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ORIGINAL ARTICLE

Classification of normal sagittal spine alignment: refounding the Roussouly classification

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Abstract
Purpose Although the Roussouly classification of common variants in spinal sagittal alignment is well accepted, no studies have implemented it in an asymptomatic adult population. In addition, no study investigated the radiographic features of asymptomatic patients with an anteverted pelvis. The aim of this prospective radiographic study of 296 asymptomatic adults without spinal pathology was to investigate how the Roussouly classification could include the anteverted pelvis concept.
Methods Pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and the lumbar parameters lumbar lordosis (Global LL), lordosis tilt angle (LTA), total number of lordotic vertebra (LL verteb), and C7 plumbline/sacrofemoral distance ratio (C7PL ratio) were evaluated in 296 healthy volunteers (126 males, 170 females; mean age, 27 years; range 18–48 years). Comparison between the five types of the Roussouly classification used Student, ANOVA, and Tukey tests for quantitative variables and χ^2, Fischer, and Holm tests for qualitative variables.
Results Mean PI and PT were, respectively, (39°, 10°) for type 1, (41°, 10°) for type 2, (53°, 13°) for type 3, and (62°, 12°) for type 4 ($p < 0.0001$ and $p < 0.01$). A sizable portion (16%) of the population (type 3 AP) showed low-grade PI (mean, 48° ± 6°) despite having SS > 35°. PT was low or negative (mean 4° ± 3°). C7PL ratio was >1 (in front of the hip axis) in 13% of all cases, and between 0 and 1 (between sacrum and hip axis) in 49%.
Conclusion Although asymptomatic adults stood with stable global balance, the sagittal spinal alignment of healthy subjects, newly divided in 5 sagittal types, varied significantly. Type 3 AP appears as a new and unusual sagittal shape with low-grade PI, very low or negative PT, and hyperlordosis. Whereas most asymptomatic adults stood with C7PL behind the hip axis, a sizeable portion had C7 in front of the hip axis. This could be a new controversial aspect of ideal spinal balance.

Keywords Roussouly classification · Sagittal balance · Spinal alignment · Anteverted pelvis

Introduction

Various spinal shapes and positional parameters have been described by radiographic assessment of asymptomatic volunteers to understand human sagittal balance in the standing position [1–6]. Most of these studies used the same three anatomic landmarks to characterize spinopelvic balance: C7 plumbline (C7PL), sacral plate (SP) inclination, and the center of the femoral heads (FH). Spinopelvic balance is dependent on the combination of pelvic shape (FH–SP relation) and spinal shape [a sequence of spinal curves: lumbar lordosis (LL) and thoracic kyphosis TK].

The shape of the pelvis is determined by a morphologic parameter: pelvic incidence (PI). This parameter is a constant and stable parameter through adulthood. Thus, pelvic rotation around the femoral heads allows adaptation of

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sacral plate inclination (sacral slope: SS) by pelvic retroversion (increased pelvic tilt: PT) or anteversion (decreased PT), according to the well-known geometrical relation: PI = PT + SS [7].

Assessment of spinal curvatures is more controversial. Some authors set anatomical limits to the different spinal curves: T4–T12 for TK and L1–S1 for LL [8], Berthonaud et al. [1] introduced the “inflexion point” as a limiting functional variable between LL and TK, where lordosis curvature switches to kyphosis. In a previous study [5], Roussouly et al. suggested a classification of common variants in spinal sagittal alignment according to SP inclination, in an asymptomatic population, defining four types of spinopelvic shape, based on Berthonaud’s concept of spinal segmentation [1]. Thus, the concept of short and long lumbar lordosis has emerged, refining the pre-existing anatomical segmentation of L1–S1 lumbar lordosis [8].

The aim of the present prospective radiographic study was to investigate the accuracy of the Roussouly classification to describe all type of spinal shapes. It involved quantifying and describing general fluctuations in the sagittal alignment of the lumbar spine and pelvis in a population of asymptomatic subjects. The study also attempted to enhance the statistical significance of the Roussouly classification by describing the common patterns of reciprocal relationships between sacral orientation and the characteristics of spinal sagittal shape.

Materials and methods

A total of 296 adult volunteers were enrolled in the study. Mean age was 27 years (range 18–48 years), with 170 females and 126 males. The entire population was Caucasian. Consent to participate in the study was obtained from each patient. At enrolment, patients were free from current or history of spinal, hip, or pelvic disease. History of back pain, deformity, hip or lower limb discrepancy or disease, and radiographic abnormalities such as scoliosis, spondylolisthesis, or Scheuermann’s kyphosis were exclusion criteria.

The radiographic protocol was standardized. For each subject, a standing 30 cm × 90 cm left strict lateral radiograph including spine and pelvis was obtained from the base of the skull to the proximal femur, limiting the pelvic rotation in the coronal plan. The distance between the radiographic source and the film was 230 cm for all radiographs. Subjects stood in a comfortable position, shoulders, and elbows flexed, with hands placed on supports, with hips and knees fully extended. This standing position with the hands supported, while flexing the shoulders, 30° was found to be the best way to move the arms anterior to the spine with the least effect on overall sagittal balance in a healthy cohort (similar to our cohort) [9]. Plain radiographs were scanned using a VXR8 film scanner in jpg or bitmap format at 75 dpi if not available in digital format.

Sacropelvic parameters [PI, PT, and SS (Fig. 1)], and local and global spinal parameters [global LL angle (LL Glob (°)), inflexion point (InP) location, lordosis tilt angle (LTA), total numbers of lordotic vertebrae (LL verteb), and C7-Barrey ratio (%) [10] (Figs. 2, 3)] were measured by a single observer using the KEOPS software (SMAIO, France) as previously described in sagittal spinal alignment studies [11, 12]. The KEOPS software was found to have better repeatability and reproducibility of computerized radiologic measurements when compared to manual standard radiologic measures [13]. KEOPS software performed subject distribution according to the Roussouly criteria [5] (Fig. 3).

Data were analyzed using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA). Comparison between the four types of sagittal spinal shape on the Roussouly classification used Student, ANOVA, and Tukey tests for quantitative variables and χ^2, Fisher, and Holm tests for qualitative variables. $p = 0.05$ was chosen as significance level.

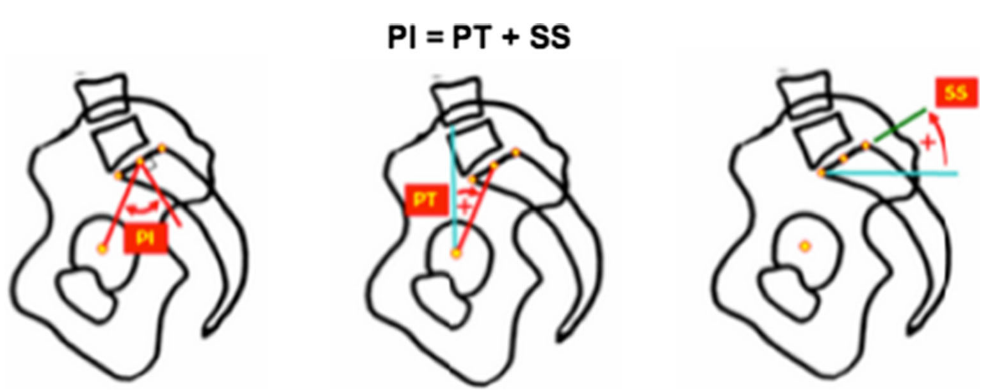

Fig. 1 Sacropelvic parameters: pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS)

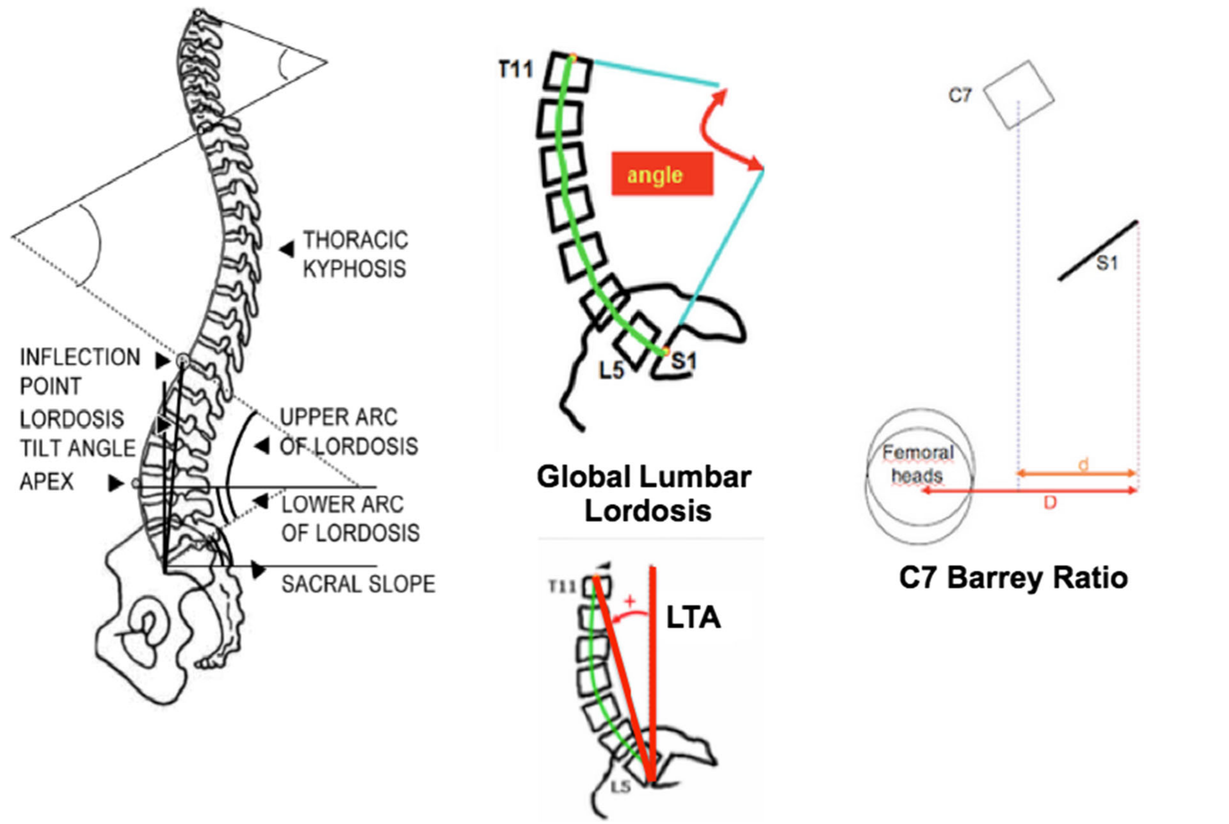

Fig. 2 Local and global spinal parameters. Inflexion point (InP): the location of IP determines the limit between the lordotic and the kyphotic curves. LL verteb: number of vertebras included in the lordotic curve. Global LL angle (°): the angle sustended by the superior endplate of the last lordotic vertebra and the sacral plateau. Lordosis tilt angle (LTA): angle sustained between the *line* drawn from the sacral superior anterior corner to the inflexion point and the *vertical line*. C7 Barrey ratio (*d*/*D*): horizontal distance from the center of upper sacral endplate to C7 plumbline (*d*) divided by horizontal distance from the center of upper sacral endplate to femoral heads (*D*). Positive when in front of the center of upper sacral endplate and negative when behind the posterior-superior sacral corner

Results

Sacropelvic sagittal morphology (Tables 1, 2, 3, 4)

PT values were found to be different between males (mean 13°) and females (mean 11.3°) ($p = 0.03$). Regarding the distribution of PT values in PT cut-off fields, 61% of males had PT > 12° versus only 45% of females, while females more often had PT values <12° (55, versus 39% of males) (Table 1).

PI, a parameter with broad range, showed a significant variation according to PT cut-off values. For a small PT cut-off value (8° < PT < 12°), PI varied widely, from 32° to 75°. For very low or negative PT values (<8°), mean PI was 43° (Table 2).

The proportion of very low or negative PT values (<8°) in the entire population was 29% (Table 3). 25% of subjects with high SS (>35°) had very low or negative PT (Table 4).

Pelvic and spinopelvic sagittal alignment (Table 5; Fig. 4)

Low-grade PI

Type 1 and 2 sagittal shapes (SS < 35°) had low mean PI values: respectively, 39° ± 5° and 41° ± 6°. Type 1 short hyperlordosis was the least frequent shape (12% of the entire population). It included a mean 3 vertebrae in the lumbar curve, with mean amplitude of 51° ± 6°. The lumbar curve showed the strongest backward tilt: mean LTA, −8° ± 4°. Type 2 flat lordosis (22% of the population) had a slightly longer (4 vertebrae) but less pronounced lumbar curve (LL Glob = 48° ± 5°). Mean LTA was −6° ± 3°.

Type 3 + anteverted pelvis (AP): a new, unusual shape (Figs. 5, 6): a sizable portion (16%) of the population showed low-grade PI (mean 48°) despite having SS > 35°. PT was low or negative (mean 4° ± 3°). The lumbar curve

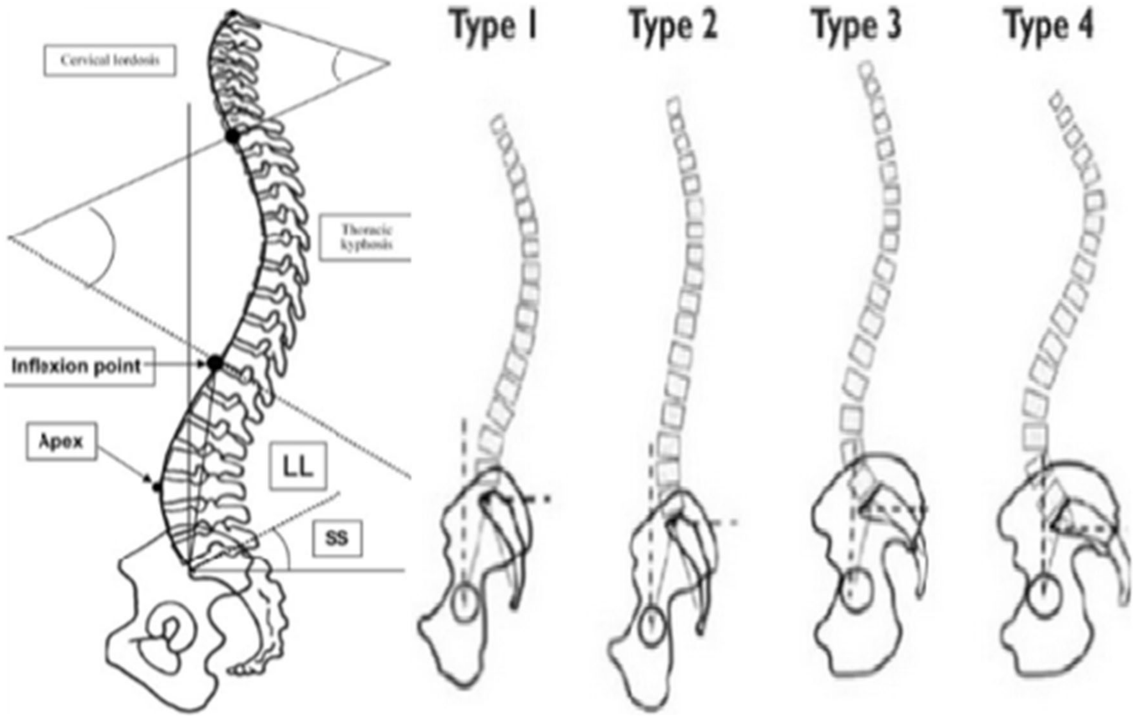

Fig. 3 Subdivision of the sagittal spinal curvatures according to the Roussouly classification

Table 1 Proportion of males and females according to the pelvic tilt cuts

PT (°)	<8	(8, 12]	(12, 20]	(20, 30]	>30	
Female	34%	21%	31%	14%	0%	
Male	22%	17%	52%	8%	1%	$p < 0.001$

Males stood with a higher PT than females

in this type 3-AP had a mean amplitude of 64° ± 7° and included five vertebrae. Mean LTA was −5° ± 4°.

High-grade PI

Type 3 (35° < SS < 45°) and type 4 (SS > 45°) sagittal shapes had high mean PI: respectively, 53° ± 7° and 62° ± 8°. Type 3 was the most frequent shape (30% of the entire population). The number of vertebrae included in the lumbar curve was 4.5 ± 1, with a mean amplitude of 58° ± 10° and mean LTA of −5° ± 4°.

Type 4 hyperlordosis (20% of the population) had a longer (5.5 ± 1 vertebrae) and more ample lumbar curve (LL Glob, 69° ± 6°). The lumbar curve tilted forward, with mean LTA of −2° ± 4°.

Global sagittal balance (Figs. 7, 8)

Displacement of the C7 plumbline in front of both hip axis and the center of the upper sacral endplate (C7 Barrey ratio, >100%) was frequent, being found in 13% of asymptomatic subjects (Fig. 7), and more frequently in males (22%) than females (7%) (Fig. 8).

There were significant differences between the four types in terms of C7 plumbline location (Table 4):

- In type 1, the C7 plumbline was located behind the posterior-superior corner of the sacral endplate (mean C7 Barrey ratio, −10%).

Table 2 Mean, minimum, and maximum values of PI according to the pelvic tilt cuts

Pelvic tilt cut	No	Min_incidence (°)	Mean_incidence (°)	Max_incidence (°)
<8°	86	22.31	43.03244186	61.54
(8°, 12°]	57	30.64	47.16877193	61.17
(12°, 20°]	119	32.74	54.78394958	75.8
(20°, 30°]	33	46.17	64.32272727	90.02
>30°	1	68.38	68.38	68.38

This variation of PI values shows that PI is a parameter with broad recruiting among the entire population

Table 3 Proportion of normal subjects according to the pelvic tilt (PT) cuts

PT (°)	No	Proportion (%)
<8	86	29
(8, 12]	57	19.3
(12, 20]	119	40.2
(20, 30]	33	11.2
>30	1	0.3

Twenty-nine percent of the entire population has very low or negative PT

- In type 2 and type 3-AP shapes, the C7 plumbline moved slightly forward and was located around the sacral plate (mean C7 Barrey ratio, 5%) for type 3-AP, and slightly anteriorly to the anterior-superior corner of the sacral endplate (mean C7 Barrey ratio, 18%) for type 2.
- In type 3 and type 4, C7 Barrey ratio was, respectively, 30 and 46%. The C7 plumbline remained located between the hip axis and sacral endplate.

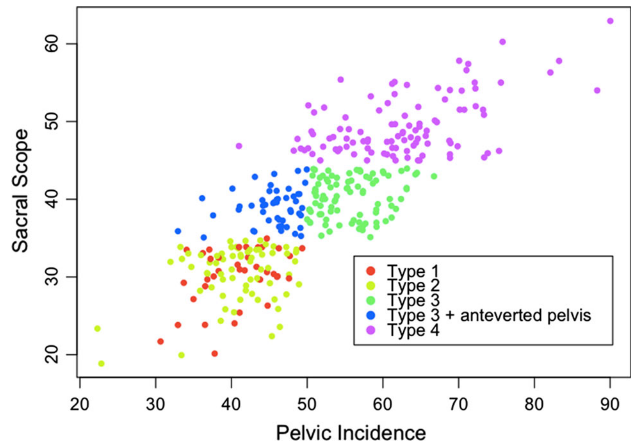

Fig. 4 Sagittal spinal types distribution according to (pelvic incidence) PI values lightening the limits of PI values among the different types

Discussion

The present study attempted to investigate the ability and accuracy of the Roussouly classification to distribute and organize a large asymptomatic cohort of adult volunteers into the four types of sagittal spine alignment [5]. A previously undescribed subgroup of type 3 (35° < SS < 45°), identified as "anteverted type 3" or type 3AP has emerged.

Type 3AP have been shown to represent 16% of this healthy population. This new type has showed important characteristics of type 3 (35° < SS < 45°, and long LL) despite a low-grade PI which is one of types 1 and 2 characteristics. In the framework of the relation PI = PT +SS, type 3AP could be considered, indeed, as a subgroup of the type 3, because type 3AP has showed the characteristics of an anteverted pelvis.

The anteverted pelvis (low or negative PT) has been little described. Ferrero et al. [14] investigated disability in patients with adult spinal deformity and low PT before and after operative treatment and found high levels of disability. The limits of PT are not very clear. The relation PI = PT + SS does not allow a proportional relation between PI and PT, and the statistical correlation is quite low ($R = 0.6$) [4, 5]. With higher values of PI, PT cannot exceed 20°–25°, because hip extension is limited. In pathology, it is well demonstrated that pelvic retroversion is a compensatory mechanism of an anterior imbalance induced by hypolordosis, hyperkyphosis, or thoraco-lumbar kyphosis. The literature on pelvic anteversion (small or negative PT) is poor. In an adolescent cohort, Mac-Thiong et al. [15] showed that pelvic anteversion is more frequent in children and adolescents, thus seeming to be a phenomenon of immature imbalance. In fact, this is the first

Table 4 Entire population has been split into two groups: low SS (type 1 and 2 <35°) and high SS (type 3 and 4 >35°)

PT (°)	<8 (%)	(8, 12] (%)	(12, 20] (%)	(20, 30] (%)	>30	
Type 1–2 (SS < 35°)	36	26	36	2	0	
Type 3–4 (SS > 35°)	25	16	42.5	16	0.5	$p < 0.001$

Twenty-five percent of subjects with high SS have very low or negative PT defining the new type 3+ anteverted pelvis

Table 5 Characteristics of the sacro-pelvic, lumbar spine, and spinal parameters according to the type of the sagittal profile

SS (°)	%	PI (°)	PT (°)	LL Glob (°)	LTA (°)	N verteb LL	C7 ratio (%)
Type 1 29 ± 4	12	39 ± 5	10 ± 5	51 ± 6	−8 ± 4	3 ± 0.5	−10
Type 2 30 ± 4	22	41 ± 6	10 ± 5	48 ± 5	−6 ± 3	4 ± 0.5	18
Type 3AP 44 ± 6	16	48 ± 6	4 ± 3	64 ± 7	−6 ± 4	5 ± 1	5
Type 3 39 ± 3	30	53 ± 7	13 ± 7	58 ± 10	−4 ± 4	4.5 ± 1	30
Type 4 49 ± 4	20	62 ± 8	12 ± 7	69 ± 6	−2 ± 4	5.5 ± 1	46

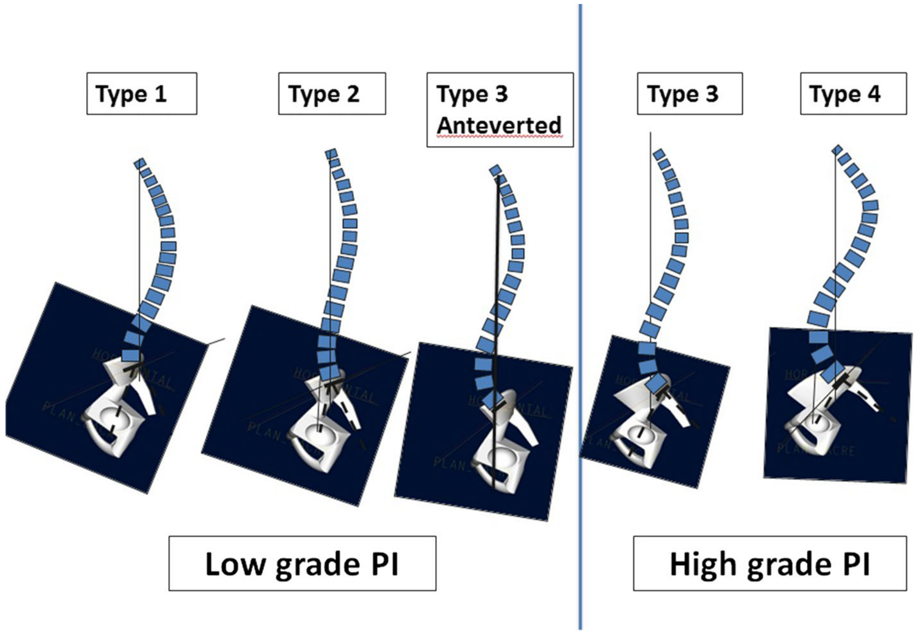

Fig. 5 New Roussouly classification integrating the anteverted pelvis shape

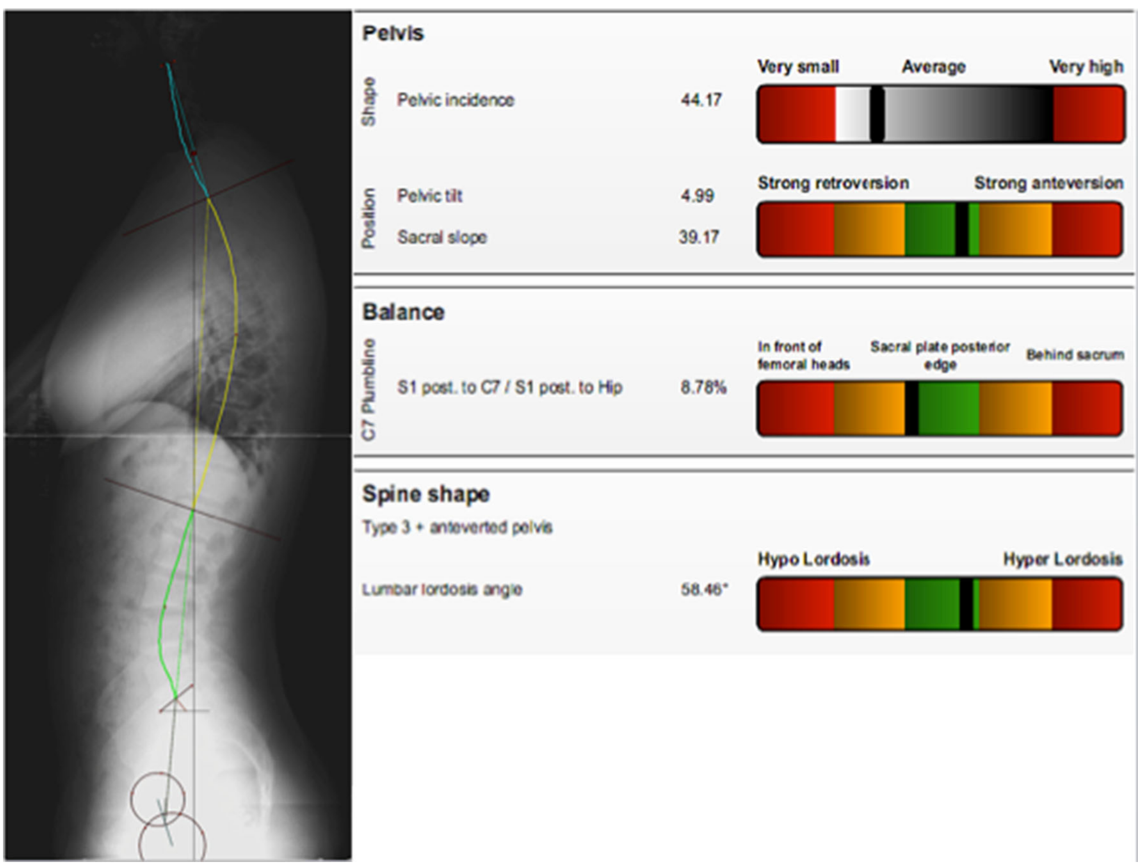

Fig. 6 Example illustrating the pelvic and spinal sagittal shape of an anteverted type 3

study that describes the demographic and radiographic features of pelvic anteversion in asymptomatic adult patients.

Several studies [8, 16–20] attempted to investigate pelvic parameters such as PI values among healthy adults as well as PI distribution in normal population, to highlight

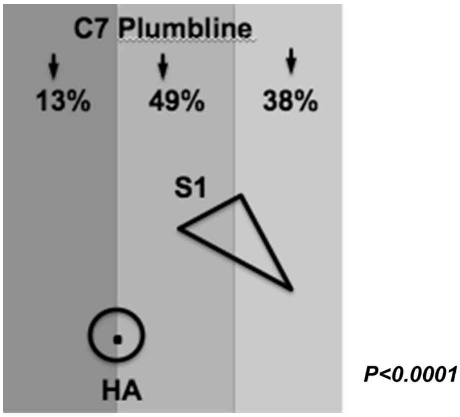

Fig. 7 Sagittal global balance in asypmtomatic population. C7 plumbline was located in front of both hip axis (*HA*) and the center of the sacral endplate (*S1*) in 13% of the population without pathological significance

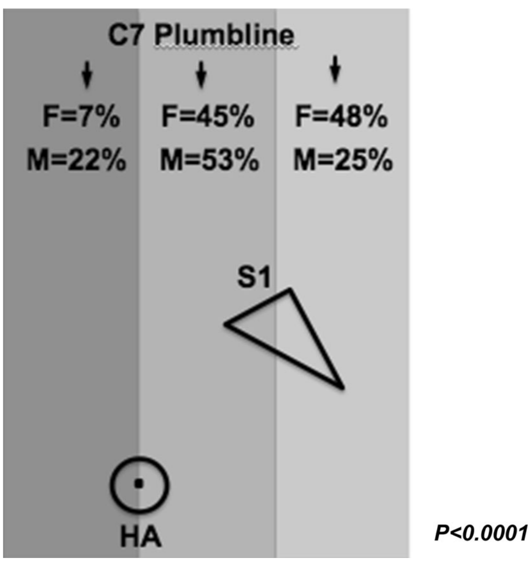

Fig. 8 Sagittal global balance comparison between males (M) and females (F). There are more males standing with C7 plumbline located anteriorly to both HA and S1 than females

any relationship between PI and LL. Although several studies demonstrated a strong correlation between SS and PI [4, 7, 12], the geometrical relation, PI = PT + SS, allows for the possibility of high SS with smaller PI if PT is small or negative: e.g., PI = 40°, PT = 0°, and SS = 40°. Even more, several studies in healthy subjects showed higher correlation of LL to SS than LL to PI (0.9 vs 0.6, respectively) [5, 21]. However, initially, the direct relation between Global LL and SS was described first by Stagnara [22], with a segmentation from “static” flat back to “dynamic” curved back, with low and high SS, respectively. The original Roussouly classification maintained this strong relation, introducing a geometrical relation between SS and the lower arc of lordosis (between the S1 plateau and the horizontal line through the LL apex). Four types were identified: types 1 and 2 for low SS (<35°), type 3 for average SS (35° < SS < 45°), and type 4 for high SS (>45°). Moreover, the present study demonstrated the possibility of higher-than-expected SS with small PI: type 3 LL may be found associated with small PI when the pelvis is anteverted (small or negative PT). This situation is not exceptional as 16% of the present population could be characterized as “anteverted type 3”.

Two causes may explain the possibility of excessive pelvic anteversion: fixed hip flexion contracture and hyperlordosis. The first cause was described as hip spine syndrome in osteoarthritis of the hip or bilateral hip congenital dislocation [23, 24]. The authors of these studies reported that the sagittal alignment of the spine in patients with bilateral hip congenital dislocation was compensated for by anterior angulation of the pelvis (high SS and low PT) and by lumbar hyperlordosis (LL increase) inducing a posterior shift of C7-plumbline behind the sacrum. On the other hand, hyperlordosis with anteverted pelvis is also well known in cerebral palsy, but the respective roles of spinal lordosis and hip flexion contracture remain unclear. In the present population, hip pathology was excluded. As well, the slight hyperlordosis of the “anteverted type 3” group (mean LL Global = 64° ± 7°) could induce the pelvic anteversion. In fact, “anteverted type 3” had a discordance between a high LL and a low PI, caused by a high SS.

This new finding confirms that LL is less correlated to PI than to SS as found by several authors [5, 12, 21], and that theoretical LL value should be calculated from SS and not PI [8]. This dissonance between a high LL and a low PI could call surgeon attention in some clinical cases (Fig. 9) where spinal fusion leads to diminish the LL and, therefore, to induce a pelvic retroversion. In addition, in the framework of clinical applications, the spine surgeon would pay attention to avoid overbending the rod during spinal fusion avoiding hyperreduction, with postoperative hyperlordosis which leads in this case (Fig. 10) to a postoperative iatrogenic anteverted pelvis.

Furthermore, an anteverted pelvis (PT close to 0° or negative) places the sacral plateau just over or in front of the femoral heads. This frontal positioning of the spine with respect to the femoral heads induces anterior imbalance, in a paradoxical situation combining hyperlordosis with anterior imbalance. For example, in some cases of posterior subtraction osteotomy procedure for global

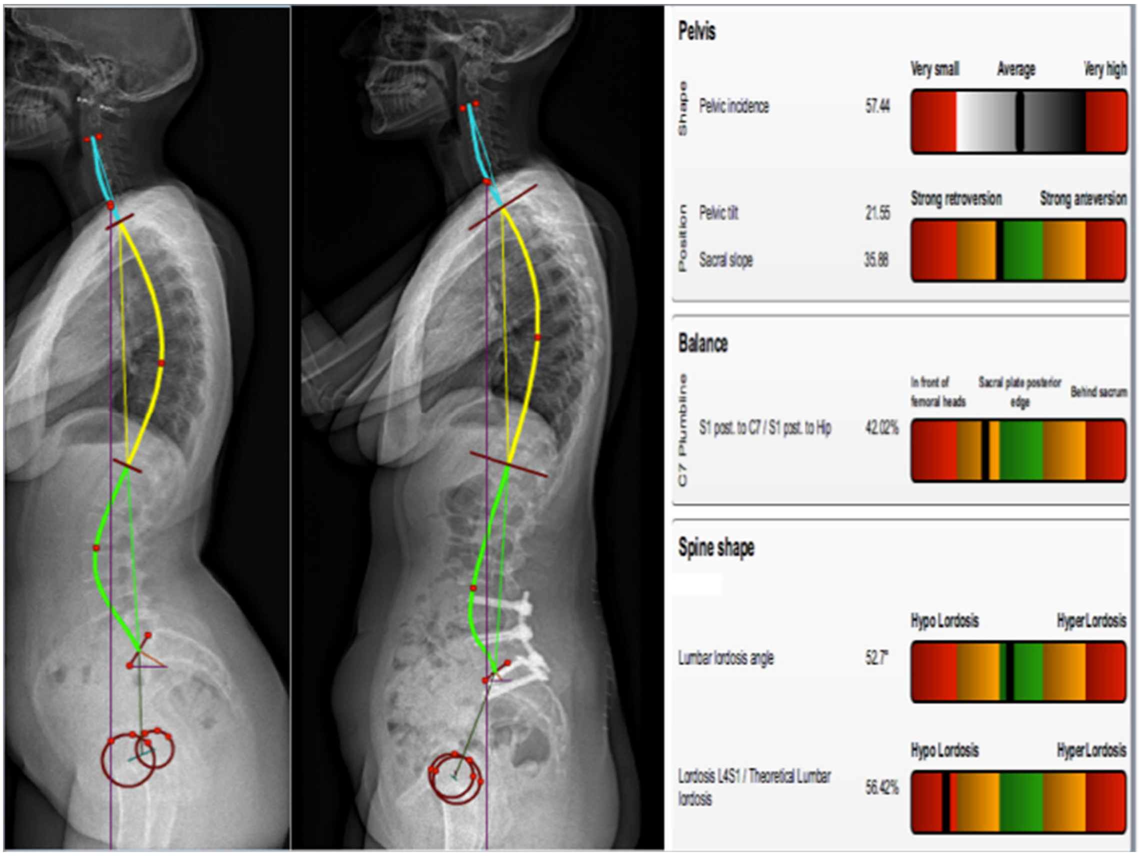

Fig. 9 Pre (*left*) and postoperative (*middle*) sagittal pelvic and spinal shape analysis (*right*) illustrating surgical implications and effects of a spinal fusion on an anteverted pelvis complaining from severe low back pain and high disability to stand up upright. In this case, spinal fusion leads to diminish the lumbar lordosis magnitude and, therefore, to induce a pelvic retroversion (PT increasing)

sagittal imbalance, overcorrection of the LL induced an anteverted pelvis. This finding was not observed in the present study of asymptomatic subjects. In fact, C7PL remained above the sacrum in anteverted type 3. The C7PL positioning changed with spinopelvic type: type 1 had the most posterior C7PL, while types 3 and 4 showed a more frontal position, sometime in front of the femoral heads. It seems that, with higher PI, the mechanisms compensatory balance (pelvic retroversion, and increasing LL) are insufficient to position C7PL over the sacrum. This could be a new controversial aspect of ideal balance parameters in the treatment of pathological cases of unbalanced high PI.

The last finding of this study was a gender difference in PT values. As in the previous studies, we found no gender difference in PI, but a significant sex difference emerged for PT, with smaller mean PT in females. The present analysis was not able to explain this difference, factors such as BMI, muscle strength, and size not having been taken into account. However, new balance criteria and expected PT values may need to be used in spinal balancing when treating female patients. Lumbar lordosis restoration may be more necessary in women.

This study has certain limitations. Sample size was too small to achieve high statistical power. The population mainly comprised young adults, and differences are likely with adolescents or older patients. The population comprised only Caucasian subjects, and differences with Asian or African populations were not considered; ethnic morphological differences may change the setting of balance parameters [19].

Conclusion

This new analysis of sagittal balance in asymptomatic volunteers allowed to demonstrate an undescribed type in the Roussouly's classification associating low PI, low PT, and type 3 LL: "anteverted type 3". This spinopelvic morphology may be found in pathology or in iatrogenic situation where a hyperlordosis induces an anteverted pelvis. PT is the key parameter in evaluating the sagittal pelvic balance with three main pelvic positioning: anteverted, normal, and retroverted, respectively, linked to hyperlordosis, adapted lordosis, and hypolordosis. Our study seemed to demonstrate a gender difference in

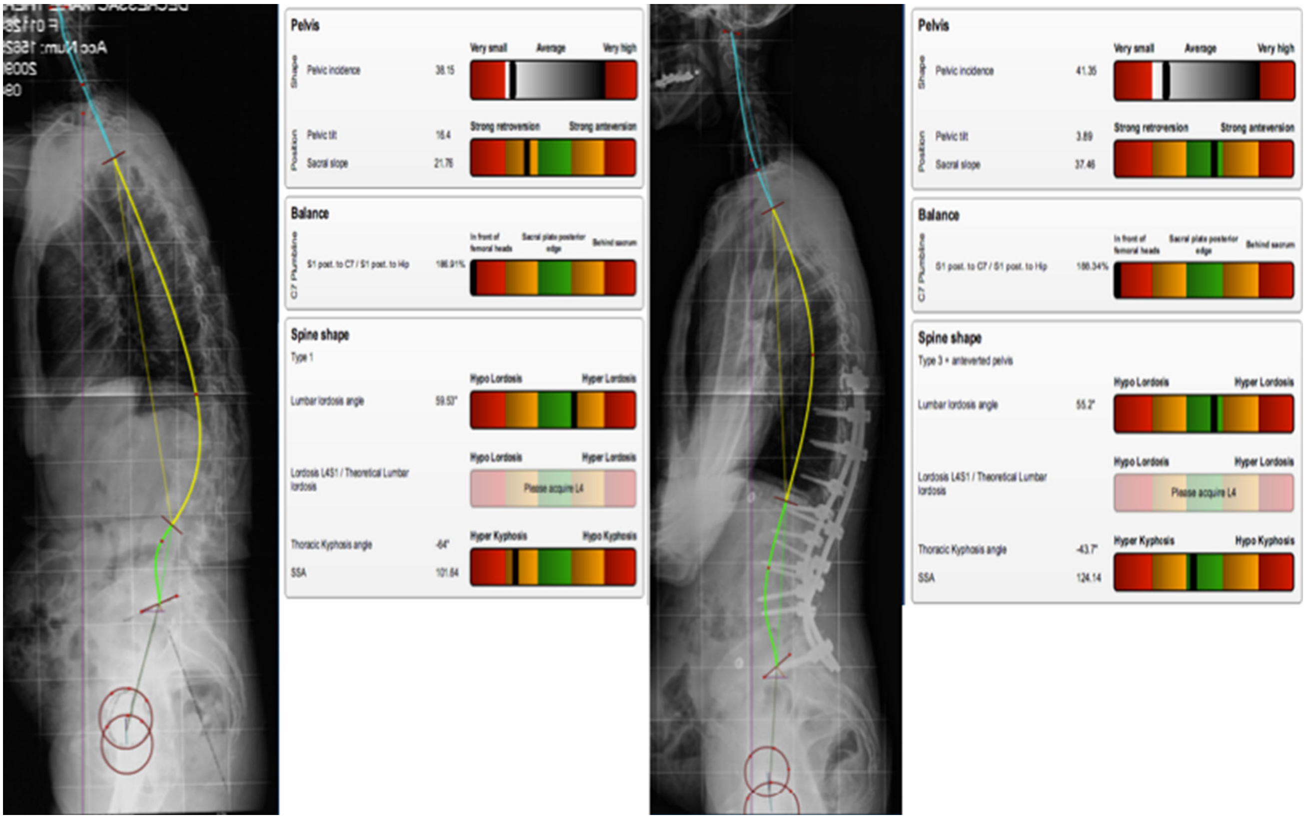

Fig. 10 Pre (*left*) and postoperative (*right*) sagittal pelvic and spinal shape analysis illustrating surgical implications and effects of a spinal fusion a type 1 spinal sagittal shape switching postoperatively to an anteverted type 3. In that case, spinal fusion leads to increase the lumbar lordosis curvature and, therefore, to induce a pelvic anteversion (PT decreasing)

average PT values, females having smaller PT than males. We found again that the Global LL being highly correlated to the SS.

Compliance with ethical standards

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Conflict of interest The authors declare that they have no competing interests.

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