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Clinical Study

Physiological variations in the sagittal spine alignment in an asymptomatic elderly population

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Abstract

BACKGROUND CONTEXT: Sagittal plane alignment is of crucial importance for the treatment of spinal deformities. When planning corrective strategies, spine surgeons need to refer to normative parameters' ranges which characterize the alignment in the asymptomatic population. Changes are known to occur with age. For the Caucasian population, the reference ranges are extensively documented for the young and middle-aged adults. In contrast, only a few studies have evaluated individuals in advanced age (>60 years) and in groups of limited numbers of subjects (less than 50).
PURPOSE: To describe the normative parameter ranges of sagittal spine alignment in a large population of asymptomatic elderly subjects.
STUDY DESIGN/SETTING: Monocentric, prospective, cross-sectional study.
PATIENT SAMPLE: One hundred sixty asymptomatic elderly volunteers (age>60 years, Caucasian heritage), consecutively enrolled.
OUTCOME MEASURES: Sagittal parameters of spine and pelvis: thoracic kyphosis (TK); lumbar lordosis (LL); sacral slope (SS); pelvic incidence (PI); pelvic tilt (PT); sagittal vertical axis (SVA); T1 pelvic angle (TPA); mismatch between PI and LL (PI-LL); Roussouly classification of the lumbopelvic profile.
METHODS: Each subject underwent one radiographic scan, performed in standing position with EOS low-dose system (EOS Imaging, Paris, France). The radiographic images were processed with sterEOS software allowing identification of the anatomical parameters and the presence of scoliosis. SVA, TPA, and the lumbopelvic profile were manually measured in the lateral images. The results were compared to previous studies describing younger adult populations. The study was supported by the Italian Ministry of Health in the amount of $15,000. The authors declare that there are no conflicts of interests.
RESULTS: Overall, the average values of the spinopelvic parameters were the followings: TK, 55±14°; LL, 57±12°; PI, 55±11°; SS, 38±10°; PT, 16±7°. The average PI-LL, SVA, and TPA was −3±11°, 25±32 mm, and 14.6±7.4°, respectively. TK, TPA, and SVA were found increasing with age. As for classification of the lumbopelvic profile, 16% of subjects were excluded because they were considered not to belong to any of the Roussouly types. In the classified subjects, the distribution was similar to that of younger adults. Asymptomatic scoliosis (average Cobb angle, 22±7°) was identified in 27% of individuals.
CONCLUSIONS: The ranges of values pointed out differences compared to younger adults and represent an important resource for spine surgeons in planning the surgical correction of spinal deformities. The characteristic changes occurring with age, as well as the observed presence of mild or moderate asymptomatic scoliosis, should be carefully taken into account. The classification

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of the lumbopelvic profile based on the Roussouly scheme revealed some limitations, although similar frequencies were identified compared to younger adults.

Keywords: Asymptomatic elderly subjects; Low-dose radiography; Normative ranges; Roussouly classification; Spine sagittal alignment

Introduction

Sagittal plane alignment is of crucial importance for the treatment of spinal disorders. In cases of deformities, surgical corrective strategies are targeted at restoring or preserving physiological spine alignment. To this aim, the anatomical parameters characterizing the sagittal alignment such as thoracic kyphosis (TK), lumbar lordosis (LL), and spinopelvic parameters (ie, sacral slope [SS] pelvic incidence [PI], and pelvic tilt [PT]) [1,2], as well as indices of global balance (eg, sagittal vertical axis [SVA] and T1 pelvic angle [TPA]) [3,4], and lumbopelvic harmony (eg, the mismatch between PI and LL [PI-LL]) are to be considered [5–8]. In particular, SVA, TPA, and PI-LL were demonstrated as highly related to patient-reported outcomes [4,9–12] and the optimization of these parameters has become a focal target when planning adult deformity correction minimizing the risk of disease progression [13–16]. As an additional evaluation factor, an influential and widely employed classification system of the lumbopelvic profile in sagittal plane has been proposed by Roussouly et al. [17]. Considering the lumbar shape and the spinopelvic inclination, the method allows defining four different lumbopelvic types, which have been recently extended to five by accounting for the presence of pelvic anteversion [18].

When planning corrective strategy, spine surgeons need to refer to normative parameters' ranges characterizing the alignment in the asymptomatic population and acquired via radiographic examination in volunteer subjects. In fact, spine alignment is known to differ significantly among ethnicities [19]. As concerns the Caucasian population, the reference ranges are extensively documented for the young and middle-aged adult subjects [3,20–23], but only a few studies have evaluated individuals in advanced age (>60 years) [24–26]. In this regard, particular changes are known to occur in the elderly. The lower part of the lumbar spine keeps its lordosis, whereas the central part tends to flatten [27]. Compensation mechanisms such as pelvic retroversion, knee flexion, and pelvic shift can be activated in the course of the aging process to counteract the effects of spine degenerative changes (eg, facet joints arthritis, disc degeneration, and atrophy of extensor muscles) [8,28,29]. The previous studies which examined asymptomatic elderly individuals have reported increased SVA and TPA in comparison to younger adults (corresponding to a more frontward imbalanced posture), differences in PI-LL, and the tendency to decrease the degree of lumbar lordosis and sacral tilt [24–26]. Unfortunately, limited numbers of subjects with age greater than 60 years have been examined. An extensive evaluation of a larger population would better substantiate the description of the parameters' ranges. Furthermore, the Roussouly classification of the lumbopelvic profile has been applied to asymptomatic subjects in adulthood (range: 18–48 years) [17,18,30,31] but not extended to the elderly yet. This is a potential limitation when planning corrective strategy in aged patients. In this regard, the presence of spine deformities whose prevalence has been recognized to be around 30% in the asymptomatic elderly population [32] could potentially impact the results of the classification.

The present work is aimed at providing spine surgeons with a comprehensive description of the normative ranges of the spinal sagittal parameters in the elderly to support the planning of surgical corrective strategies. A group of 160 asymptomatic Caucasian volunteers, over 60 years old, was enrolled in a prospective radiographic study based on low-dose system (EOS Imaging, Paris, France). The spinal and pelvic anatomical parameters, and the classification of the lumbopelvic profile, were obtained from the radiographic images and compared with those previously found in younger adults. The presence of scoliosis and its impact on the classification of the lumbopelvic profile were evaluated as well.

Materials and methods

A group of 160 asymptomatic elderly volunteers was evaluated in the period 2017 to 2018 at IRCCS Istituto Ortopedico Galeazzi (Milan, Italy). The enrollment was fostered by the national elderly association "Senior Italia FederAnziani." The members interested in participating and fulfilling the inclusion criteria were enrolled consecutively. The inclusion criteria were the followings: age over 60 years old; no significant painful episodes related to the spine, and absence of irradiating pain, in the last 2 years; no previous spine treatment or surgeries; no previous diagnosis of scoliosis or other diseases (vertebral, neurological, muscular); no obesity condition (verified during data processing by checking that BMI<30 kg/m^2). Subject assent to participate in the study and to the use of anonymized data was given by signing an informed consent form. The study was approved by the local Ethical Committee. The volunteers were of European heritage and drawn from the Italian population. The elderly association and the volunteers did not receive any economic incentive.

Each subject underwent low-dose biplanar radiographic scan of the whole body with the EOS system (EOS Imaging, Paris, France) [33]. The scan was performed in upright posture, with arms raised and fingertips on cheekbones. The digitized images were simultaneously acquired in the coronal and sagittal planes (Fig. 1A,B). The images were processed through sterEOS software, version 1.5 (EOS Imaging, Paris, France) by an operator with 5 years of experience. Accuracy, reliability, and repeatability of the EOS full spine reconstruction have been demonstrated elsewhere [34,35]. The 3D reconstruction of the thoracolumbar spine and pelvis was obtained (Fig. 1C,D), allowing identification of the following parameters: TK from T1 to T12 (TK_T1T12) and from T4 to T12 (TK_T4T12), LL from L1 to L5 (LL_L1L5) and from L1 to S1 (LL_L1S1), the pelvic parameters (PI, SS, PT), and the presence of scoliotic curves (characterized by Cobb angle larger than 10°). In presence of two curves, the Cobb angle of the most severe was considered for the comparisons. The PI-LL mismatch was evaluated as well as PI minus LL_L1S1.

In addition, the measurement of SVA and TPA and the classification of the lumbopelvic profile were obtained by examining the lateral plane image (Fig. 2). SVA was manually measured as the horizontal offset from the plumb line dropped from the centroid of C7 to the posterior corner of the sacral endplate (Fig. 2A) [3]. SVA was considered positive (or negative) when the C7 plumb line resulted frontward (or backward) with respect to the sacral corner. TPA was obtained as the angle subtended by the lines drawn from the midpoint of the segment connecting the centers of the femoral heads to the center of T1 vertebral body and to the middle of the S1 endplate (Fig. 2B) [4]. Accuracy and repeatability in measuring SVA and TPA have been demonstrated by other authors [26,36]. The lumbopelvic profile was identified according to the classification scheme (based on four types) proposed by Roussouly et al. [17] by accounting for the computed SS and by visually assessing the shape of the lumbar curve and of the apex position (Fig. 2C–F). The recently proposed fifth category, which distinguishes the subjects belonging to type 3 and characterized by the presence of an anteverted pelvis (type 3 + AP), was considered as well by assuming PT<10° as a condition of anteversion [18].

Since it was not previously evaluated in other studies, the inter-rater and intrarater reliability of the classification of the lumbopelvic profile was assessed using the Cohen's kappa statistic, which determines the agreement in case of qualitative (categorical) items [37]. Kappa value ranges from −1 to 1, indicating minimum and maximum agreement, respectively. A value larger than 0.8 is considered almost perfect, between 0.6 and 0.8 substantial, between 0.4 and 0.6 moderate, between 0.2 and 0.4 fair, between 0 and 0.2 slight, and between 0 and −1 poor [38]. Two raters, both experienced orthopedists, performed the classification task twice with 2-weeks interval. The intrarater agreement was determined for each rater comparing between the two

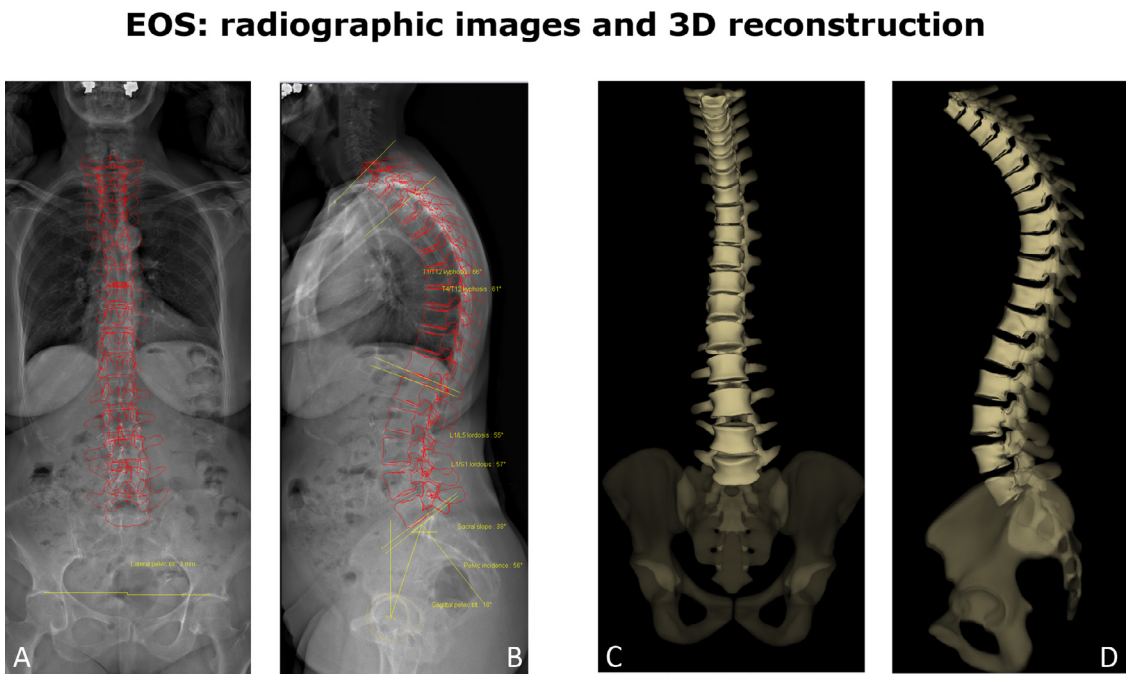

Fig. 1. Spine model reconstruction performed through sterEOS software for a female subject, overlaid over the frontal (A) and lateral (B) radiographic images simultaneously acquired with the EOS system. The anatomical parameters' values are reported as well. The (C) and (D) pictures depict the corresponding 3D spine model.

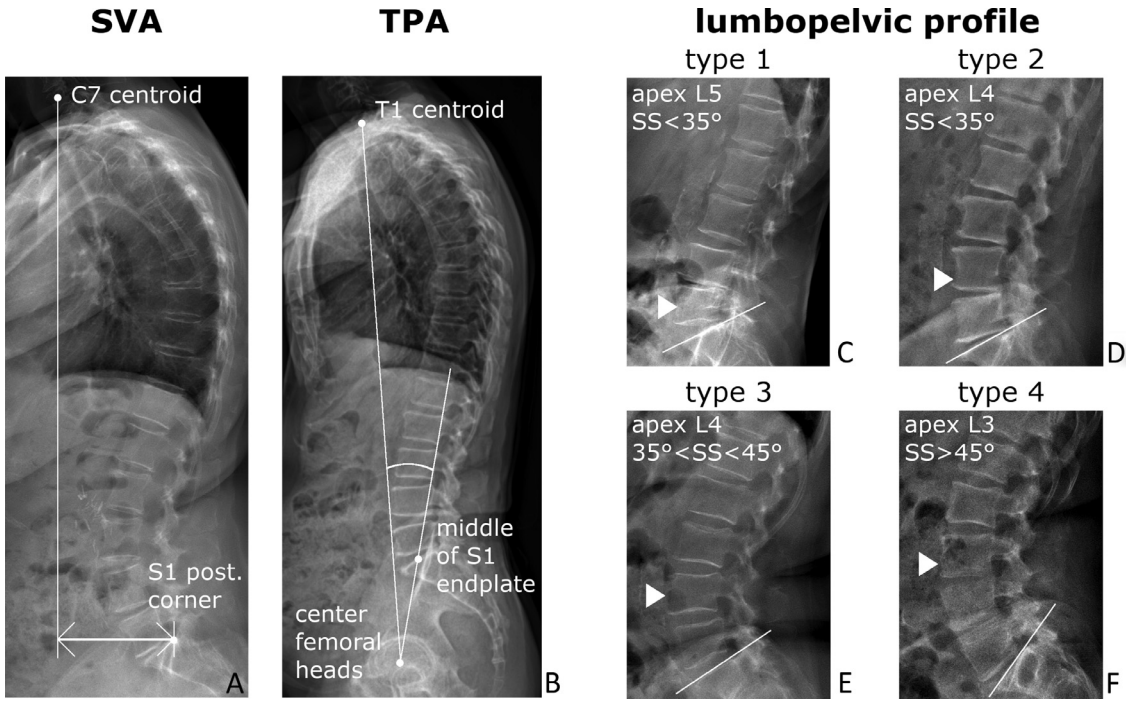

Fig. 2. From left to right: sagittal vertical axis (SVA), measured as distance between the sacrum posterior upper corner and the plumb line dropped from the centroid of C7 (A); T1 pelvic angle (TPA), obtained as the angle subtended by the lines drawn from the midpoint of the segment connecting the centers of the femoral heads to the T1 centroid and to the middle of the S1 endplate (B); lumbopelvic profile, defined according to the four lumbopelvic types (C–F) proposed by Roussouly et al. [17] as function of the sacral slope (SS) and the position of the lumbar curve apex.

tasks. The inter-rater agreement was computed comparing between raters twice.

Statistical analysis

For anatomical parameters, the difference in the mean values between females and males was checked by unpaired *t* test or Wilcoxon rank sum test in case of non-Gaussian distribution. The differences among the age-related groups were tested according to one-way ANOVA (or Kruskall-Wallis test where necessary) with post hoc comparisons performed in case of significance. The correlation coefficient, r, between the radiographic parameters was computed according to Pearson correlation, or Spearman rank correlation in case that a normal distribution was not achieved. The coefficient ranges from −1 to 1, where 0 indicates null linear correlation and −1 and 1 indicate full negative and positive correlations, respectively. The statistical significance of the coefficient was tested according to two-tailed *t* test or permutation distribution test assessing Pearson and Spearman coefficients, respectively. The difference in the frequency of subjects in the specific lumbopelvic type (comparing the present study vs. previous work and all subjects vs. nonscoliotic ones) was assessed by chi-square test (or Fisher exact test if necessary). All the tests accounted for 0.05 as significance level alpha. The analyses were performed in MATLAB software, version 8.6 (MathWorks Inc., Natick, MA).

Results

Demographics

Six individuals in 160 were excluded from the analyses: five revealed to be obese thus meeting the exclusion criteria, and one decided to withdraw after being enrolled. Data of 154 subjects (102 females and 52 males) were analyzed (Table 1). The percentage of females and males was 66% and 34%, respectively, and generally preserved when distinguishing by age (three groups: 60–69, 70–79, and >79 years). Overall, the age ranged from 61 to 89 years, with mean±SD equal to 74±6 years. The average BMI was 25±3. Weight and height were similar among the age groups.

Radiographic results

Overall, the average TK_T1T12 and LL_L1S1 were 55±14° and 57±12°, respectively (Table 2). The average pelvic parameters were the followings: PI, 55±11°; SS, 38±10°; PT, 16±7°. The average PI-LL mismatch, SVA, and TPA was −3±11°, 25±32 mm, and 14.6±7.4°, respectively. The parameters measuring the thoracic kyphosis (TK_T1T12 and TK_T4T12) and the global balance (SVA and TPA) were found increasing with age, whereas the other parameters were generally similar (Table 3). The average SVA was larger in males compared to females (32±35 and 22±30 mm, respectively) and ranged with age

Table 1
Demographic data by gender and age (expressed as number of subjects and percentage, or mean±SD and range)

		Gender		Age		
	All	Female	Male	60–69	70–79	>79
Subjects	154	102 (66%)	52 (34%)	44 (29%) (73% Females, 27% Males)	83 (54%) (67%, 33%)	27 (18%) (52%, 48%)
Age [y]	74±6, 61–89	73±6	75±7*	66±3	74±3	83±3
Weight [kg]	68±11, 40–95	65±10	76±10*	68±11	69±12	68±9
Height [cm]	164±9, 150–188	160±6	173±7*	164±8	164±9	165±10
BMI [kg/m^2]	25±3, 17–30	25±3	25±3	25±3	26±3	25±3

* Significant difference between genders. No significant differences found in the parameters among the age groups.

Table 2
Average values and percentiles for radiographic parameters (mean values expressed as mean±SD)

				Percentiles				
	Mean	Min	Max	5	25	50	75	95
TK_T1T12 [°]	54.6±13.6	20.8	86.1	31.9	45.1	55.2	63.7	78.3
TK_T4T12 [°]	47.6±12.6	21.5	80.4	26.9	38.2	46.5	57.4	69.7
LL_L1L5 [°]	45.1±11.5	8.2	70.1	23.5	38.3	45.5	52.9	62.1
LL_L1S1 [°]	56.7±12.3	19	94.8	35.4	50.1	56.4	64.1	77.3
PI [°]	53.5±11.5	28.1	101.7	35.2	45.1	52.2	59.9	73.8
SS [°]	37.5±9.5	11.7	77.9	22.4	31.3	37.9	42.9	51.2
PT [°]	16±6.5	2.1	34.8	5.4	11.5	16.1	20.2	28
PI-LL [°]	−3.3±10.7	−26	29.9	−19.6	−10.2	−4.3	3	16.5
SVA [mm]	25.3±31.9	−59.5	134.8	−20.8	2.7	24.1	43.9	79.7
TPA [°]	14.6±7.4	0.2	38.7	2.9	10	13.7	18.5	28.4

PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; PI-LL mismatch; SVA, sagittal vertical axis; TPA, T1 pelvis angle.

Thoracic kyphosis from T1 to T12 (TK_T1T12) and from T4 to T12 (TK_T4T12). Lumbar lordosis from L1 to L5 (LL_L1L5) and from L5 to S1 (LL_L5S1).

Table 3
Differences in radiographic parameters, by gender and by age (expressed as mean±SD)

	Gender		Age			Post hoc comparisons		
	Female	Male	60–69 (A)	70–79 (B)	>79 (C)	A vs. B	A vs. C	B vs. C
TK_T1T12 [°]	53.8±13.7	56.1±13.6	49.4±13.2	54.4±13.2	63.5±11.3		*	*
TK_T4T12 [°]	47.5±12.5	47.9±12.8	40.8±10	48±12.1	57.7±10.8	*	*	*
LL_L1L5 [°]	46±11.6	43.5±11.3	44.9±13.7	44.9±11	46.4±9.1			
LL_L1S1 [°]	56.5±12.3	57.3±12.6	56.1±13.3	56.8±12.5	57.8±10.4			
PI [°]	52.8±11.5	54.8±11.5	51.6±8.9	54.1±12.8	54.8±11.2			
SS [°]	36.9±9	38.7±10.3	37.7±8.3	37.6±10.6	36.8±7.6			
PT [°]	16±6.5	16.1±6.5	13.9±6.1	16.5±6.5	17.9±6.7		*	
PI-LL [°]	−3.6±11.1	−2.5±9.9	−4.5±11.2	−2.7±10.5	−3±10.7			
SVA [mm]	21.6±29.7	32.5±34.9#	18.1±27.8	23.3±28.1	43.1±42		*	*
TPA [°]	14.3±7.4	15.4±7.4	12.5±7.2	14.6±6.7	18.3±8.4		*	*

PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; PI-LL mismatch; SVA, sagittal vertical axis; TPA, T1 pelvis angle.

Thoracic kyphosis from T1 to T12 (TK_T1T12) and from T4 to T12 (TK_T4T12). Lumbar lordosis from L1 to L5 (LL_L1L5) and from L5 to S1 (LL_L5S1).

The # and * symbols indicate significant difference between females and males, and between age-related groups in the post hoc comparisons, respectively.

from 18±28 to 43±42 mm. Age-based tables for females and males are also provided in details in Table 4. The comparison with the parameters' ranges in younger adults and the correlation between the radiographic parameters are reported in Tables 5 and 6, respectively.

As for classification of the lumbopelvic profile, 24 in 154 subjects (16%) were excluded because they were considered not classifiable, that is, not belonging to any of the five types. The remaining 130 subjects were evaluated and classified as follows: 17 (13%) type 1, 28 (21%) type 2, 17

Table 4
Normative values by age and gender (expressed as mean±SD)

	Age 60–69		Age 70–79		Age >79	
	Female	Male	Female	Male	Female	Male
TK_T1T12 [°]	48.1±14.1	52.9±10	54.8±12.4	53.6±14.8	62.7±12.1	64.3±10.8
TK_T4T12 [°]	41.3±11.5	39.5±4.6	48.6±11.8	46.7±12.7	57.3±10	58.1±12
LL_L1L5 [°]	45.5±14.9	43.3±10.3	45.1±10	44.3±13.1	50.4±8	42.1±8.3
LL_L1S1 [°]	55.8±14	57±11.8	56.3±12.2	57.7±13.4	58.8±8.4	56.6±12.5
PI [°]	51.3±9.2	52.4±8.5	53.7±12.8	54.7±13.1	52.8±11.6	57±10.8
SS [°]	37.2±8.4	38.9±8.4	36.9±10.1	39±11.8	36±6.2	37.7±9.1
PT [°]	14.1±6.2	13.5±5.9	16.8±6.6	15.7±6.2	16.8±6.4	19.2±7
PI-LL [°]	−4.5±11.8	−4.5±9.8	−2.6±10.9	−3±9.8	−6±10.5	0.3±10.3
SVA [mm]	15.5±30.7	24.9±17.3	21.8±28.7	26.5±27.1	35±28.8	51.9±52.5
TPA [°]	12.4±7.6	12.6±6.4	14.7±7	14.4±6	16.8±7.8	19.9±9.1

PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; PI-LL mismatch; SVA, sagittal vertical axis; TPA, T1 pelvis angle.

Thoracic kyphosis from T1 to T12 (TK_T1T12) and from T4 to T12 (TK_T4T12). Lumbar lordosis from L1 to L5 (LL_L1L5) and from L5 to S1 (LL_L5S1).

Table 5
Comparison between the elderly population and younger adults populations of asymptomatic volunteers from Caucasian heritage (values expressed as mean±SD)

			Younger adults			
	Elderly population (present study) N=154, age 74±6		Iyer et al. [26] N=71, age 21–60 (*)	Vialle et al. [21] N=300, age 35±12	Berthonnaud et al. [23] N=160, age 26±6	Jackson e al. [3] N=100, age 39±9 (§)
TK [°]	54.6±13.6 (T1T12)	47.6±12.6 (T4T12)	44.9±4.2 (T2T12)	40.6±10 (T4T12)	47.5±4.8 (†)	42.1±8.9 (T1T12)
LL [°]	45.1±11.5 (L1L5)	56.7±12.3 (L1S1)	59.9±2 (L1S1)	43±11.2 (L1L5)	42.7±5.4 (‡)	60.9±12 (L1S1)
PI [°]	53.5±11.5		49.3±3	54.7±10.6	51.8±5.3	-
SS [°]	37.5±9.5		38.2±1.4	41.2±8.4	39.7±4.1	-
PT [°]	16±6.5		12.6±1.1	13.2±6.1	12.7±3.2	-
PI-LL [°]	−3.3±10.7		−10.6±2.8	-	-	-
SVA [mm]	25.3±31.9		−18.1±6.1	-	-	−0.5±25
TPA [°]	14.6±7.4		6.1±1.6	-	-	-

TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; PI-LL mismatch; SVA, sagittal vertical axis; TPA, T1 pelvis angle.

-, parameter not assessed in the reference study.

* The mean±SD values reported in the corresponding column were computed as the average of the mean values presented in the age decades (from 21 to 60 years) in the original article.

† Computed between cervicothoracic and thoracolumbar inflection points.

‡ Computed between thoracolumbar inflection point and L5.

§ Values reported as mean±SE in the original article.

(13%) type 3 + AP, 56 (44%) type 3, and 12 (9%) type 4 (Table 7). Females and males were similarly distributed. The intrarater and inter-rater reliability in classifying the lumbopelvic profile revealed generally almost perfect agreement. Intrarater kappa was 0.87 and 0.83 for the two raters, respectively, and inter-rater kappa was 0.80 and 0.75 in the two classification tasks, respectively.

Overall, the presence of asymptomatic scoliosis was identified in 42 in 154 (27%) subjects, 33 (21%) females and 9 (6%) males. The Cobb angle ranged from 12° to 41°, with an average value equal to 22±7° and similar between genders (22±7° and 22±8° for females and males, respectively). Considering only the nonscoliotic subjects, the classification of the lumbopelvic profile (98 in 130) provided the following frequencies: 12 (12%) type 1, 23 (24%) type 2, 40 (41%) type 3 + AP, 15 (15%) type 3, and 8 (8%) type 4 (Table 7).

Discussion

In this study, we report a comprehensive description of the normative ranges of the spinal sagittal parameters in a Caucasian elderly population of 154 volunteers ranging in age from 61 to 89 years. The presented tables provide spine surgeons with reference parameters' ranges to support the planning of the surgical corrective strategies (Tables 2–4).

Table 6
Correlation between the radiographic parameters

	TK_ T1T12	TK_ T4T12	LL_ L1L5	LL_ L1S1	PI	SS	PT	PI-LL	SVA
TK_T4T12	0.87*								
LL_L1L5	0.35*	0.39*							
LL_L1S1	0.33*	0.37*	0.82*						
PI	0.07	0.07	0.48*	0.6*					
SS	0.02	0.03	0.58*	0.8*	0.83*				
PT	0.1	0.08	0.01	−0.1	0.57*	0.01			
PI-LL	−0.3*	−0.35*	−0.43*	−0.51*	0.38*	−0.03	0.73*		
SVA	0.1	0.19*	−0.12	−0.23*	0.22*	0.11	0.24*	0.51*	
TPA	0.08	0.13	−0.02	−0.15	0.56*	0.11	0.83*	0.78*	0.65*

PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; PI-LL mismatch; SVA, sagittal vertical axis; TPA, T1 pelvis angle.

Thoracic kyphosis from T1 to T12 (TK_T1T12) and from T4 to T12 (TK_T4T12). Lumbar lordosis from L1 to L5 (LL_L1L5) and from L5 to S1 (LL_L5S1).

* Indicates correlation value significantly different from zero.

Table 7
Frequencies (expressed as number of subjects and percentage) in the lumbopelvic types for the elderly population and for younger adult population

	Type 1	Type 2	Type 3 + AP	Type 3	Type 4
Elderly population (N=130*, age 61–89)	17 (13%)	28 (21%)	17 (13%)	56 (44%)†	12 (9%)†
Females (N=86)	12 (14%)	17 (20%)	12 (14%)	38 (44%)	7 (8%)
Males (N=44)	5 (11%)	11 (25%)	5 (11%)	18 (41%)	5 (11%)
Not-scoliotic subjects (N=98)	12 (12%)	23 (24%)	15 (15%)	40 (41%)	8 (8%)
Younger adults (from [18]) (N=296, age 18–48)	12%	22%	16%	30%	20%

* Twenty-four in 154 subjects (16%) were excluded because identified as not belonging to any of the lumbopelvic types.

† Significant difference between the frequency in elderly population and younger adults, in the considered type.

Overall, the sagittal alignment of the spine and pelvis confirmed to be highly variable among the individuals. TK_T1T12 ranged from 21° to 86°, LL_L1S1 from 19° to 95°, and the pelvic parameters PI, SS, and PT ranged from 28° to 102°, from 12° to 78°, and from 2° to 35°, respectively (Table 2). The parameters' ranges are generally in good agreement with those reported in previous studies evaluating smaller elderly cohorts [24–26]. In particular, SVA, TPA, and TK were found increasing with age (Table 3), confirming the tendency of assuming more frontward postures. In this regard, when evaluating younger asymptomatic adults (age<60 years, Caucasian heritage), other authors pointed out average SVA (−18.1±6.1 mm and −0.5±25 mm) and TPA (6.1±1.6°) that are lower than that found in the present study (25.3±31.9 mm and 14.6±7.4°, respectively; Table 5). However, the frontward postures recognized in the elderly volunteers resulted not merely determined by increased TK or loss of LL. These parameters were found indeed poorly correlated (r<0.25) to SVA and TPA, which describe the global balance (Table 6). It is worth noting that differently from SVA, TPA does not vary on the basis of the extent of pelvic retroversion and measures sagittal balance independent of postural compensatory mechanisms. Thus, the frontward posture in the elderly results as a consequence of multiple factors which characterize the global alignment at spinal, pelvic, and lower limbs level.

As for lumbopelvic harmony, PI-LL mismatch ranged from −26° to 30° (Table 2). The average value (−3.3±10.7°) was similar between genders and among age groups, and resulted less negative compared to that found in younger adults (−10.6±2.8°, Table 5). These findings deserve particular attention and should be carefully considered by spine surgeons since targeting reference values of SVA, TPA and a threshold of PI-LL<10°, has been suggested to obtain a satisfactory alignment when correcting deformity [4,9–16]. Moreover, Iyer et al. have suggested that understanding that older patients can tolerate larger frontward postures may help surgeons to avoid over-correction, which has been associated with complications such as proximal junctional kyphosis [26,39].

A limitation of our study is that the female population was double that of males (102 vs. 52 subjects). This occurred because, different from age, sex was not used as a screening criterion during the recruitment process. However, the average values of the parameters were similar between the two genders, and only SVA was found moderately larger in males (Table 3). This tendency was confirmed when distinguishing by age (Table 4). Regarding the evaluated volunteers, only Caucasian subjects were enrolled. Since

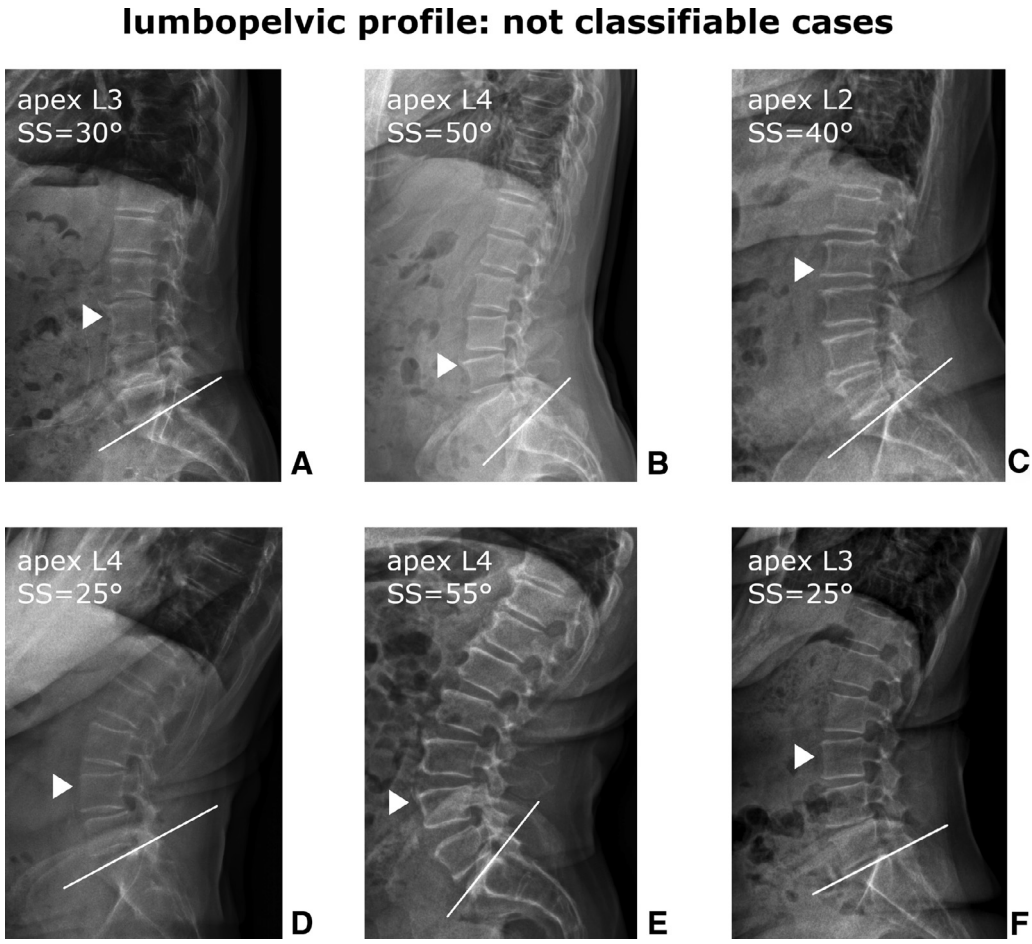

Fig. 3. From (A) to (F): examples of lumbopelvic profiles evaluated as not classifiable cases since not belonging to any of the Roussouly types illustrated in Fig. 2.

different ethnicities may have different sagittal alignment profiles [19], spine surgeons must consider this inclusion criterion as a potential limitation.

As for classification of the lumbopelvic profile, the elderly exhibited higher frequency of type 3 (44%), which is commonly perceived as the well-balanced posture (Table 7). Compared to younger adults (age ranging from 18 to 48 years) [18], the frequencies of type 3 and type 4 were moderately larger (43% vs. 30%, p=.01) and lower (9% vs. 20%, p=.01), respectively, whereas they were very similar in the other types. However, it is worth noting that 24 in 154 subjects (16%) were excluded from the classification because they were evaluated as not matching any lumbopelvic type (Fig. 2C–F). Specifically, some individuals exhibited a condition of flat spine, frontward posture, and pelvic retroversion (Fig. 3A). In other cases, the flat spine was associated with pelvic anteversion (Fig. 3B). In few subjects, the apex of the lumbar curve reached the L2 level (Fig. 3C). Other cases were the followings: apex at L4, as in type 3, but SS out of the corresponding allowed range 35° to 45° (Fig. 3D,E); apex at L3, as in type 4, but SS well below the limit of 45° (Fig. 3F). It can be concluded that, despite the frequencies in the lumbopelvic types being similar between elderly individuals and younger adults, some limitations have to be taken into account when applying the Roussouly classification. Indeed, a considerable number of elderly subjects, although asymptomatic, presented with degenerative changes that are known to be related to the aging process (loss of lumbar lordosis, imbalanced posture, pronounced pelvic anteversion/retroversion) and cannot be definitely classified according to the reference classification scheme.

Although the present study has included only asymptomatic volunteers who had no knowledge of previous diagnoses of scoliosis, the presence of such spine deformity was revealed in 42 in 154 (27%) individuals. In accordance with previous studies [32], this finding points out a definite incidence of spine deformities in the elderly population without clinical symptoms. Females had more than males (33 vs. 9 subjects) but the measures of the deformities were similar (Cobb angle equal to 22±7°, overall). However, the presence of scoliosis did not substantially affect the distribution of the lumbopelvic profile. Indeed, similar frequencies were reported in the lumbopelvic types when considering all subjects and only the nonscoliotic individuals (Table 7).

Conclusions

An overview of the normal ranges of the sagittal spine parameters in asymptomatic elderly volunteers, ranging in age from 61 to 89 years, has been presented. The normative values, gender-based and reported by age, pointed out some differences compared to younger adults and represent an important resource for spine surgeons in planning the surgical correction of spinal deformities. The characteristic changes occurring with age (such as loss of lumbar lordosis and frontward posture) as well as the observed presence of mild or moderate asymptomatic scoliosis should be carefully taken into account. The classification of the lumbopelvic profile based on the Roussouly scheme revealed some limitations when applied to the elderly, although similar frequencies were identified compared to younger adults.

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