



# Adult spinal deformity surgical decision-making score

## Part 1: development and validation of a scoring system to guide the selection of treatment modalities for patients below 40 years with adult spinal deformity

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Received: 24 September 2018 / Revised: 4 January 2019 / Accepted: 26 February 2019 / Published online: 7 March 2019  
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### Abstract

**Purpose** We aimed to develop and internally validate a simple scoring system: the adult spinal deformity (ASD) surgical decision-making (ASD-SDM) score, which is specific to the decision-making process for ASD patients aged below 40 years. **Methods** A multicentre prospective ASD database was retrospectively reviewed. The scoring system was developed using data from a derivation cohort and was internally validated in a validation cohort. The accuracy of the ASD-SDM score was assessed using the area under the receiver operating characteristic curve (AUC).

**Results** A total of 316 patients were randomly divided into derivation (253 patients, 80%) and validation (63 patients, 20%) cohorts. A 10-point scoring system was created from four variables: self-image score in the Scoliosis Research Society-22 score, coronal Cobb angle, pelvic incidence minus lumbar lordosis mismatch, and relative spinopelvic alignment, and the surgical indication was graded into low (score 0–4), moderate (score 5–7), and high (score 8–10) surgical indication groups. In the validation cohort, the AUC for selecting surgical management according to the ASD-SDM score was 0.789 (SE 0.057,  $P < 0.001$ , 95% CI 0.655–0.880). The percentage of patients treated surgically were 21.1%, 55.0%, and 80.0% in the low, moderate, and high surgical indication groups, respectively.

**Conclusions** The ASD-SDM score, to the best of our knowledge, is the first algorithm to guide the decision-making process for the ASD population and could be one of the indices for aiding the selection of treatment for ASD.

### Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.

**Key points**

- A total of 316 patients with adult spinal deformity (ASD) were analysed to develop and internally validate a scoring system: the ASD surgical decision-making score (ASD-SDM score), specific to the decision-making process for ASD patients younger than 40 years.
- The ASD-SDM score is the first algorithm to guide the decision-making process for the ASD population, and could aid the selection of the treatment modalities for ASD.

**Surgical rate according to the three surgical indication groups of the validation and derivation sets**

Group	Validation set (%)	Derivation set (%)
Low (Point score 0 to 4)	21.1	18.5
Moderate (Point score 5 to 7)	55.0	57.1
High (Point score 8 to 10)	80.0	70.6

**Take Home Messages**

- The ASD-SDM score, calculated based on four parameters, can range from 0 to 10.
- Higher scores indicate the need for surgery and were related to a worse self-image score in the Scoliosis Research Society-22 score and greater coronal Cobb angle.
- Sagittal malalignment based on a pelvic incidence minus lumbar lordosis mismatch and relative spinopelvic alignment were additional parameters influencing the selection of management and were incorporated into the ASD-SDM score.

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s00586-019-05932-3>) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

**Keywords** Adult spinal deformity · Surgical indication · Decision-making process · Scoliosis · Scoring system

## Introduction

Adult spinal deformity (ASD) is a complex clinical entity, including various aetiologies, such as de novo deformity, idiopathic deformity, and failed back surgery syndrome. To systematically clarify this entity, several classification systems have been proposed, based on spinal deformity, aetiology, and severity of disease state [1–3].

A major topic in ASD management is the decision-making process. Patients with scoliosis in adolescence usually do not present with pain and disability. Their primary concerns are the perception of one's appearance. Therefore, the curve magnitude and location in the coronal plane are essential factors determining whether or not to pursue surgical treatment. However, ASD covers a wide spectrum of spinal and spinopelvic deformities in both the coronal and sagittal planes, with various clinical presentations. Thus, the indicators for surgical treatment are diverse, complicating the decision-making process in clinical practice.

Several studies have investigated factors influencing decision-making in ASD by examining the discriminating factors between surgical and nonsurgical patients. These studies indicate that the health-related quality of life (HRQoL) score, severity of symptoms, coronal deformity, and sagittal malalignment are important for selecting surgical management and provide information on the decision-making process for the ASD population [4–10]. However, the relative influence of these factors on the decision-making process has not been reported. Moreover, decision-making algorithms for ASD are non-existent. Previous reports have shown that surgical treatment provides better improvement of HRQoL for ASD compared to nonsurgical treatment [11, 12]. However, nonsurgical treatment is also effective, with a minimal complication rate [13–15]. The decision-making process for the ASD population still remains under debate, and the establishment of surgical indications for the ASD population is necessary.

Previous studies have shown that the ASD population can be dichotomised into younger and older patients [16, 17]. A majority of younger ASD patients have spinal deformity of adolescent onset: adult idiopathic scoliosis. However, older ASD patients have more mixed aetiologies such as de novo deformity and failed back syndrome, apart from adult idiopathic scoliosis. These two populations have different features regarding perceived problems, in addition to spinal deformities [16]. Therefore, the decision-making processes for younger and older ASD patients have to be considered separately. In the present study, we developed and internally validated a weighted scoring system that is specific to the

decision-making process for ASD patients younger than 40 years.

## Materials and methods

### Patient cohort

This study was a retrospective analysis of a multicenter prospective database of consecutive ASD patients, who had been evaluated and had undergone either surgical or nonsurgical treatment at six European spine centres, sharing the database, from June 2007 to September 2017. Each enrolled site obtained institutional review board approval according to the common protocol. The inclusion criteria were patients ranging in age from 18 to 40 years with whole spine radiographs showing at least one of the following: coronal Cobb angle  $\geq 20^\circ$ ; sagittal vertical axis  $\geq 5$  cm; thoracic kyphosis  $\geq 60^\circ$ ; or pelvic tilt (PT)  $\geq 25^\circ$ . Patients with congenital deformity, post-traumatic deformity, neuromuscular disease, or Scheuermann disease were excluded. Patients were divided into surgical and nonsurgical groups at enrolment into the database, according to the selected treatment modality.

### Analysed variables

Considering previous studies, we selected the variables, regarding the baseline symptomatology, HRQoL measures, and radiographic variables, in addition to demographic data of the ASD patients. These variables were analysed to develop the weight scoring system: the ASD surgical decision-making (ASD-SDM) score.

### Demographic data

Demographic data, including age, body mass index (BMI), comorbidity, and previous spine surgery, were collected. BMI ( $\text{kg}/\text{m}^2$ ) was categorised as normal,  $< 25$ ; overweight, 25–30, and obese:  $\geq 30$ . Comorbidities were evaluated according to the Charlson comorbidity index (CCI) and classified into two groups (CCI = 0 or 1 and  $\geq 2$ ) [18].

### Baseline symptomatology, HRQoL measures, and radiographic variables

Regarding baseline symptomatology, back and leg pain are the most common symptoms of ASD, and several studies have shown that surgical patients have greater back and leg pain than nonsurgical patients [6, 7, 10]. In the present

study, back and leg pain evaluated using a numerical rating scale (NRS, 0–10 points) was collected for analysis.

The patient-reported outcome measures of HRQoL are essential for evaluating the severity of disease state in the ASD population [5, 7–10]. A majority of previous studies, investigating the decision-making factors for ASD treatment, reported that a worse HRQoL score, apart from back and leg pain, is an important factor influencing the selection of surgical management. Presently, the Short Form (SF)-36, Oswestry Disability Index (ODI), and Scoliosis Research Society (SRS-22) score are universal HRQoL measures for evaluating ASD. Of these, the SRS-22 is the only disease-specific instrument for ASD. It was initially developed for patients with adolescent idiopathic scoliosis (AIS) [19] but was also found to be relevant in ASD [20]. Although the SF-36 is a general health instrument and ODI is an assessment tool that is specific to back pain, the SRS-22 has four subdomains: pain, function, self-image, and mental health domains, which reflect the diverse symptoms in this population [20, 21]. Of these four domains, the pain, function, and self-image domains were analysed in the present study because these three domains are particularly associated with the decision-making process in the ASD population [5, 7].

Regarding radiographic factors, some studies have shown that coronal deformity is another essential factor for decision-making in ASD [5, 7, 10], and we analysed the largest value of coronal Cobb angle as coronal deformity.

A few recent studies have demonstrated that sagittal malalignment is also related to the decision-making process. To date, multiple spinopelvic sagittal parameters have been introduced for the evaluation of sagittal deformity in patients with ASD. Among them, Fujishiro et al. [5] showed that the sagittal parameter representing the amount of lumbar lordosis (LL) in relation to pelvic incidence (PI), such as PI-LL mismatch, was a strong indicator for pursuing surgical treatment. On the other hand, Boissière et al. [4] showed that relative spinopelvic alignment (RSA) was an accurate parameter for decision-making. RSA indicates the amount of malalignment relative to the ideal global tilt (GT) as defined by the magnitude of PI and is calculated by the following equation:  $RSA = GT - \text{ideal } GT = GT - (PI \times 0.48 - 15)$ , and its greater value indicates sagittal imbalance due to positive sagittal balance and/or pelvic retroversion [22]. The sagittal balance has a corresponding effect on each adjacent segment, leading to high correlations among the sagittal parameters. Hence, a number of sagittal parameters could not be entered in multivariate analysis owing to multicollinearity issues. In the present study, PI-LL mismatch and RSA were selected, based on aforementioned two studies, as analysed variables for the evaluation of sagittal deformity.

## Statistics

The patients were randomly divided into derivation (80%) and validation (20%) sets. The ASD-SDM scoring system was developed using the derivation set. All variables were compared between surgical and nonsurgical groups with univariate analyses. Factors with  $P < 0.15$  in the univariate analyses were included in the multivariate logistic regression using a forward stepwise procedure. Significant factors in the multivariate analyses were included in univariate multinomial logistic regression, and the score was assigned by its own parameter estimate. The scoring system was subsequently validated in the validation set.

In the univariate analyses comparing the variables between the surgical and nonsurgical patients, the Mann–Whitney  $U$  test was used for continuous variables, and Pearson's Chi-square test or Fisher's exact test was used for ordinal and nominal variables. The performance of a scoring system for discriminating between surgical and nonsurgical patients was tested using the area under the curve (AUC) of the receiver operating characteristic curve analyses. The Cochran–Armitage test was used to assess the trend between the ASD-SDM score and selection of surgical treatment. The surgical rates, according to the ASD-SDM score between the derivation and validation sets, were statistically compared using Pearson's Chi-square test. All statistical analyses were performed using JMP (version 11.0; SAS Institute Inc., Cary, NC, USA).  $P < 0.05$  was considered statistically significant.

## Results

### Patient demographics

A total of 316 patients constituted the overall sample. The mean age was  $26.7 \pm 6.9$  years, and 79.7% of the cohort were women ( $n = 252$ ). One hundred ten patients (34.8%) were treated surgically, and 206 patients (65.2%) were treated nonsurgically. Random allocation to the derivation and validation sets yielded 80% ( $n = 253$ ) and 20% ( $n = 63$ ) of the sample, respectively. There were no significant differences in the ratio of surgical patients, demographic data, baseline symptomatology, HRQoL measures, and radiographic variables between the sets (Table 1).

### Development of the scoring system

The derivation set consists of 253 patients (average age 26.8 years, 80.6% female). Eighty-seven patients (34.4%) were treated surgically.

Table 2 shows the results of univariate and multivariate analyses between the surgical and nonsurgical patients in

**Table 1** Characteristics of the derivation and validation sets

	All (n = 316)	Derivation set (n = 253)	Validation set (n = 63)	P
Ratio of surgical patients (%)	34.8	34.4	36.5	0.752
<i>Demographic variables</i>				
Age, years	26.7 ± 6.9	26.8 ± 6.8	26.5 ± 7.1	0.657
Gender (female sex) (%)	79.7	80.6	76.2	0.484
BMI (normal/overweight/obesity) (%)	82.9/15.5/4.1	82.9/15.5/1.6	88.9/11.1/0	0.277
Comorbidity (CCI ≥ 2) (%)	2.5	2.4	3.2	0.662
Previous spine surgery (%)	27.5	26.5	31.8	0.403
<i>Baseline symptomatology</i>				
Back pain (NRS)	4.7 ± 2.9	4.7 ± 2.8	4.7 ± 3.0	0.970
Leg pain (NRS)	1.8 ± 2.6	1.9 ± 2.7	1.6 ± 2.4	0.580
<i>HRQoL measures</i>				
SRS-22 pain	3.6 ± 0.9	3.5 ± 0.9	3.6 ± 0.9	0.553
SRS-22 self-image	3.2 ± 0.8	3.2 ± 0.8	3.1 ± 0.8	0.742
SRS-22 function	4.1 ± 0.8	4.0 ± 0.8	4.2 ± 0.7	0.251
<i>Radiographic variables</i>				
Coronal curve (°)	47.1 ± 18.2	47.2 ± 17.9	46.7 ± 19.2	0.522
PI-LL mismatch (°)	12.2 ± 9.2	12.4 ± 9.1	11.5 ± 9.7	0.349
RSA (°)	-0.5 ± 9.2	-0.4 ± 9.2	-1.0 ± 7.2	0.904

Values are shown as mean ± standard deviation or percentage

*BMI* body mass index, *CCI* Charlson comorbidity index, *NRS* numerical rating scale, *HRQoL* health-related quality of life, *SRS-22* Scoliosis Research Society-22 score, *PI-LL* pelvic incidence minus lumbar lordosis, *RSA* relative spinopelvic alignment

**Table 2** Results of univariate and multivariate analyses

	Univariate analysis			Multivariate analysis	
	Surgical (n = 87)	Nonsurgical (n = 166)	P	B (SE)	P
Age, years	26.9 ± 6.6	26.7 ± 6.9	0.682	Not included	
BMI (normal/overweight/obesity) (%)	71.3/24.1/4.6	86.8/12.7/0.6	0.005		NS
Comorbidity (CCI ≥ 2)	2.3	2.4	> 0.999	Not included	
Previous spine surgery	17.2	31.3	0.016		NS
Back pain (NRS)	5.3 ± 2.7	4.4 ± 2.9	0.028		NS
Leg pain (NRS)	2.3 ± 2.9	1.6 ± 2.6	0.121		NS
SRS-22 pain	3.3 ± 0.9	3.7 ± 0.8	< 0.001		NS
SRS-22 self-image	2.8 ± 0.7	3.4 ± 0.8	< 0.001	-0.935 (0.206)	< 0.001
SRS-22 function	3.7 ± 0.9	4.2 ± 0.7	< 0.001		NS
Coronal curve (°)	53.5 ± 20.1	43.8 ± 15.8	< 0.001	0.031 (0.009)	< 0.001
PI-LL mismatch (°)	14.2 ± 10.0	11.5 ± 8.5	0.057	0.037 (0.017)	0.033
RSA (°)	2.4 ± 11.2	-1.8 ± 7.6	0.009	0.038 (0.017)	0.029

Values are presented as mean ± standard deviation or percentage in the univariate analysis

*B* parameter estimate, *SE* standard error, *BMI* body mass index, *NS* not statistically significant, *CCI* Charlson comorbidity index, *NRS* numerical rating scale, *SRS-22* Scoliosis Research Society-22 score, *PI-LL* pelvic incidence minus lumbar lordosis, *RSA* relative spinopelvic alignment

the derivation set. In the univariate analyses, there were no significant differences in age ( $P = 0.682$ ) and comorbidities based on CCI ( $P > 0.999$ ) between the surgical and nonsurgical patients. However, the surgical patients had significantly higher BMI, lower rates of previous spinal surgery, greater

NRS-derived back pain, worse SRS-22 scores, greater coronal curve, and greater RSA than the nonsurgical patients. The surgical patients had greater NRS-derived leg pain and PI-LL mismatch; however, the differences did not reach statistical significance ( $P = 0.121$  and  $0.057$ , respectively).

Multivariate logistic regression analysis revealed that four factors: worse self-image score on the SRS-22, greater coronal Cobb angle, greater PI-LL mismatch, and greater RSA retained their significance regarding the selection of surgical management, and these factors were included as parameters in the ASD-SDM scoring system.

Initially, the self-image domain in SRS-22 was categorised into five groups at intervals of 0.5 from 2 point; coronal Cobb angle was categorised into five groups at intervals of 10° from 30°; PI-LL mismatch was categorised into six

groups at intervals of 5° from 0°; and RSA was categorised into seven groups at intervals of 5° from 0°. However, when the data were fitted into the logistic regression model using the above categories, the parameter estimates of some neighbouring categories were found to be similar. Thus, the parameters were re-categorised and the fitting process was repeated. Finally, the self-image domain was categorised into three groups, coronal Cobb angle into four groups, and PI-LL mismatch and RSA into two groups. Each score was assigned by rounding the average of the two smallest parameter estimates (0.239 for coronal curve ranging from 40 to 50; 0.222 for PI-LL mismatch) to the nearest integer (Table 3).

**Table 3** Results of the multinomial logistic regression and its conversion to point score

Factors	B (SE)	OR (95% CI)	P	Assigned point
<b>SRS-22 self-image</b>				
> 3.5	–	–	–	0
2.5–3.5	0.523 (0.169)	2.8 (1.5–5.6)	0.002	2
< 2.5	0.961 (0.190)	6.8 (3.3–14.7)	< 0.001	4
<b>Coronal curve (°)</b>				
< 40	–	–	–	0
40–50	0.239 (0.196)	1.6 (0.7–3.5)	0.222	1
50–60	0.514 (0.190)	2.8 (1.3–6.0)	0.007	2
> 60	0.795 (0.192)	4.9 (2.3–10.6)	< 0.001	3
<b>PI-LL mismatch (°)</b>				
< 15	–	–	–	0
> 15	0.222 (0.133)	1.6 (0.9–2.6)	0.093	1
<b>RSA (°)</b>				
< 5	–	–	–	0
> 5	0.516 (0.159)	2.8 (1.5–5.3)	0.001	2

B parameter estimate, SE standard error, OR odds ratio, CI confidence intervals, SRS-22 Scoliosis Research Society-22 score, PI-LL pelvic incidence minus lumbar lordosis, RSA relative spinopelvic alignment

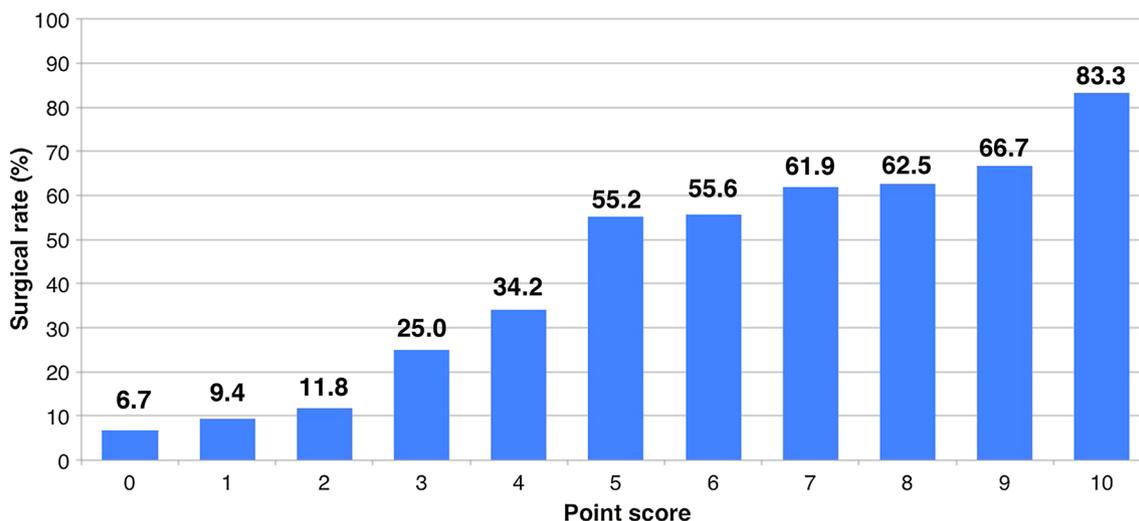
The ASD-SDM score, calculated by adding the scores of these four parameters, can range from 0 to 10, and the observed surgical rate is shown in Fig. 1. The AUC of the ASD-SDM score for predicting the selection of surgical treatment was 0.767 [standard error (SE) 0.031, P < 0.001, 95% confidence interval (CI) 0.702–0.821]. The associated equation for the fitted logistic regression model of the ASD-SDM score is shown below:

$$\log \left( \frac{P_{\text{surgery}}}{1 - P_{\text{surgery}}} \right) = -2.496 + 0.445 \times \text{point score}$$

The probability of surgical rate at each score was estimated using the following formula:

$$P_{\text{surgery}}(\%) = \frac{1}{1 + e^{-(-2.496 + 0.445 \times \text{point score})}} \times 100$$

According to this formula, the estimated surgical rate (ESR) was calculated. The surgical decision-making was graded into three classes according to ESR: low surgical indication group (ESR < 33.3%; total score,



**Fig. 1** Observed surgical rate according to the total score in the derivation set

0–4), moderate surgical indication group (ESR > 33.4% to < 66.6%; total score, 5–7), and high surgical indication group (ESR > 66.7%; total score, 8–10) (Table 4). Tables S1, S2, and S3 (Online Resource) show the results of univariate analyses of the analysed variables between surgical and nonsurgical patients in the low, moderate, and high surgical indication groups, respectively.

### Validation of the scoring system

The validation set consisted of 63 patients (average age 26.5 years, 76.2% female). There were 23 surgical patients (36.5%) and 40 nonsurgical patients (63.5%).

The mean ASD-SDM score of the validation set was 3.9 (range 0–10). The Cochran–Armitage test showed a significant linear trend, with higher ASD-SDM scores associated

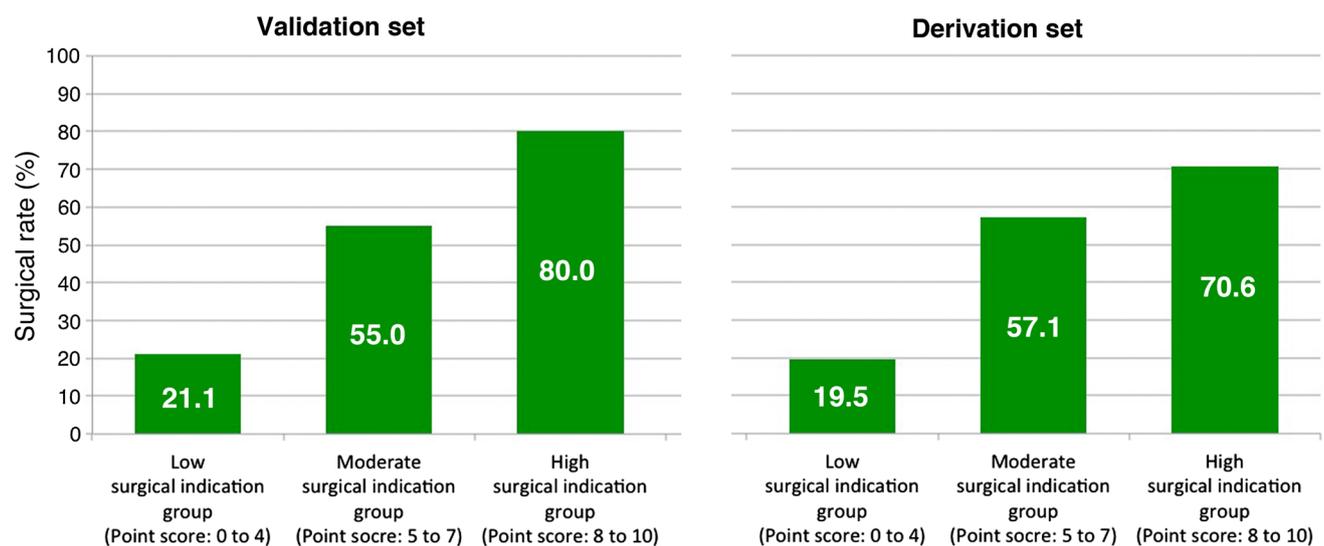
with a higher ratio of surgically treated patients. The distribution of subjects based on surgical indication, which was established by the derivation set, is shown in Fig. 2. The surgical rate was 21.1% for the low surgical indication group, and 55.0% and 80.0% for the moderate and high surgical indication groups, respectively. This distribution was comparable to that in the validation set ( $P=0.911$ , Pearson's Chi-square test) (Fig. 2). The AUC for predicting surgical management was 0.789 (SE = 0.057,  $P < 0.001$ , 95% CI 0.655–0.880) and was also comparable to that for the validation set.

### Discussion

The ASD population is notably heterogeneous. Previous studies have suggested that this heterogeneity is caused by aetiology and age, and that dichotomising the ASD population into two groups, namely, younger age with nondegenerative aetiologies and older age with degenerative aetiologies, is necessary [17, 23]. Even in the decision-making process, previous studies have indicated that there are definite differences between younger and older ASD patients; thus, the decision-making process should be considered separately for both populations. Bridwell et al. [24] employed less than 40 years of age to define younger ASD population and concluded that there were definite differences in the decision-making process between younger and older populations. Bradford et al. [25] proposed up to 40 years of age to classify younger ASD population regarding the surgical indication. In the present study, we developed an internally validated scoring system to guide the decision-making process for

**Table 4** Surgical indication according to the estimated surgical rate

Total score	Estimated surgical rate (%)	Surgical indication
0	7.6	Low
1	11.4	
2	16.7	
3	23.9	
4	32.8	Moderate
5	43.3	
6	54.3	
7	65.0	High
8	74.3	
9	81.9	
10	87.6	



**Fig. 2** Surgical rate according to the three surgical indication groups of the validation (left) and derivation (right) sets

younger ASD population, which was defined as less than 40 years of age.

For adolescent patients with scoliosis, the perception of spine and trunk appearance caused by spinal deformity in the coronal plane is a primary concern, and the curve magnitude is the most important factor when considering surgical treatment. In the present scoring system for younger ASD patients, the higher weighted score was assigned to a worse perception of appearance, based on the self-image score in SRS-22, and a greater coronal Cobb angle (Table 3). This trend in the decision-making process is common for adolescent patients with scoliosis.

Previous studies have shown that the spinal deformity of the younger ASDs arises in childhood or adolescence, and the majority of younger ASD patients present with a radiological extension of the adolescent spinal deformity, although older ASD patients are more likely to have *de novo* deformity in adulthood. Therefore, younger ASD patients would be treated largely according to those with AIS. This is because the surgical decision-making processes for younger ASD patients and AIS patients are similar.

However, there were different features in the surgical decision-making process between younger ASD and AIS patients. The present study showed that the radiographic sagittal parameters were additional significant decision-making factors for younger ASD patients. This is consistent with previous studies investigating the factors influencing decision-making in ASD [4, 5]. A recent study by Fujishiro et al. [5] showed that the lack of LL relative to PI was one of the factors influencing surgical treatment in both younger and older ASD patients, while Boissière et al. [4] showed that the RSA could be used as a single sagittal modifier for decision-making in ASD.

PI-LL mismatch, incorporated into the SRS-Schwab ASD classification system, is the difference between PI and LL, and is the index of regional malalignment in the lumbar spine. On the other hand, RSA, recently introduced by Yilgor et al. [22], is the difference between ideal and measured GT. GT, first described by Obeid et al. [26], includes spinal and pelvic malalignment, enabling a global evaluation of the spinopelvic complex balance. GT equals the sum of PT and C7 vertical tilt (C7VT), which is the angle between the vertical axis and a line drawn from the centre of C7 to the centre of the sacral endplate, and is a parameter that simultaneously assesses the spinal sagittal balance and ante- or retroversion of the pelvis. Moreover, it offers the advantage of being less affected by patient positioning and clarifying malalignment even when PT and SVA seem opposite [26]. Therefore, RSA, which is calculated based on GT, is the index of global malalignment compared to the PI-LL mismatch. In the present scoring system, greater mismatches in both of these sagittal parameters were independent factors influencing the selection of surgical management.

Although some studies have investigated sagittal alignment in AIS patients, it remains understudied. Clément et al. [27] showed that thoracic scoliosis induced a decrease in thoracic kyphosis, whereas thoracolumbar and lumbar deformities maintained a kyphotic thoracic spine and tended to increase upper LL. Abelin-Genevois et al. [28] had recently proposed the sagittal classification of AIS into three types based on the presence and location of thoracic hypokyphosis. However, a meta-analysis by Pasha and Baldwin concluded that there were no definitive differences either among the curve types or between AIS patients and the normal population [29]. Further, the natural history of sagittal alignment in AIS patients is unknown, although the progression of coronal deformity in AIS has been well documented [30, 31].

In 2005, Aebi [3] introduced the ASD classification system based on its pathogenesis, via a review of the literature. This classification system differentiates between deformities carried into adulthood, adult idiopathic scoliosis, and those arising in adulthood ‘*de novo*’. Further, adult idiopathic scoliosis was classified into two patterns based on the presence of secondary degeneration [3]. Aebi [3] mentioned that, in most cases of adult idiopathic scoliosis, a flat-back syndrome and/or a loss of physiological LL were observed, regardless of the presence of secondary degeneration. In the present study, surgical patients had a greater PI-LL mismatch and RSA compared to nonsurgical patients. Further, these two sagittal parameters were significant factors influencing the selection of treatment, even after multivariate analysis (Table 2). The sagittal malalignment in patients pursuing surgical treatment in the present study seems consistent with Aebi’s view.

Guler et al. [32] showed that the patients with *de novo* deformity had greater sagittal imbalance compared to the patients with adult idiopathic scoliosis. However, these studies and the current study suggest that both regional and global sagittal alignments worsen in some AIS patients owing to degeneration and/or progression of coronal deformity, although these may be less than the sagittal malalignment in patients with *de novo* deformity. Moreover, these sagittal imbalances are important factors when selecting surgical management in the younger ASD population.

The present study has some limitations. First, although the data were collected prospectively, the present study was retrospective. Therefore, we might not have addressed other specific factors while selecting the treatment modality. Second, although the ASD-SDM score was internally validated, it was not externally validated. To demonstrate the generalisability of the scoring system, the verification of external validity is necessary. Third, because all six clinics represented in the database were specialised spine centres, most patients had undergone evaluation, conservative treatments, and/or referral for surgical evaluation before visiting

the clinics, and the treatment modality was selected after thorough consultation between patients and surgeons at the time of enrolment into the database. Therefore, it is difficult to simply apply the present scoring system to newly diagnosed patients. However, the ASD-SDM score could be a reference used to guide the decision-making process even in newly diagnosed patients and the transition from nonsurgical to surgical treatment by monitoring its score throughout the clinical course. Fourth, in the present study, we employed less than 40 years of age to define the younger ASD population based on the previous literature [16, 17, 23–25]; however, various age ranges have been adopted to stratify the ASD population in previous studies, and it has to be recognised that this cut-off age is not necessarily the only definitive point to differentiate a younger ASD population from an older one.

Finally, although the strength of the present scoring system comprised validated and universal measures, this was a cross-sectional study, as the scoring system was based on baseline patients' data alone, and the outcomes of surgical and nonsurgical treatments were not considered. However, the present study did not aim to establish a definite surgical indication for the younger ASD population but to propose a simple scoring system for guiding the decision-making process, which is complex in clinical settings. In the future, the refinement of this scheme with the consideration of treatment effects and the establishment of surgical indication for ASD are necessary.

Despite these limitations, the present study, to our knowledge, is the first to propose a scoring system to guide the decision-making process for ASD patients aged < 40 years and to aid in the selection of treatment modalities for this patient group.

**Acknowledgements** Grants/research support: Cawley DT: Irish Orthopaedic Association, Irish Institute of Trauma and Orthopaedic Surgery, Société Française de Chirurgie Orthopédique et Traumatologique; Pellise F: Depuy Synthes, K2M; Perez-Gruoso F.S: Depuy Synthes, K2M; Acaroglu E: Fondation Cotrel, Depuy Synthes, Medtronic, Consultant: Medtronic, AOSpine; Alanay A; Depuy Synthes Consultant: Depuy Spine, Stryker, Medtronic; Obeid I: Depuy Synthes; ESSG: Depuy Synthes.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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