REVIEW ARTICLE

Pelvic parameters: origin and significance

J. C. Le Huec · S. Aunoble · Leijssen Philippe · Pellet Nicolas

Abstract

Introduction The adoption by humans of an upright position resulted in broadening and verticalisation of the pelvis together with the appearance of characteristic spinal curves, has profoundly modified the structure of the muscles supporting the spine.

Material In order to characterise the sagittal balance of the pelvis, it is necessary to define parameters based on notable biomechanical forces involved in the transmission of constraints. The angle of incidence was constructed to enable reproducible analysis of the anatomical characteristics of the pelvis in the sagittal plane. The angle of incidence is the algebraic sum of two complementary angles: pelvic tilt (PT) and sacral slope (SS). Since the value of incidence is fixed for any given patient, the sum of pelvic tilt and sacral slope is a constant value: when one increases, the other necessarily decreases.

Result The position of the lumbar spine, attached to the sacral plateau, is thus affected by the pelvic tilt and by the sacral slope. Consequently, the pelvic parameters affect the entire underlying sagittal spinal profile.

Conclusion Global spinal balance involves harmonisation of lumbar lordosis and thoracic kyphosis taking into account the pelvic parameters.

Keywords Sagittal balance · Incidence angle · Pelvic tilt · Sacral slope · Pelvic parameters

Introduction

The adoption by humans of an upright position resulted in broadening and verticalisation of the pelvis together with the appearance of characteristic spinal curves and profoundly modified the structure of the muscles supporting the spine [1]. Human bipedalism is an exclusive, stable and ergonomic posture. Transition to an upright posture has resulted in the pelvis becoming a key structure within the human motor apparatus. This pelvic vertebra, as it was called by Dubousset [2], forms the bond between the trunk and the posterior limbs. Since the femoral heads are highly mobile, they play an important role in the spatial orientation of the pelvic vertebra. They constitute the point at which the thoraco-lumbar load on the pelvis is transferred to the lower limbs. The sacral plateau, which forms the base to support the spine, is the point of transfer of load from the trunk to the pelvis. The frontal spinal position of the spine and pelvis is straightforward: the normal spine is vertical having a median axis that passes through the middle of the sacrum and the pubic symphysis (Fig. 1). The normal pelvis is horizontal, with symmetrical points at equal height. However, the geometry of the sagittal pelvic position is more complex. Characterisation of the sagittal balance of the pelvis requires the definition of certain parameters based on notable biomechanical features involved in the transmission of constraints [4].

Characterisation of landmarks for pelvis analysis

The incidence angle was constructed to enable reproducible analysis of the anatomical characteristics of the pelvis in the sagittal plane. Its construction is based on the definition of two notable points and a surface [5]. The femoral

J. C. Le Huec (✉) · S. Aunoble · L. Philippe · P. Nicolas
Spine Unit 2, Bordeaux University Hospital,
Surgery Research Lab, 33076 Bordeaux, France
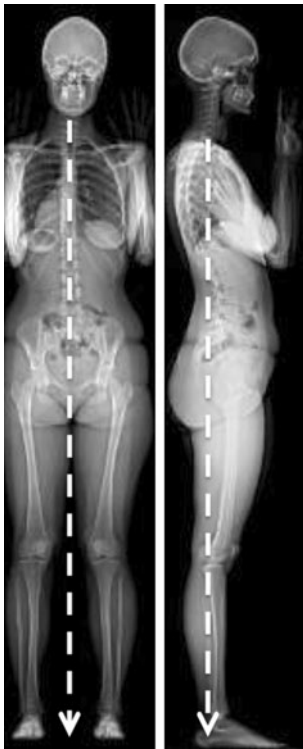e-mail: j-c.lehuec@u-bordeaux2.fr

Fig. 1 Simultaneous AP and lateral radiographic view of the full body in standing position with the low-dose EOS system (Biospace, Paris, France). **a** AP view, the load is transmitted through the mid-sacrum at a point equidistant from both femoral heads. **b** lateral view of the spine and pelvis

Fig. 2 Construction of the pelvic thickness *line* CS. **a** femoral head and sacral plateau. **b** the *line* between C and S is the sacral thickness. **c** the orientation of the sacral plateau is independent of CS, which is the same as in **b**

head responsible for transmission of constraints from the pelvis to the lower limbs is a point that must be taken into consideration. The sacral plateau on which the vertebral column rests constitutes a second mandatory point as well as a surface. Let us take a lateral vertical section of the pelvis (Fig. 2a, b) and draw the sagittal view and including only the femoral head (the two heads are taken as being superimposed) and the sacrum (Fig. 2c). If we draw a straight segment between point C, the centre of the femoral head, and point S, the centre of the sacral plateau of S1, we see that the length and direction of this straight segment CS reflects the various pelvic sections of differing thicknesses in the anteroposterior direction. This parameter is known as the sagittal pelvic thickness (SPT). Isolated analysis of this segment CS takes no account of an important element, namely the more or less vertical position of the sacrum in the pelvis; however, this parameter varies widely between individuals, as indicated in Fig. 1 (Fig. 3a–b). We must, therefore, find another reference point indicative of these two parameters (pelvic thickness and sacral position). A method was first described by During et al. [3], who combined the CS segment with the tangent at the sacral plateau and the resulting angle: the 'pelvisacral angle'
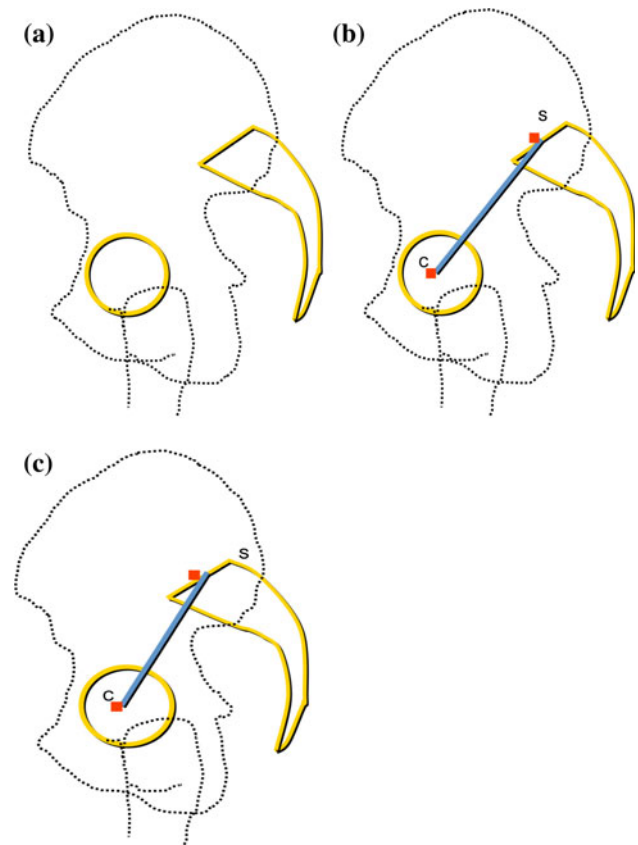
(PSA) (Fig. 3c). Some years later, Duval-Beaupère [4] and then Legaye [5] coined the term 'pelvic incidence' to describe the complement of this angle (Fig. 3d) by drawing a perpendicular line through the centre of the sacral plateau. This mimics a vector for the load transmitted to the sacral plateau. The segment CS and the perpendicular line dropped from the sacral plateau form the incidence angle. The mean value of this angle of incidence is $55° \pm 10°$ [6], but this mean value means nothing. The incidence angle is a key characteristic of the pelvis: it is an anatomical feature unique to each individual that becomes set at the end of growth, regardless of its position. There is, thus, no such thing as good or bad incidence but simply a fixed angle providing anatomical characterisation of the pelvis. The incidence angle is readily calculated and has become the most widely used reference angle. Digital X-rays, and more recently, the EOS® system (Biospace, Paris, France), have made it possible to obtain remarkable images, as well as measuring software such as the Optispine system (SMAIO, Optimage, Lyon, France) may be used to carry out all relevant calculations in a few mouse clicks. The EOS system, the medical application stemming from the
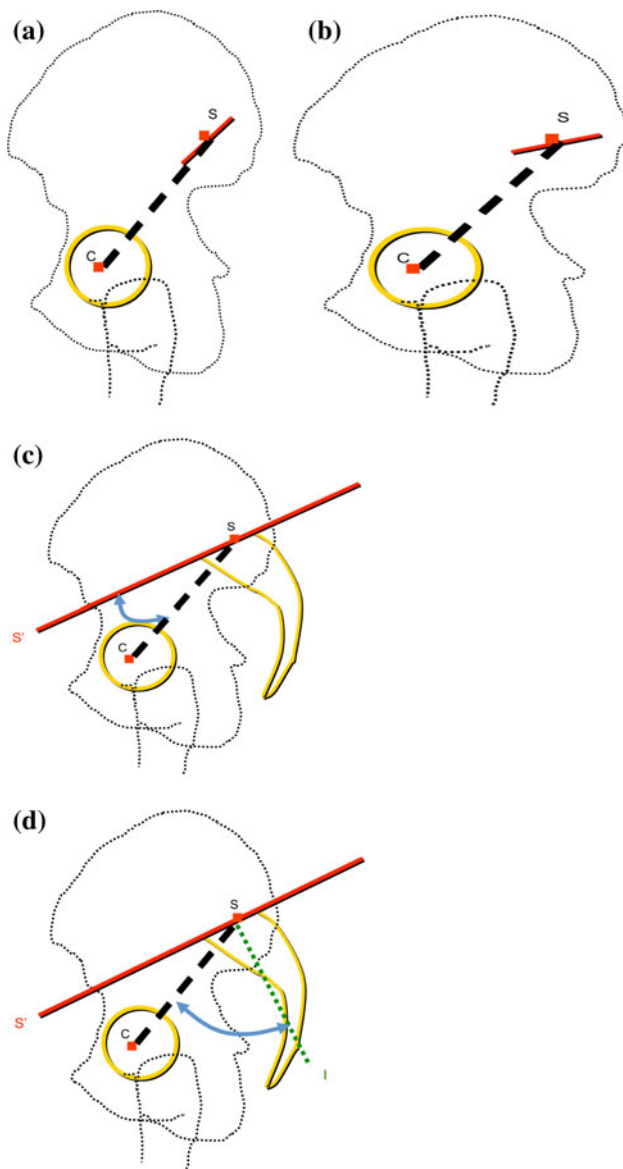
Fig. 3 **a** Vertical sacral slope with a narrow pelvis. **b** greater horizontal sacral slope with a large pelvis. **c** *red line* (sacral slope SS') is independent of pelvic thickness. CS; the angle between the red line SS' and the *blue line* CS is the pelvic-sacral angle. **d** the perpendicular to the SS' *line* applied on the sacral plateau defines the incidence angle: angle between CS line and this perpendicular to SS'

Fig. 4 Primates have a horizontal pelvis with no lordosis and they use their *upper* limb as a counterbalance

discovery made by Nobel Prize winner Georges Charpak [2], represents a considerable advance (Fig. 3), since it requires very little irradiation, involves no parallax deformation, and allows simultaneous acquisition of frontal and lateral images and 3D reconstructions of the spine, pelvis and lower limbs in standing position. In particular, this system may be used to assess any associated abnormalities in the axial plane. The angle of incidence is a major parameter that has a direct bearing on the balance of the spine, which rests on the sacral plateau [5, 6] (Figs. 4, 5).

Pelvic orientation in the space is an important 3D parameter

Pelvic tilt and sacral slope are two angles directly correlated with the pelvic incidence angle. The angle of incidence is the algebraic sum of two angles: pelvic tilt (PT) and sacral slope (SS). This may be easily demonstrated.

Pelvic tilt is the angle between a vertical line and the CS segment (Fig. 6). It denotes the spatial orientation of the pelvis, which varies according to position, with a greater or lesser degree of tilt forwards or backwards in relation to a transverse axis passing through the two femoral heads. In the standing position, the mean pelvic tilt angle, which is open at the back, is $13° \pm 6°$ [6]. In a subject standing normally, the pelvis is inclined forward slightly. The greater the angle of pelvic tilt, the further the centre of gravity is projected behind the femoral heads [7, 8]. As pelvic tilt increases, the sacral plateau becomes increasingly horizontal, while the body of the sacrum becomes vertical. In this position, the acetabulum almost completely covers the femoral head towards the back, thus limiting extension. This point is of critical importance in relation to hip prostheses, which may become dislocated at the front as a result of a posterior cam effect [7, 8] (Fig. 7).

The sacral slope (SS) is the angle of the sacral plateau to the horizontal (Fig. 8). The degree of the sacral slope
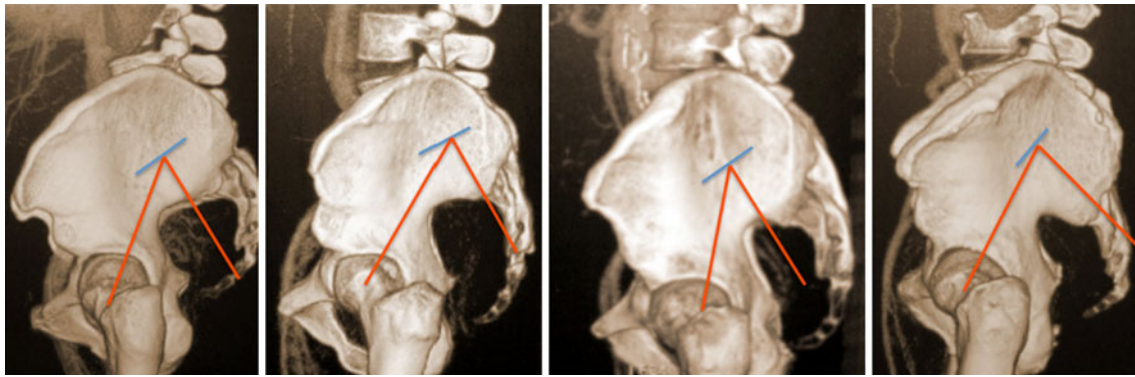
Fig. 5 CT scan 3-D reconstruction of the pelvis, lateral view showing femoral head, sacrum and both iliac wings and variation of shape in humans with the corresponding pelvic parameters

determines the position of the lumbar spine, since the sacral plateau forms the base of the spine [5, 9].

A simple geometrical construction based on the properties of right-angled triangles (Fig. 9) shows the incidence to be the sum of the pelvic tilt and the sacral slope. The latter two parameters are positional angles and vary inversely to one another: I (incidence) = PT + SS. Since the value of the incidence is fixed for a given patient, the sum of the pelvic tilt and the sacral slope is invariable, and

as one increases, the other necessarily decreases. In other words, for a given incidence, a specific pelvic tilt will be associated with a specific sacral slope.

Analysis and interpretation of pelvic parameters and values

Pelvic incidence (PI) determines the relative position of the sacral plate in relation to the femoral heads. The lower value of PI is approximately 35°, the higher around 85° and the average being 51.9° [8]. Patients with a very low PI present a pelvis with a very short pelvic ring on the anterior–posterior (AP) diameter. It is a *vertical pelvis*. These pelvises are narrow horizontally and are strong vertically. The femoral heads are just below the sacral plate. Inversely, a pelvis with a high-grade PI has a large AP axis; it is a large horizontal pelvis. In the sagittal plane, the femoral
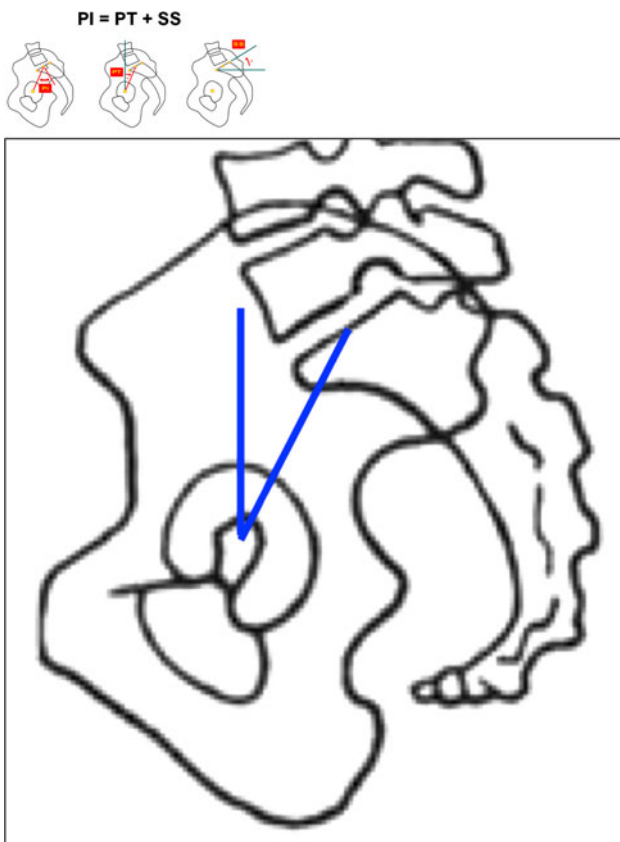

Fig. 6 The pelvic tilt *vertical line* through the femoral head and a *line* from the mid-sacral plateau and femoral head
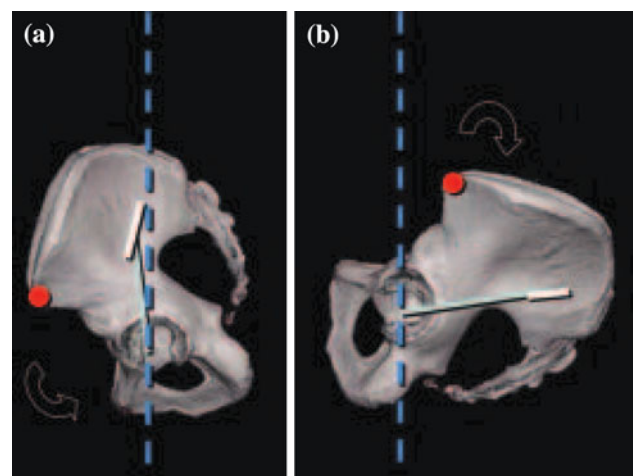

Fig. 7 a *Left* maximum pelvis anterior rotation: which is the same as a complete hip flexion and can facilitate hip dislocation. **b** *Right* maximum pelvis posterior rotation: which shows the limit of pelvis backtilt (the extension reserve)
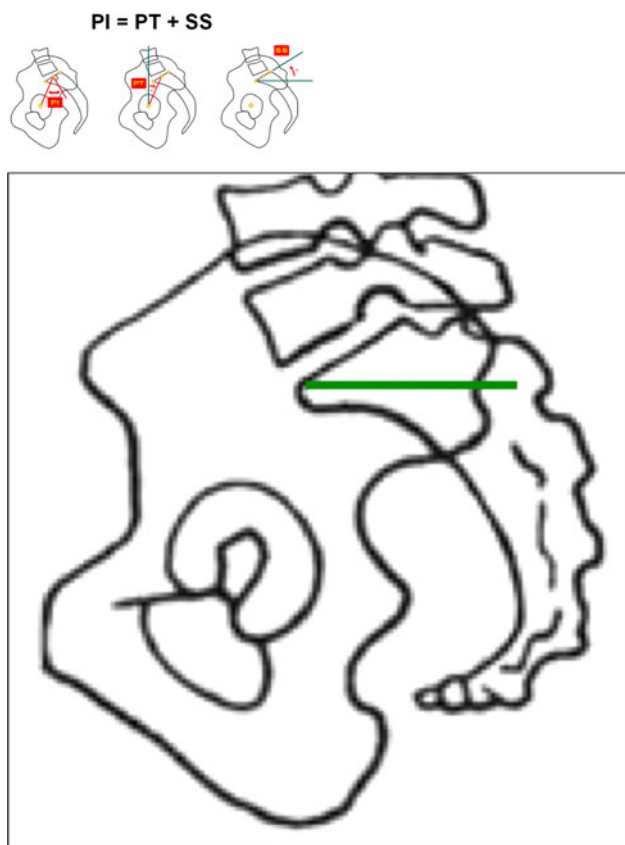
PI = PT + SS

Fig. 8 Sacral slope: angle between a *horizontal line* and the orientation of the sacral plateau

PI = PT + SS

PI = PT + SS

Fig. 9 Geometrical construction showing that SS and PT are complementary angles, since the *horizontal line* of SS and the *vertical line* of PT are perpendicular. The *red triangle* comprises the pelvic tilt angle on its *left side* and the sacral slope angle on its *right side*

heads are placed ahead the midpoint of the sacral plate. Finally, in patients with very low PI, the human pelvis morphology is closed to the pelvis of the big primates. As aforementioned, the vertical shape is less adapted to the verticality. By this way, a vertical pelvis has a low sacral slope (SS) and, therefore, a low ability of pelvic tilting; conversely, a horizontal pelvis has a high SS and higher possibilities of retroversion.

The pelvis can rotate around the femoral heads, following the bicoxo-femoral axis. When the pelvis rotates backward (retroversion), PT (pelvic tilt) increases; when the pelvis rotates forward (anteversion), PT decreases. PT is a positional parameter, as well as the SS. The possibility of rotation of the pelvis around the femoral heads axis is one of the best mechanisms of regulation of sagittal balance. Mac-Thiong et al. suggested that the non-pathological upper limit of PT would ideally be less than 50% of PI [18]. Likewise, the ideal values for SS should exceed 50% of PI. In pathology, SS never reaches a negative position, less than 0°. The minimal value of SS is 0°, which is the horizontal sacral plate. This situation corresponds to the maximal retroversion possible. A negative SS is not possible in erect human beings. In summary, the ability of
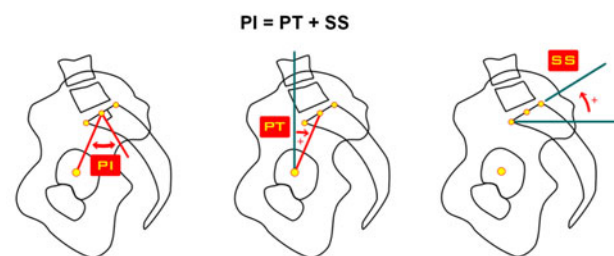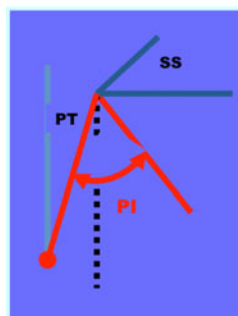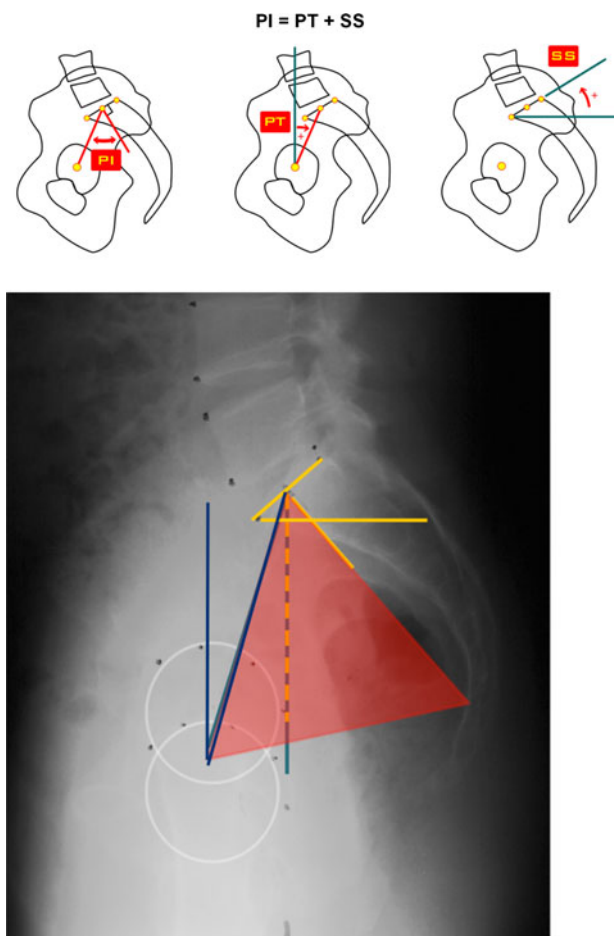
Fig. 10 Two different incidence angles with two different types of the shapes of the lumbar spine adapted to the shape of the pelvis

retroversion is limited by the value of the PI. Patients with a small PI have a small capacity to compensate their sagittal imbalance through pelvis retroversion. The limited posterior offset of the sacrum regarding the femoral heads can be observed in lateral radiographs. The same poor ability of compensation seems theoretically to occur in different pathologies when there is a low PI like in ankylosing spondylitis.
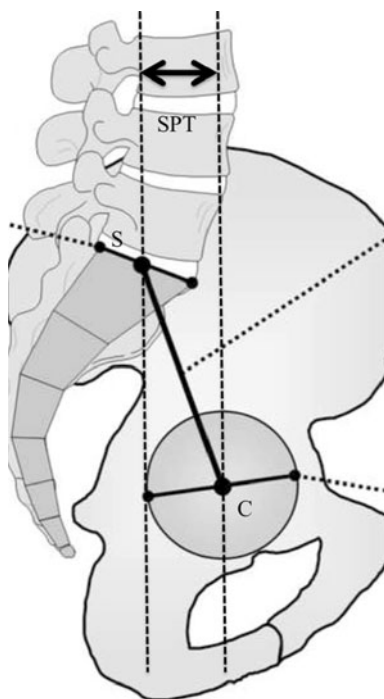

Fig. 11 Sagittal pelvic thickness measurement: the sagittal pelvic thickness (SPT), the length between S (mid-sacral plateau point) and the vertical passing through the centre of the femoral heads

The position of the lumbar spine, which is attached to the sacral plateau, is thus affected by the pelvic position. Consequently, the pelvic parameters affect the entire underlying sagittal profile of the spine. In conclusion, the greater the incidence, the greater the sacral slope and the higher the degree of lumbar lordosis [5, 8] (Fig. 10 diagram of the spine with two different incidences showing the relationship independent of ageing process).

The varying length of the CS segment, which represents the sagittal pelvic thickness (SPT), defined as the distance between the upper sacral plateau and the coxofemoral joints [9], has been inadequately studied. Sagittal pelvic thickness was proposed by Duval-Beaupère et al. to define the sagittal anatomy of the pelvis [4] (Fig. 11). Boulay showed a significant negative relationship ($p < 0.05$) between pelvic incidence and sagittal pelvic thickness. However, he noted a more reliable correlation between anatomic and X-ray measurements of pelvic incidence than of sagittal pelvic thickness [9]. This was ascribed to the artefact of radiographic distortion and primarily to variations in the stature of subjects with regard to values. SPT is nevertheless an important parameter, since it completes the angle of incidence in analysis of sagittal balance. A high angle of incidence associated with a low SPT does not possess the same ability to compensate for imbalance, with the other values remaining constant. It allows better assessment of the lever effect of muscles between the pelvis, the spine, the hips and the sacroiliac joints. It is of particular value in the assessment of adolescent spondylolisthesis [10].

Other noteworthy parameters have been described in the literature, of which only one is relevant: the pelvic radius as described by Jackson [11–13]. Jackson's pelvic radius technique involves measurements based on a line drawn between the hip axis and the posterior corner of S1 (PR). The angle formed between this line and the sacral endplate, PRS1, is a developmental measure of sacro-pelvic morphology and is similar to During's angle [3]; as previously demonstrated, it is practically the complementary angle to PI (Fig. 12). The PRS1 angle has been previously reported as correlating strongly with lumbar lordosis [11]. As the PRS1 angle changes, a corresponding change is noted in lumbar lordosis. The angle formed between PR and T12, PR-T12, provides a single, simultaneous measurement of pelvic morphology and of lumbar lordosis [11, 12]. It offers a simple way of rapidly assessing lumbo-pelvic sagittal balance on a standard lateral lumbar radiograph. Unfortunately, this is not in itself sufficient to allow global analysis of the varying degrees of sagittal balance described by Roussouly [14]. For this reason, the pelvic parameters described by Duval-Beaupère and Legaye [4, 5] will be used in combination with the new spinal parameters described by Roussouly [15].

Fig. 12 PRS1 (**a**) and the Pelvic Incidence (PI) (**b**), their relationship to sacral slope (SS) and pelvic angulation or tilt (PA or PT) and between each other (PRS1 $\approx 90° - $PI)
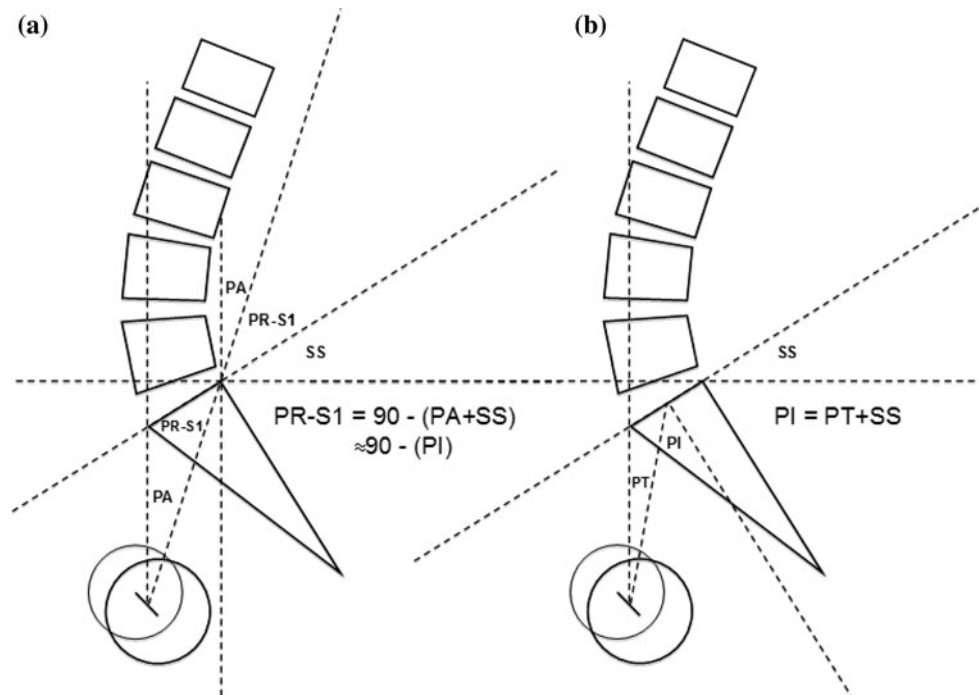
Conclusion

In practice, the incidence of an individual is correlated together with his or her sacral slope. Duval-Beaupère [4] showed lumbar lordosis to be proportional to sacral slope. The pelvis and lumbar spine adapt in accordance with the degree of pelvic tilt and lumbar lordosis [8]. Global spinal balance involves harmonisation with overlying lumbar lordosis and thoracic kyphosis [15]. Ideally, this dynamic chain results in perfect sagittal balance in which body weight is positioned along a line slightly behind the axis of rotation of the two femoral heads [16, 17]. Analysis of variations in the shape of the spine along the sagittal plane is thus necessary, given the extremely wide variations in pelvic configuration.

Conflict of interest None.

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