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ORIGINAL ARTICLE

Factors associated with having an indication for surgery in adult spinal deformity: an international european multicentre study

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Abstract

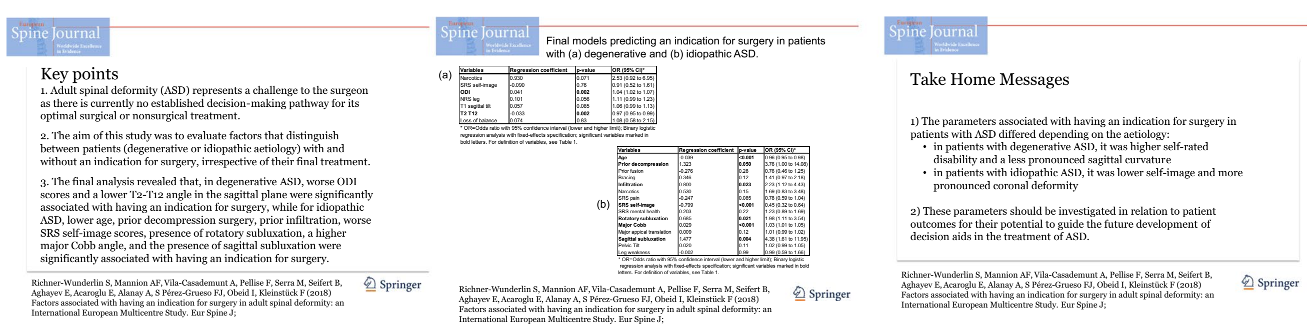
Purpose The aim of this study was to evaluate factors that distinguish between patients with adult spinal deformity (ASD) with and without an indication for surgery, irrespective of their final treatment.

Methods Baseline variables (demographics, medical history, outcome measures, coronal, sagittal and neurologic parameters) were evaluated in a multicentre, prospective cohort of patients with ASD. Multivariable analyses were carried out for idiopathic and degenerative patients separately with the dependent variable being "indication for surgery" and baseline parameters as independent variables.

Results In total, 342 patients with degenerative ASD and 624 patients with idiopathic ASD were included in the multivariable models. In patients with degenerative ASD, the parameters associated with having an indication for surgery were greater self-rated disability on the Oswestry Disability Index [odds ratio (OR) 1.04, 95% confidence interval (CI) 1.02–1.07] and a lower thoracic kyphosis (OR 0.97 95% CI 0.95–0.99), whereas in patients with idiopathic ASD, it was lower (worse) SRS self-image scores (OR 0.45 95% CI 0.32–0.64), a higher value for the major Cobb angle (OR 1.03 95% CI 1.01–1.05), lower age (OR 0.96 95% CI 0.95–0.98), prior decompression (OR 3.76 95% CI 1.00–14.08), prior infiltration (OR 2.23 95% CI 1.12–4.43), and the presence of rotatory subluxation (OR 1.98 95% CI 1.11–3.54) and sagittal subluxation (OR 4.38 95% CI 1.61–11.95).

Conclusion Specific sets of variables were found to be associated with an indication for surgery in patients with ASD. These should be investigated in relation to patient outcomes for their potential to guide the future development of decision aids in the treatment of ASD.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-018-5754-2) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Keywords Adult spinal deformity · Indication for surgery · Decision-making · Multivariable analyses · Prognostic factors

Introduction

Adult spinal deformity (ASD) encompasses a complex spectrum of spinal diseases that present in adulthood, including adult scoliosis, degenerative scoliosis or sagittal and coronal imbalance, with or without spinal stenosis [1]. ASD represents a challenge to the physician as there is currently no established decision-making pathway to determine the optimal surgical or nonsurgical treatment. Patients with ASD constitute a heterogeneous patient population with diverse clinical presentations, treatment indications and treatment outcomes. They report greater daily use of analgesics, greater functional limitations and lower health-related quality of life (HRQoL) compared with population norms [2–5]. Pellisé et al. [6] and the European Spine Study Group (ESSG) compared the relative burden of ASD with that of four self-reported chronic conditions (arthritis, chronic lung disease, diabetes, congestive heart failure) in the general population of eight industrialised countries and found that the global burden of ASD was large (lower SF36 scores in all domains) compared with these other chronic diseases [6]. Due to the gain in life expectancy and the rising expectations of older patients, the clinical management of ASD has become an increasingly important issue [7].

Several studies have attempted to evaluate decision-making processes in relation to surgical and nonsurgical treatment modalities and to investigate both patients' and surgeons' reasoning underlying treatment decisions [7–14]. In 2007, Glassman et al. [7] carried out a comparison of surgical and nonsurgical patients with a primary diagnosis of adult idiopathic scoliosis to reveal an array of clinical and radiographic parameters that were able to distinguish between them. Subsequently, similar analyses were conducted in patients with adult degenerative or idiopathic spinal deformity, mainly in American studies [7–12]. In 2016, Pizones et al. [13] and ESSG first provided similar analyses on a European patient population, analysing surgical and nonsurgical patients with untreated main thoracolumbar or lumbar idiopathic curves.The predominantly American studies, comparing patients who underwent surgery with those who did not, provide a certain amount of information regarding the factors that appear to influence the choice of treatment (surgery versus no surgery) in ASD, and hence the factors that might guide the indication for surgery. However, it is the patient that has the final say, regardless of the surgeon's recommendation; as such, if some patients ultimately refuse surgery, the data characterising treatment groups would be biased, since these patients would be analysed in the nonsurgical group despite their having an indication for surgery.

The European Spine Study Group (ESSG) is a group of European spinal deformity surgeons who instigated a comprehensive, prospective, multicentre, international ASD database to evaluate the clinical outcomes of patients with ASD undergoing nonsurgical or surgical treatment [6]. The aim of this study was to evaluate factors that distinguish between ESSG patients with and without an indication for surgery and in doing so to provide further data on the factors influencing treatment decision-making in European patients (ESSG cohort) with degenerative or idiopathic ASD.

Materials and methods

This was a post hoc cross-sectional analysis of the baseline data collected within the framework of the international multicentre ASD database of the ESSG (see above) and comprised the data from 6 European study sites, in 4 countries. An attempt was made to recruit into the ESSG database all consecutive patients who fulfilled the study admission criteria. The inclusion criteria were: ≥ 18 years of age; coronal spinal curvature $\geq 20°$ or a sagittal vertical axis (SVA) > 5 cm or a pelvic tilt > 25° or a thoracic kyphosis > 60°. Patients with cognitive impairment or confined to a wheelchair were excluded. Institutional review board approval was obtained at each participating institution prior to patient enrolment in the study.

The database was queried for patients registered between October 2010 and August 2016 (August 2015 for nonsurgical patients, when recruitment ceased) and diagnosed with either idiopathic or degenerative ASD. A new variable indicating whether the referring surgeon had considered that there had been an indication for surgery was retrospectively added (November 2015) to the database. The information was extracted from the patients' charts, focusing on the initial visits where the treatment decision was made and documented by the treating clinician. This was used to define two groups as "indication for surgery" versus "no indication for surgery" at presentation (regardless of subsequent treatment received) for comparison of their baseline characteristics. Baseline variables were exported from the database and grouped into six blocks: demographics, medical history, HRQoL questionnaires, coronal parameters, sagittal parameters and neurologic parameters (see Table 1 for details). Analyses were carried out separately for idiopathic and degenerative deformity patient groups. Continuous variables are presented as mean ± standard deviation (SD). Each block was analysed separately using binary logistic regression analysis with the dependent variable being "indication for surgery"

Table 1 47 baseline variables grouped into 6 blocks

Demographics	Medical history	Questionnaires	Coronal parameters	Sagittal parameters	Neurologic parameters
Gender[1]	Prior decompression[6]	SRS function	Coronal balance[21]	Sagittal subluxation[32]	Leg weakness[40]
Age[2]	Prior fusion[7]	SRS pain	Rotatory subluxation[22]	T10 L2 angle[33]	Numbness in legs[41]
BMI[3]	Years of spine problems[8]	SRS si[14]	Classification csvl[23]	L1S1 angle[34]	Loss of balance[42]
Smoker[4]	Bracing[9]	SRS mh[15]	Leglength discrepancy[24]	Pelvic tilt[35]	Bladder and/or bowel incontinence[43]
Comorbidity[5]	Previous therapies[10]	SF36 mcs[16]	Schwab curvetype[25]	Pelvic incidence[36]	Toe and/or heel walk[44]
	Infiltrations[11]	SF36 pcs[17]	Major Cobb angle[26]	T1 sagittal tilt[37]	Gait[45]
	Narcotics[12]	ODI[18]	Major curve location[27]	PI-LL[38]	
	Nsaids[13]	NRS leg[19]	Major apical translation[28]	T2 T12[39]	
		NRS back[20]	T1 ribbangle[29]		
			Pelvic obliquity[30]		
			Sacral obliquity[31]		

[1]Female = 0; male = 1, [2]Years; [3]kg m^{-2}, [4]No smoker = 0; smoker = 1, [5]Number of comorbidities all summed up; [6/7]No prior decompression/fusion = 0; prior decompression/fusion = 1, [8]Coded as 1 = less than 1 years; 2 = 1–2 years; 3 = 2–5 years; 4 = 5–10 years; 5 = greater than 10 years, [9]No bracing used as a therapy = 0; bracing used = 1; [10]Including chiropractor, physical therapy, rehabilitation, [11]No infiltrations = 0, prior infiltrations = 1; [12]No use of narcotics = 0; use of narcotics = 1, [13]Non-steroidal anti-inflammatory drugs; [14]SRS (1 worst; 5 best) self-image scores, [15]SRS mental health scores, [16]SF36 mental, [17]Physical component scores (scoring 0–100, the smaller the number the worse the score), [18]Oswestry disability index (scoring 0–100, the higher) the score the more disability, [19]Numeric rating scale 0–10 for leg and, [20]Back pain, [21]Alignment of C7 plumbline to centre sacral vertical line CSVL, [22]Lateral olisthesis or rotatory subluxation of 2 vertebra in anterior/posterior radiographs, [23]A = CSVL between pedicles, B = CSVL touches apical pedicle, C = apical vertebral bodies are completely lateral to CSVL, [24]Difference between the height of the tangent to the top of the highest femoral head and the height of the lower femoral head, [25]T = main thoracic curve > 30°, L = thoracolumbar curve > 30°, D = both curves > 30°, N = both curve < 30°, [26]Major Cobb angle in coronal plane, [27] Proximal thoracic PT, main thoracic MT, thoracolumbar/lumbar TL/L, lumbosacral LS, no coronal deformity, [28]Greatest distance between apical vertebra and CSVL, [29]T1 tilt in coronal plane, [30]Pelvic alignment in the coronal plane, [31]Tilt in the sacral endplate in the coronal plane, [32]Antero- or retrospondylolisthesis, [33]Angle between thoracic vertebra T10 and lumbar vertebra L2, [34]Angle between lumbar vertebra L1 and sacral endplate, [35]Angle subtended by a vertical reference line originating from the centre of the femoral head and the midpoint of the sacral end plate, [36]Angle subtended by a line that is drawn from the centre of the femoral head to the midpoint of the sacral end plate and a line perpendicular to the centre of the sacral endplate, [37]Angle between the vertical plumbline and the line between T1 and the middle of the femoral heads, [38]Pelvic incidence minus lumbar lordosis, [39]Angle between thoracic vertebra T2 and T12, [40]No leg weakness = 0; leg weakness = 1, [41]No numbness in legs = 0, numbness in legs = 1, [42]No loss of balance = 0, loss of balance = 1, [43]No bladder and/or bowel incontinence = 0; bladder and/or bowel incontinence = 1, [44]Not normal = 0, normal = 1, [45]Unsteady = 0, steady = 1

(yes/no) and all items from the block as independent variables. Forward, backward and simultaneous variable entry was used to find the best and most consistent predictive ability with the fewest independent variables. All significant parameters ($p \leq 0.05$) from each block were added to the final prediction model. Only complete cases were included, i.e. if a patient had missing data for any of the variables to be included in the final prediction model, they were excluded from the analysis. Figure 1 shows the process of data inclusion and indicates the proportion of missing data for each block. In order to account for potential unobservable factors, the 7 study sites were added as an additional factor variable within the models. The predicted group membership (indication vs. no indication for surgery) was compared with the actual group membership. The accuracy of the model was measured by the area under the curve of the Receiver Operating Characteristics (ROC) analysis. The predicted probability of having an indication for surgery was entered as the test variable, and the variable indication yes/no was used as the outcome variable. The level of significance was set to 0.05 throughout the study. All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, N.Y., USA).

Results

The database contained a total of 1300 patients with degenerative or idiopathic ASD (207 male and 1093 female; mean ± SD age, 49.6 ± 20.1 years), of which 444 (67.5 ± 10.6 years) had degenerative ASD and 856 (40.3 ± 17.4 years) idiopathic ASD. In total, 706 patients had had an indication for surgery (54.3 ± 19.2 years) and 516 had not (44.2 ± 19.9 years). The baseline data for all variables for patients with and without an indication for surgery are shown in Table 2 (degenerative ASD) and Table 3 (idiopathic ASD). For both aetiologies, indicators of symptom severity (e.g. worse HRQoL scores, presence of neurologic deficits, non-surgical treatments received to date) were more marked in patients with an indication for surgery. In the degenerative ASD group, those with an indication for surgery had a less

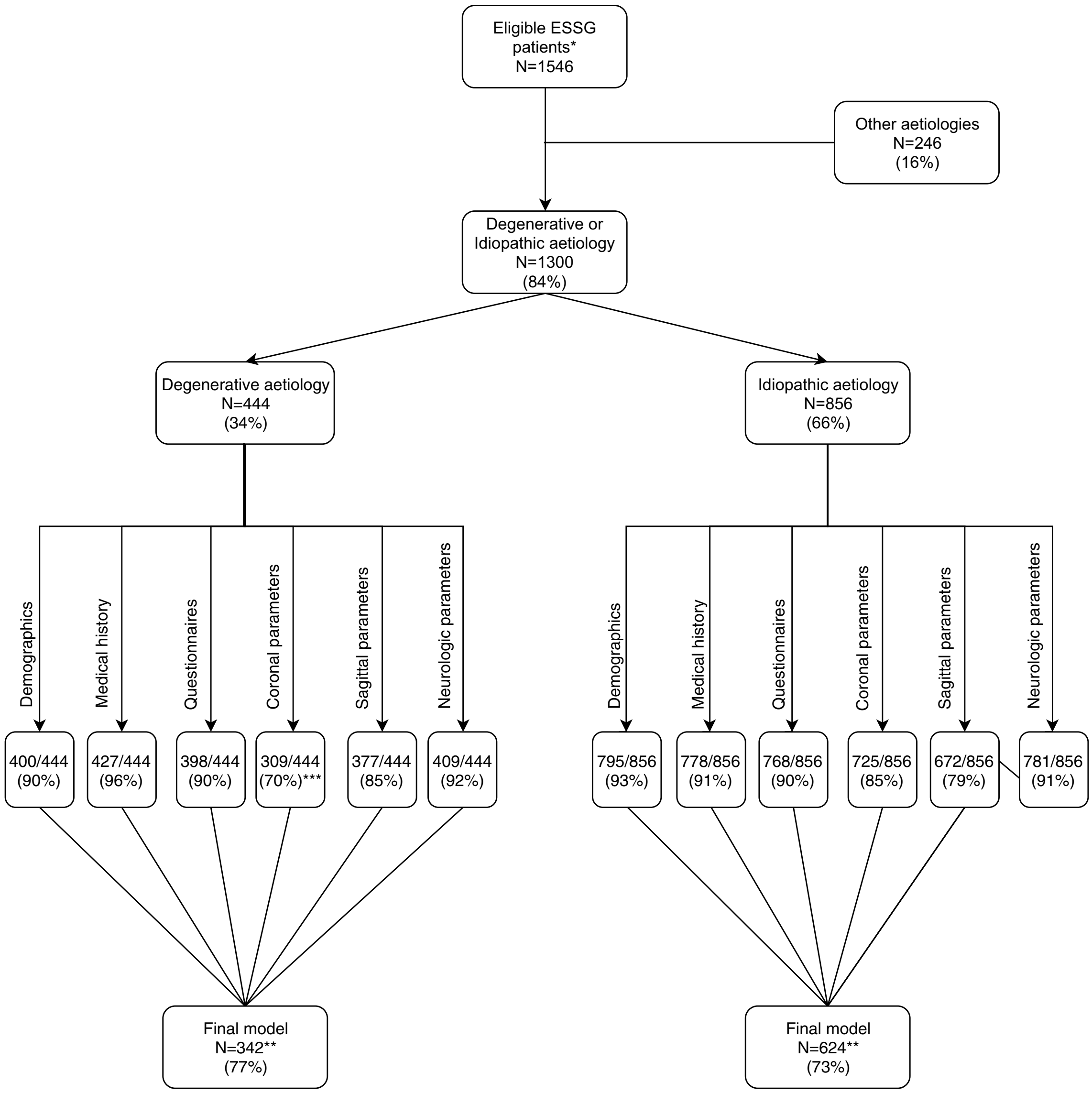


Fig. 1 Flow diagram of the process of data inclusion and proportion of data available for each of the blocks of parameters (independent variables). Proportion of data available for each of the blocks of parameters in %; *data exported in August 2016; **Complete cases used in the final model for patients with degenerative and idiopathic ASD; ***No variables selected for the multivariable model from this block

favourable sagittal profile [e.g. less lumbar lordosis, greater value for pelvic incidence minus lumbar lordosis (PI-LL)]; in the idiopathic ASD group, it was instead the parameters representing coronal plane deformity (e.g. greater major Cobb angle, presence of rotatory subluxation) that were more pronounced in the patients with an indication for surgery. In the degenerative ASD group, there were no significant differences between the "indication" groups for demographic variables; in the idiopathic ASD group, however, patients with an indication were slightly older, with higher BMI and more comorbidities.

From the total 444 patients with degenerative ASD, 342 (77%) with complete data were included in the multivariable model (267 with an indication for surgery vs. 75 without). Excluded cases were mostly due to missing radiological data (coronal balance, T1 rib angle, T1 sagittal tilt, T2–T12 angle). The final analysis revealed that, in degenerative ASD, just two variables were significantly associated with having an indication for surgery: worse ODI scores ($p = 0.002$) and a lower T2–T12 angle in the sagittal plane ($p = 0.002$) (i.e. less thoracic kyphosis) (Table 4).

Overall, 285 (83%) patients with degenerative ASD were correctly predicted through the model (i.e. as having an indication or not), with ROC analysis showing good accuracy of prediction, as measured by an area under the curve of 0.841 ($p < 0.001$; sensitivity = 95%; specificity = 41%).

Table 2 Baseline demographics and HRQoL data for patients with degenerative ASD, with and without an indication for surgery

Variables	Surgical indication		*p* value*
	Yes	No	
Total number of degenerative patients**	317	110	
Demographics			
Gender			0.11
Female	264 (83.3%)	84 (76.4%)	
Male	53 (16.7%)	26 (23.6%)	
Age (years)	67.6 ± 9.5	67.1 ± 13.5	0.72
BMI (kg m^{-2})	26.9 ± 4.8	26.1 ± 4.8	0.16
Number of smokers	59 (18.9%)	15 (13.6%)	0.21
Number of comorbidities	2.4 ± 1.7	2.3 ± 1.7	0.49
Medical history			
Prior surgery			
Prior decompression surgery	63 (20.7%)	19 (17.9%)	0.54
Prior fusion surgery	57 (18.2%)	12 (11.1%)	0.088
Years with spine problems			0.33
Less than 1 years	12 (3.8%)	7 (6.4%)	
1–2 years	15 (4.8%)	10 (9.1%)	
2–5 years	40 (12.8%)	15 (13.6%)	
5–10 years	67 (21.5%)	19 (17.3%)	
Greater than 10 years	178 (57.1%)	59 (53.6%)	
Bracing	77 (24.3%)	29 (26.4%)	0.66
Previous therapies	199 (62.8%)	67 (60.9%)	0.73
Infiltrations	128 (40.4%)	36 (32.7%)	0.16
Narcotics	93 (29.3%)	11 (10.0%)	< **0.001**
NSAIDs	188 (59.3%)	60 (54.5%)	0.38
Questionnaires			
SRS 22 questionnaire domains			
SRS function	2.8 ± 0.7	3.5 ± 0.8	< **0.001**
SRS pain	2.5 ± 0.8	3.1 ± 0.8	< **0.001**
SRS self-image	2.5 ± 0.8	3.1 ± 0.8	< **0.001**
SRS mental health	3.1 ± 0.9	3.6 ± 0.9	< **0.001**
SF 36 questionnaire domains			
SF36 mental component score	41.3 ± 12.5	46.6 ± 12.7	< **0.001**
SF36 physical component score	33.8 ± 7.6	39.9 ± 8.9	< **0.001**
Oswestry disability Index (ODI)	48.1 ± 17.2	31.7 ± 17.4	< **0.001**
Numeric rating scales			
NRS leg pain	5.4 ± 3.1	3.7 ± 3.1	< **0.001**
NRS back pain	6.6 ± 2.5	5.9 ± 2.3	< 0.001
Coronal parameters			
Coronal balance (mm)	23.3 ± 22.4	19.9 ± 17.5	0.18
Rotatory subluxation	140 (44.9%)	65 (60.7%)	**0.005**
Classification CSVL			0.62
A (CSVL between pedicles)	75 (24.1%)	21 (19.8%)	
B (CSVL touches apical pedicle)	89 (28.6%)	34 (32.1%)	
C (apical vertebral bodies completely lateral to CSVL)	147 (47.3%)	51 (48.1%)	
Leg lengths discrepancy (mm)	− 0.43 ± 6.7	− 0.47 ± 8.6	0.97
Schwab curve type			0.34
Double curve (main thoracic and thoracolumbar more than 30°)	20 (6.4%)	12 (11.3%)	
Thoracolumbar/lumbar curve only	97 (31.0%)	32 (30.2%)	
Thoracic curve only	8 (2.6%)	4 (3.8%)	

Table 2 (continued)

Variables	Surgical indication		*p* value*
	Yes	No	
No major coronal deformity	188 (60.1%)	58 (54.7%)	
Major Cobb angle (°)	29.3 ± 14.1	31.2 ± 11.3	0.18
Major curve location			**0.035**
Proximal thoracic; no coronal deformity; lumbosacral/sacral	41 (13.1%)	6 (5.6%)	
Thoracolumbar/lumbar; main thoracic	273 (86.9%)	101 (94.4%)	
Major apical translation (mm)	28.6 ± 16.5	29.1 ± 18.2	0.79
T1 ribb angle (°)	4.0 ± 4.5	3.2 ± 3.5	0.15
Pelvic obliquity (°)	1.89 ± 1.6	1.94 ± 1.5	0.80
Sacral obliquity (°)	− 0.87 ± 4.9	− 1.12 ± 5.0	0.66
Sagittal parameters			
Sagittal subluxation	78 (25.4%)	27 (25.2%)	0.97
T10–L2 angle (°)	9.6 ± 15.9	9.5 ± 18.0	0.97
L1–S1 angle (°)	− 37.24 ± 19.1	− 44.4 ± 17.3	**0.001**
Pelvic tilt (°)	26.1 ± 9.4	24.5 ± 9.8	0.13
Pelvic incidence (°)	57.0 ± 13.2	56.5 ± 12.7	0.73
T1 sagittal tilt (°)	0.22 ± 5.9	− 2.63 ± 4.9	< **0.001**
PI-LL (°)	19.4 ± 18.2	11.9 ± 16.3	< **0.001**
T2–T12 (°)	37.5 ± 17.1	45.4 ± 15.0	< **0.001**
Neurologic parameters			
Leg weakness	167 (54.9%)	48 (44.4%)	0.061
Numbness in legs	159 (52.5%)	41 (38.0%)	**0.010**
Loss of balance	131 (43.4%)	32 (29.9%)	**0.014**
Bladder and/or bowel incontinence	57 (18.0%)	20 (18.2%)	0.96
Toe and/or heel walk impairment	116 (36.6%)	24 (21.8%)	**0.004**
Gait impairment (unsteady)	61 (21.4%)	12 (11.0%)	**0.018**

Significant *p*-values ($p \leq 0.05$) are shown in bold

**p* values after independent samples *t* test (continuous variables) or Pearson Chi-square test (categorical variables)

**For 17/444 cases, this information was not available or unsure

Data are mean ± standard deviation (SD) or frequency with per cent of group total

From the total 856 patients with idiopathic ASD, 624 (73%) with complete data were included in the multivariable model (317 with an indication for surgery vs. 307 without). Excluded cases were mostly due to missing radiological data (coronal balance, leg length discrepancy, major apical translation, PI-LL, pelvic tilt, pelvic incidence, T1 sagittal tilt). The final analysis revealed that the following variables were significantly associated with having an indication for surgery: lower age ($p < 0.001$), prior decompression surgery ($p = 0.050$), prior infiltration ($p = 0.023$), lower (i.e. worse) SRS self-image scores ($p < 0.001$), presence of rotatory subluxation ($p = 0.021$), a higher value for the major Cobb angle ($p < 0.001$) and the presence of sagittal subluxation ($p = 0.004$) (Table 5).

Overall, 465 (75%) patients with idiopathic ASD were correctly predicted through the model, with ROC analysis showing good accuracy of prediction, as measured by an area under the curve of 0.826 ($p < 0.001$; sensitivity = 75%; specificity = 74%).

Discussion

This study aimed to identify factors associated with having an indication for surgery in the ESSG cohort of patients with degenerative or idiopathic ASD. In univariable analyses, patients with an indication for surgery (both idiopathic and degenerative) showed consistently worse HRQoL scores, in all domains, than those with no such indication. These findings are consistent with those reported previously in relation to actual treatment received (surgical versus nonsurgical) [7, 9, 11, 14]. In multivariable analyses, one HRQoL variable remained significant in the model for both idiopathic and degenerative groups, although the precise domain selected

Table 3 Baseline demographic and HRQoL data for patients with idiopathic ASD, with and without an indication for surgery

Variables	Surgical indication		*p* value*
	Yes	No	
Total number of idiopathic patients**	389	406	
Demographics			
Gender			0.65
Female	330 (84.8%)	349 (86.0%)	
Male	59 (15.2%)	57 (14.0%)	
Age (years)	43.4 ± 18.1	38.0 ± 16.6	**< 0.001**
Mean BMI (kg m^{-2})	23.2 ± 4.4	22.3 ± 3.8	**0.004**
Number of smokers	76 (19.7%)	86 (21.3%)	0.59
Number of comorbidities	1.3 ± 1.6	0.8 ± 1.3	**< 0.001**
Medical history			
Prior surgery			
Prior decompression surgery	21 (5.6%)	9 (2.2%)	**0.016**
Prior fusion surgery	96 (24.8%)	146 (36.0%)	**0.001**
Years with spine problems			0.08
Less than 1 years	4 (1.0%)	15 (3.7%)	
1–2 years	15 (3.9%)	16 (4.0%)	
2–5 years	38 (9.8%)	36 (8.9%)	
5–10 years	53 (13.7%)	69 (17.1%)	
Greater than 10 years	277 (71.6%)	268 (66.3%)	
Bracing	182 (46.8%)	151 (37.2%)	**0.006**
Previous therapies	264 (67.9%)	265 (65.3%)	0.44
Infiltrations	74 (19.0%)	27 (6.7%)	**< 0.001**
Narcotics	77 (19.8%)	23 (5.7%)	**< 0.001**
NSAIDs	186 (47.8%)	182 (44.8%)	0.40
Questionnaires			
SRS 22 questionnaire domains			
SRS function	3.5 ± 0.9	4.0 ± 0.8	**< 0.001**
SRS pain	2.9 ± 1.0	3.6 ± 0.9	**< 0.001**
SRS self-image	2.7 ± 0.8	3.4 ± 0.8	**< 0.001**
SRS mental health	3.2 ± 0.8	3.5 ± 0.8	**< 0.001**
SF 36 questionnaire domains			
SF36 mental component score	43.5 ± 10.8	46.2 ± 10.3	**< 0.001**
SF36 physical component score	39.8 ± 9.9	44.8 ± 9.1	**< 0.001**
Oswestry disability Index (ODI)	30.5 ± 19.0	19.7 ± 16.1	**< 0.001**
Numeric rating scales			
NRS leg pain	3.0 ± 3.3	2.1 ± 2.8	**< 0.001**
NRS back pain	6.1 ± 2.5	4.5 ± 2.7	**< 0.001**
Coronal parameters			
Coronal balance (mm)	18.6 ± 16.3	15.9 ± 11.9	**0.010**
Rotatory subluxation	113 (29.2%)	54 (13.5%)	**< 0.001**
Classification CSVL			0.017
A (CSVL between pedicles)	54 (14.0%)	75 (18.9%)	
B (CSVL touches apical pedicle)	77 (20.0%)	99 (25.0%)	
C (apical vertebral bodies completely lateral to CSVL)	254 (66.0%)	222 (56.1%)	
Leg lengths discrepancy (mm)	− 0.5 ± 5.7	− 0.6 ± 5.5	0.81
Schwab curve type			**< 0.001**
Double curve (main thoracic and thoracolumbar more than 30°)	209 (54.1%)	166 (41.8%)	
Thoracolumbar/lumbar curve only	84 (21.8%)	62 (15.6%)	
Thoracic curve only	52 (13.5%)	76 (19.1%)	

Table 3 (continued)

Variables	Surgical indication		*p* value*
	Yes	No	
No major coronal deformity	41 (10.6%)	93 (23.4%)	
Major Cobb angle (°)	54.26 ± 19.7	44.3 ± 18.0	< **0.001**
Major curve location			0.90
Proximal thoracic; no coronal deformity; lumbosacral/sacral	12 (3.1%)	13 (3.3%)	
Thoracolumbar/lumbar; main thoracic	374 (96.9%)	385 (96.7%)	
Major apical translation (mm)	45.5 ± 23.0	34.3 ± 21.5	< **0.001**
T1 ribb angle (°)	4.4 ± 4.3	4.4 ± 4.4	0.85
Pelvic obliquity (°)	2.17 ± 1.9	2.01 ± 1.8	0.25
Sacral obliquity (°)	− 1.94 ± 5.5	− 1.86 ± 4.4	0.83
Sagittal parameters			
Sagittal subluxation	35 (9.1%)	11 (2.7%)	< **0.001**
T10–L2 angle (°)	10.12 ± 16.6	5.3 ± 13.9	< **0.001**
L1–S1 angle (°)	− 50.1 ± 18.7	− 56.5 ± 14.3	< **0.001**
Pelvic tilt (°)	18.2 ± 10.9	14.9 ± 10.1	< **0.001**
Pelvic incidence (°)	53.8 ± 12.9	54.2 ± 12.5	0.65
T1 sagittal tilt (°)	− 3.62 ± 4.5	− 4.8 ± 3.5	< **0.001**
PI-LL (°)	3.6 ± 19.4	− 2.5 ± 15.3	< **0.001**
T2–T12 (°)	38.6 ± 17.8	39.8 ± 15.2	0.31
Neurologic parameters			
Leg weakness	122 (32.3%)	74 (18.4%)	< **0.001**
Numbness in legs	123 (32.3%)	82 (20.3%)	< **0.001**
Loss of balance	105 (27.7%)	73 (18.1%)	**0.001**
Bladder and/or bowel incontinence	33 (8.5%)	31 (7.6%)	0.66
Toe and/or heel walk impairment	43 (11.1%)	23 (5.7%)	**0.006**
Gait impairment (unsteady)	14 (3.7%)	12 (3.0%)	0.56

Significant *p*-values ($p \leq 0.05$) are shown in bold

**p* values after independent samples *t* test (continuous variables) or Pearson Chi square test (categorical variables)

**For 61/856 cases, this information was not available or unsure

Data are mean ± standard deviation (SD) or frequency with per cent of group total

Table 4 Factors associated with an indication for surgery in patients with degenerative ASD in the final model

Variables	Regression coefficient	*p* value	OR (95% CI)[a]
Narcotics	0.930	0.071	2.53 (0.92–6.95)
SRS self-image	− 0.090	0.76	0.91 (0.52–1.61)
ODI	0.041	**0.002**	1.04 (1.02–1.07)
NRS leg	0.101	0.056	1.11 (0.99–1.23)
T1 sagittal tilt	0.057	0.085	1.06 (0.99–1.13)
T2 T12	− 0.033	**0.002**	0.97 (0.95–0.99)
Loss of balance	0.074	0.83	1.08 (0.58–2.15)

[a]OR = Odds ratio with 95% confidence interval (lower and upper limit); binary logistic regression analysis with fixed-effects specification; significant variables marked in bold letters. For definition of variables, see Table 1

for inclusion differed between the two ASD aetiologies. Patients with degenerative ASD had a significantly greater chance of having an indication for surgery if their pain-related disability scores (ODI) were worse, highlighting the major importance to the older population of being able to carry out functional tasks such as walking, sitting or lifting. These findings are comparable with those of Bess et al. [9], who concluded that pain and disability determine the treatment modality in older patients, whereas deformity guides it for younger patients. In the present study, patients with idiopathic ASD who had an indication for surgery had significantly worse SRS self-image scores.

In univariable analyses, there were no significant indication-dependent differences in demographic variables for patients with degenerative ASD. However, patients with idiopathic ASD and an indication for surgery were significantly older and had a higher BMI than those with no indication. In multivariable analyses for idiopathic patients, however, age

Table 5 Factors associated with an indication for surgery in patients with idiopathic ASD in the final model

Variables	Regression coefficient	*p* value	OR (95% CI)[a]
Age	−0.039	**<0.001**	0.96 (0.95–0.98)
Prior decompression	1.323	**0.050**	3.76 (1.00–14.08)
Prior fusion	−0.276	0.28	0.76 (0.46–1.25)
Bracing	0.346	0.12	1.41 (0.97–2.18)
Infiltration	0.800	**0.023**	2.23 (1.12–4.43)
Narcotics	0.530	0.15	1.69 (0.83–3.48)
SRS pain	−0.247	0.085	0.78 (0.59–1.04)
SRS self-image	−0.799	**<0.001**	0.45 (0.32–0.64)
SRS mental health	0.203	0.22	1.23 (0.89–1.69)
Rotatory subluxation	0.685	**0.021**	1.98 (1.11–3.54)
Major Cobb	0.029	**<0.001**	1.03 (1.01–1.05)
Major apical translation	0.009	0.12	1.01 (0.99–1.02)
Sagittal subluxation	1.477	**0.004**	4.38 (1.61–11.95)
Pelvic tilt	0.020	0.11	1.02 (0.99–1.05)
Leg weakness	−0.002	0.99	0.99 (0.59–1.66)

[a]OR = Odds ratio with 95% confidence interval (lower and upper limit); binary logistic regression analysis with fixed-effects specification; significant variables marked in bold letters. For definition of variables, see Table 1

had an inverse relationship with the likelihood of having an indication, i.e. after controlling for all other significant variables, there was a greater chance of having an indication for surgery with younger age, and BMI was not significant in the model. The findings with respect to age may be explained by the fact that surgery is considered in order to avoid the progression and worsening of curves in adult idiopathic scoliosis patients [15] such that, all else being the same, surgery is typically conducted at a younger age.

In univariable analyses, patients with an indication for surgery (both degenerative and idiopathic aetiologies) showed greater neurologic impairment and were more likely to use narcotics, possibly reflecting a worse symptom status. However, in multivariable analyses none of these variables were significant, most likely because the information regarding symptom status was carried by other more significant variables (such as patient-rated HRQL measures). Significantly, more idiopathic patients with an indication for surgery had used bracing and had had prior infiltrations, and the latter was also significant in the multivariable model. This was likely a reflection of the fact that patients with an indication for surgery had exhausted all available nonsurgical treatments. Further, infiltrations are typically used for diagnostic purposes [16] and for initial nonsurgical pain treatment [17] before proceeding to surgery. Unfortunately, we were unable to ascertain within the database the specific reasons for prior infiltrations (diagnostic or therapeutic). Compared with those with no indication for surgery, fewer idiopathic patients with an indication had previously undergone fusion but a higher proportion had received decompression surgery, with the latter also playing a significant role in the final multivariable model. This may reflect a strategy in which the first surgical approach involves the least invasive intervention possible.

In univariable analyses of coronal plane parameters, patients with degenerative ASD who had an indication for surgery were significantly more likely to have rotatory subluxation, although this variable was no longer significant in the multivariable model. In previous studies, rotatory subluxation has been one of the radiographic parameters that has been shown to be most highly correlated with patient-reported outcomes [18], possibly because it is associated with spinal canal stenosis. Idiopathic patients with an indication for surgery showed significantly more marked coronal deformity than those without an indication for surgery, manifest in univariable analyses as a higher incidence of rotatory subluxation, larger major Cobb angles and more major apical translation. Fu et al. [11] and Bess et al. [9] also found larger maximal scoliosis/larger main thoracic curves, and Glassman et al. [7] confirmed higher thoracolumbar apical translations in surgical patients. In multivariable analyses, two indicators of the severity of deformity in the coronal plane—rotatory subluxation and major Cobb angle—remained significantly associated with having an indication for surgery in patients with idiopathic ASD. These findings also fit with the worse scores for self-reports of self-image, mental health and disability for patients with an indication for surgery.

In univariable analyses, trends for an association between a number of sagittal parameters and an indication for surgery were seen in both degenerative and idiopathic aetiologies. In the multivariable model, patients with degenerative ASD had a significantly greater chance of having an indication for surgery if they had lower T2–T12 angles, characterising the less-pronounced curvature of the spine in the sagittal plane. Low thoracic kyphosis is very probably a compensatory mechanism for low lumbar lordosis and PI-LL mismatch. Finally, in the multivariable analysis for patients with idiopathic ASD, the presence of spondylolisthesis (both retro- and anterolisthesis) also increased the chances of having an indication for surgery. Segmental malalignment has important consequences for the motion segment and for the neural elements, and on the function as well as the alignment of adjacent segments of the spine [19]. Neurologic symptoms are an important part of the clinical presentation of adult deformity, and an important reason to pursue operative care for deformity [10].

There are several limitations to this study. First, having an indication for surgery was evaluated by the treating surgeon and it is possible that different surgeons had different treatment philosophies and thresholds for surgery. However, including a number of different surgeons with their respective expert opinions may have prevented the bias otherwise associated with a single surgeon's perspective. Moreover, all the surgeons whose patients were included in the present study are considered to be highly experienced, opinion leaders in deformity surgery, applying a "best-practice" approach to decision-making. Second, a disadvantage of stepwise binary logistic regression is that the absence of a single data point for a given patient renders a patient unusable for the entire analysis, which results in a lower analysed number of patients. However, 966 out of 1300 patients could be analysed in the prediction model, providing an analysis that still had a higher number of patients compared with previous studies ($n = 139$–497). Third, not all patients included in the study actually presented for treatment as such; instead, some of them in the nonsurgical group were simply enrolled during their routine follow-up visit. Nonetheless, had they experienced notable problems characteristic of those defining the surgical patient, then they would presumably still have been eligible for surgery, and hence we feel they still make a valid "no indication" comparator group. For future studies, it might be wise to better define the nature of baseline visits in this patient population to obtain a more homogeneous patient cohort. This might also strengthen the model allowing for a higher number of correctly predicted cases. Finally, the decision-making processes of the patient were not considered in the analysis, although the study did at least focus on the suitability for surgery rather than the actual treatment received.

It was not possible within the confines of the present study to include an analysis of treatment outcomes related to having an indication or not; however, this will be the focus of future projects as the current dataset matures. With the surgical "indicators" identified in the present study, it should be possible to evaluate whether patients who are predicted on the basis of their presenting history, symptoms and radiology to have an indication for surgery actually have better outcomes than those patients that represent less convincing surgical cases; and similarly, whether those predicted to have an indication really do fare better after surgery than after nonsurgical care.

The present study provides a further perspective on surgical decision-making in a large number of European ASD patients and includes the analysis of additional, potential predictors. Degenerative and idiopathic patient groups were analysed separately, and in relation to their indication for surgical treatment regardless of the actual treatment received. This obviates the potential bias seen when a surgical indication is given for a certain patient, but surgery is refused by the patient for whatever reason. This methodological difference compared with previously published studies in this field may provide a more objective analysis regarding treatment decision-making pathways. Future studies on this patient cohort should include analyses of the outcomes to confirm and strengthen the model and to evaluate whether those patients who fulfil the model's "surgical indication" criteria benefit more from surgery than those who do not. In this way, the variables associated with having an indication for surgery may help in establishing thresholds for surgery and guiding the development of decision aids for the treatment of ASD.

Conclusion

This study evaluated a large cohort of patients with either degenerative or idiopathic ASD, from 4 European countries, and provided separate, comprehensive but parsimonious multivariable models predicting an indication for surgery or not. Different parameters influenced the chances of having an indication for surgery for these patient groups: it was predominantly disability and a less-pronounced sagittal curvature in the group with degenerative ASD, and predominantly low self-image and more pronounced coronal deformity in the patients with idiopathic ASD. These factors may represent the starting point for expert groups to hone the indications and help guide decision-making in relation to the surgical treatment of patients with degenerative or idiopathic ASD.

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Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

References

1. Birknes JK, White AP, Albert TJ, Shaffrey CI, Harrop JS (2008) Adult degenerative scoliosis: a review. Neurosurgery 63(3 Suppl):94–103. https://doi.org/10.1227/01.neu.0000325485.49323.b2
2. Baldus C, Bridwell KH, Harrast J, Edwards C 2nd, Glassman S, Horton W, Lenke LG, Lowe T, Mardjetko S, Ondra S, Schwab F, Shaffrey C (2008) Age-gender matched comparison of SRS instrument scores between adult deformity and normal adults: are all SRS domains disease specific? Spine 33(20):2214–2218. https://doi.org/10.1097/BRS.0b013e31817c0466
3. Baldus C, Bridwell K, Harrast J, Shaffrey C, Ondra S, Lenke L, Schwab F, Mardjetko S, Glassman S, Edwards C 2nd, Lowe T, Horton W, Polly D Jr (2011) The Scoliosis Research Society Health-Related Quality of Life (SRS-30) age-gender normative data: an analysis of 1346 adult subjects unaffected by scoliosis. Spine 36(14):1154–1162. https://doi.org/10.1097/BRS.0b013e3181fc8f98
4. Berven S, Deviren V, Demir-Deviren S, Hu SS, Bradford DS (2003) Studies in the modified Scoliosis Research

Society Outcomes Instrument in adults: validation, reliability, and discriminatory capacity. Spine 28(18):2164–2169. https://doi.org/10.1097/01.brs.0000084666.53553.d6 **(discussion 2169)**
5. Dickson JH, Mirkovic S, Noble PC, Nalty T, Erwin WD (1995) Results of operative treatment of idiopathic scoliosis in adults. J Bone Joint Surg Am 77(4):513–523
6. Pellise F, Vila-Casademunt A, Ferrer M, Domingo-Sabat M, Bago J, Perez-Grueso FJ, Alanay A, Mannion AF, Acaroglu E (2015) Impact on health related quality of life of adult spinal deformity (ASD) compared with other chronic conditions. Eur Spine J 24(1):3–11. https://doi.org/10.1007/s00586-014-3542-1
7. Glassman SD, Schwab FJ, Bridwell KH, Ondra SL, Berven S, Lenke LG (2007) The selection of operative versus nonoperative treatment in patients with adult scoliosis. Spine 32(1):93–97. https://doi.org/10.1097/01.brs.0000251022.18847.77
8. Smith JS, Fu KM, Urban P, Shaffrey CI (2008) Neurological symptoms and deficits in adults with scoliosis who present to a surgical clinic: incidence and association with the choice of operative versus nonoperative management. J Neurosurg Spine 9(4):326–331. https://doi.org/10.3171/spi.2008.9.10.326
9. Bess S, Boachie-Adjei O, Burton D, Cunningham M, Shaffrey C, Shelokov A, Hostin R, Schwab F, Wood K, Akbarnia B (2009) Pain and disability determine treatment modality for older patients with adult scoliosis, while deformity guides treatment for younger patients. Spine 34(20):2186–2190. https://doi.org/10.1097/BRS.0b013e3181b05146
10. Pekmezci M, Berven SH, Hu SS, Deviren V (2009) The factors that play a role in the decision-making process of adult deformity patients. Spine 34(8):813–817. https://doi.org/10.1097/BRS.0b013e3181851ba6
11. Fu KM, Bess S, Shaffrey CI, Smith JS, Lafage V, Schwab F, Burton DC, Akbarnia BA, Ames CP, Boachie-Adjei O, Deverin V, Hart RA, Hostin R, Klineberg E, Gupta M, Kebaish K, Mundis G, Mummaneni PV (2014) Patients with adult spinal deformity treated operatively report greater baseline pain and disability than patients treated nonoperatively; however, deformities differ between age groups. Spine 39(17):1401–1407. https://doi.org/10.1097/brs.0000000000000414
12. Fu KM, Smith JS, Sansur CA, Shaffrey CI (2010) Standardized measures of health status and disability and the decision to pursue operative treatment in elderly patients with degenerative scoliosis. Neurosurgery 66(1):42–47. https://doi.org/10.1227/01.neu.0000361999.29279.e6 **(discussion 47)**
13. Pizones J, Perez Martin-Buitrago M, Perez-Grueso FJ, Vila-Casademunt A, Alanay A, Obeid I, Kleinstuck F, Acaroglu ER, Pellise F (2017) Function and clinical symptoms are the main factors that motivate thoracolumbar adult scoliosis patients to pursue surgery. Spine 42(1):E31-e36. https://doi.org/10.1097/brs.0000000000001694
14. Fujishiro T, Boissiere L, Cawley DT, Larrieu D, Gille O, Vital JM, Pellise F, Perez-Grueso FJS, Kleinstuck F, Acaroglu E, Alanay A, Obeid I (2018) Decision-making factors in the treatment of adult spinal deformity. Eur Spine J. https://doi.org/10.1007/s00586-018-5572-6
15. Maruyama T, Takeshita K (2009) Surgery for idiopathic scoliosis: currently applied techniques. Clin Med Pediatrics 3:39–44
16. Datta S, Everett CR, Trescot AM, Schultz DM, Adlaka R, Abdi S, Atluri SL, Smith HS, Shah RV (2007) An updated systematic review of the diagnostic utility of selective nerve root blocks. Pain Phys 10(1):113–128
17. Manchikanti L, Kaye AD, Boswell MV, Bakshi S, Gharibo CG, Grami V, Grider JS, Gupta S, Jha SS, Mann DP, Nampiaparampil DE, Sharma ML, Shroyer LN, Singh V, Soin A, Vallejo R, Wargo BW, Hirsch JA (2015) A systematic review and best evidence synthesis of the effectiveness of therapeutic facet joint interventions in managing chronic spinal pain. Pain Phys 18(4):E535–E582
18. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, Farcy JP (2005) Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine 30(9):1082–1085
19. Ames CP, Scheer JK, Lafage V, Smith JS, Bess S, Berven SH, Mundis GM, Sethi RK, Deinlein DA, Coe JD, Hey LA, Daubs MD (2016) Adult spinal deformity: epidemiology, health impact, evaluation, and management. Spine Deform 4(4):310–322. https://doi.org/10.1016/j.jspd.2015.12.009

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