Current Reviews in Musculoskeletal Medicine (2020) 13:247–263
https://doi.org/10.1007/s12178-020-09630-2

HOT TOPICS

Predicting Patient-Centered Outcomes from Spine Surgery Using Risk Assessment Tools: a Systematic Review

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Published online: 9 May 2020

Abstract

Purpose of Review The purpose of this systematic review is to evaluate the current literature in patients undergoing spine surgery in the cervical, thoracic, and lumbar spine to determine the available risk assessment tools to predict the patient-centered outcomes of pain, disability, physical function, quality of life, psychological disposition, and return to work after surgery.

Recent Findings Risk assessment tools can assist surgeons and other healthcare providers in identifying the benefit-risk ratio of surgical candidates. These tools gather demographic, medical history, and other pertinent patient-reported measures to calculate a probability utilizing regression or machine learning statistical foundations. Currently, much is still unknown about the use of these tools to predict quality of life, disability, and other factors following spine surgery. A systematic review was conducted using PRISMA guidelines that identified risk assessment tools that utilized patient-reported outcome measures as part of the calculation. From 8128 identified studies, 13 articles met inclusion criteria and were accepted into this review.

Summary The range of c-index values reported in the studies was between 0.63 and 0.84, indicating fair to excellent model performance. Post-surgical patient-reported outcomes were identified in the following categories (n = total number of predictive models): return to work (n = 3), pain (n = 9), physical functioning and disability (n = 5), quality of life (QOL) (n = 6), and psychosocial disposition (n = 2). Our review has synthesized the available evidence on risk assessment tools for predicting patient-centered outcomes in patients undergoing spine surgery and described their findings and clinical utility.

Keywords Risk calculators · Risk assessment · Patient-reported outcome · Spine surgery

Abbreviations

AUC	Area-under-curve
EMR	Electronic medical record
EQ-5D	EuroQOL-5 Dimension questionnaire
PPV	Positive predictive value
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PRO	Patient-reported outcome
PROBAST	Prediction Model Study of Bias Assessment Too

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PROM	Patient-reported Outcome Measures
QOD	Quality Outcomes Database
QOL	Quality of life
ROB	Risk of bias
SF-6D	Short Form 6 Dimension
SpineSCOAP	Spine Surgical Care and Outcomes Assessment Program

Introduction

Up to 40% of patients report persistent pain, functional limitations, and poor quality of life after surgery for back pain and between 20 and 24% undergo a reoperation [1, 2]. Problematically, there is substantial variation in the indications for recommending surgery for back pain among surgeons [3••, 4]. There is emerging research to support the use of predictive modeling techniques to enable surgeons to make more data-driven clinical decisions in patients with back pain [5••, 6••, 7]. Risk calculators or risk assessment tools in surgery can help providers make a decision based on probabilities of unfavorable outcomes calculated from information regarding the patient's medical history, patient-reported outcomes (PRO), and other relevant information for a surgery [8, 9]. The implementation and use of predictive strategies will be integral to sustaining spinal surgery and supporting patients in a value-based care model. Having the ability to predict outcomes based on factors unique to each patient can help facilitate improved clinical decision-making in selecting appropriate patients and managing patient expectations [8, 10].

Risk assessment tools quantify the benefit or risk of treatment by using information known to predict clinically relevant outcomes through predictive modeling to calculate the probability of an outcome [8]. Traditionally, surgeons have relied on the combination of patients' preference, physical exam findings, and imaging to make surgical recommendations, whereas risk assessment tools shift from deterministic thinking towards probabilistic thinking, which is better suited for prognosis and treatment decision-making [11, 12]. Risk assessment tools are informed by predictive models developed by a variety of methods such as classical regression modeling, machine learning, and neural networks [13]. Moreover, the use of risk assessment tools provides an opportunity to employ a data driven approach to decision-making by developing predictions about which patients will benefit from surgery. An integral part of the determination of success and overall patient experience following spine surgery are patient-reported improvements in pain and physical function [10]. The implementation of risk assessment tools in spine surgery and routine clinical practice that specifically predict patient-centered outcomes rather than traditional metrics of success, such as lack of infection, readmission, or revision, may improve patient satisfaction and clinical outcomes [5••, 14]. However, much is unknown about which risk assessment tools are being used by spine surgeons that focus on predicting patient-centered outcomes, such as pain, physical function, disability, quality of life, and returning to work. As our healthcare system evolves towards value-based care, particularly in spine care, patient-reported outcome measures (PROMs) are not only being used as the indicator for a successful outcome from spine surgery, but in determining the value of care delivered [15]. Therefore, the purpose of this systematic review is to evaluate the current literature in patients undergoing spine surgery in the cervical, thoracic, and lumbar spine to determine the available risk assessment tools that predict the patient-centered outcomes of pain, disability, physical function, quality of life, psychological disposition, and return to work after surgery.

Methods

Review Design

This systematic review identified studies that describe the risk prediction tools, calculators, or algorithms to predict patient-reported outcomes from spine surgery. This review was written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement [16].

The protocol for this review is available in the PROSPERO registry (CRD42019136188) [17].

Data Sources and Search Strategy

A comprehensive literature search was performed in the following biomedical databases: MEDLINE (via PubMed), Embase (via Elsevier), and Scopus (via Elsevier) from inception to June 2019. A medical librarian (BT) created the primary literature search in PubMed using a combination of text words and Medical Subject Headings (MeSH) terms. Primary search concepts included spine surgery, risk assessment, and PROs with no restriction by language or date. The search was then translated into two additional databases, Embase and Scopus by the librarian to ensure consistency in search strategies. A detailed search strategy is included in Appendix. The combined searches yielded a total of 8128 references imported for screening into Covidence, a systematic review management software for organization and data management [18]. Covidence identified 2358 duplicate citations, resulting in 5770 unique citations for review. The team found one additional citation to review through the process of hand searching, exploration, and scanning reference lists resulting in 5771 articles for review.

Inclusion and Exclusion Criteria

The inclusion criteria for this systematic review were the following: patients aged 18 years and older; patients received spine surgery to cervical, thoracic or lumbar spine as an intervention; PROMs collected pre- and post-surgery; and implementation or description of outcomes from a risk assessment tool was reported. Exclusion criteria were the following: patient with cancer or cancer-related neck or back pain and reporting of statistical analyses that do not directly result in the formation of a risk assessment tool or predicted outcomes are not patient reported. We added filters for study type to exclude case studies or reports, editorials, letters to the editor, and studies not written in English.

Study Selection and Data Extraction

Once databases were searched, titles and abstracts of studies were uploaded into Covidence. The article selection process was done in two phases. In the first phase, five authors (HW, JB, NH, BP, EW) performed independent reviews of titles and abstracts in Covidence using the predefined inclusion and exclusion criteria detailed above. Articles were moved to full text review if found to be relevant to this review. In the second phase, the two authors (NH and JB) independently reviewed full-text articles for eligibility. Any conflicts were resolved by the third reviewer (HW). Two independent reviewers (NH and JB) assessed the 152 full-text studies for eligibility and agreed upon n = 13 for inclusion in this systematic review (kappa = 0.76).

Quality Assessment

Risk of bias (ROB) was conducted using the Prediction Model Study of Bias Assessment Tool (PROBAST) [19]. This unique tool examines bias in prediction models and the authors found this tool most applicable for this review in contrast to traditional ROB tools such as Black and Down and Ottawa New Castle tools [20, 21]. PROBAST contains two overarching domains, risk of bias and application, and ranks outcomes as high, unclear, and low. The domain of risk of bias relates the shortcomings of the study to the accuracy of the predictive model, while the application domain assesses the agreement between the predictive model and the purpose of this review.

Results

Search Outcome

Our preliminary search yielded 8128 articles for title and abstract review. After irrelevant articles and duplicates were removed and hand selected articles were added, 5771 articles were included for title and abstract review. A total of 153 articles were moved forward for full text review by two authors. After conflicts were resolved, 13 articles remained for inclusion in the systematic review. See Fig. 1 for PRISMA flow diagram [16].

Risk of Bias

Since the outcomes in all studies are patient-reported, the study cannot be without bias regarding how the outcome was determined. Item 3.5 in PROBAST states “Was the outcome determined without knowledge of predictor information?” [22]. All studies reported multiple predictors that the patient could not be blinded to (age, educational level, etc.) due to the nature of these studies. Hence, all studies received high ROB for their reported outcome; however, this bias was attributed to the nature of the outcome rather than bias in study design. There were no concerns for the studies regarding their applicability to this systematic review. All studies received a low ROB assessment for the participants and predictor domains. For the participants domain, all studies met the criteria for PROBAST (clear inclusion/exclusion criteria and a valid study design, as all studies were either prospective or retrospective using prospective data). For the predictor domain, all criteria were met for all studies.

The three studies that received an unclear ROB for the analysis domain were given this rating because there was no mention of the statistical methods that were used for participants with missing data. Lubelski et al. and McGirt et al. were deemed to have high ROB for the analysis domain because they used list-wise deletion with participants who had missing data [3••, 23]. Hegarty and Shorten et al. also received a high ROB for the analysis domain because of a small sample size and had no mention of the statistical methods that were used for participants with missing data [24]. The other unmentioned studies scored low for the analysis domain. See Table 1.

Sources of Data and Data Collection for Articles

The majority of the studies included in this review utilized prospective cohorts of patients derived from registries (QOD, Spine SCOAP) or single site cohorts. Three studies used retrospective cohorts in their risk assessment evaluation [3••, 25••, 26••]. Risk assessment tools predicted patient-reported outcomes at 12 months in the majority of the studies, but in one study predicted outcomes as early as 3 months [27••]. A total of 24,446 patients were included in the predictive analyses with patients ranging in age from 18 to 91 years old. Patient preoperative diagnosis and surgical procedures as well as study inclusion and exclusion criteria are detailed in Table 2.

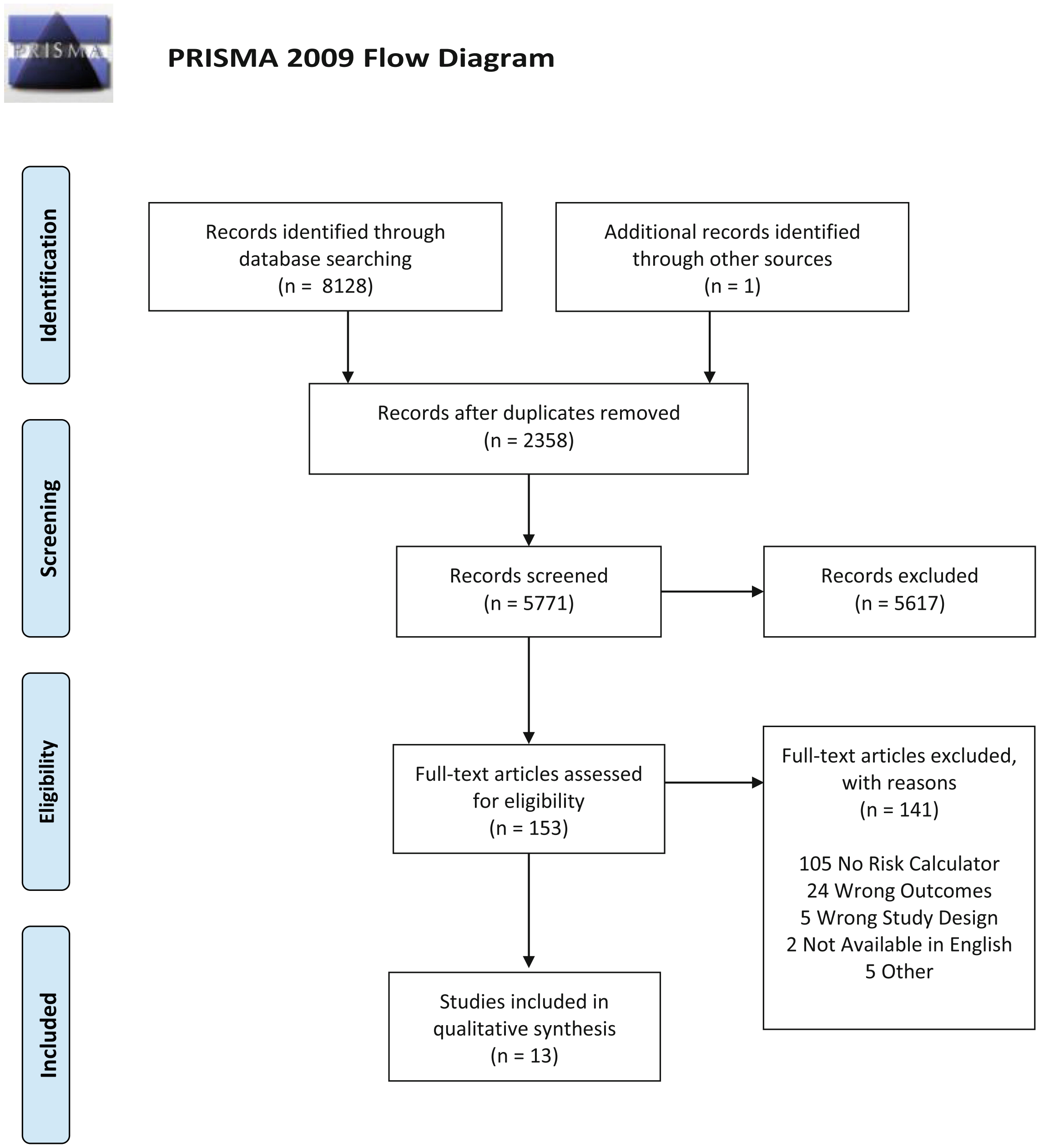

Fig. 1 PRISMA flow diagram displaying the comprehensive literature search conducted

Predictive Models Informing Risk Assessment Tools

Our review identified 13 articles containing 28 predictive models that predicted patient-centered outcomes following spine surgery. C-index, area under the curve (AUC), R^2, or positive predictive values (PPV) were reported for the studies to determine the goodness of fit, performance, accuracy, or discriminatory performance of the predictive models informing the risk assessment tools. The range of c-index values reported in the studies was between 0.63 and 0.84, indicating fair to excellent model performance. AUC values are reported in the studies to range between 0.55 and 0.90, indicating poor to excellent performance. Lubelski et al. reported R^2 values for patient-reported outcome change based predictive models which ranged from 0.35 to 0.47 [3••]. Similarly, Merali et al. and Siccoli et al. had PPV values ranging from 0.72 to 0.98, demonstrating good to excellent model precision [25••, 26••]. Genov et al. utilized positive predictive values to assess the accuracy of their risk assessment models, demonstrating 65% for 1st postoperative day pain and 70% for chronic pain syndrome 5–7 months after surgery [28]. Variables considered for each predictive model, final variables included in the risk assessment tool and measures statistical fit, and accuracy of prediction are reported in Table 3.

Table 1 PROBAST risk of bias assessment for studies included in this review

Study	ROB				Applicability			Overall	
	Participants	Predictors	Outcomes	Analysis	Participants	Predictors	Outcomes	ROB	Applicability
Asher et al. (2017) [27••]	–	–	+	?	–	–	–	+	–
Devin et al. (2018) [29]	–	–	+	–	–	–	–	+	–
Genov et al. (2018) [28]	–	–	+	–	–	–	–	+	–
Hegarty and Shorten (2012) [24]	–	–	+	+	–	–	–	+	–
Khor et al. (2018) [5••]	–	–	+	–	–	–	–	+	–
Lee et al. (2016) [31]	–	–	+	?	–	–	–	+	–
Lubelski et al. (2018) [3••]	–	–	+	+	–	–	–	+	–
McGirt et al. (2017) [6••]	–	–	+	?	–	–	–	+	–
McGirt et al. (2015) [23]	–	–	+	+	–	–	–	+	–
Merali et al. (2019) [26••]	–	–	+	–	–	–	–	+	–
Sharma et al. (2019) [30]	–	–	+	–	–	–	–	+	–
Siccoli et al. (2019) [25••]	–	–	+	–	–	–	–	+	–
Staartjes et al. (2019) [32]	–	–	+	–	–	–	–	+	–

PROBAST Prediction model Risk Of Bias Assessment Tool, *ROB* risk of bias

– indicates low ROB/concern regarding applicability, + indicates high ROB concern regarding applicability, and ? indicates unclear ROB concern regarding applicability

Predicted Patient-Reported Outcomes by Spine Region

We included studies in patients undergoing cervical spine (n = 3), thoracolumbar spine (n = 2), and lumbar spine (n = 8) surgery [3••, 5••, 6••, 23–32]. These studies reported predictive models (n = total number of models) to estimate post-surgical patient-reported outcomes of the following: return to work (n = 3), pain (n = 9), physical functioning and disability (n = 5), quality of life (QOL) (n = 6), and psychosocial disposition (n = 2) reported in Table 4**.**

Risk Assessment Tools Predicting Patient-Reported Outcomes

Return to Work

Three studies included risk assessment tools to predict patients returning to work after spine surgery at 3 months and 12 months [23, 27••, 29]. All models were derived from the Quality Outcomes Database (QOD) and predicted return to work in patients undergoing cervical and lumbar spine surgery with good to excellent predictive accuracy.

Pain

Six studies reported risk assessment tools for post-operative pain (n = 9) after lumbar or thoracolumbar surgeries. Post-operative pain was predicted at day 1 post-surgery, 3 months, 6 months, and 12 months [5••, 6••, 24, 25••, 28, 32]. Khor et al. generated c-index range of 0.66–0.79 and Siccoli et al. gave AUC values of 0.71–0.85, both demonstrating greatest predictive accuracy [5••, 25••]. The risk assessment tools by Khor et al. and Siccoli et al. demonstrated the greatest predictive accuracy for pain at 3 months with c-index range 0.66–0.79 for Khor et al. and AUC values 0.71–0.85 for Siccoli et al. [5••, 25••].

Physical Functioning and Disability

Five studies reported risk assessment tools to predict post-operative physical functioning and disability [5••, 6••, 23, 25••, 32]. Patient data for these risk assessment tools were derived from Spine Surgical Care and Outcomes Assessment Program (SpineSCOAP) and QOD registries along with single institution datasets for patients undergoing various lumbar surgeries. Khor et al., McGirt et al., and McGirt et al. predicted disability at 12 months with statistical accuracy considered fair [5••, 6••, 23]. Staartjes et al. predict disability at 6 weeks and 12 months with excellent predictive accuracy while Siccoli predicts disability at 12 months with good accuracy [25••, 32].

Quality of Life

Five studies reported risk assessment tools that predicted quality of life at 12 months following lumbar surgery informed by the EQ-5D [3••, 6••, 26••, 30, 31]. The study by Merali et al. reported a risk assessment model informed by the SF-6D and Modified Japanese Orthopedic Association tools each

Table 2 Summary of relevant characteristics: surgeries, inclusion and exclusion criteria, which were utilized in the studies to develop risk assessment tools

Authors (year)	No. of cases	Median Pt age, years (range if reported)	Registry	Study design	Diagnosis/procedure	Inclusion criteria	Exclusion criteria	Follow-up time period
Asher et al. (2017) [27]	4694	52	Quality Outcomes Database	Prospective	Adult patients with primary stenosis, spondylolisthesis, disc herniation, symptomatic mechanical disc collapse, revision surgery: recurrent same-level disc herniation and adjacent-segment disease	Adult patients with primary stenosis, spondylolisthesis, disc herniation, symptomatic mechanical disc collapse, revision surgery: recurrent same-level disc herniation and adjacent-segment disease	Spinal fusion, tumor, fracture, traumatic dislocation, deformity, pseudoarthritis, recurrent multilevel stenosis, and neurological paralysis from pre-existing disease or injury age less than 18 years; incarceration	6 weeks and 3 months
Devin et al. (2018) [29]	4689	52	Quality Outcomes Database	Prospective	Adult employed patients diagnosed with cervical degenerative spine disease undergoing surgery. Return to work being the primary outcome of interest	Patients undergoing cervical spine surgery for degenerative cervical spine disease; completes 3-month information for RTW; completion of baseline information regarding employment status, type, and intensity	Age less than 18 years; infection; tumor or malignancies; spine fracture or dislocation; spine deformities; severe cognitive and psychiatric impairment; neurologic paralysis from pre-existing disease; neuropathy; incarceration	3 months
Genov et al. (2018) [28]	291	(18–70)	None	Prospective	Lumbar discectomy; nerve decompression and fixation of spine with cage and transpedicular system for stenosis; nerve decompression and spinal fixation for traumatic spinal cord injury	All patients 18–70 years, with ASA grades I-III undergoing elective surgery for degenerative disease or injury of the spine	History of previous lumbar or thoracic spine; complicated or combined traumatic SCI; problems of communication with patient; history of allergic reactions to analgesics; contraindications to use of non-steroidal anti-inflammatory drugs, paracetamol, and opioid analgesics; refusal to participate in study	5–7 months
Hegarty and Shorten (2012) [24]	53	(18–65)	None	Prospective	Adults with intervertebral disc herniation confirmed by MRI	Patients ages 18–65 years; ASA grades I-II; elective lumbar discectomy; intervertebral disc herniation confirmed by MRI; persistent symptoms at least 12 weeks; presents of radicular or low back pain; positive nerve root tension sign; neurologic deficit	Previous spinal surgery; cauda equina syndrome; known spinal or genetic abnormalities; pregnancy; vertebral fractures; spinal infection or tumor; inflammatory spondyloarthropathy; preoperative analgesia management in 2 weeks prior to surgery; preoperative pain VAS greater than 3/10; unwillingness to participate	3 months
Khor et al. (2018) [5]	1965	61.3	Spine SCOAP	Prospective	Adults with stenosis, spondylolisthesis/lumbar fusion	NA—SCOAP Registry	Procedures on more than 5 spinal levels; trauma; tumor; infection	2, 6, 12, 18, 24, 30, and 36 months
Lee et al. (2016) [31]	376	69 (51–91)	None	Prospective	Adults with decompressive laminectomy and fusion procedure for degenerative conditions: intervertebral disc herniation; spinal stenosis; degenerative spondylolisthesis; degenerative lumbar scoliosis	Adults undergoing elective decompressive laminectomy and fusion procedure for intervertebral disc herniation, spinal stenosis, degenerative spondylolisthesis, or degenerative lumbar scoliosis	NR	3 and 12 months
Lubelski et al.	952	52.5		Retrospective	Anterior or posterior cervical decompression and/fusion			12 months

Table 2 (continued)

(2018) [3]			Electronic Medical Records			Anterior or posterior cervical decompression and/or fusion between 2007 and 2013	Age younger than 18 years old; non-spondylolytic causes of radicular pain; neuromuscular disease	
McGirt (2017) [6]	7618	60	Quality Outcomes Database	Prospective	Stenosis, spondylolisthesis, disc herniation, revision surgery for disc herniation and adjacent-segment disease	Patients undergoing elective lumbar surgery for primary stenosis, spondylolisthesis, disc herniation and symptomatic mechanical disc collapse; patients undergoing revision surgery for same level disc herniation and adjacent segment disease	Spinal infection, tumor, fracture, traumatic dislocation, deformity, pseudoarthritis, recurrent multilevel stenosis, neurological paralysis from preexisting spinal disease or injury; age under 18 years; incarceration	12 months
McGirt (2015) [23]	1803	55.92	Single-center spine registry	Prospective	Degenerative lumbar diagnoses	Every consecutive patient undergoing lumbar spine surgeries over a 4-year period	NR	3 and 12 months
Merali et al. (2019) [26]	757	56	Multi-center AOSpine CSM North America or International study-specific registry	Retrospective	Surgical decompression of the cervical spine, with or without instrumented fusion	Age ≥ 18 years; symptomatic with DCM with one or more signs; cervical cord compression confirmed with imaging; no previous cervical spine surgery	Asymptomatic DCM; active infection; neoplastic disease; rheumatoid arthritis; trauma; ankylosing spondylitis; concomitant lumbar stenosis	6, 12, and 24 months
Sharma et al. (2019) [30]	191	64.3	Electronic Medical Records utilizing Knowledge Program	Prospective	Adult patients w/ the radiographic evidence of thoracolumbar spinal deformity that underwent anterior, posterior, or circumferential lumbar and thoracolumbar fusion of greater than 3 vertebral levels	Included in the sample were patients 25 yr of age or over with idiopathic, degenerative, or iatrogenic diagnoses of adult spinal deformity.	Spinal fracture, malignancy, or infection	12 months
Siccoli et al. (2019) [25]	635	62	Prospective registry at a single spine center in the Netherlands	Retrospective	Single or multi-level decompression surgery without or without fusion for lumbar spinal stenosis	> 80% of baseline data completion; single or multi-level decompression surgery indicated;	NR	6 weeks; 12 months
Staartjes et al. (2018) [32]	422	49	Prospective institutional registry of spinal interventions at a single center in the Netherlands	Prospective	Adult patients diagnosed with lumbar disc herniation with failed conservative management for more than 8 weeks. Underwent lumbar microdiscectomy	Radiologically confirmed single-level LDH and failed conservative management for more than 8 weeks; completed baseline and 12-month PROs; greater than 80% of demographic information available	NR	12-months post-op

NR not reported, *ASA* American Society of Anesthesiologists, *DCM* degenerative cervical myelopathy, *LDH* lumbar disc hernia, *PRO* patient-reported outcome, *SpineSCOAP* Spine Surgical Care and Outcomes Assessment Program component examining three time points, 6, 12, and 24 months [26••]. Patient data for these risk assessment tools was derived from EMR data, QOD registry, and Multi-center AOSpine CSM North America or International study-specific registries for patients undergoing elective cervical and lumbar surgeries [3••, 6••, 26••, 30, 31]. The predictive accuracy of these tools ranged from fair to good, with Sharma et al. exhibiting the greatest predictive accuracy with a c-index value of 0.764 [30].

Psychological Disposition

Lubselski et al. reported two risk assessment models using psychometric PRO measures that measure mental health at 12 months following elective cervical spine surgery [3••]. These models were informed by the EQ-5D, Patient Health Questionnaire-9, and Pain/Disability Questionnaire tools and did not demonstrate good predictive accuracy.

Discussion

Summary of Findings

Our review identified 13 articles containing 28 models that inform risk assessment tools to predict patient-centered outcomes following spine surgery. The risk assessment tools and predictive models informing the tools estimated patient outcomes of pain, disability, physical function, quality of life, and psychological disposition. Most studies reported on risk assessment tools in the lumbar spine, followed by cervical and thoracic spine. The risk assessment tools estimated outcomes at a range of follow-up time points from 1-day post-operatively to 12 months postoperatively. C-index or AUC was reported in the majority of the included studies to indicate the goodness of fit of the models used in the risk assessment tools. Traditionally, a c-index of 0.7 indicates good fit and an AUC value of 0.80 indicates excellent fit [33]. The fit of the models used in the risk assessment tools that are reported in this review demonstrated fair to excellent model fit. The ROB assessment indicated that although there were potential blinding issues of predictors and outcomes, this is to be expected in risk assessment. The authors feel that the studies included in this review were of acceptable quality and reporting on risk assessment tools have external applicability outside of spine surgery.

Comparison of Our Review to Current Literature

When attempting to compare the findings of our review with other systematic reviews on the availability of risk assessment tools to predict patient-centered outcomes in those undergoing spine surgery, we were unable to find any published reviews on this topic but recognize that there are many published studies on predictive modeling of patient-centered outcomes. There are, however, review by Osorio et al. discussing the predictive tools available to adult spine surgery to model for complications and a variety of singular tools for death, infection, readmission, medical complications, etc. [13, 34•, 35–37, 38••]. After critically examining the literature, it appears that creating risk assessment tools for PROMs is a new frontier and an area for growth. As risk assessment models utilized prior to elective surgery continue to grow with value-based healthcare, refinement among variables included in models will likely increase diagnostic accuracy and overall performance.

Strengths and Limitations

There are numerous strengths of this systematic review. First, the authors were able to synthesize the body of literature regarding the available risk assessment tools specific to predict patient-centered outcomes in patients undergoing spine surgery. There are many published tools and reviews for risk assessment tools for surgical complications, mortality, and morbidity in patients undergoing spine surgery, but less literature focusing on patient-centered outcomes after surgery which are becoming a key component of value-based care [13]. Our review included reporting risk assessment tools in a representative but diverse patient population including single institution and patient registries. Moreover, several included studies such as Devin et al., McGirt et al., Merali et al., and Staartjes et al. reported models with excellent discriminatory capabilities and McGirt et al. examine the utility of predictive models in clinical practice [6••, 23, 26••, 29, 32]. The second strength of this review is the reporting of risk assessment tools across the entire spine region. There is a preponderance of literature examining outcomes in patients with low back pathologies due to the costly nature of diagnosing and treatment of low back pain [39]. In this review, we were able to report on the availability of risk assessment tools, not only patients undergoing lumbar surgeries, but also patients undergoing cervical and thoracic surgery which provides a synthesis of tool for use in other spine regions where there is less focus on predicting outcomes. Lastly, our review offers an insight into the many factors informing the risk assessment tools and heterogeneity of follow-up time points for predicted outcomes.

Our study also has some noted limitations. We did not perform a meta-analysis of outcomes nor did we focus our review of the relative contribution or similarities of the predictors to the risk assessment tools. The authors instead decided to utilize a qualitative focus this review on the reporting of the available risk assessment tools for predicting patient-centered outcomes after spine surgery to provide a concise overview of the tools available rather than statistical and quantitative comparisons on the risk assessment tools. The scope of

Table 3 Predictive models informing risk assessment tools and statistical summaries

Authors (year)	No. of cases	Variables considered for model	Variables in final model	C-index	AUC/ROC
Asher et al. (2017) [27]	4694	NR	Age; gender; race; smoking status; employment; occupation type; past surgery; number of spinal levels; ASA grade; BMI; diabetes; osteoporosis; CAD; education level; anxiety; depression; dominant symptom; motor deficit; symptom duration; principal spinal diagnosis; workers' compensation; liability insurance for disability; insurance type; ambulatory status; lumbar fusion, anterior, posterior or combined approach; preoperative ODI, EQ-5D, and NRS-BP/LP scores	0.71 (good)	NR
Devin et al. (2018) [29]	4689	Age; gender; ethnicity; insurance status; education level; occupation level; occupation intensity; employment type; workers' compensation status; smoking status; diabetes mellitus; CAD; PVD; anxiety; depression; osteoporosis; median BMI; ASA grade; symptom duration; predominant symptom; ambulation; presence of motor deficit; presence of cervical instability; pseudarthrosis; adjacent-segment disease; ACDF; disc herniation; foraminal stenosis; central stenosis; minimally invasive surgery; number of levels fused; NDI; VAS; NASS satisfaction score at 3 months	Age; full time vs part time; education level; employment; occupation intensity; workers' compensation; baseline NDI; symptom duration; predominant symptom; levels fused	0.81 (excellent)	NR
Genov et al. (2018) [28]	291,272	Age; gender; BMI; education Level; smoking; pain at rest and in motion; pain intensity, duration and frequency; analgesic use; VAS; situational and Personal Anxiety Index; Beck Depression Index; Tampa Scale of Kinesiophobia; Pain Catastrophizing Scale; pain threshold and pain tolerance	Mild dynamic pain on 1st postoperative day: motion pain before surgery (VAS); expected pain (VAS); pain threshold; gender; **Constant chronic pain syndrome 5–7 months after surgery: age; motion pain on the 1st postoperative day (VAS); **Constant	NR	NR
Hegarty and Shorten (2012) [24]	53	Gender; age; VAS; PPI; McGill Word; RMF; Pain Catastrophizing Scale; Anxiety score; Depression score	Age, RMF, PPI	0.658	NR
Khor et al. (2018) [5]	1965	NR	Age; sex; race; insurance; ASA score; smoking status; diagnoses; prior surgery status; prescription opioid use; asthma; and baseline PRO scores	0.66–0.79	ODI: 0.66 NRS-BP: 0.79 NRS-LP: 0.69
Lee et al. (2016) [31]	376	ED-5Q domains: mobility (M); self-care (S); usual activities (A); pain/discomfort (P); anxiety/depression (D)	Regression equation for ED-5Q subcategories to determine risk: S + A + 2xP + D > = 9	NR	NR
Lubelski et al. (2018) [3]	952	Age; gender; race; marital status; BMI; smoking status; income; comorbidities; presenting symptoms; symptom duration; type of surgery; indications for surgery; total number of operated spinal levels	30-day ED visit: race; BMI; zip code; median income; surgical approach; spondylosis; total number of operated levels 30-day readmission: race; BMI; diagnosis of disc herniation or myelopathy; surgical approach; number of levels; terminal level; history of cancer 90-day reoperation: BMI; presenting symptoms; presence of disc herniation; surgical approach; presence of diabetes; change ED-5Q: herniation; myelopathy; surgical approach; diabetes mellitus; preoperative EQ-5D; preoperative PDQ change	*3-day ED visit: 0.63 *30-day readmission: 0.78 *90-day Reoperation: 0.91	NR

Table 3 (continued)

			PHQ-9: age; herniation; surgical approach; diabetes mellitus; preoperative PHQ-9 change in PDQ: BMI; smoking status; spondylosis; surgical approach; preoperative EQ-5D		
McGirt (2017) [6]	7618	Age; gender; BMI; race; education level; history of surgery; smoking status; comorbid conditions; ASA grade; symptom duration; predominant presenting symptom; workers' compensation; liability insurance; insurance status; ambulatory ability; baseline PROs; surgery-specific variables: number of levels, need for arthrodesis and surgical approach	Age; gender; BMI; race; education level; history of prior surgery; smoking status; comorbid conditions; ASA grade; symptom duration; indication for surgery; number of levels surgically treated; history of fusion surgery; surgical approach; receipt of workers' compensation; liability insurance; insurance status; ambulatory ability; baseline PROMs	Disability: 0.69 QOL: 0.69 Back pain: 0.67 Leg pain: 0.64	NR
McGirt (2015) [23]	1803	Age; gender; race; BMI; employment; symptom duration; prior surgeries; narcotic use; smoking status; insurance; acute or chronic; neurologic symptoms; past medical history; baseline PRO scores; fracture; deformity; spinal diagnosis	Age; gender; baseline ODI; prior surgery; narcotic use (days); private insurance; number of levels involved; ASA grade ≥ 2; hypertension; arthritis; diabetes; BMI; MSPQ; fusion	NR	0.72–0.84 for 5 predictive models 0.82 for unplanned postoperative outcome Complications: 0.82* Readmission: 0.79* Inpatient rehabilitation: 0.84* Return to work: 0.83 Unplanned outcome: 0.78*
Merali et al. (2019) [26]	6-month: 605 12-month: 583 24-month: 539	Patient demographics; clinical presentation; surgical treatment; detailed medical co-morbidities	6 months: 41 features 12 months: 108 features 24 months: 101 features	NR	SF-6D 6 months: 0.71 12 months: 0.70 24 months: 0.73 mJOA 6 months: 0.73 12 months: 0.73 24 months: 0.67
Sharma et al. (2019) [30]	191	Age; sex; race; BMI; diagnosis; EQ-5D score; history of spinal trauma; history of spinal surgery; operative approach (anterior vs posterior); number of spinal levels fused; comorbid dyslipidemia, obesity, hypertension, diabetes mellitus, tobacco use disorder	Pre-op EDQ score, sex, pre-op diagnosis (degenerative, idiopathic, iatrogenic), previous spinal surgery history, obesity, sex-by-obesity interaction term	0.739 BS sample = .764	0.89
Siccoli et al. (2019) [25]	635	Baseline PROs; sex; age; height; weight; BMI; smoking status; regular alcohol intake; ASA grade; prior surgery at index level; single or multi-level decompression; index levels; present of concomitant spondylolisthesis; predominant presenting symptoms (claudication or radiculopathy)	NR	NR	6 weeks: ODI: 0.71 NRS-BP: 0.75 NRS-LP: 0.87 *Reop overall: 0.63 *Reop at level: 0.70 *Prolonged surgery: 0.61 *Extended stay: 0.77 12 months: ODI:0.73 NRS-BP: 0.72 NRS-LP: 0.75

Table 3 (continued)

Staartjes et al. (2018) [32]	422	Age; gender; height (cm); weight (kg); BMI; smoking status; alcohol consumption; recreational drug use; ASA grade; prior discectomy at the index level; location of herniation; classification as a far-lateral or sequestered herniation; classification as broad bulging disc without annular rupture compressing nerve roots; presence of stenosis or spondylolisthesis at index level; baseline PROMs—ODI, NRS-BP, NRS-LP	Age; BMI; gender: ASA score; smoking status; prior discectomy at index level; sequestered disc herniation; NRS leg pain; NRS back pain; ODI; predicted likelihood of achieving MCID in leg pain, back pain, and functional disability	NR	*Reop overall: 0.66 *Reop at level: 0.61 *Prolonged surgery: 0.54 *Extended stay: 0.58 NRS-LP = .87 (deep learning), 0.78 (regression) NRS-BP = .90 (deep learning), 0.55 (regression) ODI = 0.84 (deep learning), 0.72 (regression)

Authors (year)	R2	Positive predictive value (PPV)	Validation cohort	Model (application) available
Asher et al. (2017) [27]	NR	NR	BS	http:// statcomp2.vanderbilt.edu:37212/app_0/
Devin et al. (2018) [29]	NR	NR	BS	Nomogram created
Genov et al. (2018) [28]	NR	1st-postop day pain: PPV: 70%, 95% CI (63–76) CPS 5–7 months after surgery PPV: 65%; 95% CI (59–71)	BS	Formula given; MS Excel
Hegarty and Shorten (2012) [24]	NR	NR	BS	NR
Khor et al. (2018) [5]	NR	NR	15% of sample	https://becertain.shinyapps.io/lumbar_fusion_calculator
Lee et al. (2016) [31]	NR	NR	Positive predictions 86% with cutoff value = 9	S + A + 2xP + D >= 9 domains from ED-5Q
Lubelski et al. (2018) [3]	EQ-5D: 0.43 PHQ-9: 0.35 PDQ: 0.47	NR	BS	http://riskcalc.org/PatientsEligibleforCervicalSpineSurgery/
McGirt (2017) [6]	NR	NR	NR	Not functional http://statcomp2.vanderbilt.edu:37212/app_0/
McGirt (2015) [23]	12-month ODI: 0.51 Validated—12-month ODI: 0.47	NR	20% of cohort	NR
Merali et al. (2019) [26]	NR	SF-6D 6 months: 0.90 12 months: 0.98 24 months: 0.92 mJOA 6 months: 0.82 12 months: 0.91 24 months: 0.96	70% training/validation,30% testing dataset	NR
Sharma et al. (2019) [30]	NR	NR	BS	Nomogram provided in paper
Siccoli et al. (2019) [25]	NR	6 weeks: ODI: 0.73 NRS-BP: 0.84	BS; 70% training, 30% testing	NR

Table 3 (continued)

		NRS-LP: 0.79 12 months: ODI: 0.80 NRS-BP: 0.76 NRS-LP: 0.72		
Staartjes et al. (2018) [32]	NR	NR	Training/validation/testing cohorts of 60%/20%/20% of data	NR

NR not reported, *ACDF* anterior cervical discectomy and fusion, *ASA* American Society of Anesthesiologists, *BS* bootstrapping, *BMI* body mass index, *CAD* coronary artery disease, *ODI* Oswestry Disability Index, *NDI* Neck Disability Index, *ED-5D* EuroQOL-5 Dimension Questionnaire, *PRO* patient-reported outcome, *PVD* peripheral vascular disease, *MCID* minimal clinically important difference, *NASS* North American Spine Society, *NRS* Numeric Rating Scale, *BP* back pain, *LP* leg pain, *VAS* Visual Analog Scale, *QOL* quality of life, *PDQ* Pain/Disability Questionnaire, *PHQ-9* Patient Health Questionnaire-9, *PPI* persistent pain intensity, *Reop* reoperation, *RMF* Roland-Morris Functional score

*Statistic reported as a component of a given risk assessment model but does not fit inclusion criteria and therefore is not discussed in this review

**Constant value included in model

our review aimed to include studies that reported on validated risk assessment tools rather than development of individual predictive models. Therefore, there are many studies which report predictive models for assessing outcomes from surgery that exist but were not included in this review due to the strict inclusion criteria. We also only included risk assessment tools for patient-centered outcomes only, rather than surgical complications. Our rationale for this approach was the lack of a review solely devoted to patient-centered outcomes. Lastly, the studies included in this review were not without bias. Due to the nature of studies reporting and assessing risk assessment tools, it is difficult to blind or limit the knowledge of preoperative predictors in the studies.

Clinical Implications

Risk assessment tools are becoming increasingly utilized in the process of shared decision-making between clinician and patient as healthcare begins to shift towards value-based care. Caution should be utilized before solely relying on risk assessment tools for predicting outcomes prior to surgery as that is not the intended use of these tools, but to be used in conjunction with clinical judgment and objective findings [6••]. There are several ways in which the application of risk assessment tools can enhance the healthcare experience and improve clinical decision-making. Patient-centered care can be facilitated through the use of individualized risk assessment tools where a patient's particular factors and PROMs give the probability of success for a spine surgery that are often not considered in everyday clinical practice in a quantifiable manner [23]. Interpreting the results of risk assessment tools allows physicians and patients to both have an understanding of risks involved with surgery and timeline functional improvements postoperatively [3••, 25••, 32]. Ideally, risk assessments would lower the occurrence of unnecessary and inappropriate surgeries, along with resulting complications and reoperations [32]. Clinicians can then educate patients on the best ways to minimize risk by adjusting modifiable risk factors prior to elective surgery and visualize the significance of each variable in the model [3••].

Conclusion

Risk assessment tools and predictive modeling techniques are gaining momentum within the field of spine surgery as a means to improve care and subsequently the value of spine surgery. PROMs, a patient-centered metric, are increasingly being regarded as a common endpoint of spine surgery next to surgical complications. This notion is supported by the shift towards value-based patient care,

Table 4 Categorization of included PROs predicted by risk assessment tools by spinal region and PRO category

PRO category	Spinal region			No. of models	Incorporated PROMs
Return to work	Cervical	Thoracolumbar	Lumbar	*n* = 3	
Asher et al. (2017) [27••]			x	1	ODI, EQ-5D, NRS-BP, NRS-LP
Devin et al. (2018) [29]	x			1	NDI, VAS-AP and VAS-NP
McGirt (2015) [23]			x	1	ODI; SF-12; MSPQ; VAS-BP; VAS-LP; VAS-NP
Pain (back and leg pain)				*n* = 9	
Genov et al. (2018) [28]		x		2 *Post-op and chronic pain	STRAI; BDI; TSK-17; PCS
Hegarty and Shorten (2012) [24]			x	1 *Persistent pain	VAS; MPQ; RMDQ; HADS; PCS; SF-36
Khor et al. (2018) [5••]			x	2	NRS-BP; NRS-LP; ODI
McGirt (2017) [6••]			x	2	ODI; ED-5Q; NRS-BP; NRS-LP
Siccoli et al. (2019) [25••]			x	2	Dutch validated ODI; NRS-BP; NRS-LP
Physical functioning and disability				*n* = 6	
Khor et al. (2018) [5••]			x	1	NRS-BP; NRS-LP; ODI
McGirt (2015) [23]			x	2	ODI; SF-12; MSPQ; VAS-BP; VAS-LP; VAS-NP
McGirt (2017) [6]			x	1	ODI; ED-5Q; NRS-BP; NRS-LP
Siccoli et al. (2019) [25••]			x	1	Dutch validated ODI; NRS-BP; NRS-LP
Staartjes et al. (2018) [32]			x	1	NRS-BP; NRS-LP; Dutch validated ODI
Quality of Life				*n* = 5	
Lee et al. (2016) [31]			x	1	EQ-5D
Lubelski et al. (2018) [3••]	x			1	EQ-5D; PHQ-9; PDQ
McGirt (2017) [6••]			x	1	ODI; ED-5Q; NRS-BP; NRS-LP
Merali et al. (2019) [26••]	x			1	SF-6D; mJOA
Sharma et al. (2019) [30]		x	x	1	EQ-5D
Psychological Disposition				*n* = 2	
Lubelski et al. (2018) [3••]	x			2	EuroQOL (EQ-5D); Patient Health Questionnaire-9 (PHQ-9); Pain/Disability Questionnaire (PDQ)

BDI Beck Depression Inventory, *ED-5Q* EuroQuol-5 dimensions, *HADS* Hospital Anxiety and Depression Scale questionnaire, *MJOA* Modified Japanese Orthopedic Association, *MPQ* McGill Pain Questionnaire, *MSPQ* Modified Somatic Perceptions Questionnaire, *NDI* Neck Disability Index, *NRS-BP* Numeric Rating Scale—back pain, *NRS-LP* Numeric Rating Scale—leg pain, *ODI* Oswestry Disability Index, *PCS* Pain Catastrophizing Scale, *PDQ* Pain/Disability Questionnaire, *PHQ-9* Patient Health Questionnaire-9, *RMDQ* Roland-Morris Questionnaire, *STRAI* State-Trait Anxiety Inventory, *TSK-17* Tampa Scale of Kinesiophobia-17; VAS-AP, VAS-BP, VAS-LP; VAS-NP

where not only avoiding complications is considered, but also the patient's outcomes are of paramount importance. Our review has synthesized the available evidence on risk assessment tools for predicting patient-centered outcomes in patients undergoing spine surgery and described their findings and clinical utility. Further research in this area is needed to validate some of the reported risk assessment tools as well as further refine the tools to be more easily implemented in clinical practice.

Compliance with Ethical Standards

This review was written in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement [16]. The protocol for this review is available in the PROSPERO registry (CRD42019136188) [17].

Conflict of Interest Hannah J. White, Jensyn Bradley, Nicholas Hadgis, Emily Wittke, Brett Piland, Brandi Tuttle, Melissa Erickson, and Maggie Horn declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This review does not contain any studies with animal or human studies performed by the authors.

Appendix. Comprehensive search strategy used to identify relevant studies

PubMed https://mclibrary.duke.edu/pubmed

Set		Results
1	(“spine/surgery”[mesh] OR “Spinal Diseases/surgery”[mesh] OR “Lumbosacral Region/surgery”[mesh] OR “Diskectomy”[Mesh] OR discectomy[tiab] OR diskectomy[tiab] OR diskectomies[tiab] OR discectomies[tiab] OR Microdiscectomy[tiab] OR “Spinal Fusion”[Mesh] OR fusion[tiab] OR fusions[tiab] OR “Laminectomy”[Mesh] OR Laminectomy[tiab] OR “laminoplasty”[MeSH Terms] OR laminoplasty[tiab] OR Laminotomy[tiab] OR “Total Disc Replacement”[Mesh] OR “disc replacement”[tiab] OR foraminotomy[tiab] OR “foraminal decompression”[tiab] OR kyphoplasty[tiab] OR kyphoplasties[tiab] OR “facetectomy”[tiab] OR “arthrodesis”[MeSH Terms] OR “arthrodesis”[tiab] OR “cementoplasty”[MeSH Terms] OR “cementoplasty”[tiab] OR “vertebroplasty”[MeSH Terms] OR “vertebroplasty”[tiab] OR corpectomies[tiab] OR corpectomy[tiab] OR spondylodesis[tiab] OR spondylodeses[tiab] OR Spondylosyndesis[tiab]) OR ((“spine”[MeSH Terms] OR “spine”[tiab] OR spinal[tiab] OR disc[tiab] OR “lumbosacral region”[MeSH Terms] OR “lumbosacral”[tiab] OR “lumbar”[tiab]) AND (“Decompression, Surgical”[Mesh] OR “decompression”[tiab] OR “stabilization”[tiab] OR “surgery”[tiab] OR “Arthroplasty, Replacement”[mesh] OR “Surgical Procedures, Operative”[Mesh] OR “operative”[tiab] OR “operation”[tiab] OR “surgery”[Subheading] OR “surgery”[tiab] OR “surgeries”[tiab] OR “surgical”[tiab]))	353,221
2	“risk assessment”[mesh] OR “Risk Adjustment”[mesh] OR “risk calculator”[tiab] OR “risk calculators”[tiab] OR “risk assessment”[tiab] OR “risk prediction”[tiab] OR “risk stratification”[tiab] OR “risk stratified”[tiab] OR “stratified risk”[tiab] OR “SpineSage”[tiab] OR “Outcomes Assessment Program”[tiab] OR “Quality Outcomes Database”[tiab] OR “prediction tool”[tiab] OR “Predictive tool”[tiab] OR “prediction tools”[tiab] OR “Predictive tools”[tiab] OR “Predictive analytics”[tiab] OR “predictive model” OR “Predictive Value of Tests”[mesh] OR “machine learning”[MeSH Terms] OR “machine learning”[tiab]	507,154
3	“patient reported outcome measures”[MeSH Terms] OR “physical function”[tiab] OR “patient reported outcome”[tiab] OR “patient reported outcome measures”[tiab] OR “failed back surgery syndrome”[MeSH Terms] OR “failed back surgery syndrome”[tiab] OR “postoperative complications”[mesh] OR “postoperative complications”[tiab] OR “back pain”[MeSH Terms] OR “low back pain”[MeSH Terms] OR “back pain”[tiab] OR “Opioid-Related Disorders”[mesh] OR “opioid dependency”[tiab] OR “opiate dependency”[tiab] OR “opiate dependence”[tiab] OR “opioid dependence”[tiab] OR “opiate addiction”[tiab] OR “opioid addiction”[tiab] OR “opiate abuse”[tiab] OR “opiate misuse”[tiab] OR “Functional impairment”[tiab] OR “functional outcome”[tiab] OR “functional outcomes”[tiab] OR “disability”[tiab] OR “Disability Evaluation”[mesh] OR “Pain Measurement”[mesh] OR “Pain, Postoperative”[mesh] OR “pain”[MeSH Terms] OR “pain”[tiab] OR “pains”[tiab] OR “painful “[tiab] OR “discomfort “[tiab] OR “suffering “[tiab] OR “sufferings “[tiab] OR “ache “[tiab] OR “aches “[tiab] OR “aching”[tiab] OR “sore “[tiab] OR “soreness “[tiab] OR “analgesia “[tiab] OR “quality of life”[mesh] OR “quality of life”[tiab] OR “function test”[tiab] OR “function tests”[tiab] OR “functional testing”[tiab] OR “measure function”[tiab] OR “functional measure”[tiab] or “measuring function”[tiab] OR “measure functions”[tiab]	1,887,576
4	#1 AND #2 AND #3	2093
5	NOT ((“Adolescent”[Mesh] OR “Child”[Mesh] OR “Infant”[Mesh]) NOT “Adult”[Mesh])	1964
6	#4 NOT (Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp])	1730

Database: Embase http://proxy.lib.duke.edu/login?url=http://www.embase.com

Set		Results
1	‘spine surgery’/exp OR ‘spine disease’/exp/dm_su OR ‘discectomy’/exp OR ‘laminectomy’/exp OR ‘laminoplasty’/exp OR ‘percutaneous vertebroplasty’/exp OR ‘cementoplasty’/exp OR ‘kyphoplasty’/exp OR ‘spine fusion’/exp OR ‘spondylodesis’/exp OR ‘arthrodesis’/exp OR ‘spine surgery’:ab,ti OR ‘discectomy’:ab,ti OR ‘diskectomy’:ab,ti OR ‘discectomies’:ab,ti OR ‘diskectomies’:ab,ti OR ‘laminectomy’:ab,ti OR ‘laminoplasty’:ab,ti OR ‘percutaneous vertebroplasty’:ab,ti OR ‘cementoplasty’:ab,ti OR ‘kyphoplasty’:ab,ti OR ‘spine fusion’:ab,ti OR ‘spondylodesis’:ab,ti OR ‘arthrodesis’:ab,ti OR ‘microdiscectomy’:ab,ti OR ‘fusion’:ab,ti OR ‘fusions’:ab,ti OR ‘laminotomy’/exp OR ‘total disc replacement’/exp OR ‘foraminotomy’/exp OR ‘kyphoplasty’/exp OR ‘facetectomy’/exp OR ‘corpectomy’/exp OR ‘laminotomy’:ab,ti OR ‘total disc replacement’:ab,ti OR ‘foraminotomy’:ab,ti OR ‘kyphoplasty’:ab,ti OR ‘facetectomy’:ab,ti OR ‘corpectomy’:ab,ti OR ‘corpectomies’:ab,ti OR ‘spondylodeses’:ab,ti OR ‘spondylosyndesis’:ab,ti OR ((‘spine’/exp OR ‘lumbosacral spine’/exp OR ‘spine’:ab,ti OR ‘spinal’:ab,ti OR ‘disc’:ab,ti OR ‘lumbosacral region’:ab,ti OR ‘lumbosacral’:ab,ti OR ‘lumbar’:ab,ti) AND (‘spinal cord decompression’/exp OR ‘decompression’:ab,ti OR ‘stabilization’:ab,ti OR ‘surgery’:ab,ti OR ‘operative’:ab,ti OR ‘surgeries’:ab,ti OR ‘surgical’:ab,ti OR ‘operation’:ab,ti OR ‘spinal’:ab,ti OR ‘surgery’:lnk OR ‘spinal’:ab,ti OR ‘surgery’/exp OR ‘replacement arthroplasty’/exp))	686,268
2	‘risk assessment’/exp OR ‘risk calculator’/exp OR ‘risk prediction’/exp OR ‘risk prediction model’/exp OR ‘risk stratification’/exp OR ‘prediction’/exp OR ‘predictive value’/exp OR ‘predictive model’/exp OR ‘machine learning’/exp OR ‘risk assessment’:ab,ti OR ‘risk calculator’:ab,ti OR ‘risk calculators’:ab,ti OR ‘risk prediction’:ab,ti OR ‘risk stratification’:ab,ti OR ‘predictive value’:ab,ti OR ‘predictive model’:ab,ti OR ‘machine learning’:ab,ti OR ‘risk adjustment’:ab,ti OR ‘risk stratified’:ab,ti OR ‘stratified risk’:ab,ti OR ‘SpineSage’:ab,ti OR ‘outcomes assessment program’:ab,ti OR ‘quality outcomes database’:ab,ti OR ‘prediction tool’:ab,ti OR ‘prediction tools’:ab,ti OR ‘predictive tool’:ab,ti OR ‘predictive tools’:ab,ti OR ‘predictive analytics’:ab,ti	1,184,970
3	‘patient-reported outcome’/exp OR ‘physical function’/exp OR ‘physical performance’/exp OR ‘failed back surgery syndrome’/exp OR ‘postoperative complication’/exp OR ‘backache’/exp OR ‘back pain’/exp OR ‘low back pain’/exp OR ‘patient-reported outcome’:ab,ti OR ‘physical function’:ab,ti OR ‘physical performance’:ab,ti OR ‘failed back surgery syndrome’:ab,ti OR ‘postoperative complication’:ab,ti OR ‘backache’:ab,ti OR ‘low back pain’:ab,ti OR ‘opiate addiction’/exp OR ‘Opioid-Related Disorders’:ab,ti OR ‘opioid dependency’:ab,ti OR ‘opiate dependency’:ab,ti OR ‘opiate dependence’:ab,ti OR ‘opioid dependence’:ab,ti OR ‘opiate addiction’:ab,ti OR ‘opioid addiction’:ab,ti OR ‘opiate abuse’:ab,ti OR ‘opiate misuse’:ab,ti OR ‘functional disease’/exp OR ‘disability’/exp OR ‘physical disability’/exp OR ‘pain measurement’/exp OR ‘postoperative pain’/exp OR ‘pain’/exp OR ‘discomfort’/exp OR ‘suffering’/exp OR ‘quality of life’/exp OR ‘quality of life assessment’/exp OR ‘function test’/exp OR ‘functional disease’:ab,ti OR ‘disability’:ab,ti OR ‘physical disability’:ab,ti OR ‘pain measurement’:ab,ti OR ‘postoperative pain’:ab,ti OR ‘pain’:ab,ti OR ‘pains’:ab,ti OR ‘painful’:ab,ti OR ‘discomfort’:ab,ti OR ‘suffering’:ab,ti OR ‘sufferings’:ab,ti OR ‘quality of life’:ab,ti OR ‘quality of life assessment’:ab,ti OR ‘function test’:ab,ti OR ‘function tests’:ab,ti OR ‘functional testing’:ab,ti OR ‘functional impairment’:ab,ti OR ‘functional outcome’:ab,ti OR ‘functional outcomes’:ab,ti OR ‘disability evaluation’:ab,ti OR ‘ache’:ab,ti OR ‘aches’:ab,ti OR ‘aching’:ab,ti OR ‘sore’:ab,ti OR ‘soreness’:ab,ti OR ‘analgesia’:ab,ti OR ‘measure function’:ab,ti OR ‘functional measure’:ab,ti OR ‘measuring function’:ab,ti OR ‘measure functions’:ab,ti	3,714,634
4	#1 AND #2 AND #3	5117
5	NOT (([child]/lim OR [infant]/lim OR [newborn]/lim OR [preschool]/lim OR [school]/lim OR [very elderly]/lim) NOT ([adult]/lim OR [middle aged]/lim OR [young adult]/lim))	4915
6	NOT (‘case report’/exp OR ‘case study’/exp OR ‘editorial’/exp OR ‘letter’/exp OR ‘note’/exp OR [conference abstract]/lim)	3735

Database: Scopus http://proxy.lib.duke.edu/login?url=http://www.scopus.com

Set		Results
1	TITLE-ABS-KEY ("spine surgery" OR "lumbosacral surgery" OR "Diskectomy" OR "discectomy" OR "diskectomies" OR "discectomies" OR "Microdiscectomy" OR "Spinal Fusion" OR "Laminectomy" OR "laminoplasty" OR "Laminotomy" OR "disc replacement" OR "foraminotomy" OR "foraminal decompression" OR "kyphoplasty" OR "kyphoplasties" OR "facetectomy" OR "arthrodesis" OR "cementoplasty" OR "vertebroplasty" OR "corpectomies" OR "corpectomy" OR "spondylodesis" OR "spondylodeses" OR "Spondylosyndesis") OR TITLE-ABS-KEY (("spine" OR "spinal" OR "disc" OR "lumbosacral" OR "lumbar") AND ("decompression" OR "stabilization" OR "surgery" OR "replacement arthroplasty" OR "operative" OR "operation" OR "surgery" OR "surgeries" OR "surgical"))	206,607
2	TITLE-ABS-KEY ("risk assessment" OR "Risk Adjustment" OR "risk calculator" OR "risk calculators" OR "risk prediction" OR "risk stratification" OR "risk stratified" OR "stratified risk" OR "SpineSage" OR "Outcomes Assessment Program" OR "Quality Outcomes Database" OR "prediction tool" OR "Predictive tool" OR "prediction tools" OR "Predictive tools" OR "Predictive analytics" OR "predictive model" OR "Predictive Value" OR "machine learning")	1,191,809
3	TITLE-ABS-KEY ("patient reported outcome" OR "patient reported outcomes" OR "physical function" OR "failed back surgery syndrome" OR "failed back surgery syndrome" OR "postoperative complications" OR "postoperative complications" OR "back pain" OR "low back pain" OR "back pain" OR "Opioid-Related Disorders" OR "opioid dependency" OR "opiate dependency" OR "opiate dependence" OR "opioid dependence" OR "opiate addiction" OR "opioid addiction" OR "opiate abuse" OR "opiate misuse" OR "Functional impairment" OR "functional outcome" OR "functional outcomes" OR "disability" OR "Pain Measurement" OR "Postoperative pain" OR "pain" OR "pains" OR "painful "OR "discomfort "OR "suffering "OR "sufferings "OR "ache "OR "aches "OR "aching" OR "sore "OR "soreness" OR "analgesia "OR "quality of life" OR "function test" OR "function tests" OR "functional testing" OR "measure function" OR "functional measure" or "measuring function" OR "measure functions")	2,756,655
4	#1 AND #2 AND #3	3755
5	#4 AND (TITLE-ABS-KEY ("aging" OR "older adult" OR "elderly" OR "geriatric" OR "adult" OR {middle age} OR {middle aged} OR "aged"))	2655

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- • Of importance
- •• Of major importance

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