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Clinical Study

Global tilt and lumbar lordosis index: two parameters correlating with health-related quality of life scores— but how do they truly impact disability?

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Abstract

BACKGROUND CONTEXT:: Many radiological parameters have been reported to correlate with patient's disability including sagittal vertical axis (SVA), pelvic tilt (PT), and pelvic incidence minus lumbar lordosis (PI–LL). European literature reports other parameters such as lumbar lordosis index (LLI) and the global tilt (GT). If most parameters correlate with health-related quality of life scores (HRQLs), their impact on disability remains unclear.

PURPOSE: This study aimed to validate these parameters by investigating their correlation with HRQLs. It also aimed to evaluate the relationship between each of these sagittal parameters and HRQLs to fully understand the impact in adult spinal deformity management.

STUDY DESIGN: A retrospective review of a multicenter, prospective database was carried out.

PATIENT SAMPLE: The database inclusion criteria were adults ($>$18 years old) presenting any of the following radiographic parameters: scoliosis (Cobb $\geq$20°), SVA $\geq$5 cm, thoracic kyphosis $\geq$60° or PT $\geq$25°. All patients with complete data at baseline were included.

OUTCOME MEASURES: Health-related quality of life scores, demographic variables (DVs), and radiographic parameters were collected at baseline.

FDA device/drug status: Not applicable.

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METHODS: Differences in HRQLs among groups of each DV were assessed with analyses of variance. Correlations between radiographic variables and HRQLs were assessed using the Spearman rank correlation. Multivariate linear regression models were fitted for each of the HRQLs (Oswestry Disability Index [ODI], Scoliosis Research Society-22 subtotal score, or physical component summaries) with sagittal parameters and covariants as independent variables. A $p<.05$ value was considered statistically significant.

RESULTS: Among a total of 755 included patients (mean age, 52.1 years), 431 were non-surgical candidates and 324 were surgical candidates. Global tilt and LLI significantly correlated with HRQLs ($r=0.4$ and -0.3, respectively) for univariate analysis. Demographic variables such as age, gender, body mass index, past surgery, and surgical or non-surgical candidate were significant predictors of ODI score. The likelihood ratio tests for the addition of the sagittal parameters showed that SVA, GT, T1 sagittal tilt, PI–LL, and LLI were statistically significant predictors for ODI score even adjusted for covariates. The differences of R^2 values from Model 1 were 1.5% at maximum, indicating that the addition of sagittal parameters to the reference model increased only 1.5% of the variance of ODI explained by the models.

CONCLUSION: GT and LLI appear to be independent radiographic parameters impacting ODI variance. If most of the parameters described in the literature are correlated with ODI, the impact of these radiographic parameters is less than 2% of ODI variance, whereas 40% are explained by DVs. The importance of radiographic parameters lies more on their purpose to describe and understand the malalignment mechanisms than their univariate correlation with HRQLs.

Keywords: Adult spinal deformity; Disability; Global tilt; Health-related quality of life scores; Lumbar lordosis index; Oswestry Disability Index

Introduction

Disability and pain are the most important considerations for adequate surgical adult spinal deformity (ASD) management [1]. Glassman et al. revealed the impact of sagittal vertical axis (SVA) on symptoms severity, with progressive balance and symptoms increasing in a linear fashion [2]. Many radiographic parameters were then described to assess spinal malalignment. Some parameters were correlated to Health-Related Quality of Life Scores (HRQLs) and led to the Scoliosis Research Society (SRS)-Schwab classification description [3] (which includes SVA, pelvic tilt [PT], and pelvic incidence minus lumbar lordosis [PI–LL] parameters). In parallel, the European literature described other parameters such as the lumbar lordosis index (LLI) and the global tilt (GT). The LLI (ratio between lumbar lordosis and pelvic incidence) demonstrated a therapeutic impact in ASD management and is highly correlated with sagittal malalignment [4]. The GT combines the C7 vertical tilt and the PT and is less affected by patient positioning than SVA or PT [5]. LLI and GT are two parameters that have demonstrated importance but have not been validated clinically.

In recent literature, finding parameters that correlated most with disability has appeared as an attempt to justify significance in spinal malalignment evaluation. A question we raise is about the utility to describe such parameters for ASD management. Is the parameter most correlated with HRQLs the most useful to understand and treat malalignment?

The purpose of this study was to validate the relationship between LLI, GT, and HRQLs. We also wanted to evaluate the relationship between each of these sagittal parameters and HRQLs to fully understand the impact in ASD management.

Materials and methods

Study design

This study is a multicenter, prospective analysis of patients with ASD included from six spine centers. Institutional review board approval was obtained at each site for the patient enrollment and data collection protocols. Inclusion criteria were: age ≥18 years old, and a radiographic diagnosis of ASD. Adult spinal deformity was defined by a preoperative full-spine radiography presenting at least one of the following criteria: coronal Cobb angle ≥20°; sagittal vertical axis ≥5 cm; PT ≥25°; or thoracic kyphosis ≥60°. The HRQLS were collected at baseline and 1 year after surgery for the surgical patients. All the patients had full-length standing coronal and sagittal spinal radiographs obtained in free-standing position with fists overlying ipsilateral clavicles [6].

Patient cohort and analyzed variables

Preoperative data from the surgical candidates and baseline data from the non-surgical candidates were analyzed. At the beginning of this study (July 2015), the database contained a total of 1,349 patients (544 surgical candidates and 805 non-surgical candidates). There were 594 cases excluded due to incomplete data: demographic variables (DVs) (100 cases), radiographic variables (399 cases), and HRQLs (95 cases). As a result, 755 patients with complete data for all analyzed variables were included in this study. The differences between analyzed populations and excluded populations were assessed in terms of demographic and radiographic characteristics, and HRQLs.

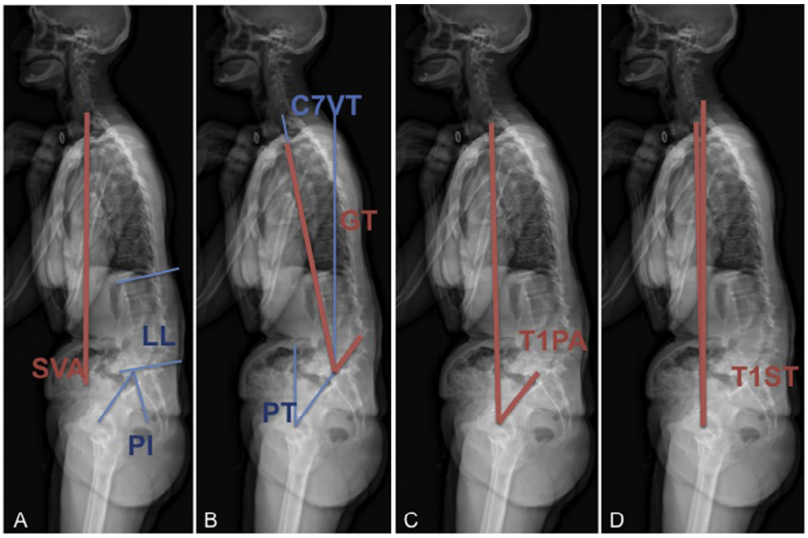

Fig. 1. Radiographic measured parameters (mean normal values in asymptomatic population): (A) sagittal vertical axis (–6.9 mm±34.8), lumbar lordosis (57.2°±13), pelvic incidence (49.6±12.1), lumbar lordosis index (ratio between lumbar lordosis and pelvic incidence [LL/PI]) (57.2/49.6=1.2); (B) global tilt (23.2° after 50 years old); (C) T1 pelvic angle (8.6°±8.5; 17.9 after 50 years old); (D) T1 sagittal angle (–1.35°±2.7).

Analyzed dependent variables were HRQLs including Oswestry Disability Index (ODI), Scoliosis Research Society (SRS)-22 subtotal score (SRS-22), and SF-36 questionnaires physical component summaries (PCS).

Analyzed demographic covariates were age (three groups: ≤40, >40 but ≤60, and >60), gender (male/female), body mass index (BMI) (three groups: <25, ≥25 but <30, and ≥30), diagnosis (six groups: idiopathic, degenerative, failed-back, posttraumatic, postinfection, and others), past spinal surgery (yes or no), and surgical or non-surgical candidates. Coronal curve types were classified into four groups based on the SRS-Schwab ASD classification [7] (N: no major coronal deformity, T: thoracic major curve, L: lumbar or thoracolumbar major curve, and D: double major curve) and were also treated as one of the demographic covariates.

Analyzed spinal sagittal radiographic parameters were SVA, GT (the sum of PT and C7 vertical tilt) [5,8], T1 pelvic angle (T1PA: the angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 superior end plate) [9], T1 sagittal tilt (T1ST: the angle between a line drawn from the center of the femoral head axis to the midpoint of the T1 vertebral body and the vertical) [10,11], PT, PI–LL, and LLI (ratio between lumbar lordosis and pelvic incidence=LL/PI) [4]. Radiographic parameters are reported in Fig. 1, with their mean values reported from the literature [11,12]. Radiographic sagittal parameters were treated as continuous variables.

Statistical analysis

Statistical analyses were performed using JMP11 software (SAS Institute, Cary, NC, USA), and STATA 14 (StataCorp, College Station, TX, USA). Characteristics of DVs and radiographic sagittal parameters were analyzed using JMP, and all regression models were implemented in STATA. Statistical significance was set at p-value<.05 (2-tailed). Overall means and frequencies of patient demographic and radiographic characteristics were computed and summarized. Differences in HRQLs among groups of each DV were assessed with analyses of variance. Correlations between radiographic variables and HRQLs were assessed using the Spearman rank correlation (rho).

Fourteen separate multivariate linear regression models were fitted for each of the HRQLs (ODI, SRS-22, or PCS) with sagittal parameters and covariants as independent variables (Table 1). To compare the goodness-of-fit between nested

Table 1
Summary of 14 regression models testing association between sagittal parameters and HRQLs. For example, if LRT between Model 1 and Model 2a is significant (p<.05), SVA would be a significant independent predictor for the HRQLs

Model 1	A reference model with only DVs as independent variables.
Model 2a	A model with DVs and SVA as independent variables.
Model 2b	A model with DVs, SVA, and PT as independent variables.
Model 3a	A model with DVs and GT as independent variables.
Model 3b	A model with DVs, GT, and PT as independent variables.
Model 4a	A model with DVs and T1PA as independent variables.
Model 4b	A model with DVs, T1PA, and PT as independent variables.
Model 5a	A model with DVs and T1ST as independent variables.
Model 5b	A model with DVs, T1ST, and PT as independent variables.
Model 6	A model with DVs and PT as independent variables.
Model 7a	A model with DVs and PI–LL as independent variables.
Model 7b	A model with DVs, PI–LL, and PT as independent variables.
Model 8a	A model with DVs and LLI as independent variables.
Model 8b	A model with DVs, LLI, and PT as independent variables.

DVs, demographic variables; HRQLs, health-related quality of life scores; SVA, sagittal vertical axis; PT, pelvic tilt; GT, global tilt; T1PA, T1 pelvic angle; T1ST, T1 sagittal tilt; PI–LL, pelvic incidence minus lumbar lordosis; LLI, lumbar lordosis index.

Table 2
Characteristics of demographic variables (number of patients and HRQLs)

		ODI		PCS		MCS		SRS-22	
Demographic variables	N (%)	Mean (SD)	p	Mean (SD)	p	Mean (SD)	p	Mean (SD)	p
Age (years)									
Age<40 (young)	231 (31)	19 (17)	<.001	46 (9)	<.001	46 (11)	.009	3.6 (0.7)	<.001
40≤Age<60 (middle aged)	222 (29)	35 (19)		38 (9)		43 (12)		3.0 (0.7)	
Age≥60 (old)	302 (40)	43 (19)		35 (9)		44 (13)		2.9 (0.7)	
Gender									
Female	613 (81)	34 (21)	.009	39 (10)	.153	44 (12)	<.001	3.1 (0.8)	.011
Male	142 (19)	29 (19)		40 (10)		48 (11)		3.3 (0.7)	
BMI (kg/m^2)									
BMI<25	444 (59)	27 (19)	<.001	41 (10)	<.001	46 (11)	.006	3.3 (0.7)	<.001
25≤BMI<30	214 (28)	38 (20)		37 (10)		43 (13)		3.0 (0.7)	
BMI≥30	97 (13)	49 (20)		33 (9)		42 (14)		2.7 (0.7)	
Past spine surgery									
No	495 (66)	32 (20)	.045	40 (10)	.016	45 (12)	.800	3.2 (0.7)	.135
Yes	260 (34)	35 (22)		38 (10)		44 (12)		3.1 (0.8)	
Diagnosis									
Idiopathic	400 (54)	26 (18)	<.001	42 (10)	<.001	46 (11)	.020	3.3 (0.8)	<.001
Degenerative	237 (31)	43 (18)		35 (9)		42 (12)		2.9 (0.7)	
Others	118 (15)	35 (22)		38 (10)		44 (13)		3.0 (0.7)	
Coronal curve type (SRS-Schwab classification)									
Type N	244 (32)	39 (21)	<.001	37 (9)	<.001	42 (12)	.008	3.0 (0.7)	<.001
Type T	75 (10)	25 (17)		44 (10)		44 (11)		3.4 (0.8)	
Type L	171 (23)	37 (20)		37 (9)		44 (13)		3.0 (0.8)	
Type D	265 (35)	27 (19)		41 (11)		46 (11)		3.3 (0.8)	
Surgical or non-surgical candidate									
Non-surgical candidate	431 (57)	27 (19)	<.001	41 (10)	<.001	46 (11)	<.001	3.4 (0.7)	<.001
Surgical candidate	324 (43)	41 (20)		36 (9)		42 (12)		2.8 (0.7)	

BMI, body mass index; N, number; ODI, Oswestry Disability Index; PCS, physical component summaries; MCS, mental component summaries; SRS-22, Scoliosis Research Society-22 subtotal score; Type N, no major coronal deformity; Type T, thoracic only; type L, lumbar only; type D, double curve; SD, standard deviation; HRQLs, health-related quality of life scores.

Note: p Values are calculated using analyses of variance.

models, the likelihood ratio test (LRT) was used [13]. The LRT is the difference in chi-square values and degrees of freedom between two models, and evaluates whether the additional variables provide a statistically significant contribution above and beyond the covariates that already exist in the model. The Akaike information criterion (AIC) was also used to compare the goodness-of-fit of non-nested models. Everything else being equal, the model with the smaller AIC is considered the better fitting model [14]. These analyses were performed as follows using STATA: First, a reference model (Model 1) was fitted for ODI with only DVs (age, gender, BMI, past surgery, diagnosis, coronal curve type, and surgical or non-surgical candidate) as independent variables. Then each of the sagittal parameters (SVA, GT, T1PA, T1ST, PT, PI–LL, and LLI) was added to Model 1 as an additional independent variable (Model 2a, 3a, 4a, 5a, 6, 7a, and 8a). The LRTs between each model and Model 1 were used to evaluate whether each of the sagittal parameters provided a statistically significant contribution to the model. Next, PT was added to Models 2a, 3a, 4a, 5a, 7a, and 8a as an additional independent variable (Model 2b, 3b, 4b, 5b, 7b, and 8b), and LRTs were also used to evaluate the statistical significance of PT's contribution to the model. In addition, R^2 value, adjusted R^2, and AIC were calculated and used to analyze the goodness-of-fit of all models. Variance inflation factor was calculated for each independent variable and used to check that no multicollinearity exists. We also checked the assumptions of normality, linearity, homoscedasticity, and independence of the residuals for each of the models. Possible interactions such as radiographic sagittal parameters and age groups were tested; however, no significant interaction was detected, and it will not be discussed in this paper.

Results

Analyzed and excluded populations (Supplementary Table)

We have compared analyzed populations with complete data (755 cases) and excluded populations with incomplete data (594 cases). The patient distributions in terms of age, BMI, diagnosis, coronal curve types, and surgical or non-surgical candidates, and mean values of GT, T1PA, PT, PI–LL, LLI, and HRQLs were statistically different between the two populations ($p<.05$). On the other hand, if adjusted by the DVs, least squared means of sagittal parameters and HRQLs were almost identical between them.

Table 3
Characteristics of radiographic sagittal parameter (means and correlations with HRQLs)

		ODI		PCS		MCS		SRS-22	
Sagittal parameters	Mean (SD)	Rho	p	Rho	p	Rho	p	Rho	p
SVA (mm)	32 (59)	0.410	<.001	−0.390	<.001	−0.102	.005	−0.346	<.001
GT (degree)	23 (17)	0.393	<.001	−0.370	<.001	−0.080	.028	−0.322	<.001
T1PA (degree)	18 (13)	0.384	<.001	−0.360	<.001	−0.073	.045	−0.310	<.001
T1ST (degree)	−3 (5)	0.324	<.001	−0.313	<.001	−0.082	.024	−0.282	<.001
PT (degree)	21 (11)	0.313	<.001	−0.284	<.001	−0.058	.110	−0.241	<.001
PI–LL (degree)	8 (21)	0.323	<.001	−0.313	<.001	−0.063	.084	−0.265	<.001
LLI (ratio)	0.88 (0.42)	−0.329	<.001	0.315	<.001	0.070	.053	0.276	<.001

SVA, sagittal vertical axis; GT, global tilt; T1PA, T1 pelvic angle; T1ST, T1 sagittal tilt; PT, pelvic tilt; PI–LL, pelvic incidence minus LL; LLI, lumbar lordosis index; Rho, Spearman rank correlation; SD, standard deviation; ODI, Oswestry Disability Index, PCS, physical component summaries; MCS, mental component summaries; SRS-22, Scoliosis Research Society-22 score; HRQLs, health-related quality of life scores.

Demographics variables (Table 2)

Among a total of 755 patients (613 women and 142 men), 431 non-surgical candidates and 324 surgical candidates were included. The mean and standard deviation (SD) of age and BMI were 52.1 (SD=18.8, range 18–87) years and 24.5 (4.7) kg/m^2, respectively. All the DVs were significantly associated with HRQLs. For example, mean ODI scores were 19, 35, and 43 for young, middle-aged, and old patients, respectively (p<.001).

Radiographic sagittal parameters (Table 3)

All sagittal parameters (SVA, GT, T1PA, T1ST, PT, PI–LL, and LLI) were significantly associated with ODI, PCS, and SRS-22. However, with mental component summaries (MCS), only SVA, GT, T1PA, and T1ST were significantly associated.

Multivariate linear regression models for ODI score

Fourteen separate multivariate linear regression models for ODI score were evaluated. In model 1, which is a reference model that consisted of only DVs, age, gender, BMI, past surgery, and surgical or non-surgical candidates were significant predictors of ODI score (Table 4). The LRTs for the addition of the sagittal parameters to Model 1 showed that SVA, GT, T1ST, PI–LL, and LLI were statistically significant predictors for ODI score even adjusted for the covariates (Table 5). The LRT for the addition of PT to Model 1 was not statistically significant; however, the LRT for the addition of PT to Models 2a, 3a, 4a, and 7a indicated that PT was significantly associated with ODI in combination with SVA, GT, T1PA, and PI–LL. Model 5a (DVs+T1ST) was the best-fit model in terms of the highest adjusted R^2 and lowest AIC. Even in the better-fit models (2a, 3b, 4b, and 5a), the differences of adjusted R^2 values from Model 1 were 1.5% at maximum, indicating that the addition of sagittal parameters to the reference model increased only 1.5% of the variance of ODI explained by the models.

Detailed analyses of the models including PT (Models 2b, 3b, 4b, and 7b) showed that regression coefficients for PT were negative, whereas those for the other sagittal parameters were positive. In Model 3b, for example, patients with 10 degrees higher GT have 3.9 points higher ODI score (worse QOL); however, patients with 10 degrees higher PT have 5.0 points lower ODI score (better QOL).

Multivariate linear regression models for other HRQLs

For PCS and SRS-22, the results of multivariate linear regression analyses were almost identical for ODI. In summary, SVA, GT, T1PA, T1ST, and PI–LL, GT+PT, and T1PA+PT were significantly associated with PCS, and SVA, GT, T1ST, GT+PT, and T1PA+PT were significantly associated with SRS-22. In the best-fit model (Model 5a), the adjusted R^2 value for PCS and SRS-22 were 0.288 and 0.316, respectively. For both PCS and SRS-22, the differences of R^2 values from the reference models were 1.1% at maximum. For MCS, only SVA+PT, GT+PT, and T1PA+PT were significantly associated with MCS. In addition, these associations were weak, and even in the best-fit model (Model 2b, SVA+PT), adjusted R^2 value was only 0.109.

Discussion

Sagittal analysis appeared in the last decade as a benchmark when considering ASD. Preoperative decision making and postoperative result analysis became closely linked to sagittal balance. The SRS-Schwab classification includes three sagittal spinopelvic modifiers (SVA, PT, and PI–LL) correlating with HRQLs [7] and with thresholds values that must be achieved postoperatively to obtain satisfactory outcomes [15]. Radiological parameter descriptions correlating with clinical scores appear to be mandatory in the recent literature to consider a radiographic parameter, and the first aim of this study was to validate GT and LLI in a single study. In this series, GT and LLI appear to be significantly correlated to HRQLs for univariate analysis.

Univariate correlation between radiographic parameters and clinical scores helped us to better understand sagittal balance and its importance. When sagittal malalignment occurs, SVA tends to be anterior to gravity line, despite the paraspinal muscles' tendency to shift the trunk backward. Different compensatory mechanisms can be involved to maintain

Table 4
Multivariate linear regression models examples for ODI

	Model 1 Adjusted R^2=0.387				Model 3a Adjusted R^2=0.389				Model 3b Adjusted R^2=0.400			
Covariates	Coef.	95% CI		p	Coef.	95% CI		p	Coef.	95% CI		p
Age				**<.001**				**<.001**				**<.001**
Age<40 (base)	0.0				0.0				0.0			
40≤Age<60	12.7	9.4	15.9	<.001	11.8	8.5	15.2	<.001	12.0	8.7	15.3	<.001
Age≥60	15.2	11.5	18.8	<.001	13.4	9.4	17.5	<.001	13.7	9.7	17.7	<.001
Gender				**<.001**				**<.001**				**<.001**
Female (base)	0.0				0.0				0.0			
Male	−6.0	−9.0	−2.9	<.001	−5.9	−9.0	−2.9	<.001	−6.7	−9.8	−3.6	<.001
BMI				**<.001**				**<.001**				**.054**
BMI<25 (base)	0.0				0.0				0.0			
25≤BMI<30	4.1	1.3	6.9	.004	4.0	1.2	6.8	.005	4.1	1.3	6.8	.004
BMI≥30	9.3	5.4	13.2	<.001	9.3	5.4	13.2	<.001	8.6	4.7	12.5	<.001
Past surgery				**.018**				**.050**				**.090**
No (base)	0.0				0.0				0.0			
Yes	3.1	0.5	5.6	.018	2.6	0.0	5.2	.050	2.2	−0.3	4.8	.090
Diagnosis				**.064**				**.123**				**.204**
Idiopathic	0.0				0.0				0.0			
Degenerative	4.2	0.6	7.7	.022	3.7	0.1	7.2	.045	3.2	−0.3	6.8	.075
Others	2.4	−1.4	6.1	.213	2.0	−1.7	5.7	.295	1.1	−2.6	4.9	.556
Coronal Schwab				**.744**				**.753**				**.767**
N (base)	0.0				0.0				0.0			
T	−2.5	−7.1	2.1	.295	−2.4	−7	2.2	.314	−2.3	−6.8	2.3	.325
L	−0.0	−3.4	3.3	.983	−0.1	−3.4	3.2	.960	−0.4	−3.7	2.9	.809
D	−0.9	−4.3	2.5	.610	−1.1	−4.5	2.3	.536	−1.3	−4.7	2.1	.451
Surgical or non-surgical candidate				**<.001**				**<.001**				**<.001**
Non-surgical candidate	0.0				0.0				0.0			
Surgical candidate	9.1	6.3	11.8	<.001	9.0	6.2	11.7	<.001	8.8	6.1	11.5	<.001
(Constant)	27.5	22.0	33.0	<.001	26.6	21.1	32.2	<.001	31.4	25.4	37.5	<.001
Radiographic variables												
GT	Not included							**.041**				**<.001**
Per 10 degree					0.9	0.0	1.8	.041	3.9	2.1	5.7	<.001
PT	Not included				Not included							**<.001**
Per 10 degree									−5.0	−7.6	−2.4	<.001

Coef., regression coefficient; CI, confidence interval; BMI, body mass index; N, no major coronal deformity; type T, thoracic only; type L, lumbar only; type D, double curve; GT, global tilt; PT, pelvic tilt; ODI, Oswestry Disability Index; Adjusted R^2, rate of variance of ODI score explained by the model.

Notes: The regression Model 3b, for example, can be interpreted as follows. Patients with age ≥60 have 13.7 points higher ODI score than those with age <40, patients with 10 degrees higher GT have 3.9 points higher ODI score, and patients with 10 degrees higher PT have 5.0 points lower ODI score. Bold values correspond to the p value determined by the *F* test for each variable.

horizontal gaze at the spinal, pelvic, or lower extremities [16,17]. Sagittal vertical axis rises when these compensatory mechanisms are overpassed, leading to severe spinal malalignment; it explains the important correlation between SVA and HRQLs because SVA describes severe malalignment [2]. Parameters describing early malalignment (eg, PT) will be less correlated with HRQLs than parameters describing severe malalignment (eg, SVA). Moreover, can the parameter most correlated with HRQLs be considered as the best parameter to understand and treat ASD?

If some radiological parameters correlate with HRQLs, other factors appear in this series to impact HRQLs such as age, gender, BMI, past surgery history, and surgical versus non-surgical candidates. These findings are inadequate in the recent literature. Indeed, age [1], gender [18], BMI [19], coronal curve [20], and past history surgery [8] have already been associated with HRQLs variability. On the other hand, it has also been described that these parameters correlate with radiological parameters. For example, there is a significant correlation between SVA and age [21]. If this information does not contradict each other, a potential confusion bias appears between HRQLs, radiological parameters, and demographic parameters. In the multivariate analysis we proposed, demographic parameters appear to explain 40.1% of ODI variance (R^2 for Model 1). If all radiological parameters independently impact ODI, the R^2 increases less than 2% for the best model, meaning unique independent impact of sagittal parameters is less than 2%. In this series, the best model explaining HRQLs variance was Model 5a (demographic variables+T1ST) and associating other radiological parameters impoverished ODI variance.

This analysis discusses three major points of information: 60% of ODI variance remains unexplained in this series; demographic variables impact ODI variance the most; and all sagittal parameters impact ODI variance in the same way (around 2%).

Table 5
Comparison of the goodness-of-fit of multivariate linear regression models for ODI score

						Likelihood ratio test			
Model	Predictors	N	R^2	Adjusted R^2	AIC	Comparison	$\Delta\chi^2$	Δdf	p-Value
1	DVs	755	0.401	0.387	6358.4	—	—	—	—
2a	DVs+SVA	755	0.413	0.398	6344.9	Model 1	15.49	1	<.001
2b	DVs+SVA+PT	755	0.416	0.400	6343.3	Model 1	19.01	2	<.001
						Model 2a	3.52	1	.061
3a	DVs+GT	755	0.405	0.389	6356.1	Model 1	4.28	1	.039
3b	DVs+GT+PT	755	0.416	0.400	6343.7	Model 1	18.63	2	<.001
						Model 3a	14.36	1	<.001
4a	DVs+T1PA	755	0.404	0.389	6356.7	Model 1	3.65	1	.056
4b	DVs+T1PA+PT	755	0.416	0.400	6343.4	Model 1	18.97	2	<.001
		755				Model 4a	15.32	1	<.001
5a	DVs+T1ST	755	0.416	0.401	6341.6	Model 1	18.77	1	<.001
5b	DVs+T1ST+PT	755	0.416	0.400	6343.4	Model 1	18.97	2	<.001
						Model 5a	0.20	1	.655
6	DVs+PT	755	0.401	0.386	6360.3	Model 1	0.00	1	.952
7a	DVs+PI–LL	755	0.406	0.390	6354.7	Model 1	5.67	1	.017
7b	DVs+PI–LL+PT	755	0.410	0.394	6351.6	Model 1	10.77	2	.005
						Model 7a	5.10	1	.024
8a	DVs+LLI	755	0.404	0.389	6356.5	Model 1	3.86	1	.049
8b	DVs+LLI+PT	755	0.406	0.390	6355.9	Model 1	6.41	2	.041
						Model 8a	2.54	1	.111

DVs, demographic variables including age, gender, BMI, past surgical history, coronal curve type, diagnosis, and surgical or non-surgical candidate; $\Delta\chi^2$, difference of chi-square values; Δdf, difference of degrees of freedom; SVA, sagittal vertical axis; PT, pelvic tilt; GT, global tilt; T1PA, T1 pelvic angle; T1ST, T1 sagittal tilt; LLI, lumbar lordosis index; PI, pelvic incidence; LL, lumbar lordosis.

Notes: Each R^2 value and adjusted R^2 indicates the rate of variance of ODI score explained by the model. AIC value represents relative goodness-of-fit of each model and lower value indicates better fit. If likelihood ratio test is significant, the additional variable has a significant association with ODI score above and beyond the covariates already existing in the compared model. Among the models, Model 5a is the best model. SVA, GT, T1ST, PI–LL, and LLI are significantly associated with ODI score even if DVs are taken into account. PT had significant impacts on ODI in models including SVA (2a), GT (3a), T1PA (4a), and PI–LL (7a).

If all sagittal parameters impact ODI variance in the same way, describing more than one radiographic parameter remains useful. For univariate analysis, a parameter will be better correlated with HRQLs if it takes into account greater compensatory mechanisms or malalignment phenomena. For example, GT will be more correlated with HRQLs than LLI because it includes spinal and pelvic malalignment as LLI represents LL. These correlations do not make LLI a less valuable tool than GT because their uses will be different. For multivariate analysis, GT and LLI impact less than 1% of ODI variance as independent factors. If the radiographic parameters appear to be moderate, it is also important to remind the cohort. Indeed, all patients included present a spinal deformity; the radiographic parameters' impact will inevitably be affected by this patient selection. This study's aim is not to reverse the importance of radiographic parameters that have widely been described, but to instead question the importance of the univariate correlation with HRQLs. Indeed, radiographic parameters' importance lies more on providing an understanding of spinal deformity than a correlation with HRQLs (as they correlate with HRQLs in the same way). For example LLI is the best parameter to manage LL variability in ASD and GT is helpful in understanding malalignment when PT and SVA seem opposite [22]. Adding compensatory mechanism to each other, in order to obtain the best univariate correlation with HRQLs, appears to us to be useless because the independent ODI variance will be practically the same, and the practical and clinical information to describe ASD will be without interest. Indeed, for surgical ASD management, restoring the local balance causing the malalignment will allow a correction of the patient's balance and the compensatory mechanism will normalize (Fig. 2). Specific parameters used for specific causes of malalignment, like GT and LLI, appear to us to be more important than general parameters highly correlated with HRQLs.

It is reported that the elderly patients might have a different clinical tolerance to sagittal imbalance and loss of lumbar lordosis [23]. In this study, interactions between radiographic sagittal parameters and age groups were tested; however, no significant interaction was detected. In addition, we performed a separate statistical analysis in the patient population aged more than 70 years (133 patients; Supplementary Table). However, this separate analysis did not provide any specific findings as compared with the original patient population. The results of this separate analysis might be attributed to insufficient sample size of the elderly patients, especially those aged more than 80 years (13 patients). As we can expect continuous progress of sample size in our database, this topic might be clarified in future studies.

In this study, 60% of ODI variance remains unexplained. If the literature widely reports sagittal malalignment and the demographic variables impact, other parameters are obvi-

Fig. 2. A 60-year-old man presenting a major malalignment induced by lack of lumbar lordosis. If many radiographic parameters can describe this malalignment (increased sagittal vertical axis (SVA), pelvic tilt (PT), or knee flexion), the lumbar lordosis index (LLI) appears to be the most helpful parameter to treat this spinal deformity. Its value was 0.12 in preoperative setting; a proper postoperative LLI (1.2 in postoperative) allowed a satisfying postoperative balance. SVA, PT, or knee flexion did not impact the surgical planning and appear to be properly normalized postoperatively.

ously involved in ODI variance. Indeed, radicular pain [24] and comorbidities [25] can negatively impact surgical outcome. Another possibility could be the stiffness negative impact due to spinal fusion [26]. Understanding this remaining 60% seems to be a challenge for future studies.

This study has several limitations. First, there is potential selection bias due to missing data. Heterogeneous patient characteristics between the analyzed and excluded patient population could result in poor external validity of the analyzed population. However, as the least squared means of sagittal parameters and HRQLs adjusted by the demographic variables were almost identical between the two populations, the bias due to missing data in the multivariate analyses would be minimal. Besides, the large-sized prospective multinational and multicenter nature of this study is an advantage for higher external validity. Second, although our overall database is established as an observational cohort study, the data used in this study are cross-sectional only. Therefore, additional studies with cohort data should be undertaken to determine cause and effect of sagittal parameters on HRQLs. Third, due to the nature of observational design, some hidden confounding factors, such as socioeconomic status or racial groups, could not be adjusted at the risk of losing internal validity.

Conclusion

Global tilt and LLI appear to be independent radiographic parameters impacting ODI variance. If most parameters described in the literature are correlated with ODI, the impact of these radiographic parameters is less than 2% of ODI variance, whereas 40% is due to demographic variables. All radiological parameters described appear to describe the same HRQL variability and to have the same impact on HRQL. The importance of radiographic parameters lies more on their purpose to solve an issue by describing the malalignment mechanisms, rather than their univariate correlation with HRQLs.

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Supplementary material

Supplementary material related to this article can be found at http://dx.doi.org/10.1016/j.spinee.2016.10.013.

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