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ORIGINAL ARTICLE

Surgeons' risk perception in ASD surgery: The value of objective risk assessment on decision making and patient counselling

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Abstract

Background Surgeons often rely on their intuition, experience and published data for surgical decision making and informed consent. Literature provides average values that do not allow for individualized assessments. Accurate validated machine learning (ML) risk calculators for adult spinal deformity (ASD) patients, based on 10 year multicentric prospective data, are currently available. The objective of this study is to assess surgeon ASD risk perception and compare it to validated risk calculator estimates.

Methods Nine ASD complete (demographics, HRQL, radiology, surgical plan) preoperative cases were distributed online to 100 surgeons from 22 countries. Surgeons were asked to determine the risk of major complications and reoperations at 72 h, 90 d and 2 years postop, using a 0–100% risk scale. The same preoperative parameters circulated to surgeons were used to obtain ML risk calculator estimates. Concordance between surgeons' responses was analyzed using intraclass correlation coefficients (ICC) (poor < 0.5/excellent > 0.85). Distance between surgeons' and risk calculator predictions was assessed using the mean index of agreement (MIA) (poor < 0.5/excellent > 0.85).

Results Thirty-nine surgeons (74.4% with > 10 years' experience), from 12 countries answered the survey. Surgeons' risk perception concordance was very low and heterogeneous. ICC ranged from 0.104 (reintervention risk at 72 h) to 0.316 (reintervention risk at 2 years). Distance between calculator and surgeon prediction was very large. MIA ranged from 0.122 to 0.416. Surgeons tended to overestimate the risk of major complications and reintervention in the first 72 h and underestimated the same risks at 2 years postop.

Conclusions This study shows that expert surgeon ASD risk perception is heterogeneous and highly discordant. Available validated ML ASD risk calculators can enable surgeons to provide more accurate and objective prognosis to adjust patient expectations, in real time, at the point of care.

Keywords Adult spinal deformity · Surgery · Risk perception · Machine learning · Computerized decision support tools

Introduction

Patient counseling and surgical informed consent are guided by the treating physician based on his/her intuition, experience and published data. This common approach may not be optimal, especially for high-risk patients facing major surgeries [1]. Patients suffering symptomatic adult spinal deformity (ASD) may have different surgical options and preferences [2]. The final treatment strategy is generally decided by the treating surgeon considering patient characteristics, preferences and invasiveness, in an effort to favorably balance risks and benefits.

A major concern regarding ASD surgery is its high rate of associated complications [3–8]. The reported incidence varies among studies, but can be greater than 70% [4], especially in patients older than 70 in whom rates > 90% have been described [9]. Perioperative and postoperative complications can have a negative impact on mid-and long-term

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health-related quality of life (HRQL) [10] and increase healthcare costs [11]. Most studies express the risk of complications providing mean odds ratios (OR) with the corresponding confidence intervals [7, 12, 13], but the ASD population is extremely heterogeneous, and mean values do not allow proper individualized risk assessment for the majority of patients. Multidisciplinary committees have been created in some centers to improve risk assessment in ASD and other pathologies requiring complex surgeries [14]. The heterogeneity and complexity of ASD patients and the diversity of therapeutic options, together with the large number of factors that may have an impact on surgical outcomes, make meaningful ASD preoperative risk assessment extremely challenging for spine surgeons.

It is well recognized that human decision making is often subject to bias [15]. The development of debiasing strategies in high-risk medical decision making has the potential to increase service quality and patient safety. Debiasing often requires moving away from heuristic decision making towards a more analytical, evidence-based and system-supported reasoning approach [16, 17]. Robust predictive models are a method to improve risk assessment by reducing subjectivity. The first computerized decision support tool (CDST) for predicting complications and outcomes in ASD surgery based on accurate machine learning (ML) algorithms has been recently published and validated [18–20]. The discrimination indices of these models range from 65.8 to 71.0%.

The accuracy of surgeon risk perception in ASD, which is still standard practice in patient counselling and informed consent, has not been investigated. The objectives of this study are to assess ASD surgeon's risk perception and to compare it to the recently validated predictive ASD risk calculators.

Methods

Study format

Nine complete ASD cases were distributed online through Survey Monkey platform to 100 surgeons from 22 countries. Each case was based on a real scenario and contained the information needed to assess the surgical risk and outcome of surgery. It included key patient demographics and preoperative data (age, gender, height, weight, previous spine surgeries, comorbidities, pain and neurological symptoms), HRQoL scores (preoperative Oswestry disability index and Scoliosis Research Society-22r subtotal score), radiographic parameters (Coronal: major cobb angle, major cobb localization and C7-Sacral vertical line; Sagittal: sagittal vertical axis, global tilt, lumbar lordosis, pelvic incidence, pelvic tilt) and other imaging (most clinically relevant MRI and CT scans images). Surgeons were also provided with the surgical indication and the proposed surgical plan for each case (number of stages and approach, number of levels fused, upper instrumented vertebra, lower instrumented vertebra, number of posterior and anterior interbody fusions, number of decompressions, number and type of osteotomies). The same preoperative parameters circulated to surgeons were used to generate risk-benefit estimates using validated CDST.

The CDST used for this study are on-line predictive ASD surgical risk calculators that were developed based on ML algorithms trained with 10 year multicentric prospective data [18–20]. The models were trained using 2,286 ASD surgical patients from 23 international sites. A random 80/20% training/testing samples approach was employed for external validation of the models. Threefold cross validation was performed to assess the internal validity of the models. Harrell's C statistic [21] assessed the discrimination of the prognostic model, and the Brier score was used for calibration. Random survival forests were fitted to each of the time-to-event prognosis models.

Clinical vignettes

The 9 clinical vignettes were carefully selected to cover the wide spectrum of deformities and patients included under the diagnosis of ASD, as well as the most relevant risk factors (patient characteristics and surgical invasiveness) of major complications and reinterventions, identified by recent ML analysis (17). Of the 9 cases, 7 (77.8%) patients were women, 4 (44.4%) had been previously operated, 2 were less than 45 years of age, 3 were between 45 and 60 years of age, and 4 were older than 60 years. Four (44.4%) patients had associated comorbidities (neurologic, cardiac, pulmonary, metabolic and osteoporosis). Surgical treatment included pelvic fixation in 6 cases, 3-column osteotomies in 5 cases (PSO 3 cases, VCR 2 cases) and combined anterior–posterior surgery in 2 cases. Length of fusion ranged from 6 to 18 segments (mean 11.3).

Variables

For each case, participating surgeons were asked to generate six probabilistic estimates: 2 outcomes (risk of major complications and reoperations) at 3 postoperative time points (72 h, 90 days and 2 years). Participants estimated the risk using a scale ranging from 0 to 100% risk.

Each surgeon also disclosed the number of years in practice, the annual number of ASD surgeries and his/her previous experience using the CDSTs.

Statistical analysis

Concordance among surgeons' responses was analyzed using Intraclass Correlation Coefficients (ICCs). Distance between surgeons' and risk calculator predictions was assessed using the mean index of agreement (MIA).

ICCs and MIA values range between 0 and 1, with values closer to 1 representing stronger concordance. Based on the 95% confident interval of the ICC and MIA estimates, values less than 0.5, between 0.5 and 0.70, between 0.70 and 0.85, and greater than 0.85 are indicative of poor, moderate, good and excellent concordance, respectively. All statistical analyses were performed using SAS version 9.4.

Results

A total of 39 surgeons from 12 countries answered the survey (39% response rate). Most participants (74.4%) had more than 10 years of surgical experience and performed a mean of 60 ASD cases annually. 82% of the respondents did not have previous experience with the use of risk calculators.

Across the nine clinical vignettes, surgeons' risk assessment of both complications and reinterventions varied markedly (Figs. 1, 2). In some cases, (Case #7) variability was particularly extreme, with surgeons' answers for both major complications and reinterventions risk assessment at 2 year follow-up ranging from 1 to 100%. In case #5, predicted major complication risk at 90 days postop ranged from 5 to 89%, and in case #3, reintervention risk at 2 years postop ranged from 1 to 80%.

Surgeons' risk perception concordance was very low and heterogeneous with ICCs below 0.5 in the assessment of the 6 estimates (2 outcomes in 3 time points). The lowest ICC was for the prediction of reintervention risk at 72 h (0.104). The highest ICC was for the reintervention risk assessment at 2 years (0.316) (Table 1).

The concordance between surgeon risk prediction and the calculator's risk estimate was also very poor. MIA ranged from 0.122 (reinterventions at 72 h) to 0.416 (major complications at 2 years). Distribution of MIA was also very heterogeneous (Table 2). Surgeon estimates of complication and reoperation probabilities in all of the clinical cases were lower than calculator probabilities at 72 h and were higher than calculator probabilities at 2 years. When comparing the average value of all surgeons' answers to the calculator's risk estimate, differences were not statistically different ($p > 0.05$) (Fig. 3)

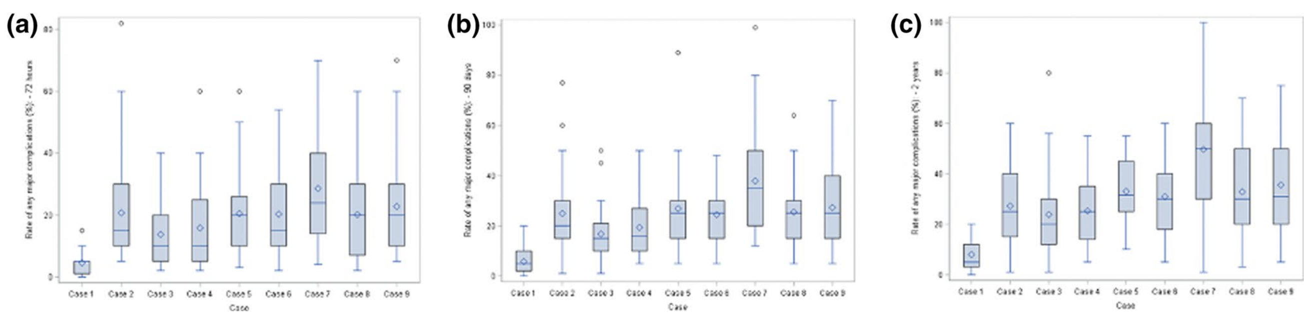

Fig. 1 **a** Surgeon's variability in major complications risk perception at **a** 72 h **b** 90 days and **c** 2 years of follow-up. A diamond represents the mean of surgeon's responses to each clinical vignette. The horizontal line corresponds to the median, the vertical bar to the corresponding 25 and 75 percentiles, and the vertical line to the range (or the last value below 1.5 folds the interquartile range)

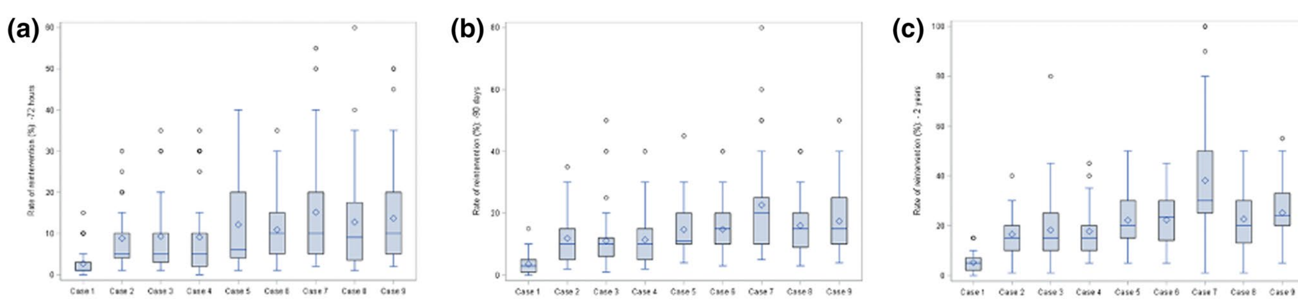

Fig. 2 **a** Surgeon's variability in reinterventions risk perception at **a** 72 h **b** 90 days and **c** 2 years of follow-up. A diamond represents the mean of surgeon's responses to each clinical vignette. The horizontal line corresponds to the median, the vertical bar to the corresponding 25 and 75 percentiles, and the vertical line to the range (or the last value below 1.5 folds the interquartile range)

Table 1 Surgeons' risk perception concordance and concordance between surgeon risk prediction and the calculator's risk estimate

		Mean of surgeons' responses	Range of surgeons' responses	ICCs among surgeon's responses	Risk estimates given by the CDST	MIAs between surgeons and CDST
Major complications 72 h	Case 1	4.56	0–15	0.181	2	0.272
	Case 2	20.72	5–82		9	
	Case 3	13.72	2–40		6	
	Case 4	15.82	2–60		15	
	Case 5	20.46	3–60		19	
	Case 6	20.31	2–54		11	
	Case 7	28.59	4–70		18	
	Case 8	20.15	2–60		8	
	Case 9	22.77	5–70		17	
Major complications 90 days	Case 1	5.79	0–20	0.287	6	0.375
	Case 2	24.95	1–77		22	
	Case 3	16.77	1–50		27	
	Case 4	19.38	5–50		39	
	Case 5	26.89	5–89		51	
	Case 6	24.49	5–48		27	
	Case 7	37.92	12–99		42	
	Case 8	25.56	5–64		24	
	Case 9	27.31	5–70		36	
Major complications 2 years	Case 1	7.95	0–20	0.309	8	0.416
	Case 2	27.26	1–60		31	
	Case 3	23.85	1–80		36	
	Case 4	25.28	5–55		51	
	Case 5	33.03	10–55		66	
	Case 6	30.97	5–60		40	
	Case 7	49.69	1–100		57	
	Case 8	32.87	3–70		36	
	Case 9	35.58	5–75		51	
Reinterventions 72 h	Case 1	2.64	0–15	0.104	0	0.122
	Case 2	8.81	1–30		3	
	Case 3	9.26	1–35		2	
	Case 4	9.08	0–35		5	
	Case 5	12.10	1–40		3	
	Case 6	10.89	1–35		3	
	Case 7	15.13	2–55		3	
	Case 8	12.75	1–60		2	
	Case 9	13.65	2–50		3	
Reinterventions 90 days	Case 1	3.54	0–15	0.230	4	0.227
	Case 2	11.86	2–35		15	
	Case 3	11.08	1–50		24	
	Case 4	11.38	2–40		25	
	Case 5	14.71	4–50		17	
	Case 6	14.79	3–40		14	
	Case 7	22.66	5–80		20	
	Case 8	16.00	3–40		12	
	Case 9	17.43	4–50		21	

Table 1 (continued)

		Mean of surgeons' responses	Range of surgeons' responses	ICCs among surgeon's responses	Risk estimates given by the CDST	MIAs between surgeons and CDST
Reinterventions 2 years	Case 1	5.13	0–15	0.316	7	0.350
	Case 2	16.49	1–40		27	
	Case 3	18.21	1–80		35	
	Case 4	17.70	5–45		42	
	Case 5	22.16	5–50		36	
	Case 6	22.29	5–45		29	
	Case 7	38.13	1–100		39	
	Case 8	22.64	10–50		27	
	Case 9	25.16	5–50		39	

Table 2 Mean index of agreement (MIA) distribution analysis

Mean index of agreement (MIA) distribution analysis	Mean	Std dev	Minimum	Maximum	Lower quartile	Median	Upper quartile
Major complications 72 h	0.272	0.211	0.000	0.831	0.135	0.213	0.356
Major complications 90 days	0.375	0.232	0.000	0.845	0.189	0.335	0.577
Major complications 2 years	0.416	0.247	0.042	0.905	0.205	0.400	0.603
Reinterventions 72 h	0.122	0.146	0.000	0.628	0.025	0.055	0.203
Reinterventions 90 days	0.227	0.174	0.000	0.694	0.082	0.213	0.318
Reinterventions 2 years	0.350	0.213	0.000	0.756	0.182	0.337	0.545

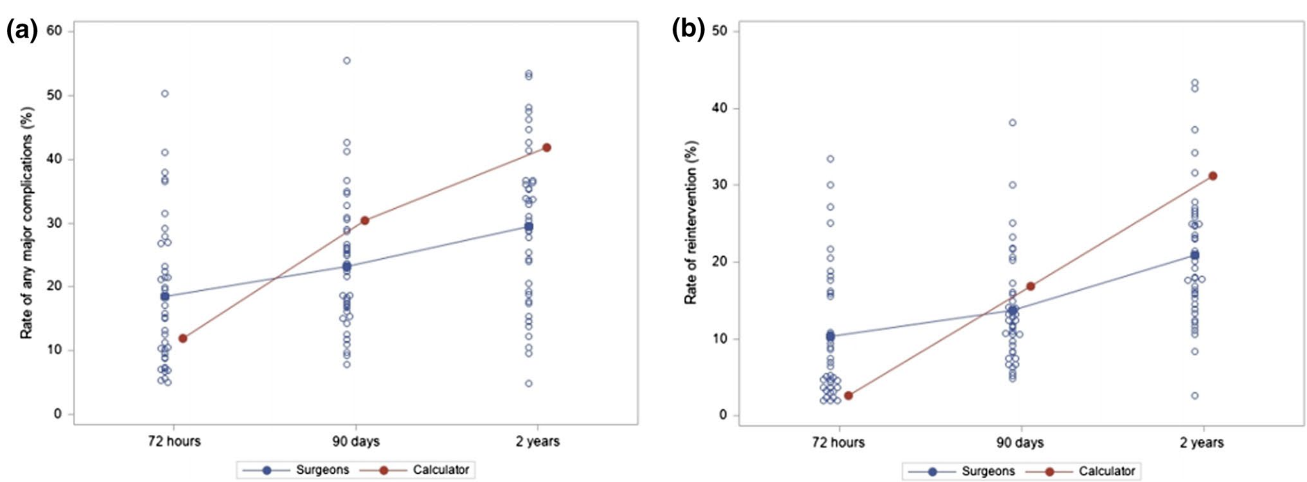

Fig. 3 Comparison of risks predicted by surgeons and the risk calculator. **a** Major complications **b** Reinterventions

(Table 3). In other words, mean surgeons' risk prediction was similar to the calculator's risk estimate. However, 46.9% of surgeon's predictions underestimated the risk below a relative 20% margin of error, while 33% of predictions overestimates risk above the same margin. Moreover, for predictions regarding the risk of complications at 90 days and 2 years, 57 and 61% of predictions underestimated the risk below a 20% margin of error.

Table 3 Major complications and reinterventions risk assessment comparison

Major complications risk assessment comparison		
		p value
72 h risk (mean values)		
Surgeons answers	18.6 (SD 15.2)	0.64
CDST results	12.0 (SD 6.2)	
90 days risk (mean values)		
Surgeons answers	23.2 (SD 15.8)	0.46
CDST results	30.4 (SD 13.2)	
2 years risk (mean values)		
Surgeons answers	29.6 (SD 19.3)	0.36
CDST results	41.8 (SD 17.0)	
Reinterventions risk assessment comparison		
72 h risk (mean values)		
Surgeons answers	10.5 (SD 10.9)	0.25
CDST results	2.7 (SD 1.32)	
90 days risk (mean values)		
Surgeons answers	13.7 (SD 10.7)	0.56
CDST results	16.9 (SD 6.6)	
2 years risk (mean values)		
Surgeons answers	20.8 (SD 15.1)	0.28
CDST results	31.2 (SD 10.6)	

Discussion

This is the first study to analyze surgeon risk perception in ASD. Our results show that individual ASD surgeon risk assessment is heterogeneous and discordant. Even when patient characteristics are held constant in the form of clinical vignettes, substantial disagreement among surgeons remains. Concordance was poor for all estimates related to risk of sustaining complications and reinterventions, at all times of follow-up. These marked differences in surgeon risk perception related to ASD surgical treatment challenge the utility of the shared decision-making process commonly employed. At the same time, these results argue for the need for more objective and accurate methods to assess surgical risk, especially for complex and heterogeneous scenarios such as ASD. Obtaining accurate individualized risk assessment and likelihood of adverse events is of utmost importance for shared surgical decision making, to set proper patient expectations, provide a balanced risk-benefit assessment and to define the needs in medical resources.

For years, risk assessment, stratification and prediction of outcomes have been transferred to expert opinion, either individually or collectively, organized in multidisciplinary committees [14]. Surgical risk is linked to multiple factors related to patient, disease and treatment characteristics, interacting together differently for each patient [22]. Individual expert risk assessment is based on professional experience subjected to confirmation bias and published evidence [15]. Data available in the medical literature typically do not enable accurate individual patient risk assessment. Mean values do not necessarily apply to individual patients and published confidence intervals may include, but do not identify, the specific risk of an individual patient being assessed. Furthermore, the interactions among the different risk factors are seldom considered when using published data, making prediction of risk based on medical literature not reliable. Multidisciplinary committees including multiple experts represent the best expression of collective intelligence and have been shown to improve individualized patient risk assessment, compared to single expert evaluation [14]. Recent reports show that patients discussed and evaluated at multidisciplinary committees assessing surgical risk and having their treatment adjusted to committee decisions have fewer complications than those who are not discussed at multidisciplinary forums (16% vs. 52%; $p<0.001$) [14]. However, evidence shows that surgical decision making based solely on the assessment of risk of complications may deny surgery to patients with the highest chances of improvement [19, 23].

Multiple reports have shown that ASD patients having the highest risks of complications are often the patients with the highest chances of experiencing HRQL improvement with surgery [19, 23]. It is extremely difficult to foresee in daily clinical practice a setting which simultaneously includes multiple experts assessing surgical risk and multiple experts assessing chances of clinical improvement, to provide the information needed (balancing risks and benefits) for adequate surgical decision making. The possibility of having different surgical treatment options, as is the case in ASD, makes accurate comprehensive informed consent and counselling, based on human (individual or collective) intelligence, extremely difficult and not very accurate [24]. Our results suggest that surgeons tend to overestimate the risk of major complications and reinterventions in the first 72 h and severely underestimate the same risks at 90 days and 2 years postop when compared to the probabilities predicted by the risk calculator.

Only one previous publication has analyzed the impact of using a ML risk calculator [25] on surgical risk assessment and surgical decision-making. Sacks et al. [26] asked a sample of surgeons to assess the risks and benefits of operative and nonoperative management of gastrointestinal disorders and to rate their likelihood of recommending an operation for 4 detailed clinical vignettes. Surgeons were randomized to the clinical vignettes alone or supplemented by data from a risk calculator. The authors compared the surgeons' judgments and decisions, with and without the help of a risk calculator. The exposure to the risk calculator led to less varied and more accurate judgments of operative risk among surgeons [26].

It is worth noting that 82% of respondents in our sample, all of them dedicated ASD surgeons, lacked previous experience with risk calculators. The low concordance among surgeons observed in our study, concerning such an important matter as surgical risk, clearly suggests that the use of calculators could substantially improve surgical risk assessment, informed consent and patient counseling in ASD surgery. Efforts to improve the accuracy of surgical decision-making and to develop data-driven risk stratification methods are likely to improve patient safety and outcomes, and thereby increase the overall quality and value of spine surgery care.

Three types of surgical risk calculators are currently available: general [ACS NSQIP [25], MySurgeryRisk [27]], spine specific [spinal risk assessment tool-RAT [28], Spine Sage [29], Spine Lumbar Fusion Outcomes Calculator [30]] and ASD specific [16, 18]. The main drawback of non-specific ASD calculators is that they do not consider most surgical techniques frequently used in ASD surgery [31] and accounting for 45% of the risk of complications [18]. In 2017, Buchlak et al. published the first ASD specific on-line risk calculator [16]. It was developed by analyzing a small sample of ASD patients from a single institution, and based in regression modeling, which renders it unable to account for complex variable interactions. In 2019, Pellisé et al. [18] and Ames et al. [20, 32] published and validated the first ASD-specific on-line risk calculators based on accurate ML models predicting 2 year follow-up complications and outcomes following ASD surgery. The ML algorithms included in this CDST were trained by using the largest and most granular, prospective, multicenter ASD database (2286 surgical ASD patients enrolled in 23 sites from 5 countries, 2 continents) [18].

The low response rate (39%) could be considered a limitation of our study. However, different reports covering different scenarios have shown that response rates from surveys are low and usually range between 5% (general population survey) [33] and 19% (generic medical survey) [34] and 30% (most similar scenario including orthopedic surgeons surveyed via email and web) [35]. With an above than expected response rate, the final sample of responders was large enough to provide statistical power allowing to identify differences. Furthermore, the self-reported characteristics of the surgeons involved (74.4% with > 10 years of professional experience and mean 60 ASD surgical cases per year) guarantees our sample includes a large majority of experienced surgeons with a proper, professionally generated, risk perception.

Conclusion

ASD surgical risk assessment exclusively based on surgeon perception is heterogeneous and highly discordant. These marked differences suggest that preoperative patient counselling and informed consent performed solely by the treating surgeon are insufficient and prone to error. The use of an accurate ASD-specific CDST, at the point of care, in daily clinical practice seems necessary to improve surgical risk stratification and shared decision making.

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Declarations

Conflict of interest Dr. Alanay reports grants from Medtronic, grants from Depuy Synthes, personal fees from Globus Medical, personal fees from Zimmer Biomet, outside the submitted work. Dr. Vila-Casademunt has nothing to disclose. Dr. Ames reports personal fees from UCSF, personal fees from Stryker, personal fees from Biomet Zimmer Spine, personal fees from DePuy Synthes, personal fees from Nuvasive, personal fees from Next Orthosurgical, personal fees from K2M, personal fees from Medicrea, personal fees from Titan Spine, personal fees from Medtronic, personal fees from ISSG, personal fees from Operative Neurosurgery, personal fees from SRS, personal fees from Global Spinal Analytics, outside the submitted work. Dr. Shaffrey reports grants from ISSG Foundation, during the conduct of the study; other from Nuvasive, other from Medtronic, other from SI Bone,

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References

1. Shaydakov ME, Tuma F (2020) Operative risk. StatPearls Publishing, Treasure Island
2. Kleinstueck FS, Fekete TF, Jeszenszky D et al (2016) Adult degenerative scoliosis: comparison of patient-rated outcome after three different surgical treatments. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 25:2649–2656. https://doi.org/10.1007/s00586-014-3484-7
3. Soroceanu A, Burton DC, Oren JH et al (2016) Medical complications after adult spinal deformity surgery: incidence, risk factors, and clinical impact. Spine 41:1718–1723. https://doi.org/10.1097/BRS.0000000000001636
4. Scheer JK, Tang JA, Smith JS et al (2013) Reoperation rates and impact on outcome in a large, prospective, multicenter, adult spinal deformity database: clinical article. J Neurosurg Spine 19:464–470. https://doi.org/10.3171/2013.7.SPINE12901
5. Smith JS, Saulle D, Chen C-J et al (2012) Rates and causes of mortality associated with spine surgery based on 108,419 procedures: a review of the scoliosis research society morbidity and mortality database. Spine 37:1975–1982. https://doi.org/10.1097/BRS.0b013e318257fada
6. Smith JS, Sansur CA, Donaldson WF et al (2011) Short-term morbidity and mortality associated with correction of thoracolumbar fixed sagittal plane deformity: a report from the scoliosis research society morbidity and mortality committee. Spine 36:958–964. https://doi.org/10.1097/BRS.0b013e3181eabb26
7. Sansur CA, Smith JS, Coe JD et al (2011) Scoliosis research society morbidity and mortality of adult scoliosis surgery. Spine 36:E593-597. https://doi.org/10.1097/BRS.0b013e3182059bfd
8. Sciubba DM, Yurter A, Smith JS et al (2015) A comprehensive review of complication rates after surgery for adult deformity: a reference for informed consent. Spine Deform 3:575–594. https://doi.org/10.1016/j.jspd.2015.04.005
9. Lonergan T, Place H, Taylor P (2016) Acute complications after adult spinal deformity surgery in patients aged 70 years and older. Clin Spine Surg 29:314–317. https://doi.org/10.1097/BSD.0b013e3182764a23
10. Núñez-Pereira S, Pellisé F, Vila-Casademunt A et al (2019) Impact of resolved early major complications on 2 year follow-up outcome following adult spinal deformity surgery. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 28:2208–2215. https://doi.org/10.1007/s00586-019-06041-x
11. Ames CP, Smith JS, Gum JL et al (2020) Utilization of predictive modeling to determine episode of care costs and to accurately identify catastrophic cost nonwarranty outlier patients in adult spinal deformity surgery: a step toward bundled payments and risk sharing. Spine 45:E252–E265. https://doi.org/10.1097/BRS.0000000000003242
12. Worley N, Marascalchi B, Jalai CM et al (2016) Predictors of inpatient morbidity and mortality in adult spinal deformity surgery. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 25:819–827. https://doi.org/10.1007/s00586-015-4104-x
13. Charosky S, Guigui P, Blamoutier A et al (2012) Complications and risk factors of primary adult scoliosis surgery: a multicenter study of 306 patients. Spine 37:693–700. https://doi.org/10.1097/BRS.0b013e31822ff5c1
14. Sethi RK, Pong RP, Leveque J-C et al (2014) The Seattle spine team approach to adult deformity surgery: a systems-based approach to perioperative care and subsequent reduction in perioperative complication rates. Spine Deform 2:95–103. https://doi.org/10.1016/j.jspd.2013.12.002
15. Elston DM (2020) Confirmation bias in medical decision-making. J Am Acad Dermatol 82:572. https://doi.org/10.1016/j.jaad.2019.06.1286
16. Buchlak QD, Yanamadala V, Leveque J-C et al (2017) The seattle spine score: predicting 30-day complication risk in adult spinal deformity surgery. J Clin Neurosci Off J Neurosurg Soc Australas 43:247–255. https://doi.org/10.1016/j.jocn.2017.06.012
17. Croskerry P, Singhal G, Mamede S (2013) Cognitive debiasing 1: origins of bias and theory of debiasing. BMJ Qual Saf 22(Suppl 2):ii58–ii64. https://doi.org/10.1136/bmjqs-2012-001712
18. Pellisé F, Serra-Burriel M, Smith JS et al (2019) Development and validation of risk stratification models for adult spinal deformity

surgery. J Neurosurg Spine. https://doi.org/10.3171/2019.3.SPINE181452
19. Ames CP, Smith JS, Pellisé F et al (2019) Artificial intelligence based hierarchical clustering of patient types and intervention categories in adult spinal deformity surgery: towards a new classification scheme that predicts quality and value. Spine 44:915–926. https://doi.org/10.1097/BRS.0000000000002974
20. Ames CP, Smith JS, Pellisé F et al (2019) Development of deployable predictive models for minimal clinically important difference achievement across the commonly used health-related quality of life instruments in adult spinal deformity surgery. Spine 44:1144–1153. https://doi.org/10.1097/BRS.0000000000003031
21. Harrell FE, Califf RM, Pryor DB et al (1982) Evaluating the yield of medical tests. JAMA 247:2543–2546
22. Mirza SK, Deyo RA, Heagerty PJ et al (2008) Development of an index to characterize the invasiveness of spine surgery: validation by comparison to blood loss and operative time. Spine 33:2651–2661. https://doi.org/10.1097/BRS.0b013e31818dad07
23. Smith JS, Shaffrey CI, Glassman SD et al (2011) Risk-benefit assessment of surgery for adult scoliosis: an analysis based on patient age. Spine 36:817–824. https://doi.org/10.1097/BRS.0b013e3181e21783
24. van de Graaf VA, Bloembergen CH, Willigenburg NW et al (2020) Can even experienced orthopaedic surgeons predict who will benefit from surgery when patients present with degenerative meniscal tears? a survey of 194 orthopaedic surgeons who made 3880 predictions. Br J Sports Med 54:354–359. https://doi.org/10.1136/bjsports-2019-100567
25. Bilimoria KY, Liu Y, Paruch JL et al (2013) Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. J Am Coll Surg 217(833–842):e1-3. https://doi.org/10.1016/j.jamcollsurg.2013.07.385
26. Sacks GD, Dawes AJ, Ettner SL et al (2016) Impact of a risk calculator on risk perception and surgical decision making: a randomized trial. Ann Surg 264:889–895. https://doi.org/10.1097/SLA.0000000000001750
27. Bihorac A, Ozrazgat-Baslanti T, Ebadi A et al (2019) My surgery risk: development and validation of a machine-learning risk algorithm for major complications and death after surgery. Ann Surg 269:652–662. https://doi.org/10.1097/SLA.0000000000002706
28. Veeravagu A, Li A, Swinney C et al (2017) Predicting complication risk in spine surgery: a prospective analysis of a novel risk assessment tool. J Neurosurg Spine 27:81–91. https://doi.org/10.3171/2016.12.SPINE16969
29. Lee MJ, Cizik AM, Hamilton D, Chapman JR (2014) Predicting medical complications after spine surgery: a validated model using a prospective surgical registry. Spine J Off J N Am Spine Soc 14:291–299. https://doi.org/10.1016/j.spinee.2013.10.043
30. Khor S, Lavallee D, Cizik AM et al (2018) Development and validation of a prediction model for pain and functional outcomes after lumbar spine surgery. JAMA Surg 153:634–642. https://doi.org/10.1001/jamasurg.2018.0072
31. Pellisé F, Vila-Casademunt A, Núñez-Pereira S et al (2018) The adult deformity surgery complexity index (ADSCI): a valid tool to quantify the complexity of posterior adult spinal deformity surgery and predict postoperative complications. Spine J Off J N Am Spine Soc 18:216–225. https://doi.org/10.1016/j.spinee.2017.06.042
32. Ames CP, Smith JS, Pellisé F et al (2019) Development of predictive models for all individual questions of SRS-22R after adult spinal deformity surgery: a step toward individualized medicine. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 28:1998–2011. https://doi.org/10.1007/s00586-019-06079-x
33. Batty GD, Gale CR, Kivimäki M et al (2020) Comparison of risk factor associations in UK Biobank against representative, general population based studies with conventional response rates: prospective cohort study and individual participant meta-analysis. BMJ 368:m131. https://doi.org/10.1136/bmj.m131
34. Weaver L, Beebe TJ, Rockwood T (2019) The impact of survey mode on the response rate in a survey of the factors that influence minnesota physicians' disclosure practices. BMC Med Res Methodol 19:73. https://doi.org/10.1186/s12874-019-0719-7
35. Welton KL, Kraeutler MJ, McCarty EC et al (2018) Current pain prescribing habits for common shoulder operations: a survey of the American shoulder and elbow surgeons membership. J Shoulder Elb Surg 27:S76–S81. https://doi.org/10.1016/j.jse.2017.10.005

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