Predicting medical complications in spine surgery: evaluation of a novel online risk calculator

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Abstract

Purpose The preoperative prediction of medical complications is essential to optimize perioperative management. SpineSage™ is a free of charge online calculator to predict medical complications in spine surgery. The current study utilizes it in patients undergoing spine surgery to assess whether the predicted risks would correlate with the actual complication rate in clinical practice.

Methods A total of 273 consecutive patients who underwent spinal surgery were assessed. The risk of medical complications was predicted for each patient, and all medical complications were recorded within 30 days of surgery. Based on their predicted risk of complication, patients were divided into three risk groups (< 15, 15–30, > 30%).

Results The predicted overall risk of medical complications was 14.7% and was comparable to the observed complication rate of 16.1%. The predicted risk for major medical complications (3.8%) was also similar to the observed complication rate (3.3%). Detailed analysis of the segmented risk groups suggests a close correlation between predicted and actual complication rates. Receiver operating characteristic analysis revealed an area under the curve of 0.71 ($p < 0.001$) for the prediction of overall medical complications and 0.85 ($p < 0.001$) for major complications.

Conclusions The online risk calculator predicted both overall and major medical complications. The tool can assist in preoperative planning and counseling of patients.

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

Keywords Spine surgery · Medical risk · Medical complications · Online calculator · Risk assessment

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Introduction

Since bundled payment programs often include the reimbursement for complication and readmission, it has become increasingly important to identify patients at risk for perioperative complications [1–4].

Being able to identify patients at risk for medical and surgical complications helps to better prepare the patient for the procedure based on patient-specific risk factors and invasiveness of the procedure and ultimately might help to reduce the overall complication rate. In the past, several significant risk factors for medical complications in spine surgery were identified utilizing multivariate analysis [5–7]. However, a risk stratification tool that is easy to integrate into clinical practice has been missing.

Lee et al. [8] created a validated model for predicting medical complications after spine surgery based on a prospective spine surgery registry. It is meant to simplify preoperative assessment by taking into consideration patient-specific risk factors as well as the invasiveness of the procedure (Fig. 1).

This risk calculator is available online free of charge. It allows the surgeon to calculate the risk for perioperative medical complication for a specific patient and procedure [8]. There are currently no data available that analyze the clinical value of this perioperative risk calculator.

The current study reports the initial clinical experience with this risk assessment tool and analyzes the following research questions: (1) Is there a difference between the predicted overall medical complication rate and the observed complication rate? (2) What is the value of the tool for patients with different risk levels? (3) Furthermore, does the tool have a diagnostic value for the prediction of complication?

Materials and methods

The current study evaluates 273 consecutive patients, who underwent one-stage spinal surgery in a tertiary care center. The study was approved by the institutional review board. All medical complications in the first 30 postoperative days were recorded. Medical complications were divided into six main organ systems (cardiac, pulmonary, gastrointestinal, neurologic, hematologic and urologic) as previously reported by Lee et al. [8]. Furthermore, in this classification system, complications were grouped into overall and major complications. Complications with a significant impact on the patients' recovery, e.g., myocardial infarction, cerebrovascular accidents (CVA/TIA) or pulmonary embolism were considered major medical complications. All other medical complications (e.g., cardiac arrhythmia, pneumonia and deep vein thrombosis) were considered overall medical complications. However, surgical complications (dural tear, iatrogenic nerve injury or hardware failure) were not considered. Detailed information was published by Lee et al. [8].

The risk of medical complications for each patient according to his/her comorbidity profile and planned surgical invasiveness was estimated online using the freely available risk calculator (SpineSage™) [8]. It provides likelihood values in absolute percentages for occurrence of a complication for an individual patient, based on the patients comorbidity profile and planned surgical invasiveness. Estimated risks of SpineSage™ were not used to make changes in the operative decision making process as it is not an approved medical product. SpineSage™ utilizes preexisting comorbidities, like hypertension, congestive heart failure or diabetes as well as

Fig. 1 The 3D model is showing that risk depends on two factors: patients' comorbidity profile and invasiveness of surgery. Risk increases either through an increased amount of preexisting medical conditions or due to more invasiveness surgery. SpineSage™ is the first predictive model that connects either factors and predicts an individual patient risk

age, gender and BMI to calculate the patient-specific risk. It also considers a history of previous spine surgery (history of any prior spinal surgery at any segment) and revision surgery (surgical-related complications to a prior surgery, e.g., hardware failure).

Surgical invasiveness is graded based on the surgical invasiveness index (SII), which was described by Mirza et al. [9]. The index considers the number of levels that are decompressed, fused or instrumented as well as the approach (posterior vs. anterior). A higher SII score indicates increased surgical invasiveness accompanied by higher blood loss and longer surgical time. Given all these informations, SpineSage™ then predicts for a patient the risk for overall medical complications and major medical complications.

Preoperative assessment also included the Charlson comorbidity index (CCI) [10] and the American Society of Anesthesiologists (ASA) score. For statistical analysis, Pearson's Chi-square test was used to compare median preoperative predicted risks with the actually occurred complication rate. For assessment of the diagnostic value of the calculator, a receiver operator characteristics (ROC) analysis to determine the area under the curve (AUC) was obtained from the predictions of the risk calculator and actually recorded medical complications. An AUC of > 0.8 was considered as a good clinical test and an AUC of > 0.7 as a fair clinical test [11]. A p value of < 0.05 was considered as statistically significant. All statistical analyses were performed using SPSS software (version 23.0 for Mac; SPSS, Chicago, ILL).

Results

The mean patients' age was 61 years (range 18–87 years), and mean BMI was 27.0 kg/m^2 (range $17\text{--}45 \text{ kg/m}^2$). The CCI median was 3 points (range 0–13 points), and patients had a median of 2 comorbidities (range 0–8). At the time of surgery, 33 patients were classified as ASA I (12.1%), 152 patients were classified as ASA II (55.7%), followed by 81 patients as ASA III (29.7%) and 7 patients as ASA IV (2.5%). Hypertension and previous spinal surgery were the most common preexisting medical risk factors. Most surgical interventions were performed for degenerative spine conditions (226 patients (82.8%)), followed by 26 patients operated on for neoplasm (9.5%), 10 patients for trauma (3.7%) and 11 patients for infection (4%). The location of surgery was lumbosacral in 215 patients (78.8%), cervical in 34 patients (12.4%) and thoracic in 24 patients (8.8%). The most common approach was the posterior approach (252 patients (92.3%)), followed by the anterior approach (17 patients (6.2%)) and only 4 patients (1.5%) underwent a combined anterior–posterior approach. Furthermore, cases were separated into three risk groups regarding their predicted overall medical risk (< 15 , $15\text{--}30$, $> 30\%$). Detailed

demographics of all groups are presented in Table 1. Values are expressed as mean/median with range or 95% confidence intervals (95% CI). For the total sample size ($n = 273$) of the current study, the 95% confidence interval is within plus/minus 4.6%.

The predicted median overall medical complication rate was 14.7% (range 3.3–89.2%), and the actually observed complication rate was 16.1% (44 patients). Pulmonary complications occurred in 16 patients (26.2%), followed by neurological complications in 11 patients (18.0%) and cardiac complications in 10 patients (16.4%). Less common were gastrointestinal complications and urological complications, both in 9 patients (14.8%), and hematologic complications, in 6 patients (9.8%). In total, 61 medical complications were documented in 44 patients.

The median predicted major complication risk was 3.8% (range 0.5–63.8%), and 3.3% (9 patients) of the patients had a major medical complication (Tables 2, 3). Two patients died, a myocardial infarction occurred in one patient, with a predicted overall medical risk of 26.3% and major medical risk of 11.2%. The second patient, with a predicted overall medical risk of 41.2% and major risk of 5.7%, had a mesenteric infarction. There was no difference in the predicted and observed major medical complication rate ($p = 0.515$) as well as in the overall medical complication rate ($p = 0.693$) (Table 2; Fig. 2).

Furthermore, analysis of the different risk groups showed in the low-risk group (predicted overall medical complication rate $< 15\%$) a median predicted risk of 10.8%. In reality, 8.7% of the patients in this group suffered a medical complication. In the medium-risk group, defined by a median estimated risk between 15 and 30%, the median predicted risk was 18.9% compared to 17.7% of the patients in this group who actually had a medical complication. In the high-risk group, with a preoperative predicted risk exceeding 30%, the median predicted risk was 41.1%. 38.5% of the patients in this group had an actual medical complication. Difference analysis suggests that the predicted and actually observed medical complication rate was not statistically different ($p > 0.05$) (Table 2; Fig. 2).

Clinical value of the risk prediction calculator was assessed using ROC analysis. The AUC for prediction of overall medical complications was 0.71 ($p < 0.001$) and for major complications 0.85 ($p < 0.001$) (Table 4; Figs. 3, 4).

Discussion

The combination of improvements in surgical techniques, extending surgical indications and an aging society with increasing medical comorbidities makes preoperative risk screening tools increasingly important to guide patients in the preoperative decision for surgery. SpineSage™ appears

Table 1 Patient demographics of all patients are presented

	Risk < 15%	Risk 15–30%	Risk > 30%	Total
Patients	138	96	39	273
Female/male	81/57	59/46	23/16	159/114
Age ^a	53 (18–75)	66 (18–87)	74 (45–87)	61 (18–87)
BMI (kg/m ²) ^a	26.7 (17–45)	27.2 (18–40)	27.0 (18–38)	27.0 (17–45)
CCI ^b	2 (0–10)	3 (0–11)	5 (0–13)	3 (0–13)
Preexisting conditions ^b	1 (0–6)	2 (0–5)	4 (0–7)	2 (0–7)
SII ^b	3 (1–18)	8 (1–31)	10 (1–30)	8 (1–31)
ASA I	21.7% (30)	3.1% (3)	–	12.1% (33)
ASA II	64.5% (89)	55.2% (53)	25.6% (10)	55.7% (152)
ASA III	13.1% (18)	38.6% (37)	66.7% (26)	29.7% (81)
ASA IV	0.7% (1)	3.1% (3)	7.7% (3)	2.5% (7)
Degenerative	90.6% (125)	84.4% (81)	51.3% (20)	82.8% (226)
Trauma	–	1.0% (1)	23.1% (9)	3.7% (10)
Neoplasm	9.4% (13)	10.4% (10)	7.7% (3)	9.5% (26)
Infection	–	4.2% (4)	17.9% (7)	4.0% (11)
Cervical	14.5% (20)	9.4% (9)	12.8% (5)	12.4% (34)
Thoracic	6.5% (9)	8.3% (8)	18.0% (7)	8.8% (24)
Lumbosacral	79.0% (109)	83.3% (79)	69.2% (27)	78.8% (215)
Anterior	11.6% (16)	1.0% (1)	–	6.2% (17)
Posterior	87.7% (121)	95.9% (92)	100% (39)	92.3% (252)
Combined	0.7% (1)	3.1% (3)	–	1.5% (4)

Moreover, patients were divided into three risk groups according to their predicted overall medical risk

BMI body mass index, *CCI* Charlson comorbidity index, *ASA* American Society of Anesthesiologists and *SII* surgical invasiveness index

^aMean

^bMedian

Table 2 Median predicted risks and actual rate of occurred medical complications of all patients and all risk groups are shown

	Major medical complications	Overall medical complications	Risk group < 15%	Risk group 15–30%	Risk group > 30%
Median predicted risk (range)	3.8% (0.5–63.8%)	14.7% (3.3–89.2%)	10.8% (2.7–14.9%)	18.9% (15.1–29.7%)	41.1% (30.4–89.2%)
Actual rate of occurred medical complications (95% CI)	3.3% (<i>n</i> =9) (95% CI 1.7–6.1)	16.1% (<i>n</i> =44) (95% CI 12.2–20.9)	8.7% (<i>n</i> =12) (95% CI 5.0–14.6)	17.7% (<i>n</i> =17) (95% CI 11.4–26.5)	38.5% (<i>n</i> =15) (95% CI 24.9–54.1)
<i>p</i> value	0.515	0.693	0.418	0.767	0.731

Medical complications with a significant impact on the patients' recovery, e.g., myocardial infarction, cerebrovascular accidents (CVA/TIA) or pulmonary embolism were considered major medical complications. All other medical complications (e.g., cardiac arrhythmia, pneumonia and deep vein thrombosis) were considered overall medical complications

to be clinically useful in predicting the overall medical complication rate as well as major medical complication rate following spine surgery.

The current study has the following limitations: (1) Patients were operated in a tertiary care center, and the results might be different in a lower-level care center. (2) The current study analyzes a limited number of patients and might be underpowered. (3) The authors included only the 30 days complication rate and might underestimate overall complication rates. However, the American College of

Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) also utilizes a 30-day complication rate. The calculation of complications in this time period is of main interest, as bundled payment programs include costs for complications and readmissions within 30 days. (4) The study enrolled all patients who were admitted to the author's institution, which resulted in a mixed patient population of degenerative, neoplasm and infection cases. In contrast, Karstensen et al. [12] and Yadla et al. [13] included similar patient groups to report medical complications.

Table 3 Detailed information of patients who occurred a major medical complication is presented

Gender	Age	Diagnosis	Level	BMI	CCI	Preexisting conditions	SII	ASA	Risk major complications (%)	Risk overall complications (%)
F	73	N	C	23.5	10	3	12	4	5.5	22.1
F	74	D	L	23.9	6	3	12	3	5.7	41.2
M	45	D	L	37.1	0	0	30	2	7.1	32.3
M	60	D	L	30.1	3	2	14	2	7.7	21.8
F	75	D	L	35.5	3	1	12	3	9.1	23.0
M	82	N	L	29.4	10	1	12	3	11.2	26.3
M	74	D	T	28.9	3	2	28	3	19.7	42.2
F	77	I	T	24.5	4	2	10	3	28.6	48.6
M	75	T	T	36.7	5	6	15	3	63.8	89.2

F female, *M* male, *N* neoplasm, *D* degenerative, *I* infection, *T* trauma, *C* cervical, *T* thoracic, *L* lumbosacral, *CCI* Charlson comorbidity index, *SII* surgical invasiveness index, *ASA* American Society of Anesthesiologists

Fig. 2 The median predicted risks and actually observed medical complication rate of all patients and risk groups are presented**Table 4** The diagnostic values of the online calculator for predicting major and overall medical complications are presented

	Major medical complications	All medical complications
AUC (95% CI)	0.71 (95% CI 0.63–0.80)	0.85 (95% CI 0.773–0.929)
<i>p</i> value	<0.001	<0.001

AUC area under the curve

In the past decade, preoperative risk stratification and individual patient counseling have become of increasing importance in spine surgery. It is well known that perioperative complications are associated with prolonged hospital stays and inferior clinical outcome [14, 15]. Furthermore, it was recently reported by Su et al. [16] that the preoperative identification of high-risk patients and planned targeted modifications of risk factors might help to prevent

Fig. 3 Receiver operator characteristic curve for the prediction of any medical complication

Fig. 4 Receiver operator characteristic curve for prediction of major complications

complications. Therefore, efforts have been made to develop preoperative risk assessment algorithms. Schoenfeld et al. [1] identified cardiac disease and an ASA score of > 2 as independent risk factors for medical complications after spine surgery. Mannion et al. [17] reported that an increasing ASA score is associated with a higher incidence of perioperative complications. They concluded that the ASA

score might be used in preoperative counseling of patients about their perioperative risk. Moreover, Arrigo et al. [18] identified the Charlson comorbidity index (CCI) as a useful predictive tool for complications following spinal metastasis surgery. Also, Whitmore et al. [19] reported that the ASA score and the CCI were useful tools in the preoperative assessment. However, surgical invasiveness was not considered, and their ability to predict occurrence of complications was limited. Veeravagu et al. [20] evaluated the spinal Risk Assessment Tool (RAT), a tool designed for patients undergoing spine surgery and compared it with the ACS-NSQIP surgical risk calculator and the CCI. The lowest accuracy was reported for the CCI. Although the RAT and the ACS-NSQIP risk calculator provided a comparable AUC, the ACS-NSQIP risk calculator tended to underestimate the occurred complication rate. These findings support the need for customized tools for spine surgery. SpineSage™ is a tool designed to ease the preoperative decision making process in patients undergoing spine surgery. The assessment is based on the individual patient comorbidity profile and the planned surgical invasiveness. However, to our best knowledge, the current study is the first independent attempt to assess SpineSage™ in daily clinical practice. Lee et al. [8] who developed SpineSage™ reported an AUC of 0.76 for the detection of any medical complication and an AUC of 0.81 for major complications, which is quite similar to the data reported in the current study. Lee et al. [8] excluded tumor patients from their statistical analysis but suggested the possibility to assess tumor patients with the online calculator. The current study included patients with tumor diagnosis, and the study showed that SpineSage™ remains an accurate tool.

Analysis of the three risk groups suggests that preexisting medical conditions and increased invasiveness of the surgery increase the risk of medical complication. SpineSage™ provided a very accurate risk assessment in all risk groups. The incidence of medical complications and major complications was also comparable to previous reports [1, 12, 13].

Conclusions

SpineSage™ provides accurate predictions of overall medical complication risk as well as major complications risks for patients undergoing spine surgery. By identifying patients at risk, it improves preoperative patient optimization as well as communication of realistic expectations prior to surgery.

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Compliance with ethical standards

Conflict of interest We certify that we have not signed any agreement with commercial interest related to this study, which would in any way limit publication of any and all data generated for the study or to delay publication for any reason. One author reports personal fees from Smith & Nephew, personal fees from Ortho Development Corporation and personal fees from DePuy, outside the submitted work. One author reports consulting for Boehringer Ingelheim, Stryker, Takeda, Pfizer and DePuy, outside the submitted work.

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