior, a combination of anterior and posterior, or posterior surgery. Techniques to perform three-column osteotomies (PSO, VCR) are also used, aiming at posterior shortening as a basis for correction.

Currently, the levels of complication from the correction of vertebral deformities in adults have been progressively decreasing due to the knowledge acquired over the last decades. All techniques have excellent short- and long-term outcomes thanks to the continuous development and advent of minimally-invasive surgical techniques.¹⁹

Final Considerations

Body imbalance in the sagittal plane is a spinal misalignment with several etiologies, including congenital, degenerative, iatrogenic, and traumatic disorders. Initially, it can be tolerated by the patient, but the exhaustion of defense mecha-

nisms results in pain, functional loss, and worsening of quality of life. Panoramic radiography is the study of choice to perform all pertinent measurements (SVA, PT, PI, SS, SSA, SPA). Currently, there are several techniques for the surgical treatment, and the choice of the most appropriate approach depends on the degree of deformity and the affected levels. An anterior, a combination of anterior and posterior, or a combined approach can be used, with or without osteotomies.

Understanding the concepts involved in vertebral alignment and its implications are critical to assess a patient with deformity both in the coronal and sagittal planes. General orthopedists must know how to recognize a patient with deformity and sagittal imbalance for an appropriate referral to specialists. Spine surgeons must have this knowledge consolidated for correct preoperative planning to avoid unsatisfactory outcomes resulting in pain and loss of quality of life.

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Conflict of Interests

The authors have no conflict of interests to declare.

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