Current Reviews in Musculoskeletal Medicine (2023) 16:39–47
https://doi.org/10.1007/s12178-022-09814-y

UPDATES IN SPINE SURGERY - TECHNIQUES, BIOLOGICS, AND NON-OPERATIVE MANAGEMENT (W HSU, SECTION EDITOR)

The Effect of Diabetes and Metabolic Syndrome on Spine Surgery Outcomes

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Accepted: 14 November 2022 / Published online: 28 December 2022

Abstract

Purpose of Review Diabetes and metabolic syndrome are highly prevalent in patients undergoing spine surgery. This review aims to capture both the findings of recently published literature investigating the effects of diabetes and metabolic syndrome on spine surgery outcomes and the current best practices in patient management.

Recent Findings Diabetes and metabolic syndrome both contribute to worse outcomes in patients undergoing spine surgery. Although patients with diabetes are at greater risk of complications, those with uncontrolled diabetes experience increased healthcare costs and greater odds of postoperative complications. Furthermore, metabolic syndrome is repeatedly shown to have an adverse effect on spine surgery outcomes, including healthcare costs and medical complications.

Summary Spine surgeons should coordinate care with primary care physicians to optimize the preoperative profile of patients with comorbidities like diabetes and metabolic syndrome to minimize operative risk. With the shift to value-based care, understanding the patient factors that lead to complications is becoming increasingly important. Future studies should build upon the current literature and design preoperative interventions for at-risk patients. Additionally, further research is needed to analyze the modulatory effects of the social determinants of health in patients with diabetes and metabolic syndrome.

Keywords Metabolic syndrome · Diabetes · Spine surgery · Surgical outcomes · Uncontrolled diabetes · Spine complications

Introduction

Diabetes mellitus (DM) and metabolic syndrome (MS) pose major public health concerns, with an estimated 463 million adults worldwide diagnosed with DM [1]. Domestically, nearly 35% of the adult population meet the criteria for MS [2]. MS and DM are especially common in older populations with 46.7% of elderly patients meeting criteria for MS and 20.5% of elderly patients diagnosed with DM [3, 4]. Elderly individuals also comprise a large percentage of patients presenting with spine pathologies [5].

DM has significant consequences ranging from microvascular complications, such as diabetic retinopathy, to increased mortality [6]. Unsurprisingly, both conditions compromise surgical outcomes, resulting in increased risk of perioperative complications, postoperative utilization of healthcare services, and greater costs [7, 8]. Considering the aforementioned factors, this article aims to review the existing literature regarding the effects of DM and MS on spine surgery outcomes.

Diabetes Mellitus Pathophysiology

DM is primarily caused by beta cell abnormalities in the pancreas which lead to insulin resistance and impaired glucose tolerance [9]. The etiology is thought to be multifactorial, composed of genetic and environmental factors [9]. Prior literature reports that 10–20% of hospitalized orthopaedic patients have diabetes [10]. The long-term sequela of DM such as peripheral artery disease, neuropathy, and renal disease are known risk factors for adverse outcomes after orthopaedic surgery [8]. Additionally, uncontrolled diabetes has been

This article is part of the Topical Collection on *Updates in Spine Surgery - Techniques, Biologics, and Non-Operative Management*

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shown to have deleterious effects on bone, ligament, soft tissue, and tendon healing [8]. In light of this, it is important to establish the effects of DM on medical complications and healthcare costs in spine surgery settings.

The Impact of Diabetes on Spine Surgery Outcomes

Lumbar fusion is increasingly utilized to treat degenerative spine disease. However, there are significant risks for diabetics undergoing lumbar fusion. A prospective study by Moazzeni et al. evaluated the impact of DM on complications and fusion rates (Table 1) [11]. The study groups were each comprised of 48 subjects: group 1 included diabetic patients and group 2 included age-and-sex matched controls. Primary outcomes included: a Persian version of the Oswestry Disability Index (ODI), the Visual Analog Scale for Pain (VAS), and fusion rates at 1-year post-operation. Fusion rates in the diabetic group were significantly lower (53% vs. 78%; $p = 0.02$). The ODI and VAS pre-operatively (ODI: $p < 0.001$, VAS: $p = 0.002$) and at 2 weeks post-operation (ODI: $p < 0.001$, VAS: $p = 0.003$) were significantly higher in the diabetic group than the control group. However, only the ODI was significantly higher in the diabetic group at 6- and 12-months post-operation ($p < 0.001$, $p = 0.002$ respectively). In addition to this, Peng et al. conducted a meta-analysis using 24 studies, finding a higher rate of surgical site infections (SSI) in patients with diabetes compared to those without (OR: 3.13, 95% CI 2.01–4.87) [12•]. These studies indicate that patients with diabetes undergoing spine surgery are at higher risk of fusion failure, SSIs and higher pain levels both before and after surgery.

The American Diabetes Association (ADA) has defined uncontrolled DM as having an HbA1c level of > 7%; however, database studies tend to use ICD codes in lieu of lab value-based diagnosis of uncontrolled DM [13]. Understanding the difference in rates of SSI, medical complications, and length of stay between uncontrolled and controlled DM cohorts is crucial to patient care because it may allow for more personalized preoperative risk stratification.

SSIs pose a significant burden to patients. Hikata et al. conducted a retrospective cohort study comparing the rate of SSI in patients with controlled and uncontrolled DM who underwent elective posterior instrumented thoracic and lumbar spinal arthrodesis [14]. Three-hundred forty-five patients were identified, 36 of which had DM. In the DM group, 19 patients had controlled DM (HbA1c < 7%) and 17 had uncontrolled DM (HbA1c ≥ 7%). The SSI rate was significantly lower in non-DM patients than DM patients (3.2% vs

Table 1 Spine surgery outcomes in patients with diabetes

Author	Year	Sample Description	Findings
Moazzeni et al.	2018	*N*=96 Lumbar fusion patients with (*n*=48) and without (*n*=48) DM	DM patients are at increased risk for worsened postoperative patient-reported outcomes and lower fusion rates
Peng et al.	2019	*N*=40,068 Spine surgery patients from 24 different studies	Meta-analysis revealed higher rate of SSI in patients with DM
Hikata et al.	2014	*N*=345 Posterior thoracic and lumbar fusion patients with DM (*n*=36; 19 controlled, 17 uncontrolled) and without DM (*n*=309)	DM patients are at increased risk for SSI and patients with uncontrolled DM are at increased risk for SSI compared to controlled DM
Guzman et al.	2014	*N*=2,568,994 Degenerative lumbar spine surgery patients with DM (*n*=423,050; 403,629 controlled, 19,421 uncontrolled) and without DM (*n*=2,145,944)	DM patients are at increased risk of medical complications and extended LOS. Uncontrolled DM was an independent predictor of inpatient mortality and associated with greater costs
Guzman et al.	2014	*N*=1,602,145 Degenerative cervical spine surgery patients with DM (*n*=223,908; 213,360 controlled, 10,548 uncontrolled) and without DM (*n*=1,378,237)	DM patients are at increased risk for medical complications and extended LOS. DM was associated with increased healthcare expenditure
Zhuang et al.	2021	*N*=46,490 DM Patients Controlled DM (*n*=42,664) Uncontrolled DM (*n*=3,826)	Compared to controlled DM, uncontrolled DM is at higher risk of deep and superficial SSI, post-operative medical complications, and increased healthcare costs
Phan et al.	2017	*N*=3,725 ACDF patients with DM (*n*=441; 270 NIDDM, 171 IDDM) and without DM (*n*=3,284)	IDDM patients had increased rate of medical complications, unplanned reoperations, and unplanned readmission. NIDDM patients had increased risk of medical complications and unplanned reoperations
Qin et al.	2016	*N*=51,277 Lumbar spine surgery patients with DM (*n*=7,869; 5,360 NIDDM, 2,509 IDDM) and without DM (*n*=43,408)	NIDDM and IDDM independently increased the risk of medical complications. IDDM was independently associated with extended LOS and unplanned readmission
Cancienne et al.	2017	*N*= 5194 Patients with DM undergoing single-level lumbar decompression	ROC analysis revealed a HbA1c threshold of 7.5% predictive for post-operative deep infection
Harrop et al.	2021	Systematic review of 5 articles	Strength B Recommendation to counsel patients with HbA1c > 7.5% before surgery on increased operative risk

16.7%, $p = 0.0005$). When sub-stratifying, patients with uncontrolled DM had significantly higher SSI rates than controlled DM (35.3% vs 0%, $p = 0.0006$). Although these findings are limited by a small sample size, it demonstrates the importance of perioperative glycemic control to optimize outcomes in patients undergoing spine surgery.

A retrospective study by Guzman et al. analyzed 2.5 million surgeries in the Nationwide Inpatient Sample (NIS) Database comparing outcomes in patients with controlled, uncontrolled, or without DM undergoing elective degenerative lumbar spine surgery [15]. Compared to the nondiabetic cohort, those with uncontrolled DM had greater odds of respiratory complications, cardiac complications, deep vein thrombosis (DVT), genitourinary complications, SSI, and shock (all $p < 0.0001$). Patients with uncontrolled DM also underwent more revision fusion procedures ($p < 0.0001$). Similarly, compared to nondiabetic patients, those with controlled DM had greater odds of respiratory complications, cardiac complications, DVT, genitourinary complications, and SSI [all $p < 0.0001$]. Patients with uncontrolled DM (6.0 days) and controlled DM (4.1 days) had greater average length of stay (LOS) than nondiabetic patients, who had an average LOS of 3.7 days ($p < 0.0001$). The uncontrolled DM cohort had greater healthcare costs than nondiabetic patients ($26,476 vs $21,250, $p < 0.0001$); however, those with controlled DM had lower healthcare costs than nondiabetics ($20,806, $p < 0.0001$) which could be explained by imprecise ICD coding. Uncontrolled diabetes was an independent predictor of inpatient mortality when compared with non-diabetics [OR: 2.31, 95% CI 1.20–4.30, $p = 0.009$] whereas controlled diabetes was not [OR: 1.10, 95% CI 0.92–1.40, $p = 0.250$].

A second study by Guzman et al. similarly analyzed 1.6 million patients in the NIS database to compare patient outcomes following elective degenerative cervical spine surgery [16]. Compared to nondiabetics, patients with uncontrolled DM had greater odds of respiratory complications, cardiac, DVT, genitourinary complications, pulmonary embolism (PE), postoperative infection, post-operative hemorrhage, and inpatient mortality (all $p < 0.0001$). Similarly, patients with controlled DM had greater odds of respiratory complications, cardiac complications, DVT, genitourinary complications, PE, postoperative infection, post-operative hemorrhage, and inpatient mortality than the nondiabetic cohort (all $p < 0.0001$). Patients with controlled DM had significantly higher healthcare costs ($16,622 vs $14,163; $p < 0.0001$) and LOS (3.2 days vs 2.4 days, $p < 0.0001$) than those in the nondiabetic cohort. Similarly, those with uncontrolled DM had even greater costs ($25,166 vs $14,163, $p < 0.0001$) and LOS (7.0 days vs 2.4 days, $p < 0.0001$) compared to those in the non-DM cohort.

A retrospective analysis by Zhuang et al. utilizing the PearlDiver Patient Records Database investigated the effect of glycemic control on outcomes after posterior lumbar fusion with instrumentation [17]. A total of 46,490 diabetic patients were included, with 42,664 (91.8%) having controlled DM and 3,826 (8.3%) having uncontrolled DM. The primary endpoint was SSI within 90 days, which was identified using ICD coding. Controlled and uncontrolled DM cohorts were divided by ICD-9 codes, which the authors argue is a comprehensive assessment of glycemic control encompassing multiple patient-related factors. When compared to the controlled DM cohort, those with uncontrolled DM had significantly greater odds of postoperative complications including deep SSI, superficial SSI, cerebrovascular event, acute kidney injury, PE, pneumonia, urinary tract infection (UTI), and transfusion ($p < 0.001$ to 0.03). The uncontrolled DM cohort also had higher healthcare costs ($27,915 vs $10,263; $p < 0.001$) than those with controlled DM.

Overall, multiple large studies show that patients with both controlled and uncontrolled DM have greater odds of adverse outcomes, both medically and financially, when compared to those without DM. In addition, patients with uncontrolled DM are at greater odds of postoperative complications compared to patients with controlled DM. These findings underscore the significance of improving glycemic control in the preoperative setting.

The criteria for determining glycemic control in patients with DM is inconsistent in the literature, with some studies using ICD codes and others HbA1c thresholds [15]. A strength of using HbA1c is that researchers can further divide patients with uncontrolled DM and investigate changes in complication risk as HbA1c increases [15]. Conversely, some authors argue that using ICD codes provides a multifaceted approach to categorizing a patient into an uncontrolled DM cohort [17]. The primary argument being that ICD codes incorporate HbA1c levels, medical comorbidities related to DM, and self-monitoring of glucose levels providing a nuanced approach to assessing glycemic control [17].

The Impact of Insulin Dependence in Patients with Diabetes

Patients with either insulin dependent diabetes mellitus (IDDM) or non-insulin dependent diabetes mellitus (NIDDM) are at increased risk of complications following spine surgery. Phan et al. conducted a retrospective analysis utilizing the ACS-NSQIP (American College of Surgeons-National Surgical Quality Improvement Program) database comparing short-term surgical outcomes following anterior cervical discectomy and fusion (ACDF) in patients with NIDDM, IDDM, and nondiabetics [18]. A total of 3725 patients were identified, with 3,284 nondiabetics, 270 patients with NIDDM, and 171 with IDDM. A univariate analysis compared IDDM patients to nondiabetics and found that the IDDM cohort had statistically significant increases in rates of sepsis (0.6% vs 0.06%, $p = 0.023$), unplanned reoperations within 30 days (3.5% vs 1.1%, $p = 0.046$), readmissions

within 30 days (7.6% vs 2.5%, $p < 0.0001$), and prolonged LOS (>5 days) (9.9% vs 5.2%, $p < 0.0001$). Multivariate analysis showed that IDDM was an independent predictor of unplanned 30-day readmissions [OR: 4.80, 95% CI 2.3–10.1, $p < 0.0001$]; however, it was not identified as a predictor of unplanned reoperations or LOS >5 days. Compared to nondiabetics, those in the NIDDM cohort experienced increased rates of UTI (1.9% vs 0.5%, $p = 0.007$), graft failure (0.4% vs 0%, $p = 0.001$), and reoperation (3.7% vs 1.6%, $p = 0.012$). Multivariate regression showed that NIDDM was not an independent predictor of reoperation within 30 days. In all, both NIDDM and IDDM were associated with increased complication rates, emphasizing the need for appropriate risk stratification and patient education, along with the importance of peri-operative glucose optimization to better outcomes.

Another retrospective ACS-NSQIP study by Qin et al. evaluated the effects of insulin dependence on patients undergoing lumbar spine surgery [19]. The study grouped patients as having NIDDM, IDDM, and no DM, including a total of 51,227 patients. Both the NIDDM (OR: 1.431, 95% CI 1.179–1.737, $p < 0.001$) and IDDM (OR: 3.41, 95% CI 2.82–4.124, $p < 0.001$) cohorts had longer lengths of stay compared to the nondiabetic cohort. Both NIDDM (OR: 1.226, $p = 0.017$) and IDDM (OR: 1.499, $p < 0.0001$) cohorts had increased risk for medical complications. The odds of readmission within 30 days were greater in patients with IDDM (OR: 1.353, $p = 0.005$), but was not significant in NIDDM patients. The authors found significantly different rates of SSIs between the nondiabetic, NIDDM, and IDDM cohorts (1.6%, 2.3%, 4.1%, respectively; $p < 0.001$). The ACS-NSQIP database is limited in that it does not stratify patients based on diagnosis of Type 1 or Type 2 DM, but rather whether an individual was insulin dependent. Therefore, patients with severe Type 2 DM can be categorized as IDDM when refractory to oral medicine, introducing heterogeneity into the IDDM cohort [19].

Summary of Current Perioperative Guidelines for Diabetes

Shared decision-making strategies between patient and provider are crucial for managing glycemic control and patient expectations in the preoperative setting. Several guidelines recommend maintaining HbA1c levels no greater than 8–9% for elective orthopaedic surgical interventions [20]. In a recent study performed by Cancienne et al. regarding complications after single-level lumbar decompression, the results showed that patients with HbA1c levels greater than 7.5% were at significantly greater risk for deep post-operative infections [21]. These data are corroborated by a meta-analysis performed by Harrop et al., showing significantly increased risk of infection and reoperation in patients with an HbA1c level over 7.5% [22]. Therefore, an HbA1c of 7.5% seems be an optimal threshold for patients pursuing elective spine surgery.

It is imperative that surgeons work synergistically with primary care providers to optimize pre-operative glucose levels. Given the movement towards value-based care, minimizing complications and healthcare costs to patients is increasingly important. The American Diabetes Association Standards of Medical Care advises an overarching perioperative glucose level of 80–180 mg/dL [23]. The ADA recommends assessing glycemic control in those with controlled DM at least twice a year [24•]. Patients having difficulties with glycemic control should be checked quarterly [24•]. Interventions targeting improved peri-operative management of DM, both through pharmacologic and lifestyle modifications, can better surgical outcomes.

Metabolic Syndrome: Etiology and Surgical Implications

MS encompasses various diseases that increase the likelihood of atherosclerotic cardiovascular disorders, DM, and stroke [25]. MS is diagnosed with the presence of at least three of the following criteria: an increased waist circumference, hyperglycemia, hypertriglyceridemia, low levels of high-density lipoprotein cholesterol (HDL), and hypertension [26–28]. The criterion for MS are outlined in Table 2. Existing literature defines MS as a risk factor for increased mortality and perioperative complications, including cardiovascular events, stroke, coma, renal failure, and infection [7]. Consequently, patients with MS are more likely to experience longer LOS and higher morbidity.

In orthopaedic surgery, MS has been associated with increased morbidity across a variety of procedures: shoulder, hip, and knee arthroplasty as well as traumatic fracture fixation [29–35]. Comorbid obesity in MS patients increases mechanical load on joints, accelerating the development of osteoarthritis [36]. In spine surgery, MS has been associated with an increased likelihood of perioperative complications and greater costs [37]. Considering the aforementioned factors, it is important for spine surgeons to understand the risk of MS on medical complications, LOS, and degenerative spine disease.

Metabolic Syndrome and Spine Surgery Outcomes

A retrospective study by Memtsoudis et al. investigated the effect of MS on surgical outcomes after primary posterior lumbar spine fusion (PSF) in over 200,000 patients using the NIS dataset (Table 3) [38]. The authors found that the incidence of MS in patients undergoing PSF tripled between 2000–2002 and 2006–2008. Having MS increased the likelihood of postoperative complications ($p < 0.0001$), prolonged

Table 2 Metabolic syndrome diagnostic criterion

Criteria	Definition
Increased Waist Circumference	>40 inches for men
	>35 inches for women
Hyperglycemia	≥110 mg/dL
Hypertriglyceridemia	≥150 mg/dL
Low HDL	<40 mg/dL for men
	<50 mg/dL for women
Hypertension	≥130/85 mmHg

LOS ($p < 0.0001$), and greater costs ($p < 0.0001$) compared to patients without MS. Similarly, a recent retrospective study by He et al. investigated perioperative outcomes in patients undergoing posterior lumbar interbody fusions [37]. The study identified 2,880 patients, 360 (12.5%) of which had MS. The authors found that patients with MS had an increased risk of cardiac complications ($p = 0.019$), pulmonary complications ($p = 0.035$), cerebrovascular events ($p = 0.023$), urinary tract infections ($p = 0.018$), pneumonia ($p = 0.026$), postoperative ICU admissions ($p = 0.02$), and DVT ($p = 0.029$). Patients with MS had a longer LOS ($p < 0.001$). Two multivariate logistic regressions were performed, with composite endpoints being ≥1 perioperative complications and extended LOS (defined as ≥75th percentile). These models found that patients with MS were more likely to have both perioperative complications (OR: 1.31, 95% CI 1.06–2.07, $p < 0.001$) and extended LOS (OR: 1.69, 95% CI 1.25–2.28, $p = 0.001$).

Using data from the ACS-NSQIP database, Chung et al. investigated 30-day outcomes in patients with MS undergoing elective lumbar spinal fusion [39]. Due to limitations in this dataset, MS was defined as the combination of hypertension managed with medication, obesity (BMI ≥30 kg/m^2), and DM. ACS-NSQIP did not contain diagnoses of dyslipidemia. Univariate analysis showed that MS patients had increased risk of both major and minor complications (5.9% vs. 4.7%, $p = 0.040$; 22.1% vs. 19.0%, $p = 0.003$). Specifically, MS was associated with a greater occurrence of pulmonary complications (1.9% vs. 1.0%; $p = 0.001$), acute renal failure (0.4% vs. 0%; $p < 0.001$), and sepsis (1.7% vs. 0.9%; $p = 0.005$). A multivariate logistic regression confirmed that patients with MS were more likely to have these three specific complications. Interestingly, MS was not associated with an increased likelihood of reoperation or readmission.

Another retrospective study by Ye et al. similarly examined 30-day outcomes in MS patients, focusing on patients undergoing corrective surgery for adult spinal deformity (ASD) [40]. Of the 6,696 patients identified, a total of 553 patients (8.3%) met criteria for MS, which was defined as the combination of diabetes, obesity, and hypertension. Multivariate regression analysis identified MS as an independent risk factor for cardiac complications (OR: 4.2, 95% CI 1.7–10.2, $p = 0.001$), pulmonary complications (OR: 1.7, 95% CI 1.1–2.5; $p = 0.017$), sepsis (OR: 2.2; 95% CI 1.2–3.9; $p = 0.009$), superficial SSI (OR: 2.8, 95% CI 1.4–5.7, $p = 0.004$), reoperation (OR: 1.7, 95% CI 1.2–2.5, $p = 0.006$), and increased LOS (OR: 1.4, 95% CI 1.0–1.9, $p = 0.039$).

Table 3 Spine surgery outcomes in patients with metabolic syndrome

Author	Year	Sample description	Findings
Memtsoudis et al.	2012	*N*=238,296 Posterior lumbar fusion patients with (*n*=12,949)and without (*n*=225,347) MS	MS patients are at increased risk for postoperative complications, prolonged LOS, and greater costs
He et al.	2020	*N*=2,880 Posterior lumbar fusion patients with (*n*=360) and without (*n*=2520) MS	MS patients are at increased risk for medical complications, ICU admission, and prolonged LOS
Chung et al.	2018	*N*=15,588 Posterior lumbar fusion patients with (*n*=1,590) and without (*n*=13,998) MS	MS patients are at increased risk for pulmonary complications, acute renal failure, and sepsis
Ye et al.	2020	*N*=6,696 Patients with (*n*=553) and without (*n*=6,143) MS undergoing adult spinal deformity correction procedures	MS is an independent risk factor for sepsis, superficial SSI, reoperation, prolonged LOS, and medical complications
Malik et al.	2019	*N*= 15,735 Patients with (*n*=1,384) and without (*n*=14,351) MS undergoing ACDF procedures	MS patients have greater odds of extended LOS, though no significant associations found between MS and complication rates
Lovecchio et al.	2018	*N*=18,605 Patients with (*n*= 1903) and without (*n*= 16,702) MS undergoing 1 to 3 level posterior lumbar fusion procedures	MS patients associated with greater odds for postoperative UTI, prolonged LOS, and readmission. MS patients associated with greater odds for wound complications, prolonged LOS, and readmission compared to obesity-only cohort.
Passias et al.	2020	*N*=312 Cost comparison of cervical, thoracic, and lumbar spinal fusion procedures in patients with (*n*=156) and without (*n*=156) MS.	Patients with MS have higher healthcare costs in spinal fusion procedures
Gandhi et al.	2014	*N*=1,502 Occurrence rates of osteoarthritis in patients with (*n*=30) and without (*n*=1,472) MS.	Accumulation of MetS risk factors increases the odds of severe spine osteoarthritis

Additionally, an analysis by Malik et al. studied 30-day outcomes in 15,735 patients in the ACS-NSQIP database undergoing elective ACDF, of which 1,384 met the criteria for MS [31]. MS was associated with greater odds of an extended LOS ≥3 days (OR: 1.32, 95% CI 1.12–1.56, $p = 0.001$). However, in contrast to Chung et al. and Ye et al., there were no significant associations between MS and medical complications.

Metabolic Syndrome Is Distinct from Obesity

The criteria for MS includes obesity, hyperglycemia, dyslipidemia, and hypertension [26–28]. A major confounder in determining whether MS is independently associated with postoperative complications is obesity, which is individually linked to poor surgical outcomes [41•]. However, recent literature shows that MS exerts a distinct effect separately from obesity.

A recent propensity score-matched analysis studied the confounding effect of obesity in a cohort of patients from the ACS-NSQIP database ($N = 18,605$) undergoing 1 to 3 level posterior lumbar fusions [42]. One-to-one matching was used to match patients using demographic information, medical comorbidities, and surgical factors. The overall incidence of medical complications was similar between patients with and without MS. However, after logistic regression, patients with MS had significantly greater odds of postoperative UTI (OR: 1.9, 95% CI 1.2–3.0, $p < 0.001$). Patients with MS were also more likely to have a prolonged LOS (>5 days) (OR: 1.34, 95% CI 1.2–1.6, $p < 0.001$) and readmission (OR: 1.48, 95% CI 1.22–1.80, $p < 0.001$). A second propensity score algorithm matched individuals with MS to an obese-only cohort. When compared with obese controls, patients with MS experienced more frequent wound complications (3.8% vs 2.7%; $p = 0.045$), prolonged postoperative stays (29.1% vs 23.9%; $p < 0.001$), and readmissions (7.4% vs 4.6%; $p < 0.001$). Medical complication rates, however, were similar between MS and obese-only patients. This study suggests that MS should be treated as a distinct, independent risk factor for adverse outcomes in patients undergoing surgery. To our knowledge, a similar study examining MS apart from DM does not exist, leaving open a crucial question for future investigations.

Effects of Metabolic Syndrome on Healthcare Costs

MS has negative effects on costs-of-care across medicine [43]. A propensity score-matched study by Passias et al. evaluated the effects of MS on the costs of cervical, thoracic, and lumbar spinal fusions [44]. The study included 312 surgeries matched by approach, with 70% being posterior approaches, 17% anterior, and 13% combined. Patients in the MS cohort experienced higher average surgical costs than those without ($60,579.30 vs $52,053.23; $p < 0.05$). When stratified by fusion location, MS patients had higher costs in cervical ($23,203.43 vs. $19,153.43; $p < 0.05$) and thoracic ($75,230.05 vs. $65,746.16; $p < 0.05$) fusion procedures. Interestingly, patients with MS had lower costs when undergoing lumbar surgery ($31,775.64 vs. $42,643.37, $p < 0.05$), which was speculated by the authors to be the result of a smaller sample size. Cost-utility was measured by quality-adjusted life-year (QALY) [45]. In this study, the average cost per QALY at one year was greater in MS patients ($639,069.32 vs $425,840.30; $p < 0.05$). Considering life expectancy, the cost per QALY in MS patients was $45,456.83, compared with $26,026.84 in non-MS patients ($p < 0.05$) [44].

Similarly, a study by Memtsoudis et al. analyzed 238,296 patients undergoing posterior lumbar fusion [38]. Patients with MS were found to have greater surgical costs when compared with patients without MS ($23,215 versus $21,739, $p < 0.0001$). The authors noted that they were unable to measure excess cost due to the non-routine discharge disposition in patients with MS, which may have skewed the analysis.

Metabolic Syndrome and Osteoarthritis

MS has been linked to an increased prevalence of osteoarthritis, including osteoarthritis of the spine [38]. Gandhi et al. investigated the greater occurrence of osteoarthritis in patients with MS through a retrospective review of data from 1,502 patients treated in a single surgeon, high volume, tertiary spine practice between 2002 and 2007 [46]. MS was characterized by having a BMI ≥30 kg/m^2, self-reported diabetes, hypertension, and hypercholesterolemia. A total of 30 patients (2.0%) had MS. Severe spinal osteoarthritis was defined as degenerative spondylolisthesis, cervical stenosis, or lumbar stenosis causing neurological symptoms. Early osteoarthritis was defined as lumbar and cervical spondylosis causing only axial pain. Severe osteoarthritis was found in 839 individuals (55.9%), with early osteoarthritis being noted in the remaining 663 patients (44.1%). Analysis showed increased odds of severe spine OA with incrementally greater number of MS risk factors. When adjusted for age and sex, patients with all MS risk factors had significantly greater odds of severe spine osteoarthritis compared to those without risk factors (OR: 3.9; 95% CI 1.4–11.6; $p < 0.01$). Overall, the accumulation of MS risk factors increased the odds of severe spine osteoarthritis.

Managing Metabolic Syndrome in Spine Surgery

Patients with MS undergoing spine surgery present with unique surgical profiles and are at an increased risk for complications. Surgeons should be mindful of this, being careful to select patients who are likely to have optimal outcomes.

Since patients with MS are more likely to experience wound complications, they may benefit from the use of minimally invasive approaches, with further research needed to evaluate differences in clinical outcomes [47]. Staged approaches to surgery and shortened procedure times may also benefit patients with MS to reduce demand. Assessing and optimizing patients' pre-operative risk, such as glucose levels, HbA1c, and BMI can minimize perioperative complications [48]. Given that MS is heavily influenced by lifestyle, targeted modifications may improve patient outcomes. Future research should pinpoint strategies for improving overall fitness in patients with MS prior to undergoing elective surgery.

Conclusions

It is important for spine surgeons to be aware of the relationship between MS and DM along with their association with adverse outcomes. Personalized patient education regarding the risks of undergoing surgery should be discussed based on past medical history. Future investigations should study MS independently from DM and assess the influence of social determinants of health on the previously discussed outcomes. Additionally, further research should be performed to better contextualize early findings suggesting that metabolic syndrome affects outcomes independently of obesity. Given the increasing prevalence of DM and MS, it is imperative that clinicians minimize adverse outcomes by optimizing comorbidities and understanding the operative risk for each individual patient.

Declarations

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

Conflict of Interest Anitesh Bajaj, Rohan M. Shah, Hogan Brecount, Steven Kurapaty, Alpesh A. Patel, and Srikanth N. Divi declare that they have no conflicts of interest.

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