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# Achieving Value in Spine Surgery: 10 Major Cost Contributors

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## Abstract

**Study Design:** Narrative Review.

**Objectives:** The increasing cost of healthcare overall and for spine surgery, coupled with the growing burden of spine-related disease and rising demand have necessitated a shift in practice standards with a new emphasis on value-based care. Despite multiple attempts to reconcile the discrepancy between national recommendations for appropriate use and the patterns of use employed in clinical practice, resources continue to be overused—often in the absence of any demonstrable clinical benefit. The following discussion illustrates 10 areas for further research and quality improvement.

**Methods:** We present a narrative review of the literature regarding 10 features in spine surgery which are characterized by substantial disproportionate costs and minimal—if any—clear benefit. Discussion items were generated from a service-wide poll; topics mentioned with great frequency or emphasis were considered. Items are not listed in hierarchical order, nor is the list comprehensive.

**Results:** We describe the cost and clinical data for the following 10 items: Over-referral, Over-imaging & Overdiagnosis; Advanced Imaging for Low Back Pain; Advanced imaging for C-Spine Clearance; Advanced Imaging for Other Spinal Trauma; Neuromonitoring for Cervical Spine; Neuromonitoring for Lumbar Spine/Single-Level Surgery; Bracing & Spinal Orthotics; Biologics; Robotic Assistance; Unnecessary perioperative testing.

**Conclusions:** In the pursuit of value in spine surgery we must define what quality is, and what costs we are willing to pay for each theoretical unit of quality. We illustrate 10 areas for future research and quality improvement initiatives, which are at present overpriced and underbeneficial.

**Keywords**
cervical, lumbar, thoracic, bone graft, trauma, MRI, radiology, neuro, computer assisted navigation, low back pain

## Introduction

The application of modern technology in medicine can lead to profound change, but also has the tendency to vastly increase expenditures. On one hand these advancements allow us new methods to combat disease, on the other hand cutting edge technology is expensive. Furthermore, the structure of the American healthcare system can incentivize the rapid development and application of technologies without proper evidence of their efficacy. And if there is evidence to support a technology's efficacy, it may incur a cost that may not justify its use. This highlights the importance of value in medicine, where these tools are judged by both their ability to objectively improve patient care, and the costs they incur.

80% of patients in the United States will experience back pain, and only 1.2% of these patients receive a surgical intervention. Despite this, those patients who receive spine surgery account for approximately 30% of the total US healthcare expenditure due to back pain.[1] While these procedures can

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provide great benefit to patients, their quality of life, and their productivity, it is important we critically analyze technologies and techniques routinely applied in spine surgery. The goal of this review should be both maximizing the quality of the patient experience and patient outcomes while minimizing cost. In the following discussion we present both new and old technologies and tools used in the diagnosis, treatment, and follow up in spine patients, and analyze them through this lens of maximizing quality, while minimizing the costs to the patient and the healthcare system as a whole. Over-Referral, Over-Imaging and Overdiagnosis

Over that last several decades there have been increases in subspecialty referrals and an overutilization of advanced imaging and evaluations of patients in general.[2] This has led to recent reanalysis of care and a shift in practice standards with a new emphasis on value-based care. There is a widespread misunderstanding and practice heterogeneity with respect to the type and timing of diagnostic imaging, consulting services, and need for specialist referral.

The utilization of CT and MRI has increased every year among academic medical centers. From 2002-2007, the use of CT increased by 28%; MRI by 19.8%, with costs over the same period growing by 151%—more than 8.3% per year.[3,4] A single-center retrospective examination of imaging utilization in the ED found that 81% of patients who underwent MRI in the acute setting, had concomitant CT examinations. MRI use increased by 2.2 per 1000 ED visits each year from 2007-2012.[5] Additional expense can be avoided by forgoing redundant CT studies; multiple studies have demonstrated the capabilities of reformatted images from abdominal or thoracic multidetector CT studies.[6,7]

The cost of radiologist interpretation of a preoperative CT in patients presenting with a single-level thoracolumbar fracture was equal to $3346; post-op CT and Xray interpretation accounts for $35,786 per 1000 patients.[8] Compulsory radiologist interpretation is not only costly, but also redundant and may not provide additional information in this setting, where the surgeon's interpretation has been shown not to differ significantly from that of the attending radiologist.[9]

Appropriate use and referral for advanced spinal imaging are heterogeneous by region, and nonadherence to guidelines accounts for a significant margin of excess spending nationally.[10,1] Although less than 2% of patients presenting with new onset back pain will undergo surgery, those who are managed operatively account for approximately 30% of back pain related healthcare spending.[1] More than ⅔ of patients who underwent diagnostic imaging were not in accordance with guidelines for appropriate use.[1] It has also been suggested that inappropriate or early imaging leads to more frequent spine surgeon referral and rates of surgery.

Regions which have higher rates of MRI use have been shown to have higher rates of surgery; the frequency of MRI in these regions exceeds that which can be explained by perioperative imaging for patients undergoing surgery, suggesting a causal relationship between MRI rate and rate of surgery.[10] Over-imaging may reveal clinically unimportant abnormalities that could unintentionally lead to further testing, patient anxiety, specialist referrals, and possibly even unnecessary surgery.[11,12]

Initial management and the mitigation of these concerns begins in the primary care setting. Deis and Findlay, in a 2010 retrospective study at their institution, found that only 26% of spine referrals to their clinic were appropriate.[13] Debono et al found that over a period of 2 months, 30% of primary care referrals to spine surgery specialists were unsuitable for surgical assessment—35% of these did not have surgical conditions, 32% had not undergone adequate medical treatment.[14] There is a need for more clear, widely accepted guidelines for initial imaging evaluations, as well as better education in the primary care setting about the indications for referrals and imaging.

## *Advanced Imaging for Low Back Pain*

The use of advance technology for low back pain is warranted only in the presence of "red flag" symptoms or indications, or in the setting of persistent radicular pain refractory to 1 month of conservative management. In the absence of red flags, advanced imaging for nonspecific low back pain is not appropriate.[15] However, there are numerous reports of imaging overuse without patients meeting appropriate recommended guidelines.[16-22] Contrary to guidelines, Webster et al report that 37% of a randomly selected national sample of patients with nonspecific low back pain underwent inappropriate MRI—resulting in an estimated $13,000 increase in associated medical costs on behalf of the subsequent sequelae of theoretically unindicated diagnostic testing and treatment.[23]

Gidwani et al. found that 31% of 110,661 lumbar spine MRI's performed in the VA health system in a single year (2012) were inappropriate. They additionally found that scans performed in the emergency department, urgent care, primary care, or internal medicine clinic settings were more likely to be inappropriate.[24] Emery et al. prospectively evaluated the appropriateness of MRI from outpatient referrals, and found that 55.7% of lumbar MRI scans were either inappropriate or of uncertain value.[25] Only 33.9% of MRI scans ordered by family practice physicians were considered appropriate—by comparison 75.7% of those ordered by neurosurgeons were appropriate. A meta analysis incorporating 6 randomized controlled trials examining patients with acute or subacute low back pain without red-flag features found *no difference* in outcomes including pain, function, quality of life, or overall patient-rated improvement, comparing patients who did vs those who did not undergo advanced imaging.[26]

Conservative estimates of the cost of MRI in the United States—excluding associated costs including disposables, radiologist and staffing time—range from $877 to $2467.[26,27] Anywhere from ⅓ to ⅔ of spinal pathologies have been noted to be readily apparent on CT imaging, including reformatted images of adjacent body tissues, rendering subsequent MRI unecessary.[27,28,29] Klein estimated in a large retrospective study that in a single year, approximately 11,000 lumbar MRI scans were performed unnecessarily in patients with recent abdominal CT scans which were suitable for diagnosis.[30] Avoiding this over-imaging would have saved an estimated 1.2 to 3.4 billion dollars in a single year.

Despite multiple attempts to reconcile the discrepancy between national recommendations for appropriate use and the patterns of use employed in clinical practice, these resources continue to be abused. Increased education has failed to change practice patterns, and practitioners may feel pressured to over-prescribe on behalf of pressures including patient satisfaction and medicolegal concerns.

## Advanced imaging for C-Spine Clearance

Failure to diagnose unstable cervical spine injury (CSI) after trauma may result in devastating clinical consequences, and is associated with excess costs which can exceed $1 million (USD) in the first 5 years after injury.[18] Per NEXUS and Canadian C-spine rules, CT or X-rays are the first test of choice for imaging for cervical spine clearance in the setting of high-probability mechanisms of injury.[31] The routine use of MRI as an adjunctive, or primary imaging modality, although highly sensitive for the detection of cervical spine fractures, is rarely necessary for C-spine clearance, which can be safely performed on the basis of clinical findings and CT imaging alone.[32,33] MRI is associated with substantial increased costs, in excess of the clinical benefits of its routine use, and is therefore not a cost-effective tool in this setting.[32,33,34]

Plackett et al performed a systematic review and meta-analysis, finding that MRI detected injury not noted on CT in 15.8% of patients, only 5 of which (1.8%) resulted in a change in management. Furthermore, none of these 5 were agreed-upon indications for surgery, though they were operated upon.[33] Most commonly, MRI detects ligamentous injury where CT cannot. Malhotra et al, in a single center retrospective series of 1,080 patients, 20% of patients had additional findings on MRI, however only 0.42% had any significant change in management on the basis of these findings.[31] Resnick et al. report a 100% sensitivity of CT for clinically significant CSI.[35] Khanna et al found similar results among patients who present obtunded and unable to be cleared clinically—MRI offered no additional findings which were clinically significant and no changes in management occurred on behalf of MRI findings.[36] Raza et al examined the overall sensitivity and specificity of newer MDCT findings for cervical spine injury, noting a negative predictive value for CSI of 99.7%.[37]

Not surprisingly, this lack of clinical benefit results in a lack of overall economic benefit, and the routine use of MRI for C-spine clearance in both neurologically intact, and obtunded patients is not cost-effective.[37,38] Wu et al. reports an average cost increase of $11,477 in patients who undergo MRI after negative CT.[34] Como et al estimate that avoidance of MRI for CSI would have theoretically yielded more than $250,000 in savings over a 2 year period at their medical center.[39,40] The rate of detection for unstable CSI on MRI is extremely low in both obtunded, and alert patients after a negative CT. [34,39,40] Neurosurgeons should be comfortable with discontinuing the cervical collar after a negative, high-quality CT.[41] From this perspective, the use of MRI as a prerequisite to clear the cervical spine increases the total healthcare costs without proof of actual benefit.

## Advanced Imaging for Other Spinal Trauma

It has become routine practice to obtain dedicated spine MRI in patients with high suspicion of, or radiographically/CT confirmed thoracolumbar fractures in order to characterize the extent of posterior ligamentous complex injuries.[42,43] However, while highly sensitive as a diagnostic tool, the applicable clinical utility of compulsory MRI for all patients has been called into question.

A small prospective study at a level 1 trauma center by Khoury et al, found that among neurologically intact patients presenting with CT-confirmed thoracolumbar fractures, MRI yielded a change in clinical management in only 15% of cases—none of which resulted in a change from nonoperative to operative management.[44] They conclude that MRI has little impact on management for such patients, and should only be obtained for patients planned for surgery on the basis of CT findings.[44] Similar results have been demonstrated by other studies.[45,46,47] Tavolaro et al performed a retrospective review of patients with ankylosing spine disease, and determined that even in this comparatively high-risk population, MRI provided clinically useful information resulting in a change in management only among patients presenting with neurological deficits, or with CT findings demonstrating noncontiguous ankylosed segments with suspected discoligamentous injury through a mobile disc.[48]

A retrospective review of 191 thoracolumbar compression fractures in a pediatric trauma center found that the addition of MRI did not affect management in 98% of cases.[49] While limited in clinical utility, the addition of MRI yielded a greater than $6,000 increase in charges. This study also notes that a significant proportion of patients will require sedation or general anesthesia in order to undergo MRI, adding another $2,650 in overall cost, as well as prolonging periods of immobility/bedrest, length of stay, and other unaccounted costs.[49]

MRI and CT have been shown to have high agreement ($k > 0.87$) for the diagnosis of fractures, and MRI offered additional sensitivity for only AOSpine type B2 fractures ($p < 0.001$).[46] Despite this modest advantage over CT alone, the assessment of need for surgery did not change after the addition of MRI.[46,47]

## Neuromonitoring for Cervical Spine

An increasingly ubiquitous feature of routine spine surgery, intraoperative neuromonitoring (IONM) provides real-time feedback of motor and sensory function in effort to mitigate or altogether prevent iatrogenic neurological injury. The most commonly utilized tools include Somatosensory Evoked Potentials (SSEPs), Motor Evoked potentials (MEPs), and electromyography (EMG).[50,51] Considerable effort has been exhausted developing these tools and our understanding of the relative efficacy, strengths, and limitations of each component modality.[50-52]

IONM is generally accepted as an effective tool for predicting and reducing neurological deficits in complex spine surgery—supported by the results of several large observational studies—however no prospective, randomized controlled trial has been conducted to date.[53-55] There is limited and inconsistent data describing the utility of IONM for more routine procedures, and the appropriate indications for use are still debated.[50,56,57] Despite a lack of quality supporting evidence, there has been a nearly 300% increase in use over the last 10 years.[54,58] However, a parallel decrease in the rate of neurological injury has NOT been observed, and there is evidence to suggest IONM lacks clinical benefit for certain procedure types.[59,60]

In a 2017 meta-analysis, Ajiboye et al found no difference in the risk of neurological injury with or without IONM (odds ratio, 0.726; $p = 0.498$) for ACDFs.[61] The same group reviewed Pearl-Diver data for ACDFs between 2007-2014, and again found no difference in the rate of neurological injury comparing cases performed with, and without IONM (0.23% and 0.27%, $p = 0.84$).[62] Badhiwala found similar results examining data from the National (Nationwide) Inpatient Sample of the Healthcare Cost and Utilization Project from 2009 to 2013, noting no significant difference in the rate of neurological injury (0.17% vs 0.22%, $p = 0.41$) or LOS > 2 days (19% vs 18%, $p = 0.15$) on multivariate analysis comparing ACDFs with and without IONM.[63] Traylanis et al. demonstrated the safety of cervical decompression and fusion in the absence of IONM in a retrospective series of 720 patients.[56]

Forgoing the use of monitoring in these patients, assuming 4 hours of monitoring time, was associated with an estimated $1,024,754 (USD).[56] Another study reported an average $1229 increase in cost per patient during the index admission year in multivariate analysis.[64] Cole et al, in addition to finding no reduction in the rate of neurological complications, found the use of IONM to be associated with increased spending, ranging from $2859 to $3841 of excess cost.[65]

## *Neuromonitoring for Lumbar Spine/Single-Level Surgery*

The limitations of IONM do not appear to be limited to cervical procedures. Despite the introduction of neuromonitoring over time, neurologic complications continue to occur.[66] Cole et al. reviewed a large national insurance database to conduct a multivariate propensity score matched analysis comparing the rate of neurological injury among single-level procedures employing IONM to those without.[65] They determined no reduction in injury for single level lumbar discectomy ($p = 0.1703$), lumbar fusion ($p = 0.1449$), and ACDF ($p = 0.5134$).[65] IONM use for single-level procedures was significantly associated with increased cost (7.84%-24.33% increase in total [USD] payments, $p < 0.0001$).[65]

Based on national claims data, the average 4-hour surgery is associated with $942 for SSEPs, $1115 for MEP, or $1423 in combination.[56] Sala et al. determined that IONM achieves cost-effectiveness if the overall cost did not exceed $977 per surgery, assuming a rate of neurological injury equal to 0.1%—of note, this model assumes a 100% injury prevention rate, and does not account for indirect false-positive costs.[67]

Furthermore, the reported incidence of major neurologic injury in the IONM era ranges from 0.4% to 1.9%, which is largely unchanged from the pre-IONM era estimates.[50,57,68] The rate of neurological injury remains stable, despite the increasing prevalence of IONM.[69] The cost of these interventions is not negligible, and appropriate use criteria requires additional investigation. These tools are powerful for the detection and prediction of postoperative neurological injury, however thus far have not been able to prevent injury as a whole. This is likely due to inconsistent practice in implementation and warrants further research.

## *Bracing and Spinal Orthotics*

Spinal orthoses have been used for many years as an adjunctive treatment for many spine conditions as a means of reducing mobility to reduce post-operative pain, improve fusion rates, or prevent graft dislodgement.[70] Various orthoses have been developed, classified in accordance with their relative rigidity and anatomical region of immobilization, representing a substantial disposable cost associated with spine surgery.[71] Controversy exists regarding the routine use of orthoses in the post-operative period of spine surgery—despite their widespread use, there is a lack of evidence of its cost-effectiveness in most spinal pathologies.[70-74]

In a Department of Health and Human Services executive summary it was found that the average Medicare reimbursement for back orthoses was estimated at approximately $919—a study conducted by the Department of Health and Human Services demonstrated that Medicare claims for lumbar orthoses more than doubled over a 4 year period.[75] In sum, Medicare allowances nationally increased from $36 million to more than $96 million over this time. The use of routine post-surgery orthoses adds cost to treatment without any additional benefit.[76] Studies examining this practice have been plagued with errors in research methodology including small sample sizes and various sources of bias, and no strong evidence yet exists to demonstrate clear benefit.[74]

A less controversial indication for the use of spinal orthoses is in the management of traumatic spine injury.[71] However, even in this scenario following operative stabilization of a thoracolumbar fracture the use of orthoses may not be a cost-effective measure.[76] Horodyski et al. examined the use of cervical collars after trauma, and in a cadaver study, called into question the ability of cervical collars to provide adequate stabilization at all.[77] Additional studies have similarly questioned the efficacy of Cervical immobilization with collar alone, and may pose additional harm to patients.[16,78,79]

Beyond the issue of cost, studies examining the quality of life after spine surgery in lumbar degenerative diseases have failed to demonstrate an improvement in pain relief and overall quality of life comparing bracing to no-bracing.[74,80] The use of bracing in the postoperative period has been analyzed in a review by Zhu et al.,[70] and though the data is limited, it appears that postoperative bracing is generally associated with higher costs. With such little data, and in the face of data which demonstrates no clear benefit, perhaps it is time to question the routine use of postoperative orthoses after spine surgery.

## Biologics

With the increasing number of spinal fusions being performed, the use of biologics in achieving an adequate arthrodesis is a point of perpetual discussion. Given the morbidity associated with iliac crest harvest, and the emphasis on minimally invasive techniques, preferences have turned to allografts, bone matrices, scaffolds and proteins to help create a fusion mass. Predicated on the principles of osteogenesis, osteoinduction and osteoconduction, the effectiveness of graft choice should be balanced with cost to ultimately yield greater value.[81]

Unfortunately, the literature examining the cost-effectiveness of biologics in spinal fusion is sparse. A systematic review by Hsu et al., was able to effectively include 6 studies in their analysis and found varying results.[82] They concluded that examining the cost-effectiveness would depend on the upfront cost of the graft, which interestingly varies by market, and whether indirect costs are to be included. If the use of BMP leads to decreased re-operation rates, and an early return to work, then the significant initial upfront cost of BMP use may be justified. [17,83] With regard to the cervical spine, the review found limited data, but one study did suggest that allograft and autograft are similarly cost-effective.[84]

Future analysis must be done to establish the cost-effectiveness of the biologic materials increasingly available for use in spinal fusion. Whether direct savings in decreased revision surgery, or indirect costs of improved functional outcomes and productivity, or both, cost-effectiveness analysis is a field ripe for future research.

## Robotic Assistance

Every field has evolved to incorporate robotics, and spine is no exception. Whether shifting current or future paradigms, technological advancements in spine surgery have led to several systems, including Mazor and ExcelsiusGPS, to be introduced to the market with varied adoption. Proponents argue that robotic assistance provides more accurate screw placements, fewer revision rates, and ultimately safer surgical options. There is support in the literature that robotic assistance in spinal fusion surgery limits operator radiation exposure, reduces infection rates, and also reduces revision rates.[85,86] However, there is paucity in the literature of unbiased and well-established cost analysis examining the feasibility of robotics in spine surgery.

More specifically, the direct and indirect cost-savings from improved outcomes must be compared to the exceptionally high, and often prohibitive, upfront costs of adopting any of the currently available systems. With increasing support showing improved operative outcomes, increasing efficiencies/scale from wider adoption and use, and lower upfront costs with a more competitive market, the cost-effectiveness of robotics in certain spinal surgeries may be inevitable.[87]

Analysis by Menger et al. was able to critically analyze the potential economic impact of robotics at an academic neurosurgical practice.[88] Using estimated costs of infections, OR time, revision surgery and length of stay, their group was able to estimate a yearly savings of over $600,000 at their institution performing over 500 elective thoracolumbar instrumentations. While the theoretical basis of cost-effectiveness is implied, this has yet to be observed or captured clinically.

Because such modeling and forecasting is predicated on previously published literature, further analysis via direct observation is necessary to guide capital investment, identify efficiencies and determine specific procedural applications for robotics.

## Unnecessary Perioperative Testing

Current practice standards require perioperative hematologic lab testing including Type & Screen and CBC for all patients undergoing elective spine surgery. However, the incidence of perioperative anemia is exceptionally low, and a transfusion requirement is likely dependent upon specific operative factors and patient characteristics. Compulsory testing of all patients may portend avoidable economic burden and risk to patient satisfaction. Standard charges for CBC and Type and Screen can range from $38-$50 per test, not including charges for venipuncture, staffing, and associated office visit fees. Testing charges conservatively approximate $150 per patient assuming preoperative CBC and Type and Screen and one postoperative CBC.

This testing is not necessary for every spine patient, especially otherwise healthy, elective patients undergoing procedures with short expected operative times. From an analysis of 11,588 patients, the rate of blood transfusion following cervical fusion was found to be only 1.47%.[89] Predicting who is at a higher risk for needing blood transfusions could reduce the need for unnecessary pre-operative testing. A multivariate analysis of 13,695 patients found increasing age, ASA class $\geq 3$, bleeding disease, and return to OR were predictive of need for transfusion lumbar fusion; multilevel surgery and extended surgical time were predictors of transfusion for both lumbar and thoracic fusion.[89]

The overuse of lab testing extends to the post-operative period as well. Patients who are at low risk for post-operative complications should have further laboratory testing used judiciously. This includes patients with post-operative fevers. Immediate low grade post-operative fevers are highly likely to be due to inflammation and stimulation of cytokines released by DAMPS during the surgery itself.[73] Ordering a full set of diagnostic studies including a chest X-ray, blood cultures, urinalysis, and lower extremity ultrasound is not necessary for a common post-operative vital sign abnormality. A meta-analysis of post-operative fevers in orthopedic surgery patients concluded that any work up of fevers in the absence of localizing symptoms before post-operative day 4 to be unwarranted, and the average cost per fever work up in this study ranged from $350-950.[90]

This discussion regarding transfusion requirements and the overuse of the CBC test is meant to illustrate a finite example of a broader issue. It is prudent to mention that the drivers of perioperative testing are often standards set by consulting treatment teams, pursuant to cardiac risk stratification or anesthesiology needs or concerns. Surgeons should play an active role in coordinating multidisciplinary discussions regarding the necessity of compulsory testing, and provide leadership in collaborative quality improvement efforts in all practice settings.

## Conclusions

Whether it's the overapplication of old technology made more readily available (MRI, CT scans, and braces), or the advent of new technologies yet unproven (robotic assistant, IONM, biologics) we must be vigilant in evaluating the value these tools provide in the care of spine patients. In the case of imaging for initial evaluation, studies must be done to decide which diagnostic methods allow for the quickest, most accurate evaluation, and protocols must be followed to reflect those analyses. While an MRI may provide more information, that information may not always translate into better outcomes for the patient while adding significantly to the cost of their overall care. Thus, in certain contexts, MRIs only serve to lower the value of the patient's care.

In the case of new technologies, the quality is often an unknown and the cost is considerable. It is then critical for surgeons and companies supporting and producing these products to both lower their cost and provide concrete evidence of the impact these technologies have on patient care, the quality they provide. On the other hand, factors lowering the overall value of care in spine surgery can also come from the overuse of elementary commodities used in medicine. A simple metabolic panel, fever work up, or blood transfusion may not significantly change expenses, but if it contributes nothing to patient care and is performed at a high rate throughout the country the aggregate effect on the value of spine surgery as a specialty is substantial.

The underlying forces driving these excess costs warrant further consideration. With respect to excessive specialist referrals, over-imaging, overdiagnosis/overutilization, the use of intraoperative imaging/robotics, and IONM, it is prudent to consider the cost of both "return to OR" events as well as those associated with litigation. Though variable by region, the costs and broad implications of litigation are substantial. This—medicolegal "awareness" is an important driver of over-utilization and should continue to be discussed.

In the pursuit of value in spine surgery we must define what quality is, and what costs are we willing to pay for each theoretical unit of quality. Here we presented what we feel are elements of spine surgery that are low value, either through significantly increasing costs, unproven benefits to the quality of patient care and outcomes, or a combination of both.

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### References

1. Kim LH, Vail D, Azad TD, et al. Expenditures and health care utilization among adults with newly diagnosed low back and lower extremity pain. *JAMA Netw Open*. 2019;2(5):e193676. doi:10.1001/jamanetworkopen.2019.3676
2. Barnett ML, Song Z, Landon BE. Trends in physician referrals in the United States, 1999-2009. *Arch Intern Med*. 2012;172(2): 163-170. doi:10.1001/archinternmed.2011.722
3. Agarwal R, Bergey M, Sonnad S, Butowsky H, Bhargavan M, Bleshman MH. Inpatient CT and MRI utilization: trends in the academic hospital setting. *J Am Coll Radiol*. 2010;7(12):949-955. doi:10.1016/j.jacr.2010.08.015
4. Beinfeld MT, Gazelle GS. Diagnostic imaging costs: are they driving up the costs of hospital care? *Radiology*. 2005;235(3): 934-939. doi:10.1148/radiol.2353040473
5. Quaday KA, Salzman JG, Gordon BD. Magnetic resonance imaging and computed tomography utilization trends in an academic ED. *Am J Emerg Med*. 2014;32(6):524-528. doi:10.1016/j.ajem.2014.01.054
6. Carter B, Griffith B, Mossa-Basha F, et al. Reformatted images of the thoracic and lumbar spine following CT of chest, abdomen, and pelvis in the setting of blunt trauma: are they necessary? *Emerg Radiol*. 2015;22(4):373-378. doi:10.1007/s10140-015-1295-8
7. Kim S, Yoon CS, Ryu JA, et al. A comparison of the diagnostic performances of visceral organ-targeted versus spine-targeted protocols for the evaluation of spinal fractures using sixteen-channel multidetector row computed tomography: is additional spine-targeted computed tomography necessary to evaluate thoracolumbar spinal fractures in blunt trauma victims? *J Trauma*. 2010;69(2):437-446. doi:10.1097/TA.0b013e3181e491d8
8. Weber MH, Sivakumaran L, Fortin M, et al. Utility and costs of radiologist interpretation of perioperative imaging in patients with

traumatic single-level thoracolumbar fractures. *J Neurosurg Spine*. 2017;27(5):578-583. doi:10.3171/2017.4.SPINE16923

9. Turen CH, Mark JB, Bozman R. Comparative analysis of radiographic interpretation of orthopedic films: is there redundancy? *J Trauma*. 1995;39(4):720-721. doi:10.1097/00005373-199510000-00019
10. Lurie JD, Birkmeyer NJ, Weinstein JN. Rates of advanced spinal imaging and spine surgery. *Spine*. 2003;28(6):616-620. doi:10.1097/01.BRS.0000049927.37696.DC
11. Gray DT, Hollingworth W, Blackmore CC, et al. Conventional radiography, rapid MR imaging, and conventional MR imaging for low back pain: activity-based costs and reimbursement. *Radiology*. 2003;227(3):669-680. doi:10.1148/radiol.2273012213
12. Weishaupt D, Zanetti M, Hodler J, Boos N. MR imaging of the lumbar spine: prevalence of intervertebral disk extrusion and sequestration, nerve root compression, end plate abnormalities, and osteoarthritis of the facet joints in asymptomatic volunteers. *Radiology*. 1998;209(3):661-666. doi:10.1148/radiology.209.3.9844656
13. Deis N, Findlay JM. Appropriateness of lumbar spine referrals to a neurosurgical service. *Can J Neurol Sci*. 2010;37(6):843-848. doi:10.1017/s0317167100051544
14. Debono B, Sabatier P, Koudsie A, Buffenoir K, Hamel O.Managing spine surgery referrals: the consultation of neurosurgery and its nuances. *Neurochirurgie*. 2017;63(4):267-272. doi:10.1016/j.neuchi.2017.05.003
15. Di Iorio D, Henley E, Doughty A. A survey of primary care physician practice patterns and adherence to acute low back problem guidelines. *Arch Fam Med*. 2000;9(10):1015-1021. doi:10.1001/archfami.9.10.1015
16. Del Rossi G, Heffernan TP, Horodyski M, Rechtine GR. The effectiveness of extrication collars tested during the execution of spine-board transfer techniques. *Spine J*. 2004;4(6):619-623. doi:10.1016/j.spinee.2004.06.018
17. Glassman SD, Carreon LY, Djurasovic M, et al. RhBMP-2 versus iliac crest bone graft for lumbar spine fusion: a randomized, controlled trial in patients over sixty years of age. *Spine*. 2008;33(26):2843-2849. doi:10.1097/BRS.0b013e318190705d
18. Webster B, Giunti G, Young A, Pransky G, Nesathurai S. Work-related tetraplegia: cause of injury and annual medical costs. *Spinal Cord*. 2004;42(4):240-247. doi:10.1038/sj.sc.3101526
19. Cherkin DC, Deyo RA, Wheeler K, Ciol MA. Physician variation in diagnostic testing for low back pain. Who you see is what you get. *Arthritis Rheum*. 1994;37(1):15-22. doi:10.1002/art.1780370104
20. Webster BS, Cifuentes M. Relationship of early magnetic resonance imaging for work-related acute low back pain with disability and medical utilization outcomes. *J Occup Environ Med*. 2010;52(9):900-907. doi:10.1097/JOM.0b013e3181ef7e53
21. Graves JM, Fulton-Kehoe D, Jarvik JG, Franklin GM. Early imaging for acute low back pain: one-year health and disability outcomes among Washington State workers. *Spine*. 2012;37(18):1617-1627. doi:10.1097/BRS.0b013e318251887b
22. Graves JM, Fulton-Kehoe D, Jarvik JG, Franklin GM. Health care utilization and costs associated with adherence to clinical practice guidelines for early magnetic resonance imaging among workers with acute occupational low back pain. *Health Serv Res*. 2014;49(2):645-665. doi:10.1111/1475-6773.12098
23. Webster BS, Bauer AZ, Choi Y, Cifuentes M, Pransky GS. Iatrogenic consequences of early magnetic resonance imaging in acute, work-related, disabling low back pain. *Spine*. 2013;38(22):1939-1946. doi:10.1097/BRS.0b013e3182a42eb6
24. Gidwani R, Sinnott P, Avoundjian T, Lo J, Asch SM, Barnett PG. Inappropriate ordering of lumbar spine magnetic resonance imaging: are providers choosing wisely? *Am J Manag Care*. 2016;22(2):e68-e76.
25. Emery DJ, Shojania KG, Forster AJ, Mojaverian N, Feasby TE. Overuse of magnetic resonance imaging. *JAMA Intern Med*. 2013;173(9):823-825. doi:10.1001/jamainternmed.2013.3804
26. Chou R, Qaseem A, Owens DK, Shekelle P; Clinical Guidelines Committee of the American College of Physicians. Diagnostic imaging for low back pain: advice for high-value health care from the American College of Physicians. *Ann Intern Med*. 2011;154(3):181-189. doi:10.7326/0003-4819-154-3-201102010-00008
27. Thornbury JR, Fryback DG, Turski PA, et al. Disk-caused nerve compression in patients with acute low-back pain: diagnosis with MR, CT myelography, and plain CT. *Radiology*. 1993;186(3):731-738. doi:10.1148/radiology.186.3.8267688
28. Lehnert BE, Bree RL. Analysis of appropriateness of outpatient CT and MRI referred from primary care clinics at an academic medical center: how critical is the need for improved decision support? *J Am Coll Radiol*. 2010;7(3):192-197. doi:10.1016/j.jacr.2009.11.010
29. Weiner DK, Kim Y-S, Bonino P, Wang T. Low back pain in older adults: are we utilizing healthcare resources wisely? *Pain Med*. 2006;7(2):143-150. doi:10.1111/j.1526-4637.2006.00112
30. Klein MA. Reuse and reduce: abdominal CT, lumbar spine MRI, and a potential 1.2 to 3.4 billion dollars in cost savings. *Abdom Radiol (NY)*. 2017;42(12):2940-2945. doi:10.1007/s00261-017-1201-9
31. Malhotra A, Wu X, Kalra VB, et al. Utility of MRI for cervical spine clearance after blunt traumatic injury: a meta-analysis. *Eur Radiol*. 2017;27(3):1148-1160. doi:10.1007/s00330-016-4426-z
32. Schoenfeld AJ, Beck AW, Harris MB, Anderson PA. Evaluating the cervical spine in the blunt trauma patient. *J Am Acad Orthop Surg*. 2019;27(17):633-641. doi:10.5435/JAAOS-D-18-00695
33. Plackett TP, Wright F, Baldea AJ, et al. Cervical spine clearance when unable to be cleared clinically: a pooled analysis of combined computed tomography and magnetic resonance imaging. *Am J Surg*. 2016;211(1):115-121. doi:10.1016/j.amjsurg.2014.12.041
34. Wu X, Malhotra A, Geng B, et al. Cost-effectiveness of magnetic resonance imaging in cervical clearance of obtunded blunt trauma after a normal computed tomographic finding. *JAMA Surg*. 2018;153(7):625-632. doi:10.1001/jamasurg.2018.0099
35. Resnick S, Inaba K, Karamanos E, et al. Clinical relevance of magnetic resonance imaging in cervical spine clearance: a prospective study. *JAMA Surg*. 2014;149(9):934-939. doi:10.1001/jamasurg.2014.867
36. Khanna P, Chau C, Dublin A, Kim K, Wisner D. The value of cervical magnetic resonance imaging in the evaluation of the obtunded or comatose patient with cervical trauma, no other abnormal neurological findings, and a normal cervical computed

tomography. *J Trauma Acute Care Surg*. 2012;72(3):699-702. doi:10.1097/TA.0b013e31822b77f9

37. Raza M, Elkhodair S, Zaheer A, Yousaf S. Safe cervical spine clearance in adult obtunded blunt trauma patients on the basis of a normal multidetector CT scan—a meta-analysis and cohort study. *Injury*. 2013;44(11):1589-1595. doi:10.1016/j.injury.2013.06.005
38. Chew BG, Swartz C, Quigley MR, Altman DT, Daffner RH, Wilberger JE. Cervical spine clearance in the traumatically injured patient: is multidetector CT scanning sufficient alone? Clinical article. *J Neurosurg Spine*. 2013;19(5):576-581. doi:10.3171/2013.8.SPINE12925
39. Como JJ, Leukhardt WH, Anderson JS, Wilczewski PA, Samia H, Claridge JA. Computed tomography alone may clear the cervical spine in obtunded blunt trauma patients: a prospective evaluation of a revised protocol. *J Trauma*. 2011;70(2):345-349; discussion 349-351. doi:10.1097/TA.0b013e3182095b3c
40. Como JJ, Thompson MA, Anderson JS, et al. Is magnetic resonance imaging essential in clearing the cervical spine in obtunded patients with blunt trauma? *J Trauma*. 2007;63(3):544-549. doi:10.1097/TA.0b013e31812e51ae
41. Tan LA, Kasliwal MK, Traynelis VC. Comparison of CT and MRI findings for cervical spine clearance in obtunded patients without high impact trauma. *Clin Neurol Neurosurg*. 2014;120:23-26. doi:10.1016/j.clineuro.2014.02.006
42. Qureshi S, Dhall SS, Anderson PA, et al. Congress of neurological surgeons systematic review and evidence-based guidelines on the evaluation and treatment of patients with thoracolumbar spine trauma: radiological evaluation. *Neurosurgery*. 2019;84(1):E28-E31. doi:10.1093/neuros/nyy373
43. Shabani S, Kaushal M, Soliman HM, et al. AOSpine Global Survey: international trends in utilization of magnetic resonance imaging/computed tomography for spinal trauma and spinal cord injury across AO regions. *J Neurotrauma*. 2019;36(24):3323-3331. doi:10.1089/neu.2019.6464
44. Khoury L, Chang E, Hill D, et al. Management of thoracic and lumbar spine fractures: is MRI necessary in patients without neurological deficits? *Am Surg*. 2019;85(3):306-311.
45. Khurana B, Karim SM, Zampini JM, et al. Is focused magnetic resonance imaging adequate for treatment decision making in acute traumatic thoracic and lumbar spine fractures seen on whole spine computed tomography? *Spine J*. 2019;19(3):403-410. doi:10.1016/j.spinee.2018.08.010
46. Rajasekaran S, Vaccaro AR, Kanna RM, et al. The value of CT and MRI in the classification and surgical decision-making among spine surgeons in thoracolumbar spinal injuries. *Eur Spine J*. 2017;26(5):1463-1469. doi:10.1007/s00586-016-4623-0
47. Vaccaro AR, Rihn JA, Saravanja D, et al. Injury of the posterior ligamentous complex of the thoracolumbar spine: a prospective evaluation of the diagnostic accuracy of magnetic resonance imaging. *Spine*. 2009;34(23):E841-E847. doi:10.1097/BRS.0b013e3181bd11be
48. Tavolaro C, Ghaffar S, Zhou H, Nguyen QT, Bellabarba C, Bransford RJ. Is routine MRI of the spine necessary in trauma patients with ankylosing spinal disorders or is a CT scan sufficient? *Spine J*. 2019;19(8):1331-1339. doi:10.1016/j.spinee.2019.03.004
49. Franklin DB, Hardaway AT, Sheffer BW, et al. The role of computed tomography and magnetic resonance imaging in the diagnosis of pediatric thoracolumbar compression fractures. *J Pediatr Orthop*. 2019;39(7):e520-e523. doi:10.1097/BPO.0000000000001316
50. Charalampidis A, Jiang F, Wilson JRF, Badhiwala JH, Brodke DS, Fehlings MG. The use of intraoperative neurophysiological monitoring in spine surgery. *Global Spine J*. 2020;10(1 Suppl):104S-114S. doi:10.1177/2192568219859314
51. Hyun S-J, Rhim S-C. Combined motor and somatosensory evoked potential monitoring for intramedullary spinal cord tumor surgery: correlation of clinical and neurophysiological data in 17 consecutive procedures. *Br J Neurosurg*. 2009;23(4):393-400. doi:10.1080/02688690902964744
52. Park J-H, Hyun S-J. Intraoperative neurophysiological monitoring in spinal surgery. *World J Clin Cases*. 2015;3(9):765-773. doi:10.12998/wjcc.v3.i9.765
53. Bhagat S, Durst A, Grover H, et al. An evaluation of multimodal spinal cord monitoring in scoliosis surgery: a single centre experience of 354 operations. *Eur Spine J*. 2015;24(7):1399-1407. doi:10.1007/s00586-015-3766-8
54. Daniel JW, Botelho RV, Milano JB, et al. Intraoperative neurophysiological monitoring in spine surgery: a systematic review and meta-analysis. *Spine*. 2018;43(16):1154-1160. doi:10.1097/BRS.0000000000002575
55. Fehlings MG, Brodke DS, Norvell DC, Dettori JR. The evidence for intraoperative neurophysiological monitoring in spine surgery: does it make a difference? *Spine*. 2010;35(9 Suppl):S37-S46. doi:10.1097/BRS.0b013e3181d8338e
56. Traynelis VC, Abode-Iyamah KO, Leick KM, Bender SM, Greenlee JDW. Cervical decompression and reconstruction without intraoperative neurophysiological monitoring. *J Neurosurg Spine*. 2012;16(2):107-113. doi:10.3171/2011.10.SPINE11199
57. Biscevic M, Sehic A, Krupic F. Intraoperative neuromonitoring in spine deformity surgery: modalities, advantages, limitations, medicolegal issues—surgeons' views. *EFORT Open Rev*. 2020;5(1):9-16. doi:10.1302/2058-5241.5.180032
58. Laratta JL, Shillingford JN, Ha A, et al. Utilization of intraoperative neuromonitoring throughout the United States over a recent decade: an analysis of the nationwide inpatient sample. *J Spine Surg*. 2018;4(2):211-219. doi:10.21037/jss.2018.04.05
59. Elsamadicy AA, Adogwa O, Lydon E, et al. Impact of intraoperative monitoring during elective complex spinal fusions (≥4 Levels) on 30-day complication and readmission rates: a single-institutional study of 643 adult patients with spinal deformity. *World Neurosurg*. 2017;101:283-288. doi:10.1016/j.wneu.2017.02.002
60. Harel R, Schleifer D, Appel S, Attia M, Cohen ZR, Knoller N. Spinal intradural extramedullary tumors: the value of intraoperative neurophysiologic monitoring on surgical outcome. *Neurosurg Rev*. 2017;40(4):613-619. doi:10.1007/s10143-017-0815-2
61. Ajiboye RM, Zoller SD, Sharma A, et al. Intraoperative neuromonitoring for anterior cervical spine surgery: what is the evidence? *Spine*. 2017;42(6):385-393. doi:10.1097/BRS.0000000000001767
62. Ajiboye RM, D'Oro A, Ashana AO, et al. Routine use of intraoperative neuromonitoring during ACDFs for the treatment of spondylotic myelopathy and radiculopathy is questionable: a

review of 15,395 cases. *Spine*. 2017;42(1):14-19. doi:10.1097/BRS.0000000000001662

63. Badhiwala JH, Nassiri F, Witiw CD, et al. Investigating the utility of intraoperative neurophysiological monitoring for anterior cervical discectomy and fusion: analysis of over 140,000 cases from the National (Nationwide) Inpatient Sample data set. *J Neurosurg Spine*. 2019;31(1):76-86. doi:10.3171/2019.1.SPINE181110
64. Ney JP, Kessler DP. Neurophysiological monitoring during cervical spine surgeries: longitudinal costs and outcomes. *Clin Neurophysiol*. 2018;129(11):2245-2251. doi:10.1016/j.clinph.2018.08.002
65. Cole T, Veeravagu A, Zhang M, Li A, Ratliff JK. Intraoperative neuromonitoring in single-level spinal procedures: a retrospective propensity score-matched analysis in a National Longitudinal Database. *Spine*. 2014;39(23):1950-1959. doi:10.1097/BRS.0000000000000593
66. Ghobrial GM, Williams KA, Arnold P, Fehlings M, Harrop JS. Iatrogenic neurologic deficit after lumbar spine surgery: a review. *Clin Neurol Neurosurg*. 2015;139:76-80. doi:10.1016/j.clineuro.2015.08.022
67. Sala F, Dvorak J, Faccioli F. Cost effectiveness of multimodal intraoperative monitoring during spine surgery. *Eur Spine J*. 2007;16(Suppl 2):S229-S231. doi:10.1007/s00586-007-0420-0
68. Lall RR, Lall RR, Hauptman JS, et al. Intraoperative neurophysiological monitoring in spine surgery: indications, efficacy, and role of the preoperative checklist. *Neurosurg Focus*. 2012;33(5):E10. doi:10.3171/2012.9.FOCUS12235
69. James WS, Rughani AI, Dumont TM. A socioeconomic analysis of intraoperative neurophysiological monitoring during spine surgery: national use, regional variation, and patient outcomes. *Neurosurg Focus*. 2014;37(5):E10. doi:10.3171/2014.8.FOCUS14449
70. Zhu MP, Tetreault LA, Sorefan-Mangou F, Garwood P, Wilson JR. Efficacy, safety, and economics of bracing after spine surgery: a systematic review of the literature. *Spine J*. 2018;18(9):1513-1525. doi:10.1016/j.spinee.2018.01.011
71. Agabegi SS, Asghar FA, Herkowitz HN. Spinal orthoses. *J Am Acad Orthop Surg*. 2010;18(11):657-667. doi:10.5435/00124635-201011000-00003
72. Campbell MJ, Carreon LY, Traynelis V, Anderson PA. Use of cervical collar after single-level anterior cervical fusion with plate: is it necessary? *Spine*. 2009;34(1):43-48. doi:10.1097/BRS.0b013e318191895d
73. Connolly PJ, Grob D. Bracing of patients after fusion for degenerative problems of the lumbar spine—yes or no? *Spine*. 1998;23(12):1426-1428. doi:10.1097/00007632-199806150-00024
74. Soliman HAG, Barchi S, Parent S, Maurais G, Jodoin A, Mac-Thiong J-M. Early impact of postoperative bracing on pain and quality of life after posterior instrumented fusion for lumbar degenerative conditions: a randomized trial. *Spine*. 2018;43(3):155-160. doi:10.1097/BRS.0000000000002292
75. Daniel R. Levinson. Executive Summary: Medicare supplier acquisition costs for L0631 Back Orthoses. Report (OEI-03-11-00600). Published online December 18, 2012. https://oig.hhs.gov/oei/reports/oei-03-11-00600.pdf
76. Piazza M, Sinha S, Agarwal P, et al. Post-operative bracing after pedicle screw fixation for thoracolumbar burst fractures: a cost-effectiveness study. *J Clin Neurosci*. 2017;45:33-39. doi:10.1016/j.jocn.2017.07.038
77. Horodyski M, DiPaola CP, Conrad BP, Rechtine GR. Cervical collars are insufficient for immobilizing an unstable cervical spine injury. *J Emerg Med*. 2011;41(5):513-519. doi:10.1016/j.jemermed.2011.02.001
78. Morris CGT, McCoy E. Cervical immobilisation collars in ICU: friend or foe? *Anaesthesia*. 2003;58(11):1051-1053. doi:10.1046/j.1365-2044.2003.03519.x
79. Plumb JOM, Morris CG. Cervical collars: probably useless; definitely cause harm! *J Emerg Med*. 2013;44(1):e143. doi:10.1016/j.jemermed.2012.05.031
80. Garber AM, Phelps CE. Economic foundations of cost-effectiveness analysis. *J Health Econ*. 1997;16(1):1-31. doi:10.1016/s0167-6296(96)00506-1
81. Abjornson C, Brecevich A, Callanan T, Dowe C, Cammisa FP, Lorio MP. ISASS recommendations and coverage criteria for bone graft substitutes used in spinal surgery. *Int J Spine Surg*. 2018;12(6):757-771. doi:10.14444/5095
82. Hsu WK, Hashimoto RE, Berven SH, Nassr A. Biological substitutes/extenders for spinal arthrodesis: which agents are cost-effective? *Spine*. 2014;39(22 Suppl 1):S86-S98. doi:10.1097/BRS.0000000000000548
83. Carreon LY, Glassman SD, Djurasovic M, et al. RhBMP-2 versus iliac crest bone graft for lumbar spine fusion in patients over 60 years of age: a cost-utility study. *Spine*. 2009;34(3):238-243. doi:10.1097/BRS.0b013e31818ffabe
84. Angevine PD, Zivin JG, McCormick PC. Cost-effectiveness of single-level anterior cervical discectomy and fusion for cervical spondylosis. *Spine*. 2005;30(17):1989-1997. doi:10.1097/01.brs.0000176332.67849.ea
85. Fiani B, Quadri SA, Farooqui M, et al. Impact of robot-assisted spine surgery on health care quality and neurosurgical economics: a systemic review. *Neurosurg Rev*. 2020;43(1):17-25. doi:10.1007/s10143-018-0971-z
86. Joseph JR, Smith BW, Liu X, Park P. Current applications of robotics in spine surgery: a systematic review of the literature. *Neurosurg Focus*. 2017;42(5):E2. doi:10.3171/2017.2.FOCUS16544
87. D'Souza M, Gendreau J, Feng A, Kim LH, Ho AL, Veeravagu A. Robotic-assisted spine surgery: history, efficacy, cost, and future trends. *Robot Surg*. 2019;6:9-23. doi:10.2147/RSRR.S190720
88. Menger RP, Savardekar AR, Farokhi F, Sin A. A cost-effectiveness analysis of the integration of robotic spine technology in spine surgery. *Neurospine*. 2018;15(3):216-224. doi:10.14245/ns.1836082.041
89. 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(6):880-891. doi:10.4184/asj.2017.11.6.880
90. Ashley B, Spiegel DA, Cahill P, Talwar D, Baldwin KD. Post-operative fever in orthopaedic surgery: how effective is the 'fever workup?' *J Orthop Surg*. 2017;25(3). doi:10.1177/2309499017727953