Quality and Safety Improvement in Spine Surgery

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Abstract

Study Design: Review article.

Objectives: A narrative review of the literature on the current advances and limitations in quality and safety improvement initiatives in spine surgery.

Methods: A comprehensive literature search was performed using Ovid MEDLINE focusing on 3 preidentified concepts: (1) quality and safety improvement, (2) reporting of outcomes and adverse events, and (3) prediction model and practice guidelines. The search was conducted under appropriate subject headings and using relevant text words. Articles were screened, and manuscripts relevant to this discussion were included in the narrative review.

Results: Quality and safety improvement remains a major research focus attracting investigators from the global spine community. Multiple databases and registries have been developed for the purpose of generating data and monitoring the progress of quality and safety improvement initiatives. The development of various prediction models and clinical practice guidelines has helped shape the care of spine patients in the modern era. With the reported success of exemplary programs initiated by the Northwestern and Seattle Spine Team, other quality and safety improvement initiatives are anticipated to follow. However, despite these advancements, the reporting metrics for outcomes and adverse events remain heterogeneous in the literature.

Conclusion: Constant surveillance and continuous improvement of the quality and safety of spine treatments is imperative in modern health care. Although great advancement has been made, issues with reporting outcomes and adverse events persist, and improvement in this regard is certainly needed.

Keywords

quality improvement, safety, outcome, adverse events, predictors, prediction model, clinical practice guidelines, protocol, spine surgery

Introduction

Spine surgery has seen rapid advancement in recent years due to novel technological innovations, safety improvements, and increased understanding of the pathophysiology of spinal conditions. With the rising number of annual spinal procedures performed worldwide, the associated growing costs are becoming a major health economic burden.[1-3] Efforts to curb the increase in hospital charges and to optimize the allocation of limited resources have led to advocacy for cost-effectiveness in health care services.[4,5] As the contemporary health care model

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shifts toward value-based care, where quality and cost of services are accountable by the providers,[6,7] quality and safety improvement in spine surgery has been a critical research focus in recent years.

The evolution of large surgical registries and multicentered prospective cohorts has generated a growing interest in spine-specific queries and attracted investigators worldwide. With critical knowledge gaps raising controversies in the field of spine surgery, recent efforts in the international spine community have led to the creation of clinical practice guidelines and protocols aimed at bringing consensus to the field. Additionally, innovative groups have initiated institutional-based programs with demonstrated success in improving the safety of high-risk spine procedures.[8,9]

The objective of this review is to summarize the concepts, methodologies, and current efforts in quality improvement. Because of the abundance of research, diversity of spinal pathologies, and a plethora of surgical treatment options, an exhaustive summary is unrealistic in the context of this article. Therefore, the goal of this review is to present a narrative overview of the direction of contemporary quality and safety improvement research, to discuss the limitations and barriers impeding rapid advancement, and to describe impactful programs and initiatives currently in practice.

Multicenter Spine Registry

Major knowledge gaps and healthcare inefficiencies are the current drivers for advancement in clinical research, while strong convincing scientific evidence ultimately sets the foundation for knowledge translation and improvement in care. Evidence-based medicine is, therefore, the key to success for quality and safety improvement. Randomized controlled trials have traditionally been placed at the pinnacle of the scientific hierarchy regarding levels of evidence.[10,11] However, the number of studies in the spine surgical literature that qualify for this designation are both limited and poor in quality.[11,12] Recently, the applicability of randomized controlled trials in spine surgery research has been called into question.[10,11] More specifically, identified limitations have included the selection of patients, ethical issues with the randomization of procedures not having strong clinical evidence of therapeutic equipoise, difficulty with blinding in clinical assessments, predetermined follow-up periods, as well as high costs associated with maintaining these surgical trials.[10,11,13]

Furthermore, several authors have alluded to the fact that the stringent inclusion process of the randomized control trial ultimately creates an "ideal" treatment group, which is not representative of the patients encountered in clinical practice.[9-11] While the quality of evidence in randomized controlled trials is not being doubted, the clinical applicability of the results in the "real" world is currently under debate. Therefore, clinical research conducted on groups more representative of the respective local population appears to be the solution needed by the spine community.

The National Inpatient Register created by the Swedish National Board of Health and Welfare began as early as 1964,[14,15] while the spine surgery specific database, "SweSpine" (the Swedish spine register), was not introduced until 1992.[16,17] The prospect and utility of the national registry was met with enthusiasm, and over the years a dramatic increase in participation of sites was noted, highlighted by a reported capture rate of 75% of all surgical procedures in Sweden by 2011.[16,17] Following its success, the turn of the century signified a major transformation in clinical spine research. A considerable increase in the number of outcomes registries and databases has been seen around the world.[18-28] Additionally, strong collaborative efforts have brought forth multicentered databases and cohorts aimed at addressing specific spinal pathologies and clinical knowledge gap.[29-33]

Nowadays, the term "registry" is used to designate databases where the data collected from multiple sources are centralized and pooled. Existing in various formats, the advantage of clinical registries and multicentered cohorts lies in their relative cost efficiency in maintenance and their adaptability to contemporary innovations in treatment.[7,10] As discussed previously, the inclusion of a more heterogeneous patient population allows a better reflection of the "real" world rather than an "ideal" population dictated by the strict conditions of a randomized control trial. Finally, the perpetual nature of prospective registries allows long-term follow-up and continuous data collection.[7,10] These characteristics make registry studies more desirable in evaluating and monitoring the performance and safety of quality improvement initiatives, patient-care programs, and clinical practice algorithms.

In 2015, van Hooff et al,[13] investigated the impact of spine-related registries on patient care improvement in degenerative spinal disorders. In their systematic review, although the authors found insufficient evidence to neither support nor deny their initial clinical research query, they concluded that the results of publications from spine registries have helped increase general knowledge, identify predictors of outcomes, and shape the current management of many common degenerative spinal conditions.[13]

Reporting of Outcomes

Accurate and reproducible measurement of clinical outcomes is quintessential for quality improvement. However, the methods used in the current spine literature to capture these changes in function, quality of life, or pain, are quite variable. Traditionally, outcomes are determined by the physician and surgeon's subjective evaluation of the patient's clinical status and radiographic findings. While these measurements are still an integral component of overall patient assessment, nowadays, preference has been shifting toward patient-reported outcome measures (PROMs). Using the format of standardized questionnaires, validated PROMs aim to quantify and capture the patient's interpretation of their quality of life, functional disability and pain.[34] Currently, these measures have been widely adopted into research and practice, and play an essential role in

facilitating the reporting, comparison, and knowledge exchange in the global spine community. Consequently, modern clinical research and outcome registries have incorporated the usage of these measurements in their assessment protocols.[13]

While numerous outcome measures are available to investigators, a select few are routinely used as the primary outcome in clinical research. The visual analog scale (VAS)[35,36] and the numeric rating scale (NRS),[36,37] because of their ease of administration and validation in multiple studies, are commonly quoted in the literature as an indicator for levels of pain.[38-42] Similarly, the Short Form questionnaires (SF36),[34,35,43] Oswestry Disability Index (ODI),[35,36,44] and EuroQol Five Dimension questionnaire (EQ5D),[45,46] and so on, have frequently been used and validated in multiple populations to measure functional results and to quantify disability.[31,39-41,47,48]

While the ODI was developed primarily for the assessment of disability in patients with lumbar spinal pathologies,[49] first published in 1980 the questionnaire has been translated into numerous languages and its applicability as well as reliability have been validated over many studies.[44,49-54] Other anatomical location specific or disease-specific measurements have also been developed over the years. The Neck Disability Index (NDI), first introduced by Vernon et al in 1991,[55] has been widely translated, repeatedly validated, and extensively used for measurement of pain and functional outcome in the cervical spine.[31,38,47,56-62] Similarly, the introduction of the Japanese Orthopaedic Association (JOA) myelopathy scale,[63] and its subsequent adaptation into the modified JOA (mJOA) to fit the North American context,[64] has been instrumental in studies of degenerative cervical myelopathy.[31,35,38,47,62,65,66]

The entire list of outcome measures for spine surgery is extensive, and categorically includes measures aimed at various aspects of care as well as particular populations.[34,67] However, given the scope of this review, an exhaustive review will not be performed. The examples of outcome measures mentioned above have shaped clinical research in the field of spine surgery in the modern era. However, because of the absence of standardized reporting, the use of outcome measures is extremely variable in published clinical studies. Given this lack of consistency in reporting metrics, a challenge arises when attempting to directly compare and evaluate studies, especially in the context of quality and safety improvement. As this issue is increasingly recognized, changes have been noted regarding data collection and reporting in the current literature. As shown by van Hooff et al 2015,[13] the majority of the major clinical registries are collecting patient data using similar metrics and PROMs. Hence, the future of clinical study holds promise, and further efforts to create a standardized method of reporting would be beneficial for comparison of studies and quality improvement.

Reporting of Adverse Events

The reporting of adverse events suffers from similar inconsistencies in the literature. In addition to the wide array of diverse procedures available in spinal surgery, adverse event reporting has been made challenging due to the terms "adverse events," "complications," "unexpected outcomes," and "iatrogenic injuries" being poorly defined and commonly used interchangeably in the literature.[68-72] Several recent systematic reviews have commented on the inconsistency in the description of adverse events, its severity, and a lack of standardized reporting in spine related clinical research studies.[73-75]

Moreover, the presence of underreporting and underestimation further diminishes appreciation for the full spectrum and incidence of adverse events.[72,76-81] Since the success of quality and safety improvement is primarily dependent on collected data, the accuracy of documentation is imperative. Chen et al[82] demonstrated that surgeons have more predilection for reporting major adverse events while overlooking minor events that have less potential for long-term consequences. Others have commented on the ethical issue surrounding underreporting or an unwillingness to expose error secondary to legal liability.[76,77,83] Hence, the reliability of self-reporting by clinicians and surgeons is becoming increasingly relevant in today's clinical research. In a previous article by Krizek[76] in 1999, the author acknowledged the poor existing literature on incidence and spectrum of adverse events, pointed out the difficulty with physicians admitting to their own mistakes, and criticized the current culture of blaming others. Therefore, to gain a complete appreciation of the incidence and spectrum of adverse events and to continue to improve the quality and safety of spine surgery, physicians and surgeons need to step out of the old stigma surrounding the reporting of errors.

Also, where previous retrospective analyses appear to have failed at capturing the occurrence of adverse events in their entirety,[76,81] the increasing popularity and growth of prospective cohorts and registries in the modern age may be the solution to this ongoing issue. Ultimately, a universally accepted definition of adverse events, a consistent method of reporting, and a systematic approach to data collection are needed.

Recognizing this underlying challenge, efforts to generate standardized medical language for the documentation and classification of adverse events have been attempted.[69,84,85] Rampersaud et al[70,86] initially proposed the Spine AdVerse Events Severity (SAVES) in 2010 and followed with the modified version (SAVES-V2) in 2016.[71] With the goal of improving the consistency of reporting and documentation in the scientific literature, the SAVES system provided a comprehensive yet straightforward framework for the categorization and classification of adverse events. The design of the assessment tool enabled easy administration by personnel with minimal prior training and demonstrated good intra- and interrater reliability.[71,80] Street et al[80] reported increased identification of adverse events with the adoption of SAVES-V2 in their institution. Subsequently, the same group further validated the system and demonstrated improved identification of adverse events with SAVES-V2 compared to the International Classification of Diseases 10th Revision (ICD-10) codes by a factor of 2.[87]

Despite numerous efforts, to date, no consensus has been reached amongst spine surgeons worldwide. However, to continue improving and advancing the quality and safety of modern treatments, accurate reporting and depiction of adverse events in the medical literature is necessary. Such a major feat, without the support, collaboration, and efforts of the international spine community, will be unachievable.

Prediction Modeling

Despite a number of limitations, research in the field has nonetheless made tremendous contributions. The improvement of outcomes and safety of surgery has been of interest to clinical investigators for decades. As value-based healthcare is gaining popularity, the prospect of risk stratification before initiating treatment has fueled considerable interest in the global community. Given the finite resources, the appropriate allocation is essential for the success of the system without compromising quality of care.

Predictive modeling is a technique whereby preclinical patient or treatment factors are fitted into a statistical model which can be used to estimate the final clinical outcomes. Currently, numerous predictors have been identified for specific spine-related conditions and treatments. Bekelis et al[88] modeled a prediction calculator for the estimation of postoperative complication risk in spine surgery. This study represented one of the largest cohorts with high-quality data collected by the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) from 2005 to 2010. The resulting model demonstrated high accuracy, good discriminative capacity, and highlighted specific patient and surgical procedural factors that increased the risk of adverse events. Currently, numerous other investigators have further carried the clinical inquiry and geared the prediction model development toward other clinical outcomes of interest.[89-95] Additionally, other teams have extended their investigations to other patient populations more representative of their local settings.[22,96-100] With the rise of contemporary value-based bundled health care models, interest in cost improvement strategies that do not compromise the quality of care have also led to the development of predictive models to estimate prolonged hospital stay and adverse discharge destination for elective spine surgery.[101-109]

The impact of predictive models on the practice of modern medicine is enormous. Whether consciously or subconsciously, clinicians and surgeons risk stratify patients encountered in clinical practice based on their previous training and experiences. The appropriate application of prediction models can further improve the clinical decision process by providing evidence-based validation and quantification of risks and benefits of treatments. Furthermore, the capacity to identify high-risk patients would be of extreme value to the surgeons and preoperative planning team, enabling better patient counseling and comprehensive discharge planning. Additionally, whether based on institutional data or a multicenter registry, prediction models provide individual institutions with the framework for internal validation, self-assessment, and clinical care pathway development.

Clinical Practice Guidelines, Checklists, and Protocols

Improvement in worldwide communication has facilitated research and development, as well as knowledge exchange. The resulting global effort to improve the quality of spine surgery has produced an enormous amount of research, which quite often can be overwhelming. To ensure quality of care and standard of practice, major organizations have provided clinical practice guidelines for common spinal conditions to assist the surgeon in making treatment decisions.[110,111] Despite significant advancement, the presence of persisting critical knowledge gaps have led to major controversy, heated debates, and variable practice in modern spine surgery.

Through a recent international effort supported by AOSpine, the American Association of Neurological Surgeons and the Congress of Neurological Surgeons (AANS/CNS), clinical practice guidelines were developed for the treatment and care of degenerative cervical myelopathy and traumatic spinal cord injury.[112-117] These articles aimed to address the controversies in current clinical practice by providing evidence-based recommendations generated through robust systematic reviews and a meticulous guideline development process.[62,112-125] The resulting clinical practice guidelines represent integrated and summarized recommendations derived from the best available evidence in the current literature and act as a guide to support decision making for surgeons and quality improvement for hospital administrations.

Because of the recognized risk of neurological complications in spinal deformity procedures, as well as weak evidence behind the proper response to intraoperative neurological monitoring alerts, several iterations of management algorithms have been proposed by various groups to address this issue.[126-128] Despite these efforts, the standardization of response protocols to crises situations was suboptimal in the global community. In light of this persistent knowledge gap, a consortium of 21 deformity experts from 14 major North American medical institutions participated in an expert panel in 2014.[129] Through the structured and validated process of the Delphi technique,[130] a consensus-based best practice guideline and a checklist for a coordinated response to intraoperative neuromonitoring alerts was established.[129]

Although considerable advancement has been made, a recent survey by Nater et al[131] revealed the persistent overall lack of confidence and consistency in the management of perioperative neurological injury among the members of the AOSpine international community. Consequently, strong interest exists amongst spine surgeons worldwide to develop evidence-based clinical practice guidelines. According to the survey, 90.6% of participants believe a guideline would be beneficial, and 94.4% were very likely to incorporate it into their practice.[131]

Other knowledge gaps still exist in various aspects of spine surgery in the contemporary era. As the awareness of clinical practice guidelines increases in the international spine community, reportedly, an estimated 87.7% of surgeons use the recommendations in their clinical practice.[131] Hence, the utility and value of evidence-based guidelines is gaining recognition. With the extensive amount of literature and resources available to investigators, more effort in this area is essential to synthesize and summarize the existing evidence into practical recommendations to aid in quality and safety improvement.

Quality Improvement Initiative

The goal of improving the quality and safety of patient care is among one of the primary drives in clinical research today. The generation of evidence-based clinical practice guidelines or expert's consensus can support clinical decision-making in individual practices. However, in order to affect health care delivery on a larger scale, a much more multidisciplinary collaborative effort is required. Current existing quality improvement initiatives vary in their degree of magnitude, and range from national to regional and institutional programs.

The NSQIP program initiated in 1994 in a consortium of Veterans Affairs Surgical Centers in the United States of America, and later expanded to include the centers of the private sector with the support of the American College of Surgeons.[132] Today, with more than 500 hospital centers, it represents one of the largest national registries with rigorous data collection, validated preoperative information, and quality-controlled outcomes measurement geared toward quality and safety assessment and improvement.[132,133] Since its introduction, NSQIP has been instrumental in the advancement of spine care nationwide in the United States of America, improving the 30-day morbidity and mortality rate by approximately 30% to 45%.[132] Today, the high-quality data have appealed to numerous investigators and attracted a wide range of spine-related studies primarily focused on surgical outcomes, adverse events, as well as predictive modeling.[88-95,101,109,134-136] A recent systematic review conducted by Marjoua et al[137] found 40 spine-specific peer-reviewed publications based on the NSQIP data between 2010 and 2015. While the magnitude and quality of data have proven the compelling research merit of NSQIP, the success of the program in improving surgical care owes to the fact that it stands as a national standard to which individual institution can compare their performance. By inspiring internal intuitional evaluation, providing an expert external review, and adaptation of quality and safety improvement programs, NSQIP continues to provide feedback and evaluation of effectiveness to further push the boundaries to perfect surgical care.[132]

Other national and regional quality improvement programs have been instituted.[19,20,138,139] Given the scope of this review, individual programs will not be discussed in detail. At the institutional level, however, execution of the quality improvement program usually faces barriers to implementation. As such, published literature on successful programs is scarce. To our knowledge, 2 exemplary programs have been reported.

First, the Northwestern High-Risk Spine Protocol, developed in 2007, was geared toward improving the safety of spine surgery for high-risk patients.[8] The full details of the protocol are described by Halpin et al.[8] Overall, the protocol is based on improved collaboration and communication between multidisciplinary teams involved in the surgical and medical care of the patient. Extensive perioperative management planning begins at the time the patient's candidacy for surgery is confirmed. Through a multidisciplinary collaborative effort, the patient undergoes a full assessment and evaluation by hospitalists and medical specialists, which includes not only the major organ systems but also psychosocial and nutritional aspects. The operative setting is heavily protocolized with careful intraoperative monitoring, including neuromonitoring, regular blood work, a standardized transfusion procedure, and frequent communication between the surgical and anesthesia teams. The same vigilant care is subsequently translated to the postoperative care, where all high-risk patients were initially monitored in the neurointensive care unit. Once extubated and transferred to the surgical ward, the ensuing patient management is conducted in consultation with the hospitalist.[8]

The strength of the Northwestern High-Risk Spine Protocol is grounded in their meticulous preoperative medical workup and optimization, strong interdisciplinary communication, protocolized operative and postoperative care, and finally the dedication of one multidisciplinary team for the entirety of the patient's care.[8] Zeeni et al[140] reported successful implementation of their intraoperative protocol with significant improvement in the duration of surgical procedures and reduced transfusion requirements.

The Seattle Spine Team's approach to high-risk spine surgery adopted a similar method of quality control to improve operative safety.[9] Their innovative algorithm is based on 3 main quality improvement checkpoints: (1) the implementation of routine multidisciplinary preoperative conferences where the indication for surgical management and candidacy of a patient is discussed among specialists in spine, anesthesia, internal medicine, rehabilitation, and nursing care; (2) ensuring the presence of an additional surgeon to assist in each procedure; and (3) judicious use of intraoperative protocols to monitor and control coagulopathy. The Seattle Spine Team's standardized method has ensured a high rate of adherence to the care protocol and minimized variability. Through their systematic approach, the group demonstrated success in reducing the incidence of perioperative adverse events in high-risk deformity cases managed through their center.[9]

Numerous quality improvement programs, whether institutional, regional or national, are continually taking place globally. Although published programs are rare, the experiences of

the Northwestern High-Risk Spine Protocol and Seattle Spine Team approach are invaluable for developing programs. Both programs have highlighted the need for a protocolized care pathway, preoperative multidisciplinary assessment, careful intraoperative monitoring and underlined the importance of clear communication.[8,9,141] Other strategies, including having 2 surgeons collaborate, intraoperative neurological monitoring, the use of tranexamic acid, staged procedures, and so on, have all been suggested as potential methods of improving quality and safety.[8,9,142-146] Recognizing the variability of the health care system and the availability of resources in individual institutions, the implementation of specific quality improvement measures may be limited. Thus, quality improvement programs need individualization, which involves extensive planning and tailoring by institutional administration and surgeons to fit the local context. Furthermore, the current evidence supporting protocolized holistic care of patients in spine surgery may be of assistance in leveraging government health care reforms and funding for quality and safety improvement programs.

Future Directions

With increasing attention toward quality and safety improvement, the future of spine surgery is both optimistic and exciting. Advancements in communication and technology have introduced a new era in information, data collection, and knowledge exchange. However, the heterogeneity of data collection and reporting creates an incomplete picture and can mask the critical outcome measures relevant to improving treatment. Therefore, in order to continuously progress, clinical investigators need to reevaluate and standardize the method of data collection, measurement of outcomes and adverse events. With numerous measures available to capture patient-reported quality of life and functional outcome, it is perhaps time to define, as a community, the most accessible and validated form of evaluation from a clinical spine surgery perspective. The effort by Rampersaud et al[70,71] in developing SAVES is one method of ensuring that adverse events are identified and classified in a similar fashion in clinical studies. As studies show, physicians are poor reporters of adverse events and tend to identify a narrow spectrum of serious complications.[82,147,148] The employment of dedicated independent reviewers can potentially improve the capture of relevant events and reduce the potential bias of the investigators.[76,82,149] Additionally, adopting an electronic medical record system that allows parallel entry for both clinical and registry databases can reduce the errors with transcription and transfer of data.[150]

To assist and promote best practices, additional work in the reviewing of literature and development of clinical practice guidelines is much needed for areas where controversy still exists. A previous initiative by the AOSpine group to develop evidence-based clinical practice guidelines targeted to relevant clinical questions through systematic reviews of literature are exemplary efforts in improving and

standardizing the care and management of traumatic and nontraumatic spinal cord injury.[112-117] Although guidelines developed in this fashion are highly regarded for their quality of evidence and relevance in supporting clinical decision-making, this approach may not be feasible for all critical clinical questions. When evidence is limited in the literature, other methods of guideline generation using consensus-based expert opinions can be employed[130,151] and can provide invaluable support to clinical decision making and quality improvement programs. Additionally, further research to develop and validate prediction models can improve patient safety and outcomes by providing a robust method of preoperative risk-stratification and tailoring patients toward specific clinical care pathways to mitigate adverse events and expedite recovery.

Finally, with previously reported successes in the literature,[8,9,141] the implementation of quality and safety improvement programs is essential to advance health care delivery. Subject to numerous barriers, the process can be both challenging and costly to the hospital infrastructure.[152,153] Furthermore, the availability of resources and expertise may vary between hospital centers. Learning from the success of predecessors, individual institutions and organizations should conduct an internal review to assess their limitations and their capacity, along with a multidisciplinary approach to design and modify a quality and safety improvement program most suited for the local context. The publication and reporting of overall progress, as well as a final protocol, can potentially assist other institutions that wish to adopt a similar approach.

Conclusion

The current evidence in spine surgery has led to the development of numerous prediction models, evidence-based clinical care guidelines, expert consensus protocols, and has resulted in the initiation of specific spine surgical care programs. However, the reporting of outcomes and adverse events remains inconsistent and needs standardization; an effort that is required of the international spine community. With numerous high-quality registries and multicentered databases in existence and involving investigators worldwide, the future of spine surgery is nonetheless promising. The enthusiasm for developing and validating prediction models and clinical practice guidelines will further encourage and inspire evidence-based clinical practice. To establish an institution-based surgical improvement program is a vision that is shared by many and yet a challenge to implement. However, the success of previous groups is proof that with efforts from multidisciplinary teams and hospital administrators, significant changes can occur. With the ultimate goal of improving the care of patients, future initiatives from the international community should be geared toward quality and safety improvement of spine surgery.

Key Points

- The introduction of registries and multicentered databases has reshaped modern clinical research in spine surgery. The perpetual nature of these systems allows continuous data collection, indefinite follow-up, constant monitoring, and feedback for quality improvement programs.
- The metrics to report outcomes and adverse events are inconsistent in the current literature. Standardization of these metrics would improve the perspective on the quality of modern spine surgery and assist in future knowledge exchange and translation.
- Predictive modeling allows risk stratification and identification of patients at high risk of adverse outcomes. Future validation of existing prediction models would improve adaptation and incorporation into quality improvement programs.
- Clinical practice guidelines, based on systematic reviews or expert's consensus, are invaluable to the spine community. Efforts in this regard to clarify areas of controversy are essential for the continuing advancement of quality and safety improvement in spine surgery.
- Quality improvement programs in the literature are rare. However, the Northwestern and Seattle Spine Team approaches have set examples for the global spine community and further encourage others to adopt similar changes to improve the care of high-risk spine patients

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References

1. Kobayashi K, Ando K, Nishida Y, Ishiguro N, Imagama S. Epidemiological trends in spine surgery over 10 years in a multicenter database. *Eur Spine J*. 2018;27:1698-1703.
2. Cortesi PA, Assietti R, Cuzzocrea F, et al. Epidemiologic and economic burden attributable to first spinal fusion surgery: analysis from an Italian Administrative Database. *Spine (Phila Pa 1976)*. 2017;42:1398-1404.
3. Thirukumaran CP, Raudenbush B, Li Y, Molinari R, Rubery P, Mesfin A. National trends in the surgical management of adult lumbar isthmic spondylolisthesis: 1998 to 2011. *Spine (Phila Pa 1976)*. 2016;41:490-501.
4. Witiw CD, Smieliauskas F, Fehlings MG. Health economics and the management of degenerative cervical myelopathy. *Neurosurg Clin N Am*. 2018;29:169-176.
5. Lu Y, Qureshi SA. Cost-effective studies in spine surgeries: a narrative review. *Spine J*. 2014;14:2748-2762.
6. Gentry S, Badrinath P. Defining health in the era of value-based care: lessons from England of relevance to other health systems. *Cureus*. 2017;9:e1079.
7. McGirt MJ, Parker SL, Asher AL, Norvell D, Sherry N, Devin CJ. Role of prospective registries in defining the value and effectiveness of spine care. *Spine (Phila Pa 1976)*. 2014;39(22 suppl 1): S117-S128.
8. Halpin RJ, Sugrue PA, Gould RW, et al. Standardizing care for high-risk patients in spine surgery: the Northwestern high-risk spine protocol. *Spine (Phila Pa 1976)*. 2010;35:2232-2238.
9. Sethi RK, Pong RP, Leveque JC, Dean TC, Olivar SJ, Rupp SM. 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*. 2014;2:95-103.
10. Asher AL, Devin CJ, Mroz T, Fehlings M, Parker SL, McGirt MJ. Clinical registries and evidence-based care pathways: raising the bar for meaningful measurement and delivery of value-based care. *Spine (Phila Pa 1976)*. 2014;39(22 suppl 1): S136-S138.
11. Lake WB, Brooks NP, Resnick DK. Comparative effectiveness research in spine surgery. *J Comp Eff Res*. 2013;2:45-51.
12. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT) observational cohort. *JAMA*. 2006;296:2451-2459.
13. van Hooff ML, Jacobs WC, Willems PC, et al. Evidence and practice in spine registries. *Acta Orthop*. 2015;86:534-544.
14. Jansson KA, Nemeth G, Granath F, Blomqvist P. Surgery for herniation of a lumbar disc in Sweden between 1987 and 1999. An analysis of 27,576 operations. *J Bone Joint Surg Br*. 2004;86: 841-847.
15. Jansson KA, Blomqvist P, Granath F, Nemeth G. Spinal stenosis surgery in Sweden 1987-1999. *Eur Spine J*. 2003;12:535-541.
16. Strömqvist B, Fritzell P, Hägg O, Jönsson B, Sanden B; Swedish Society of Spinal Surgeons. Swespine: the Swedish Spine Register: the 2012 report. *Eur Spine J*. 2013;22:953-974.

17. Strömqvist B, Fritzell P, Hägg O, Jönsson B; Swedish Society of Spinal Surgeons. The Swedish Spine Register: development, design and utility. *Eur Spine J.* 2009;18(suppl 3):294-304.

18. Asher AL, Speroff T, Dittus RS, et al. The National Neurosurgery Quality and Outcomes Database (N2QOD): a collaborative North American outcomes registry to advance value-based spine care. *Spine (Phila Pa 1976)*. 2014;39(22 suppl 1):S106-S116.

19. Flum DR, Fisher N, Thompson J, Marcus-Smith M, Florence M, Pellegrini CA. Washington State's approach to variability in surgical processes/outcomes: Surgical Clinical Outcomes Assessment Program (SCOAP). *Surgery.* 2005;138:821-828.

20. Chang V, Schwalb JM, Nerenz DR, et al. The Michigan Spine Surgery Improvement Collaborative: a statewide collaborative quality initiative. *Neurosurg Focus.* 2015;39:E7.

21. Shultz BN, Ottesen TD, Ondeck NT, et al. Systematic changes in the National Surgical Quality Improvement Program Database over the years can affect comorbidity indices such as the Modified Frailty Index and Modified Charlson Comorbidity Index for lumbar fusion studies. *Spine (Phila Pa 1976)*. 2018;43:798-804.

22. Morcos MW, Jiang F, McIntosh G, et al. Predictors of blood transfusion in posterior lumbar spinal fusion: a Canadian Spine Outcome and Research Network Study. *Spine (Phila Pa 1976)*. 2018;43:E35-E39.

23. Højmark K, Støttrup C, Carreon L, Andersen MO. Patient-reported outcome measures unbiased by loss of follow-up. Single-center study based on DaneSpine, the Danish Spine Surgery Registry. *Eur Spine J.* 2016;25:282-286.

24. Kovacs FM, Seco J, Royuela A, Reixach JC, Abraira V; Spanish Back Pain Research Network. Predicting the evolution of low back pain patients in routine clinical practice: results from a registry within the Spanish National Health Service. *Spine J.* 2012; 12:1008-1020.

25. Breakwell LM, Cole AA, Birch N, Heywood C. Should we all go to the PROM? The first two years of the British Spine Registry. *Bone Joint J.* 2015;97-B:871-874.

26. Röder C, El-Kerdi A, Grob D, Aebi M. A European spine registry. *Eur Spine J.* 2002;11:303-307.

27. Veeravagu A, Connolly ID, Lamsam L, et al. Surgical outcomes of cervical spondylotic myelopathy: an analysis of a national, administrative, longitudinal database. *Neurosurg.* 2016;40:E11.

28. Nerland US, Jakola AS, Solheim O, et al. Comparative effectiveness of microdecompression and laminectomy for central lumbar spinal stenosis: study protocol for an observational study. *BMJ Open.* 2014;4:e004651.

29. Fehlings MG, Vaccaro A, Wilson JR, et al. Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STAS-CIS). *PLoS One.* 2012;7:e32037.

30. Grossman RG, Frankowski RF, Burau KD, et al. Incidence and severity of acute complications after spinal cord injury. *J Neurosurg Spine.* 2012;17(1 suppl):119-128.

31. Fehlings MG, Santaguida C, Tetreault L, et al. Laminectomy and fusion versus laminoplasty for the treatment of degenerative cervical myelopathy: results from the AOSpine North America and International prospective multicenter studies. *Spine J.* 2017;17: 102-108.

32. Noonan VK, Kwon BK, Soril L, et al. The Rick Hansen Spinal Cord Injury Registry (RHSCIR): a national patient-registry. *Spinal Cord.* 2012;50:22-27.

33. Wilson JR, Singh A, Craven C, et al. Early versus late surgery for traumatic spinal cord injury: the results of a prospective Canadian cohort study. *Spinal Cord.* 2012;50:840-843.

34. McCormick JD, Werner BC, Shimer AL. Patient-reported outcome measures in spine surgery. *J Am Acad Orthop Surg.* 2013; 21:99-107.

35. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. *Spine J.* 2008;8: 380-384.

36. Grotle M, Brox JI, Vollestad NK. Concurrent comparison of responsiveness in pain and functional status measurements used for patients with low back pain. *Spine (Phila Pa 1976)*. 2004;29: E492-E501.

37. Haefeli M, Elfering A. Pain assessment. *Eur Spine J.* 2006; 15(suppl 1):S17-S24.

38. Stephens BF, Rhee JM, Neustein TM, Arceo R. Laminoplasty does not lead to worsening axial neck pain in the properly selected patient with cervical myelopathy. *Spine (Phila Pa 1976)*. 2017; 42:1844-1850.

39. Chang W, Yuwen P, Zhu Y, et al. Effectiveness of decompression alone versus decompression plus fusion for lumbar spinal stenosis: a systematic review and meta-analysis. *Arch Orthop Trauma Surg.* 2017;137:637-650.

40. Machado GC, Ferreira PH, Harris IA, et al. Effectiveness of surgery for lumbar spinal stenosis: a systematic review and meta-analysis. *PLoS One.* 2015;10:e0122800.

41. Noorian S, Sorensen K, Cho W. A systematic review of clinical outcomes in surgical treatment of adult isthmic spondylolisthesis. *Spine J.* 2018;18:1441-1454.

42. Arirachakaran A, Siripaiboonkij M, Pairuchvej S, et al. Comparative outcomes of epidural steroids versus placebo after lumbar discectomy in lumbar disc herniation: a systematic review and meta-analysis of randomized controlled trials. *Eur J Orthop Surg Traumatol.* 2018;28:1589-1599.

43. Guilfoyle MR, Seeley H, Laing RJ. The Short Form 36 Health Survey in spine disease—validation against condition-specific measures. *Br J Neurosurg.* 2009;23:401-405.

44. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine (Phila Pa 1976)*. 2000;25:2940-2952.

45. EuroQol Group. EuroQol—a new facility for the measurement of health-related quality of life. *Health Policy.* 1990;16:199-208.

46. Solberg TK, Olsen JA, Ingebrigtsen T, Hofoss D, Nygaard OP. Health-related quality of life assessment by the EuroQol-5D can provide cost-utility data in the field of low-back surgery. *Eur Spine J.* 2005;14:1000-1007.

47. Blizzard DJ, Caputo AM, Sheets CZ, et al. Laminoplasty versus laminectomy with fusion for the treatment of spondylotic cervical myelopathy: short-term follow-up. *Eur Spine J.* 2017;26:85-93.

48. Copay AG, Glassman SD, Subach BR, Berven S, Schuler TC, Carreon LY. Minimum clinically important difference in lumbar spine surgery patients: a choice of methods using the Oswestry

Disability Index, Medical Outcomes Study Questionnaire Short Form 36, and pain scales. *Spine J.* 2008;8:968-974.

49. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry Low Back Pain Disability Questionnaire. *Physiotherapy.* 1980;66:271-273.

50. van Hooff ML, Spruit M, Fairbank JC, van Limbeek J, Jacobs WC. The Oswestry Disability Index (version 2.1a): validation of a Dutch language version. *Spine (Phila Pa 1976).* 2015;40:E83-E90.

51. Payares K, Lugo LH, Morales V, Londono A. Validation in Colombia of the Oswestry Disability Questionnaire in patients with low back pain. *Spine (Phila Pa 1976).* 2011;36:E1730-E1735.

52. Monticone M, Baiardi P, Vanti C, et al. Responsiveness of the Oswestry Disability Index and the Roland Morris Disability Questionnaire in Italian subjects with sub-acute and chronic low back pain. *Eur Spine J.* 2012;21:122-129.

53. Monticone M, Baiardi P, Ferrari S, et al. Development of the Italian version of the Oswestry Disability Index (ODI-I): a cross-cultural adaptation, reliability, and validity study. *Spine (Phila Pa 1976).* 2009;34:2090-2095.

54. Valasek T, Varga PP, Szövérfi Z, Kümin M, Fairbank J, Lazary A. Reliability and validity study on the Hungarian versions of the Oswestry Disability Index and the Quebec Back Pain Disability Scale. *Eur Spine J.* 2013;22:1010-1018.

55. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther.* 1991;14:409-415.

56. Aslan E, Karaduman A, Yakut Y, Aras B, Simsek IE, Yagly N. The cultural adaptation, reliability and validity of Neck Disability Index in patients with neck pain: a Turkish version study. *Spine (Phila Pa 1976).* 2008;33:E362-E365.

57. Bakhtadze MA, Vernon H, Zakharova OB, Kuzminov KO, Bolotov DA. The Neck Disability Index-Russian Language Version (NDI-RU): a study of validity and reliability. *Spine (Phila Pa 1976).* 2015;40:1115-1121.

58. Cruz EB, Fernandes R, Carnide F, Domingues L, Pereira M, Duarte S. Cross-cultural adaptation and validation of the neck disability index to European Portuguese language. *Spine (Phila Pa 1976).* 2015;40:E77-E82.

59. Luksanapruksa P, Wathana-apisit T, Wanasinthop S, Sanpakit S, Chavasiri C. Reliability and validity study of a Thai version of the Neck Disability Index in patients with neck pain. *J Med Assoc Thai.* 2012;95:681-688.

60. Salo P, Ylinen J, Kautiainen H, Arkela-Kautiainen M, Hakkinen A. Reliability and validity of the Finnish version of the Neck Disability Index and the modified Neck Pain and Disability Scale. *Spine (Phila Pa 1976).* 2010;35:552-556.

61. MacDermid JC, Walton DM, Avery S, et al. Measurement properties of the neck disability index: a systematic review. *J Orthop Sports Phys Ther.* 2009;39:400-417.

62. Rhee J, Tetreault LA, Chapman JR, et al. Nonoperative versus operative management for the treatment degenerative cervical myelopathy: an updated systematic review. *Global Spine J.* 2017;7(3 suppl):35S-41S.

63. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. *Spine (Phila Pa 1976).* 1981;6:354-364.

64. Benzel EC, Lancon J, Kesterson L, Hadden T. Cervical laminectomy and dentate ligament section for cervical spondylotic myelopathy. *J Spinal Disord.* 1991;4:286-295.

65. Yukawa Y, Kato F, Ito K, et al. Laminoplasty and skip laminectomy for cervical compressive myelopathy: range of motion, postoperative neck pain, and surgical outcomes in a randomized prospective study. *Spine (Phila Pa 1976).* 2007;32:1980-1985.

66. Highsmith JM, Dhall SS, Haid RW Jr, Rodts GE Jr, Mummaneni PV. Treatment of cervical stenotic myelopathy: a cost and outcome comparison of laminoplasty versus laminectomy and lateral mass fusion. *J Neurosurg Spine.* 2011;14:619-625.

67. Vavken P, Ganal-Antonio AK, Quidde J, Shen FH, Chapman JR, Samartzis D. Fundamentals of clinical outcomes assessment for spinal disorders: clinical outcome instruments and applications. *Global Spine J.* 2015;5:329-338.

68. Bruce J, Russell EM, Mollison J, Krukowski ZH. The measurement and monitoring of surgical adverse events. *Health Technol Assess.* 2001;5:1-194.

69. Chang A, Schyve PM, Croteau RJ, O'Leary DS, Loeb JM. The JCAHO patient safety event taxonomy: a standardized terminology and classification schema for near misses and adverse events. *Int J Qual Health Care.* 2005;17:95-105.

70. Rampersaud YR, Neary MA, White K. Spine adverse events severity system: content validation and interobserver reliability assessment. *Spine (Phila Pa 1976).* 2010;35:790-795.

71. Rampersaud YR, Anderson PA, Dimar JR 2nd, Fisher CG; Spine Trauma Study Group and Degenerative Spine Study Group. Spinal Adverse Events Severity System, version 2 (SAVES-V2): inter- and intraobserver reliability assessment. *J Neurosurg Spine.* 2016;25:256-263.

72. Andrews LB, Stocking C, Krizek T, et al. An alternative strategy for studying adverse events in medical care. *Lancet.* 1997;349:309-313.

73. Hiratzka J, Rastegar F, Contag AG, Norvell DC, Anderson PA, Hart RA. Adverse event recording and reporting in clinical trials comparing lumbar disk replacement with lumbar fusion: a systematic review. *Global Spine J.* 2015;5:486-495.

74. Anderson PA, Hart RA. Adverse events recording and reporting in clinical trials of cervical total disk replacement. *Instr Course Lect.* 2014;63:287-296.

75. Dekutoski MB, Norvell DC, Dettori JR, Fehlings MG, Chapman JR. Surgeon perceptions and reported complications in spine surgery. *Spine (Phila Pa 1976).* 2010;35(9 suppl):S9-S21.

76. Krizek TJ. Surgical error: ethical issues of adverse events. *Arch Surg.* 2000;135:1359-1366.

77. Reinertsen JL. Let's talk about error. *BMJ.* 2000;320:730.

78. Berlinger N, Wu AW. Subtracting insult from injury: addressing cultural expectations in the disclosure of medical error. *J Med Ethics.* 2005;31:106-108.

79. Campbell PG, Malone J, Yadla S, et al. Comparison of ICD-9-based, retrospective, and prospective assessments of perioperative

complications: assessment of accuracy in reporting. *J Neurosurg Spine*. 2011;14:16-22.

80. Street JT, Lenehan BJ, DiPaola CP, et al. Morbidity and mortality of major adult spinal surgery. A prospective cohort analysis of 942 consecutive patients. *Spine J*. 2012;12:22-34.

81. Nasser R, Yadla S, Maltenfort MG, et al. Complications in spine surgery. *J Neurosurg Spine*. 2010;13:144-157.

82. Chen BP, Garland K, Roffey DM, et al. Can surgeons adequately capture adverse events using the Spinal Adverse Events Severity System (SAVES) and OrthoSAVES? *Clin Orthop*. 2017;475: 253-260.

83. Wu AW. Medical error: the second victim. *West J Med*. 2000;172: 358-359.

84. Mirza SK, Deyo RA, Heagerty PJ, Turner JA, Lee LA, Goodkin R. Towards standardized measurement of adverse events in spine surgery: conceptual model and pilot evaluation. *BMC Musculoskelet Disord*. 2006;7:53.

85. Mirza SK, Martin BI, Goodkin R, Hart RA, Anderson PA. Developing a toolkit for comparing safety in spine surgery. *Instr Course Lect*. 2014;63:271-286.

86. Rampersaud YR, Moro ER, Neary MA, et al. Intraoperative adverse events and related postoperative complications in spine surgery: implications for enhancing patient safety founded on evidence-based protocols. *Spine (Phila Pa 1976)*. 2006;31: 1503-1510.

87. Street JT, Thorogood NP, Cheung A, et al. Use of the Spine Adverse Events Severity System (SAVES) in patients with traumatic spinal cord injury. A comparison with institutional ICD-10 coding for the identification of acute care adverse events. *Spinal Cord*. 2013;51:472-476.

88. Bekelis K, Desai A, Bakhoum SF, Missios S. A predictive model of complications after spine surgery: the National Surgical Quality Improvement Program (NSQIP) 2005-2010. *Spine J*. 2014;14: 1247-1255.

89. Aoude A, Nooh A, Fortin M, et al. Incidence, predictors, and postoperative complications of blood transfusion in thoracic and lumbar fusion surgery: an analysis of 13,695 patients from the American College of Surgeons National Surgical Quality Improvement Program Database. *Global Spine J*. 2016;6: 756-764.

90. Aoude A, Aldebeyan S, Fortin M, et al. Prevalence and complications of postoperative transfusion for cervical fusion procedures in spine surgery: an analysis of 11,588 patients from the American College of Surgeons National Surgical Quality Improvement Program Database. *Asian Spine J*. 2017;11:880-891.

91. Sebastian A, Huddleston P 3rd, Kakar S, Habermann E, Wagie A, Nassr A. Risk factors for surgical site infection after posterior cervical spine surgery: an analysis of 5441 patients from the ACS NSQIP 2005-2012. *Spine J*. 2016;16:504-509.

92. Basques BA, Anandasivam NS, Webb ML, et al. Risk factors for blood transfusion with primary posterior lumbar fusion. *Spine (Phila Pa 1976)*. 2015;40:1792-1797.

93. Bohl DD, Ahn J, Rossi VJ, Tabaraee E, Grauer JN, Singh K. Incidence and risk factors for pneumonia following anterior cervical decompression and fusion procedures: an ACS-NSQIP study. *Spine J*. 2016;16:335-342.

94. Bohl DD, Mayo BC, Massel DH, et al. Incidence and risk factors for pneumonia after posterior lumbar fusion procedures: an ACS-NSQIP Study. *Spine (Phila Pa 1976)*. 2016;41:1058-1063.

95. Kimmell KT, Algattas H, Joynt P, et al. Risk modeling predicts complication rates for spinal surgery. *Spine (Phila Pa 1976)*. 2015;40:1836-1841.

96. Boriani S, Gasbarrini A, Bandiera S, Ghermandi R, Lador R. Predictors for surgical complications of en bloc resections in the spine: review of 220 cases treated by the same team. *Eur Spine J*. 2016;25:3932-3941.

97. Athiviraham A, Wali ZA, Yen D. Predictive factors influencing clinical outcome with operative management of lumbar spinal stenosis. *Spine J*. 2011;11:613-617.

98. Kaye ID, Marascalchi BJ, Macagno AE, Lafage VA, Bendo JA, Passias PG. Predictors of morbidity and mortality among patients with cervical spondylotic myelopathy treated surgically. *Eur Spine J*. 2015;24:2910-2917.

99. Wilson JR, Arnold PM, Singh A, Kalsi-Ryan S, Fehlings MG. Clinical prediction model for acute inpatient complications after traumatic cervical spinal cord injury: a subanalysis from the Surgical Timing in Acute Spinal Cord Injury Study. *J Neurosurg Spine*. 2012;17(1 suppl):46-51.

100. Janssen DMC, van Kuijk SMJ, d'Aumerie B, Willems P. A prediction model of surgical site infection after instrumented thoracolumbar spine surgery in adults [published online January 7, 2019]. *Eur Spine J*. doi:10.1007/s00586-018-05877-z

101. Aldebeyan S, Aoude A, Fortin M, et al. Predictors of discharge destination after lumbar spine fusion surgery. *Spine (Phila Pa 1976)*. 2016;41:1535-1541.

102. Passias PG, Poorman GW, Bortz CA, et al. Predictors of adverse discharge disposition in adult spinal deformity and associated costs. *Spine J*. 2018;18:1845-1852.

103. De la Garza Ramos R, Nakhla J, Echt M, et al. A national analysis on predictors of discharge to rehabilitation after corrective surgery for adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2019;44:118-122.

104. McGirt MJ, Parker SL, Chotai S, et al. Predictors of extended length of stay, discharge to inpatient rehab, and hospital readmission following elective lumbar spine surgery: introduction of the Carolina-Semmes Grading Scale. *J Neurosurg Spine*. 2017; 27:382-390.

105. Di Capua J, Somani S, Lugo-Fagundo N, et al. Predictors for non-home patient discharge following elective adult spinal deformity surgery. *Global Spine J*. 2018;8:266-272.

106. Carl HM, Coon D, Calotta NA, Pedreira R, Sacks JM. Surgical factors associated with prolonged hospitalization after reconstruction for oncological spine surgery. *Plast Reconstr Surg Glob Open*. 2017;5:e1271.

107. Safaee MM, Scheer JK, Ailon T, et al; International Spine Study Group. Predictive modeling of length of hospital stay following adult spinal deformity correction: analysis of 653 patients with an accuracy of 75% within 2 days. *World Neurosurg*. 2018;115: e422-e427.

108. Kanaan SF, Yeh HW, Waitman RL, Burton DC, Arnold PM, Sharma NK. Predicting discharge placement and health care

needs after lumbar spine laminectomy. *J Allied Health*. 2014;43: 88-97.

109. Basques BA, Fu MC, Buerba RA, Bohl DD, Golinvaux NS, Grauer JN. Using the ACS-NSQIP to identify factors affecting hospital length of stay after elective posterior lumbar fusion. *Spine (Phila Pa 1976)*. 2014;39:497-502.

110. North America Spine Society. Clinical guidelines. https://www. spine.org/ResearchClinicalCare/QualityImprovement/Clinical Guidelines. Accessed March 11, 2019.

111. Completed Guidelines: Congress of Neurological Surgeons. https://www.cns.org/guidelines/completed-guidelines.

112. Fehlings MG, Tetreault LA, Riew KD, et al. A clinical practice guideline for the management of patients with degenerative cervical myelopathy: recommendations for patients with mild, moderate, and severe disease and nonmyelopathic patients with evidence of cord compression. *Global Spine J*. 2017;7(3 suppl): 70S-83S.

113. Fehlings MG, Tetreault LA, Wilson JR, et al. A clinical practice guideline for the management of patients with acute spinal cord injury and central cord syndrome: recommendations on the timing (≤24 hours versus >24 hours) of decompressive surgery. *Global Spine J*. 2017;7(3 suppl):195S-202S.

114. Fehlings MG, Wilson JR, Tetreault LA, et al. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the use of methylprednisolone sodium succinate. *Global Spine J*. 2017;7(3 suppl):203S-211S.

115. Fehlings MG, Tetreault LA, Aarabi B, et al. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the type and timing of anticoagulant thromboprophylaxis. *Global Spine J*. 2017;7(3 suppl): 212S-220S.

116. Fehlings MG, Martin AR, Tetreault LA, et al. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the role of baseline magnetic resonance imaging in clinical decision making and outcome prediction. *Global Spine J*. 2017;7(3 suppl):221S-230S.

117. Fehlings MG, Tetreault LA, Aarabi B, et al. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on the type and timing of rehabilitation. *Global Spine J*. 2017;7(3 suppl):231S-238S.

118. Tetreault LA, Karadimas S, Wilson JR, et al. The natural history of degenerative cervical myelopathy and the rate of hospitalization following spinal cord injury: an updated systematic review. *Global Spine J*. 2017;7(3 suppl):28S-34S.

119. Tetreault LA, Rhee J, Prather H, et al. Change in function, pain, and quality of life following structured nonoperative treatment in patients with degenerative cervical myelopathy: a systematic review. *Global Spine J*. 2017;7(3 suppl):42S-52S.

120. Fehlings MG, Tetreault LA, Kurpad S, et al. Change in functional impairment, disability, and quality of life following operative treatment for degenerative cervical myelopathy: a systematic review and meta-analysis. *Global Spine J*. 2017;7(3 suppl):53S-69S.

121. Wilson JR, Tetreault LA, Kwon BK, et al. Timing of decompression in patients with acute spinal cord injury: a systematic review. *Global Spine J*. 2017;7(3 suppl):95S-115S.

122. Fehlings MG, Wilson JR, Harrop JS, et al. Efficacy and safety of methylprednisolone sodium succinate in acute spinal cord injury: a systematic review. *Global Spine J*. 2017;7(3 suppl): 116S-137S.

123. Arnold PM, Harrop JS, Merli G, et al. Efficacy, safety, and timing of anticoagulant thromboprophylaxis for the prevention of venous thromboembolism in patients with acute spinal cord injury: a systematic review. *Global Spine J*. 2017;7(3 suppl): 138S-150S.

124. Kurpad S, Martin AR, Tetreault LA, et al. Impact of baseline magnetic resonance imaging on neurologic, functional, and safety outcomes in patients with acute traumatic spinal cord injury. *Global Spine J*. 2017;7(3 suppl):151S-174S.

125. Burns AS, Marino RJ, Kalsi-Ryan S, et al. Type and timing of rehabilitation following acute and subacute spinal cord injury: a systematic review. *Global Spine J*. 2017;7(3 suppl):175S-194S.

126. Jarvis JG, Strantzas S, Lipkus M, et al. Responding to neuromonitoring changes in 3-column posterior spinal osteotomies for rigid pediatric spinal deformities. *Spine (Phila Pa 1976)*. 2013;38:E493-E503.

127. Pahys JM, Guille JT, D'Andrea LP, Samdani AF, Beck J, Betz RR. Neurologic injury in the surgical treatment of idiopathic scoliosis: guidelines for assessment and management. *J Am Acad Orthop Surg*. 2009;17:426-434.

128. Ziewacz JE, Berven SH, Mummaneni VP, et al. The design, development, and implementation of a checklist for intraoperative neuromonitoring changes. *Neurosurg Focus*. 2012;33:E11.

129. Vitale MG, Skaggs DL, Pace GI, et al. Best practices in intraoperative neuromonitoring in spine deformity surgery: development of an intraoperative checklist to optimize response. *Spine Deform*. 2014;2:333-339.

130. Hasson F, Keeney S, McKenna H. Research guidelines for the Delphi survey technique. *J Adv Nurs*. 2000;32:1008-1015.

131. Nater A, Murray JC, Martin AR, Nouri A, Tetreault L, Fehlings MG. The need for clinical practice guidelines in assessing and managing perioperative neurologic deficit: results from a survey of the AOSpine International Community. *World Neurosurg*. 2017;105:720-727.

132. Khuri SF. The NSQIP: a new frontier in surgery. *Surgery*. 2005; 138:837-843.

133. Pugely AJ, Martin CT, Harwood J, Ong KL, Bozic KJ, Callaghan JJ. Database and registry research in orthopaedic surgery: part 2: clinical registry data. *J Bone Joint Surg Am*. 2015;97: 1799-1808.

134. Bohl DD, Shen MR, Mayo BC, et al. Malnutrition predicts infectious and wound complications following posterior lumbar spinal fusion. *Spine (Phila Pa 1976)*. 2016;41:1693-1699.

135. Bohl DD, Webb ML, Lukasiewicz AM, et al. Timing of complications after spinal fusion surgery. *Spine (Phila Pa 1976)*. 2015;40:1527-1535.

136. Varthi AG, Basques BA, Bohl DD, Golinvaux NS, Grauer JN. Perioperative outcomes after cervical laminoplasty versus posterior decompression and fusion: analysis of 779 patients in the ACS-NSQIP database. *Clin Spine Surg*. 2016;29:E226-E232.

137. Marjoua Y, Xiao R, Waites C, Yang BW, Harris MB, Schoenfeld AJ. A systematic review of spinal research conducted using

the National Surgical Quality Improvement Program. *Spine J*. 2017;17:88-95.

138. Jackson T, Schramm D, Moloo H, et al. Accelerating surgical quality improvement in Ontario through a regional collaborative: a quality-improvement study. *CMAJ Open*. 2018;6:E353-E359.

139. Zarrabian M, Bidos A, Fanti C, et al. Improving spine surgical access, appropriateness and efficiency in metropolitan, urban and rural settings. *Can J Surg*. 2017;60:342-348.

140. Zeeni C, Carabini LM, Gould RW, et al. The implementation and efficacy of the Northwestern High Risk Spine Protocol. *World Neurosurg*. 2014;82:e815-e823.

141. Sugrue PA, Halpin RJ, Koski TR. Treatment algorithms and protocol practice in high-risk spine surgery. *Neurosurg Clin N Am*. 2013;24:219-230.

142. Ames CP, Barry JJ, Keshavarzi S, Dede O, Weber MH, Deviren V. Perioperative outcomes and complications of pedicle subtraction osteotomy in cases with single versus two attending surgeons. *Spine Deform*. 2013;1:51-58.

143. Fehlings MG, Brodke DS, Norvell DC, Dettori JR. The evidence for intraoperative neurophysiological monitoring in spine surgery: does it make a difference? *Spine (Phila Pa 1976)*. 2010; 35(9 suppl):S37-S46.

144. Luo W, Sun RX, Jiang H, Ma XL. The efficacy and safety of topical administration of tranexamic acid in spine surgery: a meta-analysis. *J Orthop Surg Res*. 2018;13:96.

145. Larson E, Evans T, Long J, Gannon E, Lyden E, Cornett C. Does prophylactic administration of TXA reduce mean operative time and postoperative blood loss in posterior approach lumbar spinal fusion surgery performed for degenerative spinal disease [published online January 11, 2019]? *Clin Spine Surg*. doi:10. 1097/BSD.0000000000000770

146. Gong M, Liu G, Chen L, Chen R, Xiang Z. The efficacy and safety of intravenous tranexamic acid in reducing surgical blood loss in posterior lumbar interbody fusion for the adult: a systematic review and a meta-analysis. *World Neurosurg*. 2019; 122:559-568.

147. Rowin EJ, Lucier D, Pauker SG, Kumar S, Chen J, Salem DN. Does error and adverse event reporting by physicians and nurses differ? *Jt Comm J Qual Patient Saf*. 2008;34:537-545.

148. Schuerer DJ, Nast PA, Harris CB, et al. A new safety event reporting system improves physician reporting in the surgical intensive care unit. *J Am Coll Surg*. 2006;202:881-887.

149. Auerbach JD, McGowan KB, Halevi M, et al. Mitigating adverse event reporting bias in spine surgery. *J Bone Joint Surg Am*. 2013;95:1450-1456.

150. Azad TD, Kalani M, Wolf T, et al. Building an electronic health record integrated quality of life outcomes registry for spine surgery. *J Neurosurg Spine*. 2016;24:176-185.

151. Fitch K, Bernstein SJ, Aguilar MD, et al. *The RAND/UCLA Appropriateness Methods User's Manual*. Santa Monica, CA: RAND; 2001.

152. Burns SP, Nelson AL, Bosshart HT, et al. Implementation of clinical practice guidelines for prevention of thromboembolism in spinal cord injury. *J Spinal Cord Med*. 2005;28:33-42.

153. de Groot S, Bevers G, Post MW, Woldring FA, Mulder DG, van der Woude LH. Effect and process evaluation of implementing standardized tests to monitor patients in spinal cord injury rehabilitation. *Disabil Rehabil*. 2010;32:588-597.