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Research paper

The influence of modifiable risk factors on short-term postoperative outcomes following cervical spine surgery: A retrospective propensity score matched analysis

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A B S T R A C T

Background: Modifiable risk factors (MRFs) represent patient variables associated with increased complication rates that may be prevented. There exists a paucity of studies that comprehensively analyze MRF subgroups and their independent association with postoperative complications in patients undergoing cervical spine surgery. Therefore, the purpose of this study is to compare outcomes between patients receiving cervical spine surgery with reported MRFs.
Methods: Retrospective analysis of the Nationwide Readmissions Database (NRD) from the years 2016 and 2017, a publicly available and purchasable data source, to include adult patients undergoing cervical fusion. MRF cohorts were separated into three categories: substance abuse (alcohol, tobacco/nicotine, opioid abuse); vascular disease (hypertension, dyslipidemia); and dietary factors (malnutrition, obesity). Three-way nearest-neighbor propensity score matching for demographics, hospital, and surgical characteristics was implemented.
Findings: We identified 9601 with dietary MRFs (D-MRF), 9654 with substance abuse MRFs (SA-MRF), and 9503 with vascular MRFs (V-MRF). Those with D-MRFs had significantly higher rates of medical complications (9.3%), surgical complications (8.1%), and higher adjusted hospital costs compared to patients with SA-MRFs and V-MRFs. Patients with D-MRFs (16.3%) and V-MRFs (14.0%) were independently non-routinely discharged at a significantly higher rate compared to patients with SA-MRFs (12.6%) (p<0.0001 and p = 0.0037). However, those with substance abuse had the highest readmission rate and were more commonly readmitted for delayed procedure-related infections.
Interpretation: A large proportion of patients who receive cervical spine surgery have potential MRFs that uniquely influence their postoperative outcomes. A thorough understanding of patient-specific MRF subgroups allows for improved preoperative risk stratification, tailored patient counseling, and postoperative management planning.
Funding: None

Introduction

Risk factors represent a set of patient conditions that are correlated with the development of undesirable disease states. Within spine surgery in general, identification of risk factors has become a popular topic of contemporary research due to increased interest in reduction of postoperative complications and optimization of outcomes following surgery [1–5]. However, there exists a paucity of studies that evaluate the individualized influence of modifiable risk factors (MRFs), defined as risk factors that may be mitigated through patient lifestyle and diet changes, on outcomes following cervical spine fusion surgery.

As such, a more comprehensive understanding of the influence of MRFs may be particularly important within cervical spine fusion

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Research In Context

Evidence before this study

Many studies have investigated the influence of individual modifiable risk factors (MRFs) on outcomes in spine surgery. However, there exists a paucity of studies that comprehensively analyze MRF subgroups and their independent association with postoperative complications in patients undergoing cervical spine surgery. Several of these limitations have previously stemmed from computational resources and limited patient numbers. By using a contemporary nationally-representative US inpatient database, we were able to query almost 30,000 patients and analyze the risks of various MRF subgroups within this surgical cohort.

Added value of this study

This retrospective study utilized three-way propensity score matching to control for inter-group demographics and surgical characteristics in patients with substance abuse, vascular, or dietary MRFs. Statistical analysis found that patients with dietary MRFs have the highest rates of medical complications and non-routine hospital discharges, and patients with substance abuse have highest readmission rates for infection.

Implications of all the available evidence

By understanding the influence of patient-specific MRFs, surgeons have an opportunity to improve preoperative risk stratification, better tailor patient counseling, and optimize postoperative management.

surgery due to the increasing proportion of high risk patients receiving surgery, and may allow for improved patient selection and postoperative management [6,7]. Accurate identification of relevant MRFs may improve patient outcomes by allowing physicians to preoperatively predict which patient factors may contribute towards poor outcomes, and through identification of MRFs, physicians may be better equipped to provide tailored perioperative management to improve overall outcomes. In addition, better understanding of MRFs would also allow physicians to more effectively alleviate the financial burden on patients receiving cervical spine fusion surgery, bearing in mind the high costs associated with postoperative complications [8,9].

Recent efforts have been made to assess the influence of MRFs on postoperative outcomes following spine surgery. Hypertension and dyslipidemia increase the risk of readmission and dyspnea following anterior cervical discectomy and fusion (ACDF), in addition to increasing the risk of disc herniation [10–12]. Substance abuse, including alcohol, nicotine, and opioid abuse, also increase the risk of perioperative complications including wound complications, cardiopulmonary complications, pseudarthrosis, and infection [13–16]. Furthermore, obesity is one of the most popularly studied dietary MRFs within the literature, and obese patients have been shown to have higher rates of early postoperative complications [17–20], hematological complications [18,19,21–23], and surgical-site infections [19–21,23–25] compared to non-obese patients. Similarly, malnutrition has been shown to be correlated with sepsis, infection, pulmonary and hematological complications, and length of hospital stay within patients receiving posterior cervical fusion [26,27]. MRFs can be generally categorized into one of three categories: vascular (V-MRF), substance abuse (SA-MRF), and dietary (D-MRF) [28–30]. Although MRFs can often co-occur and have shared consequences, there are also differences in their impact on postoperative outcomes. To date, the influence of preoperative substance abuse, vascular disease, and dietary risk factors on postoperative outcomes has not been independently evaluated. Therefore, we identified a large, contemporary cohort of adults who received cervical fusion surgery, and analyzed the predictive value of various MRFs on outcomes following surgery.

Methods

Data source

In this study, we use the Healthcare Cost and Utilization Project (HCUP) National Readmission Database (NRD) from the years 2016 and 2017. The NRD is a yearly nationally representative inpatient database from the Agency for Healthcare Research and Quality (AHRQ) with information regarding patient demographics, diagnoses, procedures, and readmissions. All data regarding patient diagnoses and procedures was queried using *International Classification of Diseases, Tenth Revision* (ICD-10) codes in all patient admissions and readmissions. This study was exempt from Institutional Review Board (IRB) approval.

Patient selection

All patients ≥18 years of age who received an elective/non-traumatic cervical fusion procedure were queried using ICD-10 coding (**Fig. 1**). Modifiable risk factor cohorts were separated into three categories and evaluated for each patient: 1) SA-MRF, including current alcohol abuse tobacco/nicotine use, and/or opioid use; 2) V-MRF, including current primary hypertension and/or dyslipidemia; and 3) D-MRF, including current malnutrition and/or obesity. Patients with non-elective procedures, spinal trauma, benign/malignant spinal tumors, non-diet related malabsorptive disorders, and overlapping MRFs (n = 43,103) were excluded from our analysis. Elixhauser comorbidity index (ECI) scores were obtained for each patient using the R 'comorbid' package [31]. Inpatient length of stay (LOS)-adjusted hospital costs were calculated to represent the inpatient cost per day in the hospital.

Data imputation

Multivariate imputation by chained equations (MICE) was used to impute all missing data using previously established and validated protocols. [32–34] Additional univariate imputation using classification and regression trees was utilized. MICE allowed successful imputation of median income by ZIP code (1.7% missing) and insurance type (0.1% missing) (**Fig. 2**). No missing data remained following MICE.

Propensity score matching

Nearest-neighbor propensity score matching for age, sex, NRD discharge weighting, ECI, insurance status, median income, hospital variables, presence of myelopathy, number of levels fused, and surgical approach was performed using the R 'MatchIt' algorithm [35]. In this technique, parametric models are chosen based on the minimum distance parameter, which is determined through logistic regression models that minimize the propensity score with no replacement. MatchIt improves parametric statistical models and reduces model dependence by preprocessing data with semi-parametric and non-parametric matching methods. Model balance, defined as the similarity of empirical covariate distributions between the two groups undergoing propensity matching, is analyzed and the model with the best balance is selected to ensure best model fit. Patients in the substance abuse and vascular MRF cohorts were each independently

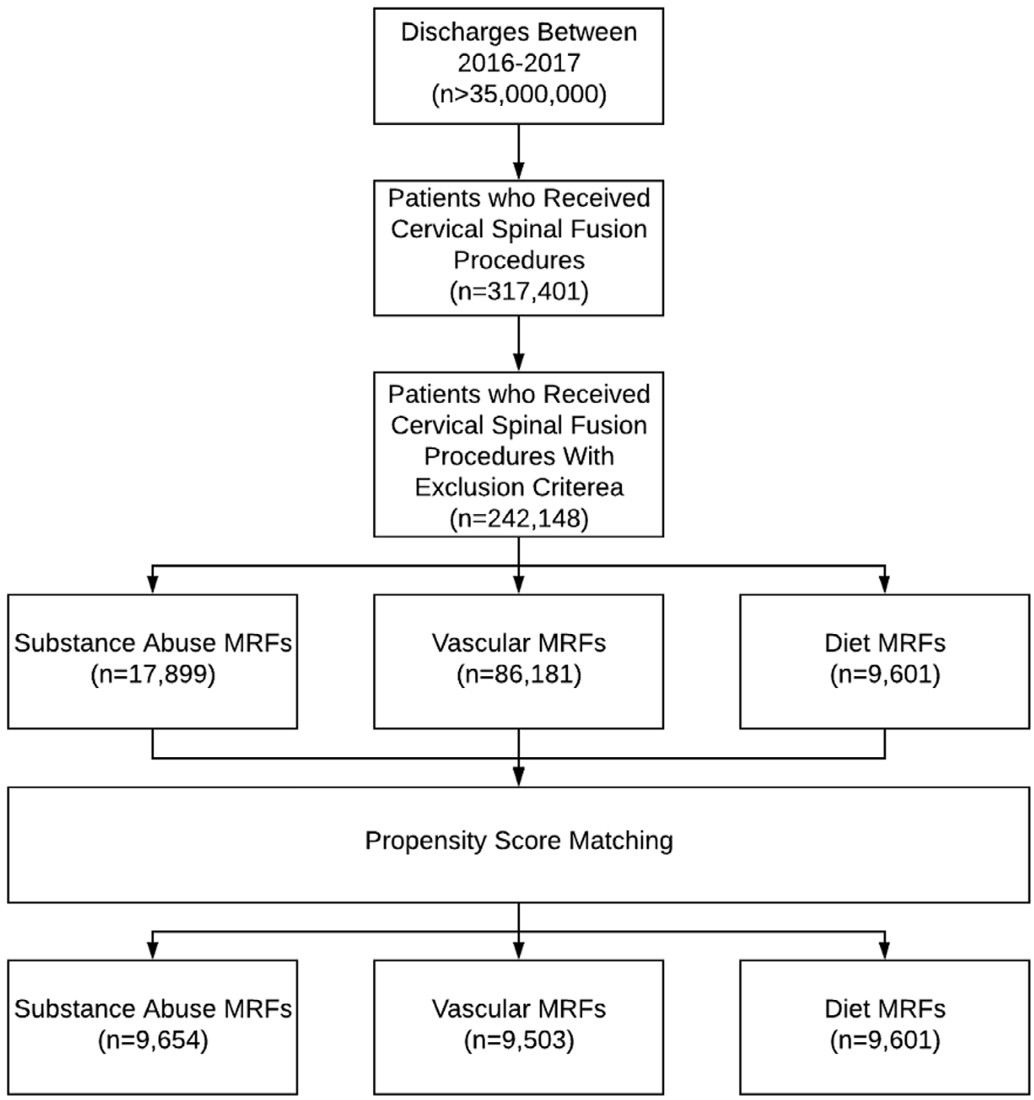

Fig. 1. Patient selection flowchart.

matched to patients in the diet cohort because it had the lowest sample size prior to weighting.

Outcomes of interest

Outcomes of interest included mortality, medical complications, surgical complications, neurological complications, nonroutine hospital discharges, and readmissions. Medical complications included postoperative infections, complications with intubation, acute kidney failure, pneumonia, myocardial infarction, cardiac arrest, thromboembolic events, pneumothorax, acute respiratory distress syndrome, and iatrogenic stroke [36]. Surgical complications included surgical-site infection, hematoma, wound complications, dysphagia, incidental durotomy, mechanical implant-related complications, and paralytic ileus. Nonroutine discharges were defined as discharges other than home. Readmissions were only queried within the same calendar year as the primary admission, as defined by the NRD.

Statistical analysis

All statistics included in this analysis were conducted in RStudio (Version 1.2.5042), all statistical tests were two-tailed, and all p-values less than 0.05 were considered significant. Outcomes were analyzed across all MRFs using analysis of variance (ANOVA) with post hoc Tukey multiple comparisons of means and unpaired Welch two-sample t-tests.

Role of the funding source

No sources of funding were used for this study. All authors had full access to the data in the study and it was mutual decided amongst authors to submit this study for publication.

Results

Patient selection

The number of patients included in each cohort was as follows: 9654 patients with SA-MRFs, 9503 patients with V-MRFs, and 9601 patients with D-MRFs. Following propensity score matching, no significant differences were found with respect to demographic, surgical, and hospital characteristics between the three cohorts (**Tables 1 & 2**).

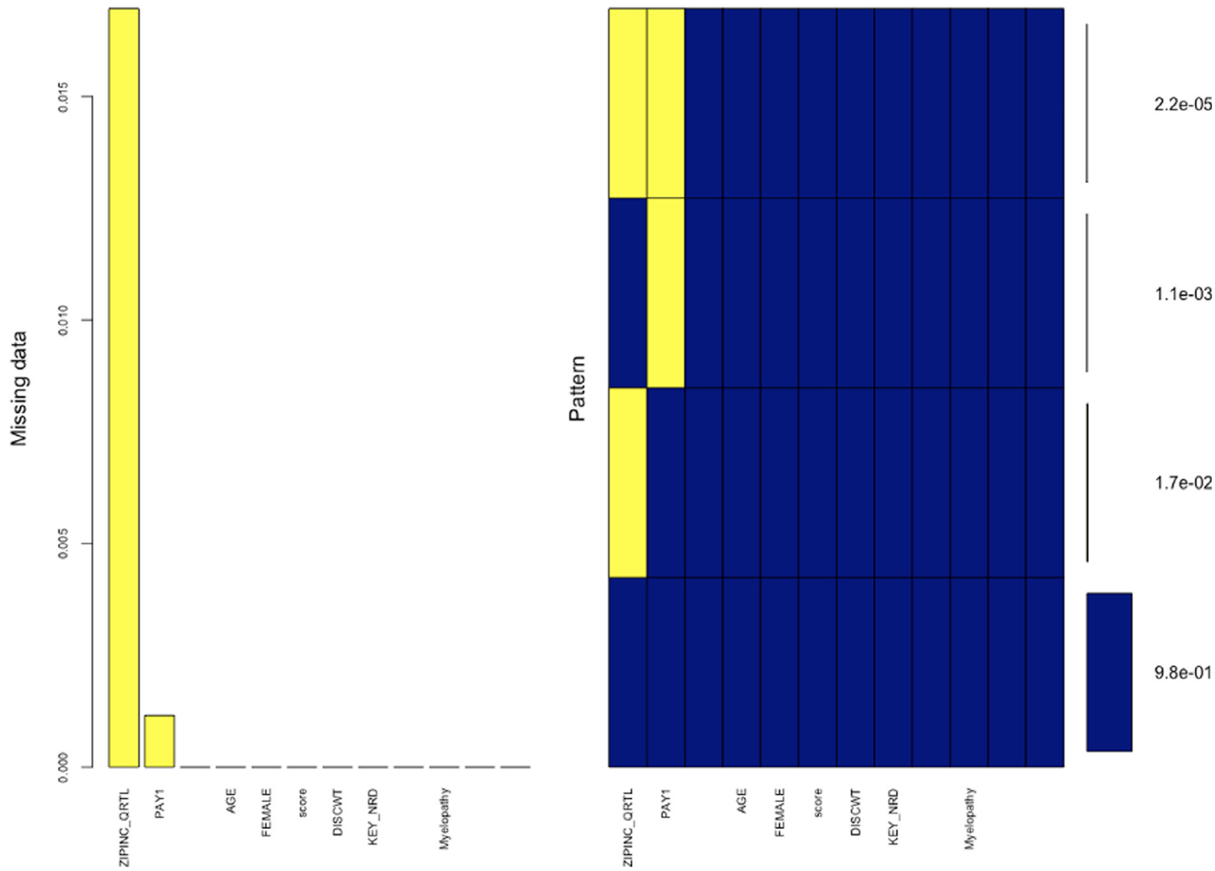

Fig. 2. Missing variables, which were imputed using the MICE algorithm. Yellow encoded missing data and blue encoded data that was not missing.

Complications, LOS, costs

Patients with D-MRFs (9.3%) and V-MRFs (9.0%) independently reported significantly higher rates of medical complications compared to patients with SA-MRFs (7.4%) ($p<0.001$ and $p = 0.0014$, respectively). Patients with D-MRFs (3.7%) had significantly higher rates of acute posthemorrhagic anemia compared to those with V-MRFs (2.1%) ($p<0.001$) and SA-MRFs (2.2%) ($p<0.001$) (**Table 3**).

Similarly, patients with D-MRFs (8.1%) had significantly higher rates of surgical complications compared to those with SA-MRFs (6.2%) ($p = 0.0016$). No differences were found between either of the cohorts with respect to mortality or neurological injury during the inpatient stay following cervical fusion (**Table 4**). Patients with D-MRFs had significantly higher LOS-adjusted hospital costs compared to patients with SA-MRFs ($p = 0.040$) and V-MRFs ($p = 0.016$) (**Table 1**).

Discharge disposition and readmission

Patients with D-MRFs (16.3%) and V-MRFs (14.0%) were independently, non-routinely discharged at a significantly higher rate compared to patients with SA-MRFs (12.6%) ($p<0.0001$ and $p = 0.0037$, respectively). Patients with D-MRFs also had higher rates of non-routine discharge compared to patients with V-MRFs ($p = 0.013$). With respect to readmission within the same calendar year, patients with SA-MRFs (11.5%) reported significantly higher rates of readmission compared to those with D-MRFs (9.9%) ($p = 0.047$) **(Table 5)**. The most common primary diagnosis at readmission in those with SA-MRFs was infection.

Discussion

MRFs serve as important predictors of perioperative patient outcomes following cervical fusion procedures. The results of this study

Table 1
Demographics for all patients with MRFs.

	Substance Abuse ($n = 9654$)	**Vascular ($n = 9503$)**	**Diet ($n = 9601$)**
Age (years)	51.2 ± 10.0	51.9 ± 11.0	51.8 ± 11.2
Sex (% female)	62.8	62.1	63.8
Elixhauser Score	1.6 ± 1.3	2.0 ± 1.4	2.0 ± 1.4
Total Inpatient Hospital Costs (US Dollars)	$19,637.77±$15,355.97	$20,016.31±$14,955.47	$22,880.30±$22,767.01
Length of Stay (days)	2.2 ± 4.0	2.1 ± 3.0	2.7 ± 5.2
LOS-Adjusted Hospital Costs ($/day)	$8926.26±$3838.99	$9531.58±$4985.16	$8474.19±$4378.27
Ratio of Specific MRFs	Alcohol:Tobacco:Opioid 1.08: 12.88: 1.00	Dyslipidemia:Hypertension 1.00: 1.87	Malnutrition:Obesity 1.00: 6.26

Table 2
Hospital and surgical characteristics for all patients.

	Substance Abuse (n = 9654)	Vascular (n = 9503)	Diet (n = 9601)
Insurance			
Medicare, n (%)	2243 (23.2%)	2336 (24.6%)	2235 (23.3%)
Medicaid, n (%)	1904 (19.7%)	1068 (11.2%)	1083 (11.3%)
Private, n (%)	3811 (39.5%)	4881 (51.4%)	5165 (53.8%)
Other (include self-pay, no charge, and other), n (%)	1696 (17.6%)	1218 (12.8%)	1118 (11.6%)
Median income by zip code			
Quartile 1, n (%)	2153 (22.3%)	2276 (24.0%)	2273 (23.7%)
Quartile 2, n (%)	2771 (28.7%)	2487 (26.2%)	2615 (27.2%)
Quartile 3, n (%)	2796 (28.7%)	2488 (26.2%)	2515 (26.2%)
Quartile 4, n (%)	1787 (18.5%)	2110 (22.2%)	2070 (21.6%)
Hospital type			
Metropolitan non-teaching, n (%)	2207 (22.9%)	2019 (21.2%)	2063 (21.5%)
Metropolitan teaching, n (%)	7088 (73.4%)	7160 (75.3%)	7324 (76.3%)
Non-metropolitan, n (%)	359 (3.7%)	324 (3.4%)	214 (2.2%)
Discharge location			
Routine/Home, n (%)	8435 (87.4%)	8167 (85.9%)	8027 (83.6%)
Short-term hospital, n (%)	7 (0.07%)	17 (0.18%)	9 (0.09%)
Skilled nursing facility, n (%)	342 (3.5%)	343 (3.6%)	501 (5.2%)
Home health care, n (%)	823 (8.5%)	965 (10.2%)	1034 (10.8%)
Number of Levels			
Single-level fusion, n (%)	3530 (36.6%)	3383 (35.6%)	3403 (35.4%)
Multi-level fusion, n (%)	6124 (63.4%)	6119 (64.4%)	6198 (64.6%)
Surgical Approach			
Anterior, n (%)	8132 (84.2%)	7906 (83.2%)	7920 (82.5%)
Posterior, n (%)	1255 (13.0%)	1344 (14.1%)	1398 (14.6%)
Combined, n (%)	267 (2.8%)	252 (2.7%)	283 (2.9%)
Myelopathy	9 (0.09%)	7 (0.07%)	7 (0.07%)

Table 3
Results of statistical comparisons between MRF groups.

	Acute Posthemorrhagic Anemia	Mortality	Medical Complications	Surgical Complications	Neurological Complications	Nonroutine Discharge	Readmission
SA-MRF vs V-MRF	$p = 1.00$	$p = 0.86$	$p = 0.0014$	$p = 0.62$	$p = 0.22$	$p = 0.037$	$p = 0.10$
SA-MRF vs D-MRF	$p<0.001$	$p = 0.39$	$p<0.001$	$p = 0.0016$	$p = 0.71$	$p<0.001$	$p = 0.047$
V-MRF vs D-MRF	$p<0.001$	$p = 0.84$	$p = 1.00$	$p = 0.073$	$p = 0.83$	$P = 0.013$	$p = 0.99$

Table 4
Complication rates for all MRF cohorts.

	Substance Abuse (n = 9654)	Vascular (n = 9503)	Diet (n = 9601)
Acute Posthemorrhagic Anemia	213 (2.2%)	197 (2.1%)	360 (3.7%)
Mortality	11 (0.1%)	3 (0.03%)	20 (0.2%)
Medical Complications	714 (7.4%)	859 (9.0%)	896 (9.3%)
Infection	41 (0.4%)	19 (0.2%)	60 (0.6%)
Intubation	2 (0.02%)	5 (0.05%)	8 (0.08%)
Pneumonia	52 (0.5%)	23 (0.2%)	76 (0.8%)
Acute Kidney Failure	6 (0.06%)	34 (0.4%)	39 (0.4%)
Urinary Tract Infection	103 (1.1%)	64 (0.7%)	153 (1.6%)
Urinary Retention	121 (1.3%)	155 (1.6%)	186 (1.9%)
Myocardial Infarction	433 (4.5%)	580 (6.1%)	449 (4.7%)
Pulmonary Embolism	7 (0.07%)	8 (0.08%)	34 (0.4%)
Deep Vein Thrombosis	9 (0.09%)	10 (0.1%)	50 (0.5%)
Cardiac Arrest	5 (0.05%)	5 (0.05%)	23 (0.2%)
Pneumothorax	2 (0.02%)	5 (0.05%)	6 (0.06%)
Acute Respiratory Distress Syndrome	0 (0.0%)	1 (0.01%)	4 (0.04%)
Iatrogenic Stroke	5 (0.05%)	2 (0.02%)	3 (0.03%)
Surgical Complications	598 (6.2%)	650 (6.8%)	780 (8.1%)
Surgical Site Infection/Wound Dehiscence	6 (23.2%)	4 (0.04%)	14 (0.1%)
Hematoma	10 (0.1%)	10 (0.1%)	9 (0.09%)
Seroma	0 (0.0%)	0 (0.0%)	5 (0.05%)
Dysphagia	529 (5.5%)	531 (5.6%)	663 (6.9%)
Wound Complications	8 (0.08%)	7 (0.07%)	17 (0.2%)
Durotomy	25 (0.26%)	58 (0.6%)	63 (0.7%)
Mechanical Complication	35 (0.36%)	57 (0.6%)	30 (0.3%)
Ileus	9 (0.09%)	7 (0.07%)	36 (0.4%)
Neurological Complications	63 (0.7%)	85 (0.9%)	81 (0.8%)
Nonroutine Discharge	1214 (12.6%)	1335 (14.0%)	1568 (16.3%)
Readmission	1112 (11.5%)	960 (10.1%)	951 (9.9%)

Table 5
Top five ICD-10 diagnosis codes for primary reason for readmission in MRF groups.

	Substance Abuse	Vascular	Diet
Diagnosis 1	Infection (n = 31)	Infection (n = 22)	Sepsis (n = 29)
Diagnosis 2	Sepsis (n = 20)	Sepsis (n = 16)	Infection (n = 22)
Diagnosis 3	Pneumonia (n = 15)	Displacement of internal fixation device of vertebrae, initial encounter (n = 9)	Pulmonary embolism (n = 13)
Diagnosis 4	Chronic obstructive pulmonary disease with (acute) exacerbation (n = 13)	Other chest pain (n = 8)	Morbid obesity (n = 12)
Diagnosis 5	Chronic obstructive pulmonary disease with acute lower respiratory infection (n = 7)	Disruption of external operation (surgical) wound, not elsewhere classified, initial encounter (n = 7)	Displacement of internal fixation device of vertebrae, initial encounter (n = 7)

demonstrated that different MRF categories may uniquely influence various postoperative outcomes, with some MRFs correlated with higher complication rates than others. A heterogeneous array of MRFs have already been analyzed within the literature of spinal fusion, of which none utilized multi-group propensity score matching to compare various different MRFs.[10,11,17,18,22,27] Because MRFs encompass complex and overlapping patient conditions, propensity score matching is necessary to fully confirm statistical findings while minimizing the influence of confounding variables. In addition, by analyzing MRFs as non-overlapping subgroups, it is possible to quantify the association between specific risk factors and various postoperative conditions. This additional step allows the authors to identify specific risk factor categories that may outweigh others with respect to predictive value when analyzing cervical fusion surgical outcomes. Previous studies have utilized multivariate and bivariate regression rather than propensity score matching to analyze MRFs within patient populations [10,11,26,37–39]. Although both methods aim to control for potential confounding, regression methods fail when dealing with a wide range of covariates, which is likely the case when analyzing a heterogeneous cohort of patients with various MRFs [40]. In such cases, propensity score matching has been shown to be the superior method for controlling for confounders[40].

The findings of this study suggest that D-MRFs, which encompass obesity and malnutrition, may contribute a higher risk for increased postoperative complications, LOS, and nonroutine discharge. Although we defined malnutrition as through ICD-10 coding that captured nutritional and caloric insufficiencies, many prior studies analyzing the influence of malnutrition on postoperative spine outcomes have utilized hypoalbuminemia (albumin $<$ 3.5 g/dL) as the main marker for malnutrition [26,38,41]. In these studies, the authors demonstrated that hypoalbuminemia-driven malnutrition may be associated with increased LOS, urinary tract infections (UTI), wound complications, bleeding complications, and 30-day readmissions [26,38,41]. Similar findings are found within our analysis of D-MRFs with regards to increased LOS and higher rates of medical and surgical complications compared to other MRF groups. While the NRD lacks plasma albumin levels, it provides broad diagnostic codes for nutritional deficiencies, which likely encompass many patients with preexisting hypoalbuminemia. This overlap in patient selection may be the reason we see comparable rates of complications within our analysis and the existing literature.

Moreover, the presence of D-MRFs may negatively impact physiological mechanisms that drive recovery. Specifically, malnutrition and obesity may result in muscle loss, atrophy, impaired wound healing, and metabolic/cardiovascular comorbidities, all of which may impede improvements in patient functional status [42,43]. This was seen in our study, in which patients with D-MRFs reported the highest rates of acute posthemorrhagic anemia following spine surgery. While the exact mechanism cannot be investigated through the NRD, we hypothesize that the patient malnutrition state, and potential hypoalbuminemia, may impair blood clotting and hemostasis [26,38,41]. Further, patients with D-MRFs also reported a higher incidence of postoperative dysphagia and ileus compared to the other groups. Therefore, the evaluation of nutritional status is important in patients undergoing cervical spinal fusion and may benefit from earlier interventions in their nutrition or the implementation of a feeding tube as appropriate [44].

Despite the high rates of complications seen in the D-MRF cohort, patients with diagnosed SA-MRFs reported significantly higher rates of readmission within a one-year interval compared to those with D-MRFs. By analyzing the common primary indications for readmission within these patients, it was demonstrated that patients with substance abuse MRFs had the highest rates of infection following the procedure. This finding may be explained by the fact that tobacco abuse [15,45,46], alcoholism [47–49], and opioid abuse [50,51] have been shown to independently increase the risk of systemic and surgical-site infections (SSI). This finding, while not novel, is important because it demonstrates a higher associated risk with substance abuse when compared to dietary and vascular MRF cohorts, which also independently increase postoperative infection rates, as shown in previous studies [19,38,52,53].

As expected, patients with V-MRFs demonstrated the highest MI rates of the groups. The high rate of medical complications seen in patients with V-MRFs may be partially explained by the physiologic influence of hypertension and dyslipidemia. Hypertension, in particular, has been associated with increased rates of dyspnea following ACDF procedures [11]. Mechanistically, it is believed that hypertension increases rates of dyspnea through its cardiovascular effects, including its ability to induce vascular endothelial dysfunction, although more research is necessary to fully understand this phenomenon [11]. Hypertension has also been associated with an increased need for readmission following spine surgery [10]. However, the mechanisms by which hypertension increases readmission must be further explored. Although the literature describing the influence of dyslipidemia in cervical spine surgery is limited, early evidence suggests that elevated lipid panels may exacerbate outcomes and increase the risk of disc herniation [12]. It is possible that dyslipidemia may have a larger impact in myelopathic patients, but the incidence of myelopathy was too small to investigate this relationship in this study.

Sub-analysis of MRFs may also be employed to increase the accuracy of risk adjustment, which have gained importance in the era of the bundled payment models. While the current Bundled Payment for Care Improvement (BPCI) model does risk-adjust for some patient comorbidities, it lacks robustness and is unable to account for the vast heterogeneity in patient-specific factors that may be encountered during cervical fusion surgery [54,55]. A 2019 study demonstrated that comorbidities such as malnutrition, stroke, drug abuse/dependence, hypercoagulopathy, and chronic kidney disease were associated with higher 90-day reimbursements and marginal cost impacts when evaluating risk adjustment for bundled payment models for cervical fusion [55]. Malnutrition specifically was shown to have the highest increase in 90-day reimbursement (+$15,536), followed by drug abuse (+$5059). [55] Similar findings have also described that recent weight loss (+$8351), electrolyte disturbances (+$4175), and coagulopathies (+$3467) may all increase the marginal cost impacts that may not be accounted for in current bundled payment models [54]. Thus, risk adjustment models that incorporate MRF groups may greatly improve the risk adjustment model's accuracy in adjusting prices and facilitate the hospital and physician reimbursement processes.

This study is not without limitations. First, by using a national database we were limited by the available data, in addition to limitations secondary to ICD coding. Second, while propensity score matching for comorbidities was implemented through the use of ECI, future studies may use specific codes for heart disease, stroke, diabetes, cancer, etc. to achieve further minimization of confounding. Third, there was a risk of Berkson's bias and selection bias because of our use of an inpatient hospital database, which we aimed to minimize by using random methods when selecting subgroups, including large sample sizes, and matching for demographics, comorbidities, and surgical characteristics. Fourth, while we attempted to investigate alcohol abuse, tobacco abuse, and opioid abuse within the SA-MRF cohort, the number of patients with tobacco abuse was significantly more than the other two groups. Similarly, while the ratio of patients with various MRFs was more similar in the V-MRF and D-MRF cohorts, it still was not one-to-one. Fifth, with increased computational resources in the future, it may be possible to perform a 4-way propensity score match to include a control group in addition to the three MRF groups. However, with our current computational resources and limitations, it was not feasible to complete a 4-way propensity score match. Our computational inability to propensity match with more than three groups also prevented us from analyzing each MRF individually. Lastly, this study utilized data from 2016 to 2017, which are two of the most recent NRD datasets provided by the HCUP. Over the past 4–5 years, there have been little, if any, changes in cervical fusion procedures and perioperative management of patients with MRFs. As such, many of the conclusions drawn from this study are still applicable today.

Overall, the incidence of cervical degenerative disease will continue to increase with age, and rates of cervical spine surgery are expected to rise as a result of increased life expectancies [9]. To this end, the high rates of global hypertension [56], obesity [57], and malnutrition [58] may be of concern for patients receiving cervical fusion procedures. This study suggests that a large proportion of patients who receive cervical fusion surgery have preexisting MRFs that uniquely influence their postoperative complication rate. A thorough understanding of patient-specific MRFs allows for improved preoperative risk stratification, tailored patient counseling, and postoperative management planning.

Declaration of Competing Interest

Disclosures outside of submitted work: ZB-consultancy: Cerapedics, Xenco Medical (past), AO Spine (past); Research Support: SeaSpine (past, paid to the institution), Next Science (paid directly to institution), Motion Metrics (paid directly to institution); North American Spine Society: committee member; Lumbar Spine Society: Co-chair Research committee, AOSpine Knowledge Forum Degenerative: Associate member; AOSNA Research committee- committee member; JCW- Royalties – Biomet, Seaspine, Amedica, DePuy Synthes; Investments/Options – Bone Biologics, Pearldiver, Electrocore, Surgitech; Board of Directors - AO Foundation (20,000 honorariums for board position, plus travel for board meetings), Society for Brain Mapping and Therapeutics, American Orthopaedic Association, Editorial Boards - Spine, The Spine Journal, Clinical Spine Surgery, Global Spine Journal; Fellowship Funding (paid directly to institution): AO Foundation. All the other authors have no conflicts to declare.

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None.

Data Sharing Statement

Data used in this study is publicly available for purchase through the Healthcare Cost and Utilization Project. Data used for this study is available upon reasonable request to the corresponding author.

Contributors

Shane Shahrestani and Joshua Bakhsheshian contributed to the conception and design of the study, acquisition of data, analysis and interpretation of data, and drafting the article. Xiao Chen, Andy Ton, Alexander Ballatori, Ben Strickland, and Djani Robertson contributed to acquisition of data, analysis and interpretation of data, and drafting the article. Zorica Buser, Raymond Hah, Patrick Hsieh, John Liu, and Jeffrey Wang critically revised the study and provided research support and funding for data acquisition and analysis.

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