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ORIGINAL ARTICLE

Adult spinal deformity surgical decision-making score. Part 2: development and validation of a scoring system to guide the selection of treatment modalities for patients above 40 years with adult spinal deformity

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Abstract

Purpose We aimed to develop and internally validate a scoring system, the adult spinal deformity surgical decision-making (ASD-SDM) score, to guide the decision-making process for ASD patients aged above 40 years.

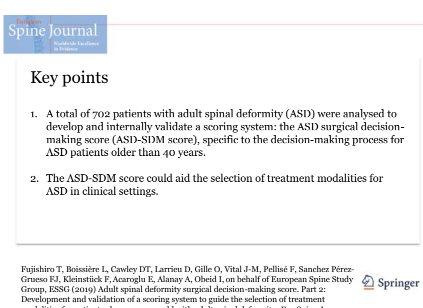
Methods A multicentre prospective ASD database was retrospectively reviewed. The scoring system was developed using data from a derivation set and was internally validated in a validation set. The performance of the ASD-SDM score for predicting surgical management was assessed using the area under the receiver operating characteristic curve (AUC).

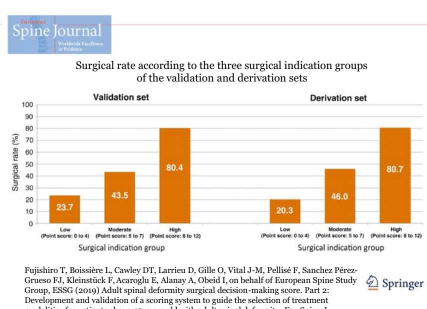
Results A total of 702 patients were included for analysis in the present study. The scoring system developed based on 562 patients, ranging from 0 to 12 points, included five parameters: leg pain scored by the numerical rating scale; pain and self-image domains in the Scoliosis Research Society-22 score; coronal Cobb angle; and relative spinopelvic alignment. Surgical indication was graded as low (score 0 to 4), moderate (score 5 to 7), and high (score 8 to 12) groups. In the validation set of 140 patients, the AUC for predicting surgical management according to the ASD-SDM score was 0.797 (standard error = 0.037, $P < 0.001$, 95% confidence interval = 0.714 to 0.861), and in the low, moderate, and high surgical indication groups, 23.7%, 43.5%, and 80.4% of the patients, respectively, were treated surgically.

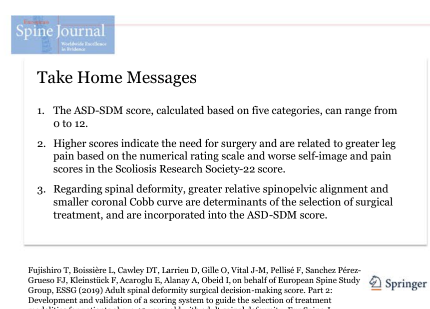
Conclusions The ASD-SDM score demonstrated reliability, with higher scores indicating a higher probability of surgery. This index could aid in the selection of surgery for ASD patients in clinical settings.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







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Keywords Adult spinal deformity · Decision-making process · Surgical indication · Surgical management · Adult scoliosis · Scoring system

Introduction

Adult spinal deformity (ASD) is one of the main topics in spinal surgery. Its prevalence exceeds 60% among the elderly [1], and several studies have shown, since the first report by Schwab et al., that ASD patients have a significantly lower average health-related quality of life (HRQoL) score than the normal population and patients with other chronic conditions [2–4]. ASD has become a significant health concern in recent years.

ASD derives from several conditions, such as idiopathic deformity, degenerative deformity, and failed-back surgery syndrome. It covers a wide spectrum of spinal and spinopelvic deformities both in the coronal and in the sagittal planes. Furthermore, ASD patients present with a different group of symptoms that are related to progressive degeneration and neural element compression. Effort has been made since the 2000s to clarify this complex condition, and several classification systems regarding ASD, based on aetiology [5], magnitude, and location of spinal deformity [6], or its relationship with HRQoL scores [7], have been proposed. These classification systems have advanced the systematic understanding and standardisation of communication among health care providers, regarding ASD.

The growing understanding of the relationship between spinal deformity and HRQoL has encouraged corrective surgery for ASD. In the last decade, there has been marked progress in the surgical management of ASD and increased knowledge regarding the avoidance of its complications. On the other hand, several studies have demonstrated the effectiveness of nonsurgical treatment with minimal complication rates [8, 9]. However, despite these advances and attention to treatment modalities for ASD, standardisation and consensus regarding decision-making for ASD are lacking; thus, deciding between surgical and nonsurgical management is difficult in clinical settings.

Previous studies have shown that most ASD cases in younger patients arise as an extension of adolescent spinal deformity into adulthood: adult idiopathic scoliosis. On the contrary, ASD in older patients encompasses mixed aetiologies, including degenerative deformity and failed-back syndrome, in addition to the aforementioned adult idiopathic scoliosis [10]. Therefore, the perceived problems differ between younger and older ASD patients [11]. Furthermore, the decision-making process between these age groups is markedly different [12–15]. A previous study proposed a scoring system that is specific to the decision-making process for patients with ASD aged below 40 years [16]. In the present study, we aimed to develop and internally validate a scoring system, based on the patient's demographics, baseline HRQoL measures, and radiographic spinal deformity, to aid in the selection of surgical or nonsurgical management for patients with ASD aged above 40 years.

Materials and methods

Patient cohort

This study was a retrospective analysis of a multicentre prospective database of consecutive ASD patients, who had been evaluated and had undergone surgical or nonsurgical treatment at six European spine centres sharing a database, from June 2007 to September 2017. Each enrolled site obtained institutional review board approval according to the common protocol.

Subjects included in the database were those with full-length standing coronal and sagittal spinal radiographs that were obtained when visiting the clinics, which showed at least one of the following: coronal Cobb angle ≥ 20°; sagittal vertical axis ≥ 5 cm; thoracic kyphosis ≥ 60°, or pelvic tilt (PT) ≥ 25°. Demographic data and HRQoL measures were collected from all subjects included in the database. Further, subjects were divided into surgical and nonsurgical groups according to the selected treatment modality at the time of enrolment.

From this database, subjects aged ≥ 41 years were included in the present study. Patients with congenital deformity, post-traumatic deformity, neuromuscular disease, or Scheuermann disease were excluded from the present study.

Analysed variables

We selected variables regarding the HRQoL measures, and radiographic variables in addition to demographic data at the time of enrolment by reviewing previous studies examining the decision-making factors in ASD treatment [13, 14, 16–22]. We analysed these to develop a weighted scoring system for selecting treatment modalities: the ASD surgical decision-making (ASD-SDM) score.

Regarding patient demographics, age, body mass index (BMI), comorbidity, and history of previous spine surgery, were collected. BMI (kg/m^2) was classified into normal, < 25; overweight, 25–30; and obese: ≥ 30. Charlson Comorbidity Index (CCI), with higher CCI indicating more severe comorbidities, was used to evaluate comorbidities [23], and patients were divided into two groups: CCI = 0 or 1; and ≥ 2.

Back and leg pain are the most common ASD symptoms, and were evaluated in the present study, using a numerical rating scale (NRS, 0–10 points). Apart from back and leg pain, patient-reported outcome measures of HRQoL are essential for evaluating ASD disease severity. Previous studies have commonly employed the Short Form (SF)-36, Oswestry Disability Index (ODI), and Scoliosis Research Society (SRS-22) score to evaluate HRQoL in ASD. Among them, only SRS-22 is ASD-specific. It has four subdomains, namely, pain, self-image, function, and mental health, which reflect the diverse symptoms both in adolescent idiopathic scoliosis and in ASD populations [24, 25]. Of these four domains, the pain, function, and self-image domains were employed for analysis in this study because previous studies indicated that they are notably related to the decision-making process for ASD management [13, 14].

Radiographically, coronal deformity is crucial in the decision-making process for ASD, and we adopted the largest value of the coronal Cobb angle. The significant relationship between sagittal deformity and the decision-making process has been also shown in recent studies [13, 17]. In the present study, pelvic incidence (PI), lumbar lordosis (LL) represented as L1-S1 lordosis, and global tilt (GT) were evaluated; PI minus LL (PI-LL) mismatch and relative spinopelvic alignment (RSA), calculated using the following equation: $GT - (PI \times 0.48 - 15)$ [26], were analysed as potential candidates for incorporation into a scoring system.

Analytic procedures and statistics

The patients were randomly divided into an 80% derivation set and a 20% validation set.

Development of the ASD-SDM score The scoring system was developed using data from the derivation cohort. All variables were compared between surgical and nonsurgical groups using 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 considering parameter estimates.

Validation of the ASD-SDM score The internal validation of the developed scoring system was subsequently performed using data from the validation cohort by investigating its trend with the selection of surgical management. Further, the ratio of surgical patients and discriminating capacity to select the treatment modalities according to the developed scoring system were compared between the validation and derivation cohorts.

The Mann–Whitney *U*-test was used for continuous variables, and Pearson's chi-square test was used for ordinal and nominal variables in the univariate analyses comparing the derivation and validation sets, and the surgical and nonsurgical patients. 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. The Cochran-Armitage test was used to assess the trend between the ASD-SDM score and surgical treatment selection. All statistical analyses were performed using JMP (version 11.0; SAS Institute Inc., Cary, NC, USA). A P value of < 0.05 was considered statistically significant.

Results

Overall, 702 patients were included for analysis in the present study. Their mean age was 63.3 years, 83.9% of patients were female, and 378 patients (53.8%) were treated surgically. The subjects were randomly divided into the derivation (80%, $n = 562$) and validation (20%, $n = 140$) cohorts. Table 1 shows the analysed variables in the derivation and validation cohorts, indicating that no significant between-group differences in the variables were noted.

Development of the scoring system

The derivation set for the development of the ASD-SDM score consisted of 562 subjects. In this cohort, the mean age was 63.3 years, 83.3% were female, and 304 patients (54.1%) were treated surgically (Table 1).

Table 2 shows the results of univariate and multivariate analyses between the surgical and nonsurgical patients in this cohort. Univariate analyses showed that surgical patients were older ($P < 0.001$) and had higher BMI ($P = 0.039$). However, there were no differences in comorbidities based on CCI ($P = 0.757$) and history of previous spine surgery ($P = 0.780$). Compared to nonsurgical patients, surgical patients had greater back and leg pain scored by NRS ($P < 0.001$, both), and worse scores in three domains in the SRS-22 ($P < 0.001$, all). Regarding radiographic variables, surgical patients had a significantly smaller coronal Cobb angle ($P < 0.001$); however, PI-LL mismatch and RSA were greater in surgical versus nonsurgical patients ($P < 0.001$, both).

After multivariate analysis, NRS-derived leg pain, pain and self-image scores in the SRS-22, coronal Cobb angle, and RSA maintained statistical significance (Table 2), and were incorporated into the weighted scoring system.

In multinomial logistic regression, the NRS-scored leg pain was categorised into 11 groups (0 to 10). However, the parameter estimates of some neighbouring categories were similar, and re-categorisations were performed. Finally, the NRS-scored leg pain was categorised into three groups (Table 3). Similarly, pain and self-image scores in the SRS-22, coronal Cobb angle, and RSA were

Table 1 Characteristics of the derivation and validation sets

	All (*n* = 702)	Derivation set (*n* = 562)	Validation set (*n* = 140)	*P*
Ratio of surgical patients (%)	53.9	54.1	52.9	0.850
Demographic variables				
Age (years)	63.3 ± 10.5	63.3 ± 10.4	63.0 ± 10.9	0.902
Gender (female sex) (%)	83.9	83.3	86.4	0.441
BMI (normal/overweight/obese) (%)	47.9/35.2/17.0	47.7/34.9/17.4	48.6/36.4/15.0	0.784
Comorbidity (CCI ≥ 2) (%)	22.1	21.2	25.7	0.256
Previous spine surgery (%)	33.9	34.3	32.1	0.690
Baseline symptomatology				
Back pain (NRS)	6.5 ± 2.4	6.5 ± 2.5	6.4 ± 2.3	0.579
Leg pain (NRS)	4.4 ± 3.4	4.5 ± 3.4	4.1 ± 3.4	0.258
HRQoL measures				
SRS-22 pain	2.6 ± 0.9	2.6 ± 0.9	2.7 ± 0.9	0.198
SRS-22 self-image	2.6 ± 0.8	2.6 ± 0.8	2.7 ± 0.8	0.400
SRS-22 function	3.1 ± 0.8	3.0 ± 0.8	3.1 ± 0.8	0.274
Radiographic variables				
Coronal curve (°)	39.1 ± 21.9	39.3 ± 22.4	38.5 ± 19.6	0.806
PI-LL mismatch (°)	19.0 ± 15.0	19.2 ± 14.8	18.2 ± 15.9	0.203
RSA (°)	17.5 ± 13.7	17.8 ± 13.7	16.5 ± 13.5	0.335

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* = 304)	Nonsurgical (*n* = 258)	*P*	*B* (SE)	*P*
Age (years)	65.0 ± 9.8	61.4 ± 10.9	< 0.001		NS
BMI (normal/overweight/obese) (%)	42.8/37.8/19.4	53.5/31.4/15.1	0.039		NS
Comorbidity (CCI ≥ 2)	21.7	20.5	0.757	Not included	
Previous spine surgery	34.9	33.7	0.780	Not included	
Back pain (NRS)	7.0 ± 2.3	6.0 ± 2.5	< 0.001		NS
Leg pain (NRS)	5.3 ± 3.2	3.5 ± 3.3	< 0.001	0.074 (0.031)	0.018
SRS-22 pain	2.4 ± 0.8	2.9 ± 0.9	< 0.001	− 0.391 (0.135)	0.004
SRS-22 self-image	2.3 ± 0.7	2.8 ± 0.8	< 0.001	− 0.532 (0.154)	< 0.001
SRS-22 function	2.8 ± 0.7	3.3 ± 0.9	< 0.001		NS
Coronal curve (°)	32.6 ± 19.3	47.2 ± 23.3	< 0.001	− 0.030 (0.005)	< 0.001
PI-LL mismatch (°)	21.5 ± 15.5	16.5 ± 13.5	< 0.001		NS
RSA (°)	20.7 ± 13.1	14.4 ± 13.7	< 0.001	0.021 (0.008)	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

categorised into five groups at intervals of 0.5 from 2, five groups at intervals of 0.5 from 2, seven groups at intervals of 10° from 0°, and seven groups at intervals of 5° from 0°, respectively. After repeating the process, they were finally categorised into three, four, three, and three groups, respectively (Table 3). A point score of each category was assigned by rounding the average of the three smallest parameter estimates of respective factors (0.310 for self-image domain in SRS-22, ranging from 3 to 3.5; 0.352 for NRS-derived leg pain, ranging from 2 to 5; and

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

Factors	*B* (SE)	OR (95% CI)	*P*	Assigned point
NRS leg pain				
0, 1	–	–	–	0
2 to 5	0.352 (0.117)	2.0 (1.3–3.2)	0.003	1
6 to 10	0.686 (0.107)	3.0 (2.6–6.0)	< 0.001	2
SRS-22 pain				
> 3.5	–	–	–	0
3 to 3.5	0.393 (0.144)	2.2 (1.3–3.9)	0.006	1
< 3	0.736 (0.120)	4.4 (2.7–7.1)	< 0.001	2
SRS-22 self-image				
> 3.5	–	–	–	0
3 to 3.5	0.310 (0.161)	1.9 (1.1–3.6)	0.049	1
2.5 to 3	0.622 (0.167)	3.5 (1.8–6.8)	< 0.001	2
< 2.5	0.898 (0.149)	6.0 (3.4–11.0)	< 0.001	3
Coronal curve (°)				
> 40	–	–	–	0
20 to 40	0.358 (0.095)	2.0 (1.4–3.0)	< 0.001	1
< 20	1.095 (0.152)	8.9 (5.0–16.7)	< 0.001	3
RSA (°)				
< 5	–	–	–	0
5 to 25	0.391 (0.119)	2.2 (1.4–3.5)	< 0.001	1
> 25	0.700 (0.137)	4.1 (2.4–7.0)	< 0.001	2

B parameter estimate, *SE* standard error, *OR* odds ratio, *CI* confidence intervals, *NRS* numerical rating scale, *SRS-22* scoliosis research society-22 score, *PI-LL* pelvic incidence minus lumbar lordosis, *RSA* relative spinopelvic alignment

0.358 for coronal curve, ranging from 20° to 40°) to the nearest integer (Table 3).

The ASD-SDM score, calculated as the sum of scores in the respective categories, ranged from 0 to 12. The surgical rate in the derivation cohort is shown in Fig. 1. The AUC of the ASD-SDM score for predicting surgery was 0.785 (standard error [SE] = 0.189, $P < 0.001$, 95% confidence interval [CI] = 0.745 to 0.819). The associated equation for the fitted logistic regression model of the ASD-SDM score is as follows:

$$\log\left(\frac{P_{\text{surgery}}}{1 - P_{\text{surgery}}}\right) = -2.864 + 0.461 \times \text{point score}$$

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

$$P_{\text{surgery}}(\%) = \frac{1}{1 + e^{-(-2.864 + 0.461 \times \text{point score})}} \times 100$$

According to this formula, the estimated surgical rate (ESR) was calculated, and surgical decision-making was graded into three classes according to ESR: low (ESR < 33.3%; total score, 0 to 4), moderate (33.4% < ESR < 66.6%; total score, 5 to 7), and high (ESR > 66.7%; total score, 8 to 12) surgical indication groups (Table 4). The results of respective factors between surgical and nonsurgical patients in the low, moderate, and high surgical indication groups are shown in Tables S1, S2, and S3 (Online Resource), respectively.

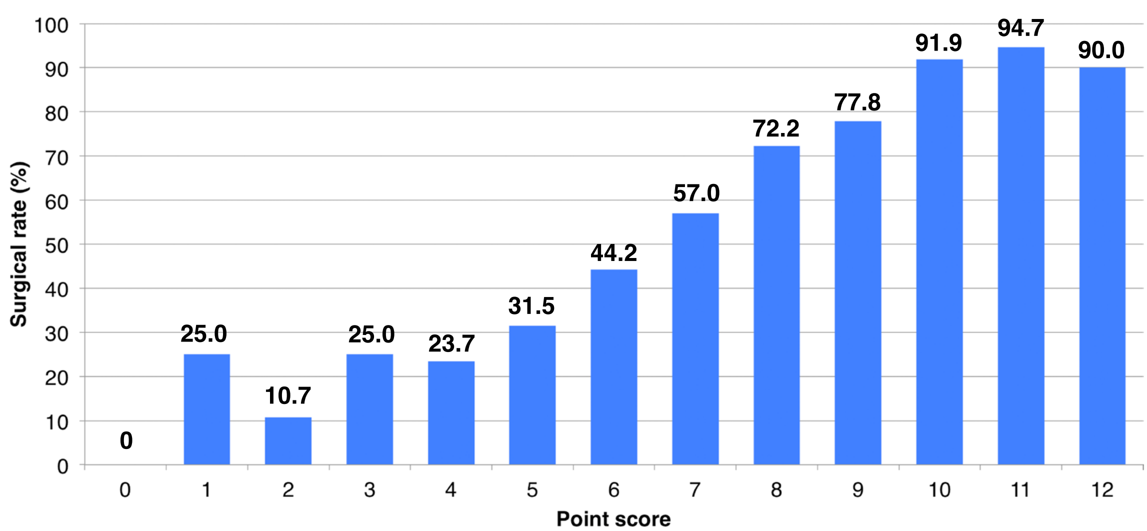

Fig. 1 Observed surgical rate according to the total score in the derivation set

Table 4 Surgical indication according to the estimated surgical rate

Total score	Estimated surgical rate (%)	Surgical indication
0	5.6	Low
1	8.3	
2	12.5	
3	18.5	
4	26.5	
5	36.4	Moderate
6	47.6	
7	59.0	
8	69.5	High
9	78.4	
10	85.2	
11	90.1	
12	93.5	

Validation of the scoring system

The validation set comprised 140 subjects. In this cohort, the mean age was 63.0 years; 86.4% were female; and 74 patients (52.9%) were treated surgically (Table 1).

The mean ASD-SDM score was 6.4 (range 0–12). The Cochran-Armitage test revealed a significant positive trend between the ASD-SDM score and ratio of surgical patients ($P < 0.001$). Figure 2 shows the distribution of subjects based on the surgical indication created from the derivation cohort. The ratios of surgical patients were 23.7%, 43.5%, and 80.4% in the low, moderate, and high surgical indication groups, respectively, and were comparable to those in the derivation set (Fig. 2). The AUC for predicting surgical management was 0.797 (SE = 0.037, $P < 0.001$, 95% CI = 0.714 to 0.861), which was comparable to that in the derivation cohort.

Discussion

Following a previous study proposing a scoring system that is specific to the decision-making process for ASD patients aged ≤ 40 years [16], we developed and internally validated a scoring system for ASD patients ≥ 41 years.

Previous studies have shown definite differences not only in the perceived problems but also in the decision-making process between younger and older ASD populations because of the diverse aetiologies of ASD [10–15]. A previous study showed that the scoring system for the decision-making process in younger ASD patients comprised four categories, with higher points assigned to coronal deformity and perception of one's appearance based on the self-image score in SRS-22, and additional points to sagittal parameters [16]. However, in the present study, five factors remained significant after multivariate analysis and were incorporated into the scoring system for decision-making in older ASD patients (Table 2), and similar points were assigned to these factors (Table 3). This indicates that the decision-making process for older ASD patients is more complex than that for younger ASD patients.

When comparing the results of the present study with those of a previous study [16], similar and different features of the decision-making process between younger and older ASD populations can be identified. Similar to younger ASD patients, the radiographic sagittal parameter was one of the significant factors for selecting treatment modality in older ASD patients.

Sagittal spinal deformity varies in patients with ASD. Previous studies have proposed multiple sagittal parameters for assessing sagittal deformity in ASD, and judgement regarding spinal sagittal alignment is generally made considering several sagittal parameters. To date, two

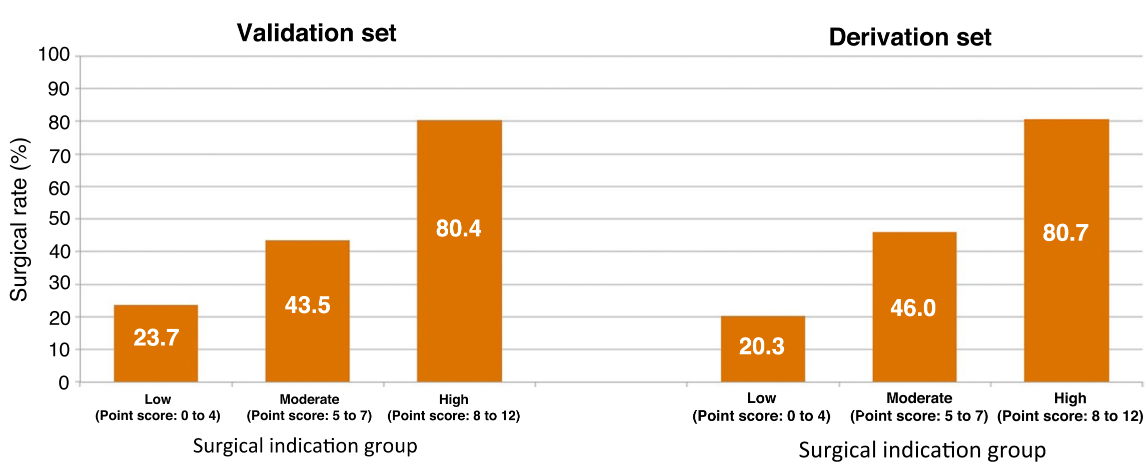

Fig. 2 Surgical rate according to the three surgical indication groups of the validation (*left*) and derivation (*right*) sets

studies have demonstrated notable correlations of sagittal parameters with the decision-making process for the ASD population. Fujishiro et al. showed that the sagittal parameter, representing the amount of LL in relation to PI, such as PI-LL mismatch, was a strong indicator of surgical treatment [13]. Boissière et al. showed that RSA was an accurate parameter for decision-making [17]. RSA was introduced as one of the sagittal parameters, which consists of *Global Alignment and Proportion Score*, and indicates the difference between the ideal and measured GT [26]. GT is the sum of pelvic tilt and C7 vertical tilt: the angle between the vertical axis and a line drawn from the centre of C7 to the centre of the sacral endplate [27]. Therefore, RSA is a sagittal parameter representing global spinopelvic balance, compared to PI-LL mismatch, and greater values indicate positive sagittal balance and/or pelvic retroversion. Because regional sagittal balance is sequentially influenced by that of the adjacent segment, the sagittal parameters are highly correlated with each other. Therefore, many sagittal parameters cannot be included in multivariate analysis owing to multicollinearity. PI-LL mismatch and RSA are not only correlated with the decision-making process but also have different characteristics, representing regional and global sagittal malalignment, respectively. For these reasons, we employed PI-LL mismatch and RSA to evaluate sagittal deformity. Consequently, RSA was incorporated into the ASD-SDM score for older ASD patients, and maintained statistical significance after multivariate analyses (Table 2), while PI-LL mismatch and RSA were incorporated into the scoring system for the younger ASD patients [16]. This indicates that surgical treatment in older ASD patients is driven more by global sagittal imbalance than by regional sagittal imbalance such as the loss of physiological lumbar lordosis.

In the present study, a smaller coronal curve was a determinant of surgery, although a greater coronal curve was more strongly associated with surgical treatment in younger ASD patients [16]. Previous studies have shown that coronal deformity is one of the decision-making factors for ASD; however, there have been some differences between studies. Glassman et al. showed that ASD patients electing for surgery were likely to have greater coronal deformity than those electing for nonsurgical treatment in a relatively young patient population (mean age 44 years) [22]. Bess et al. showed that coronal deformity was the driver for selecting surgery only for younger ASD patients [14]. Later, Fujishiro et al. showed that greater coronal deformity was a determinant of surgery for younger ASD populations, while older ASD patients who elected for surgery had smaller coronal deformity than those who opted for nonsurgical treatment [13].

Comparisons between the present study and the previous study proposing the decision-making process for younger ASD patients from the point of view of spinal deformity could clarify the differences in spinal deformity between younger and older subjects who opt for surgical treatment. The previous study showed that the surgical patients had greater coronal and sagittal deformity than nonsurgical patients in younger ASD populations [16]. However, the present study showed that surgical patients had smaller coronal and greater sagittal deformity than nonsurgical patients in older ASD population (Table 2). It is well known that older ASD patients have worse sagittal deformity than younger patients [10, 13, 28]. Studies indicate that the motivation for surgical treatment in younger ASD populations is greater coronal deformity and moderate sagittal deformity; however, this motivation changes to greater sagittal deformity rather than coronal deformity in older ASD populations. This might also suggest the difference in aetiologies between younger and older ASD patients that require surgical management. A majority of aetiology of younger ASD patients is adult idiopathic scoliosis, which is spinal deformity arising in childhood and adolescence, and its main decision-making factor is the extent of coronal deformity from the aspect of radiographic deformity. However, with advancing patient age, the aetiology that results in surgical management shifts to de novo deformity, which is characterised by sagittal malalignment rather than coronal deformity [10].

The same was valid for the self-image score in SRS-22, which was incorporated into the present scoring system (Tables 2, 3). Previous studies have shown that the perception of appearance of spinal and trunk deformity is an important decision-making factor for both younger and older ASD patients. Glassman et al. reported that a worse self-image score was the most important factor for selecting treatment modalities in ASD [22]. A recent study by Fujishiro et al. demonstrated worse self-image scores in surgically than in nonsurgically patients in both younger and older ASD populations [13]. The present study's result is consistent with that of these studies. However, there are clear differences in its interpretation between younger and older ASD patients. Namely, considering radiographic parameters mentioned above, the perceived problem of appearance that drives surgery shifts from coronal deformity to sagittal deformity with advancing age.

Back pain scored by SRS-22 pain score and leg pain based on NRS were incorporated into the present scoring system (Tables 2, 3). Previous studies have shown that pain and disability are definitive determinants of surgery in older ASD patients, although this trend is not observed in younger patients [13, 14], and the present study was consistent with these previous studies.

Back pain is the most common symptom of ASD. Glassman et al. showed that greater NRS-scored back pain led to higher rates of surgical treatment [22]. Bess et al. showed that ASD patients with more severe back pain evaluated by SRS-22 and ODI tended to opt for surgical treatment [14]. Additionally, leg pain is a common symptom in ASD patients, and a few studies have focused on this. Smith et al. examined differentiating factors, comparing surgically and nonsurgically treated patients, and showed that radicular leg pain was one of the drivers of surgery [18]. Takemoto et al. investigated the relationship between leg pain and sagittal deformity, and speculated that leg pain in the ASD population is caused by the exertion of uneconomical efforts in the lower extremities to compensate for sagittal malalignment or undue stress on sacroiliac joints [29].

In ASD, back pain is evaluated via various methods, such as pain score in SRS-22, ODI, and NRS. However, the methods for evaluating leg pain are markedly limited, and leg pain is often evaluated by NRS alone. Establishing specific instruments to evaluate disability, including both back and leg pain, in ASD may be a challenge for future studies [30].

Although most younger ASD patients have adult idiopathic scoliosis, which is spinal deformity from childhood and adolescence, ASD in older patients involves various aetiologies, including de novo deformity, adult idiopathic scoliosis, and failed-back syndrome, leading to complex decision-making in this population [12–15]. In clinical settings, there are no criteria to classify the aetiologies of ASDs, and their judgment is ambiguous, generally based only on the classifier's perception. The strength of the present scoring system is that it was developed based on universal instruments for symptoms and HRQoL, and radiographic measures, without subjective judgment of the aetiologies.

However, it is important to recognise the present study's limitations. First, this was retrospective in design, although prospectively collected data were analysed to develop the scoring system. Second, the ASD-SDM score was only internally validated. Although it was shown to be reliable, with higher points indicating higher rates of surgery, external validation is necessary to confirm the generalisability of this scoring system. Third, age above 40 years was employed to define older ASD patients in the present study; however, in previous studies, various age ranges were adopted to discriminate between younger and older ASD patients. Although, in most of these studies, the stratification between younger and older ASD patients was set from 40 to 50 years [10, 14, 15, 31], there is no consensus regarding this cut-off age. Therefore, it should be acknowledged that the age of 40 years is not necessarily the single definite point to differentiate younger patients from older patients, and special consideration appears necessary in the decision-making process for patients aged from 40 to 50 years, who cannot be simply dichotomised into younger or older populations. Finally, the scoring system was based only on preoperative patient data. For a better decision-making process, it should be clarified which subsets of patients benefit more from surgical or nonsurgical treatment, considering the therapeutic responses to the patient's symptom and HRQoL scores.

Despite these limitations, this is the first study to propose a scoring system to aid in the decision of whether to select surgical or nonsurgical management for ASD patients aged above 40 years. The ASD-SDM score is a 12-point scoring system comprising five categories: back and leg pain, perception of appearance, and radiographic spinal deformity both in the coronal and sagittal planes, to which similar points were assigned. Internal validation demonstrated the reliability of the ASD-SDM score, with higher ASD-SDM scores corresponding to a higher ratio of surgically treated patients. This scoring system should be a helpful index in the selection of treatment modalities for this patient group.

Compliance with ethical standards

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

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