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Racial Differences in Perioperative Complications, Readmissions, and Mortalities After Elective Spine Surgery in the United States: A Systematic Review Using AI-Assisted Bibliometric Analysis

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Abstract

Study Design: Systematic Review and Meta-analysis.

Objectives: To evaluate the impact of race on post-operative outcomes and complications following elective spine surgery in the United States.

Methods: PUBMED, MEDLINE(R), ERIC, EMBASE, and SCOPUS were searched for studies documenting peri-operative events for White and African American (AA) patients following elective spine surgery. Pooled odds ratios were calculated for each 90-day outcome and meta-analyses were performed for 4 peri-operative events and 7 complication categories. Sub-analyses were performed for each outcome on single institution (SI) studies and works that included <100,000 patients.

Results: 53 studies (5,589,069 patients, 9.8% AA) were included. Eleven included >100,000 patients. AA patients had increased rates of 90-day readmission (OR 1.33, P = .0001), non-routine discharge (OR 1.71, P = .0001), and mortality (OR 1.66, P = .0003), but not re-operation (OR 1.16, P = .1354). AA patients were more likely to have wound-related complications (OR 1.47, P = .0001) or medical complications (OR 1.35, P = .0006), specifically cardiovascular (OR 1.33, P = .0126), deep vein thrombosis/pulmonary embolism (DVT/PE) (OR 2.22, P = .0188) and genitourinary events (OR 1.17, P = .0343). SI studies could only detect racial differences in re-admissions and non-routine discharges. Studies with <100,000 patients replicated the above findings but found no differences in cardiovascular complications. Disparities in mortality were only detected when all studies were included.

Conclusions: AA patients faced a greater risk of morbidity across several distinct categories of peri-operative events. SI studies can be underpowered to detect more granular complication types (genitourinary, DVT/PE). Rare events, such as mortality, require larger sample sizes to identify significant racial disparities.

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Introduction

A growing body of evidence has reported on the prevalence of systemic racial and socioeconomic disparities in the United States healthcare system.[1,2] Race has been identified as a primary predictor of clinical care outcomes across nearly every field of medicine.[3] Among racial minorities, African American (AA) patients have been specifically shown to experience worse health outcomes, including chronic somatic disease burden and mortality, compared with matched White cohorts.[4-6] A growing number of studies have shown that race is a significant predictor of operative outcomes[7] after oncologic, transplant, and orthopedic surgeries.[8-10] These racial disparities have been attributed to many factors, including patient-related factors (such as comorbidities and socioeconomic status), engagement with healthcare appointments and treatments, quality of care, and limited health literacy.[11] Racial minorities oftentimes encounter racial bias from the provider, cultural barriers, and a lack of insurance coverage.[12]

Multiple cohort studies have described disparities in post-operative complications and outcomes for AA patients following spine surgery. Re-admission rates after elective spine surgery were significantly higher in AA than White patients.[13] AA patients had increased length of stays and operative times for anterior cervical decompression and fusion across different fusion levels.[14] AA patients also had an increased risk of medical complications after lumbar decompression and fusion surgery, in particular cardiac, renal, and respiratory adverse events.[14]

Pooled analyses in spine surgery further support the outcomes gap between White and AA patients. A meta-analysis in 2011 by Schoenfeld et al[15] analyzed 11 articles and eight "unfavorable" outcome measures, reporting that non-White patients were more likely to have unfavorable outcomes.[15] A further meta-analysis in 2021 by Khan et al[16] included a more robust analysis of 30 studies and 6 outcome measures, concluding that AA patients had a significantly increased risk of mortality, prolonged length of stay, non-home discharge, and 30-day re-admission compared with non-AA patients.[16]

Despite the robust analyses performed in these prior systematic reviews, both works studied a fairly small sample size and identified only a moderate number of outcomes, limiting their conclusions. These prior works also grouped all of their included studies together without considering potential differences in the composition and analysis of single institution (SI) vs national database works. Given the dominance of lower quality, retrospective cohort studies in the current literature, the origin and nature of the included work can considerably influence pooled analyses. The purpose of our review was to use an AI-assisted graphical bibliometric platform to analyze the influence of race on peri-operative outcomes and post-operative complications after elective spine surgery. We sought to characterize and present the types and frequencies of post-operative variables in the literature using an organ system-based hierarchy. We further sought to identify relative differences between works of different sample sizes and sample origin (single vs multi-institutional, low vs high-volume registry). Such findings may allow us to better characterize the landscape of pertinent studies on spine surgery-related health outcomes, correlate differences in outcomes based on sample origin, and more accurately describe relationships between race and adverse post-operative outcomes.

Methods

Literature Search

A comprehensive literature search of the PUBMED, MEDLINE(R), ERIC, EMBASE, and SCOPUS databases was performed on 11/07/2022 using a semi-automated software platform (AutoLit, Nested[17]). De-duplication was performed automatically. Only original articles in English from 2010 onward were included because the Affordable Care Act was passed in 2010. The Affordable Care Act significantly expanded the eligibility for Medicaid, government insurance targeted to low-income individuals, thereby broadly increasing access to care that included spine surgery.[18,19] Analyzing only those studies published after this major transformation would more accurately characterize racial disparities in our current healthcare system. Nested Knowledge provides a semi-automated platform for screening, organizing, and extracting data. This review was performed by 2 authors (IA and NK). A detailed methodology, including our search, screening, and raw data extraction, is publicly available on the Nested Knowledge website (https://nested-knowledge.com/).[17] This study was not registered on PROSPERO.

Study Selection

This study sought to examine if AA patients were more likely to experience an adverse outcome following elective spine surgery in the United States than White patients by performing a series of meta-analyses. Inclusion criteria were as follows: (1) patients who underwent elective surgery on any portion of the spine for degenerative disease; (2) studies tracked any peri-operative event, medical complication, or surgical complication as outlined in Table 2; and (3) outcomes were compared between non-Hispanic AA and White patients. Exclusion criteria were: (1) studies that did not utilize patients from the United States ("Not in USA" in Figure 1); (2) publication before 2010 ("Pre 2010" in Figure 1); (3) a lack of available raw incidence data for each cohort ("No Usable Data" in Figure 1); and (4) unavailable full texts ("No Full Text" in Figure 1). We excluded surgeries for tumors, infections, trauma, and spinal cord pathology to decrease heterogeneity, as outcomes for those procedures are more strongly influenced by internal and external factors ("Not Elective Spine Surgery" in

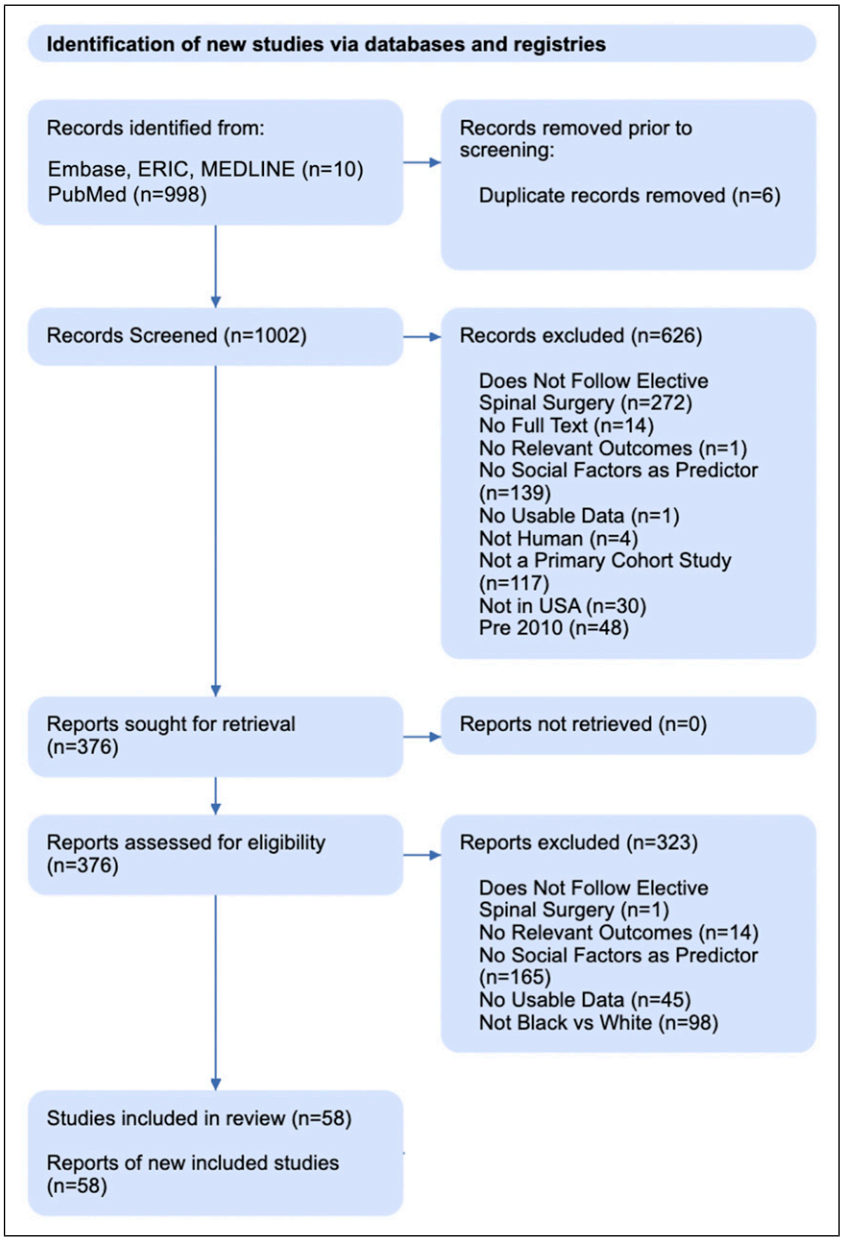

Figure 1. PRISMA diagram illustrating literature search and screening method.

Figure 1). A distinction was made between studies that investigated race as an independent variable (RaI) (i.e., studies targeted towards measuring the impact of social factors on outcomes) and studies where race was a recorded as demographic (RaD) data while measuring a post-operative outcome. This distinction is shown in Table 1 under the column header "Variable Type." Appendix A1 shows a detailed review of our queries and search terms.

Outcome Measures and Categorization

Predefined data, including study size, data source, surgery type, peri-operative outcomes, and complications, were extracted independently by 2 authors (IA and NK), with disagreements settled by the senior author (Table 1).

Four key peri-operative outcomes were chosen and recorded from the selected studies: re-admission, non-routine or non-home discharge (NRD), re-operation, and mortality. These outcomes were chosen because they are well-known and understood metrics for assessing the outcomes of major surgeries.[20] Clinical/economic significance, racial heterogeneity, and abundance of reporting in the literature were also considered. Data were collected if events occurred within 90 days of surgery, which was chosen based on the peri-operative period defined by Medicare.

Table 1. Summary Characteristics for the 53 Included Studies.

Journal article	Sample size White/Black (White:Black)	Database	Surgery type	Variable type	Medical complications	Surgical complications	Post-Op outcomes
Adogwa et al. 2016	458/142 (3.2:1)	SI	Spine surgery	RaI	Cardiovascular, DVT/PE, GU, respiratory, systemic infection	Wound infection	LOS, Re-Ad
Aladdin et al. 2020	208,088/17,326 (12:1)	HCUP	Lumbar fusion	RaI	—	—	NRD, LOS, Re-Ad
Arena et al. 2020	38,249/2545 (15:1)	Optum EHR	Posterior lumbar fusion	RaD	Neurologic	—	—
Baek et al. 2019	906/193 (4.7:1)	NSQIP	Posterior spinal fusion	RaD	—	—	NRD
Cook et al. 2018	232,525/18,048 (12.9:1)	Medicare Claims	Lumbar fusion	RaD	—	—	NRD
De la Garza-Ramos et al. 2016	27,834/7531 (3.7:1)	NIS	Spinal fusion	RaD	Neurologic	—	—
Dial et al. 2020	1463/305 (4.8:1)	SI	ACDF	RaD	—	—	Re-Ad
Doherty et al. 2020	3176/200 (15.9:1)	HCUP	Lumbar fusion	RaD	Opioid Overdose	—	—
Drazin et al. 2017[a]	513/513 (1:1)	Medicare Claims	Lumbar laminectomy/ Fusion	RaI	—	Wound infection	NRD, LOS, mortality, Re-Ad, Re-Op
Elsamadicy et al. 2016	32/28 (1.1:1)	SI	ACDF	RaI	DVT/PE, GU, respiratory	Wound infection	Re-Ad
Elsamadicy et al. 2017	438/52 (8.4:1)	SI	Complex spinal fusion	RaI	Cardiovascular, DVT/PE, GI, GU, neurologic, systemic infection	Cellulitis, Hematoma, wound drainage, wound infection	LOS, Re-Ad
Elsamadicy et al. 2018	292/53 (5.5:1)	SI	Lumbar spine surgery	RaI	DVT/PE, GU	Hematoma, wound infection	LOS, Re-Ad
Elsamadicy et al. 2020	13,250/2150 (6.2:1)	NIS	ACDF	RaI	Cardiovascular, DVT/PE, neurologic	Hematoma, wound disruption	NRD, LOS
(a) Elsamadicy et al. 2021	2096/552 (3.8:1)	KID	Posterior spinal fusion	RaI	Cardiovascular, DVT/PE, GI, GU, neurologic, respiratory	Hematoma, infection complication, wound dehiscence	NRD, LOS
(b) Elsamadicy et al. 2021	4505/383 (11.8:1)	NSQIP	Lumbar decompression/ Fusion	RaD	—	—	NRD
Engler et al. 2022	376,385/22,878 (16.5:1)	Medicare Claims	Spine surgery	RaI	DVT/PE, neurologic, respiratory	—	Mortality, Re-Ad
Feng et al. 2018	57,717/10,060 (5.7:1)	SPARCS	Cervical spinal fusion	RaD	Systemic infection	Post-Op bleeding, infection complication	Mortality
Fineberg et al. 2013	486,181/35,757 (13.6:1)	NIS	Lumbar decompression/ Fusion	RaD	Neurologic	—	—
Gephart et al. 2012	5311/368 (14.4:1)	NIS	Spinal fusion	RaD	DVT/PE	—	—

(continued)

Table 1. (continued)

Journal article	Sample size White/Black (White:Black)	Database	Surgery type	Variable type	Medical complications	Surgical complications	Post-Op outcomes
Ghenbot et al. 2022	307/63 (4.9:1)	SI	Spine surgery	RaD	—	—	Re-Op
Guan et al. 2018	201/4 (50.3:1)	QOD	Lumbar fusion	RaD	—	—	NRD
Hardman et al. 2022	40,041/4959 (8.1:1)	NIS	ACDF	RaD	Respiratory	—	—
Kashkoush et al. 2019	263,765/28,601 (9.2:1)	NIS	ACDF	RaD	—	—	Mortality
Kerezoudis et al. 2019	150,635/16,112 (9.4:1)	NSQIP	Cranial and spine surgery	RaD	—	—	Re-Op
Kim et al. 2018	4703/441 (10.7:1)	NSQIP	Spinal fusion	RaD	Cardiovascular, DVT/PE	Wound complication	Mortality
Knusel et al. 2020	4676/1577 (2.9:1)	NSQIP	Posterior lumbar decompression	RaD	—	Hematoma	—
Kohls et al. 2018	307/36 (8.5:1)	SI	Lumbar discectomy	RaD	—	—	Re-Ad
Lad et al. 2013	1052/336 (3.1:1)	Medicaid dataset	Lumbar laminectomy/ Fusion	RaI	Cardiovascular, DVT/PE, GU, neurologic, respiratory	Wound complication, infection complication	LOS, Re-Op
Lee et al. 2017	4709/442 (10.7:1)	NSQIP	Spinal fusion	RaD	—	Wound complication	—
Lee et al. 2018	2008/163 (12.3:1)	NSQIP	Posterior lumbar fusion	RaD	—	—	Re-Ad
Macki et al. 2021	16,788/1436 (11.7:1)	SSID	Lumbar spine surgery	RaI	GU	—	NRD, LOS, Re-Ad
Malik et al. 2018	19,620/1914 (10.3:1)	NSQIP	Posterior lumbar fusion	RaD	—	—	NRD
Marquez-Lara et al. 2014	147,671/15,309 (9.7:1)	NIS	ACF	RaD	Respiratory	—	—
Mohanty et al. 2022	2024/596 (3.4:1)	SI	Spine surgery	RaD	—	—	Re-Ad
Mummaneni et al. 2021	852/160 (5.3:1)	QOD	Cervical spine surgery	RaD	—	—	NRD
Murphy et al. 2017	7192/487 (14.8:1)	NSQIP	Lumbar decompression	RaD	—	—	NRD
Nandyala et al. 2014	6923/847 (8.2:1)	NSQIP	Cervical spine surgery	RaD	Respiratory	—	—
Ogura et al. 2020	1307/147 (8.9:1)	SI	Lumbar fusion	RaD	—	—	NRD
Park et al. 2018	6378/628 (10.2:1)	SSID	Lumbar fusion	RaD	—	—	Re-Ad
(a)Passias et al. 2018	1743/88 (19.8:1)	NSQIP	Thoracic lumbar surgery	RaD	—	—	NRD
(b)Passias et al. 2018	51,895/4325 (12:1)	NSQIP	Spine surgery	RaD	Cardiovascular	—	—
Passias et al. 2022	179,802/13,374 (13.4:1)	NSQIP	Spine surgery	RaD	MI	—	—
Phan et al. 2017	1252/153 (8.2:1)	NSQIP	ACDF	RaD	—	—	Re-Ad

(continued)

Table 1. (continued)

Journal article	Sample size White/Black (White:Black)	Database	Surgery type	Variable type	Medical complications	Surgical complications	Post-Op outcomes
(a)Poorman et al. 2018	220,082/25,991 (8.5:1)	NIS	Cervical spine surgery	RaD	—	—	Mortality
(b)Poorman et al. 2018	529,044/39,988 (13.2:1)	NIS	Lumbar spine surgery	RaD	—	—	Mortality
Pugely et al. 2014	13,141/912 (14.4:1)	NSQIP	Lumbar spine surgery	RaD	—	—	Re-Ad
Quinn et al. 2017[b]	51,397/5072 (10.1:1)	NSQIP	Cranial and spinal surgery	RaD	Cardiovascular	—	—
Sanford et al. 2019	4106/522 (7.9:1)	NSQIP	Spine surgery	RaI	Cardiovascular, DVT/PE, GU, neurologic, respiratory	Wound dehiscence, wound infection	LOS, Re-Ad, Re-Op
Schoenfeld et al. 2012	1367/101 (13.5:1)	SPORT	Spine surgery	RaI	—	Wound infection, Hematoma	LOS, mortality, Re-Op
Seicean et al. 2017[a]	3489/3489 (1:1)	NSQIP	Laminectomy/Fusion	RaI	Cardiovascular, DVT/PE, GU, neurologic, respiratory	Wound disruption, wound infection	NRD, LOS, mortality, Re-Ad
Sivaganesan et al. 2019	29,876/2277 (13.1:1)	QOD	Lumbar spine surgery	RaD	—	—	Re-Ad
Skolasky et al. 2014	851,641/86,541 (9.8:1)	NIS	Cervical spine surgery	RaI	Cardiovascular, neurologic, respiratory	Hematoma, operative wound, wound infection	Mortality
Snyder et al. 2019	6633/1117 (5.94:1)	NSQIP	PCDF	RaD	—	—	NRD
Thirumala et al. 2017	1,142,902/125,547 (9.1:1)	NIS	Spinal fusion	RaD	Neurologic	—	—
Wick et al. 2022	6007/646 (9.3:1)	Vizient	Cervical spine surgery	RaI	—	—	LOS, Re-Ad
Woodard et al. 2022	199/79 (2.5:1)	SI	ACDF	RaI	—	—	NRD, LOS, Re-Ad, Re-Op
Ye et al. 2018	2242/376 (5.9:1)	NSQIP	Posterior cervical fusion	RaD	—	—	NRD
Zakaria et al. 2019	4582/602 (7.6:1)	SSID	Cervical spine surgery	RaD	GU	—	Re-Ad

[a]Matched data was extracted for analysis.
[b]Study reports on both cranial and spinal surgery, cranial data was not collected
GI = Gastrointestinal, GU = Genitourinary, HCUP = Healthcare Cost and Utilization Project, KID = Kids Inpatient Database, NIS = National Inpatient Database, NRD = Non-Routine Discharge, NSQIP = ACS NSQIP, Optum EHR = Optum Electronic Health Records, QOD = Quality Outcomes Database, Re-Ad = Re-Admission, Re-Op = Re-Operation, SI = Single Institution, SSID = Michigan Spine Surgery Improvement Collaborative.

Table 2. Summarizing the List of Post-Operative Complications Gathered from Included Studies and the Classification Scheme Implemented in this Study.

Outcome type (total studies)	Outcome subtype tier 1 (total studies)	Outcome subtype tier 2 (total studies)
General complications (15)	Any complication (15)	—
Medical complications (27)	Cardiovascular complication (12)	Myocardial infarction (3)
		Cardiac arrest (3)
		Acute post-Hemorrhagic Anemia (2)
		Cardiac Arrest or MI (1)
		Hypertension (1)
		Hypotension (1)
		Post-Op shock (1)
		Peripheral vascular complication (1)
	DVT/PE (11)	—
	Neurologic complication (10)	Stroke (4)
		Delirium (2)
		Sensory deficit (1)
		Altered mental status (1)
		Nervous system complication (1)
		Coma (1)
		Central nervous system complication (1)
		Visual loss (1)
	Genitourinary (10)	UTI (6)
		Renal/Urinary (3)
		Urinary Retention (3)
		D/C with Foley (1)
	Respiratory complication (10)	Pneumonia (4)
		Unplanned Reintubation (4)
		Prolonged ventilation (2)
	Systemic infection (4)	Sepsis (3)
		Other infection (1)
	Other medical (3)	Opioid Overdose (2)
		ICU-transfer change (1)
	Gastrointestinal (2)	Ileus (1)
Surgical complications (16)	Wound complication (16)	Wound infection (9)
		Hematoma (7)
		Superficial surgical site infection (4)
		Deep surgical site infection (3)
		Surgical site infection (3)
		Infectious complication (3)
		Organ space surgical site infection (2)
		Post-Op infection (2)
		Wound dehiscence (2)
		Wound disruption (2)
		Cellulitis (1)
		Wound drainage (1)
		Post-Op bleeding (1)
		Operative wound (1)
Post-Op outcomes (43)	Re-admission (20)	—
	Discharge disposition (18)	—
	Mortality (9)	—
	Re-operation (8)	—

(n) reflects the number of studies each complication was included in. For categories of complications (i.e., Cardiovascular), the (n) denotes the number of studies in which the complication category or any of the sub-complications in that category was included.

Table 3. Summarizing the Post-Operative Complications that were Reported in Included Studies but were not Extracted for the Purposes of this Review.

Removed outcome type (total studies)	Removed outcome subtype (total studies)
Medical complications (5)	Extended LOS (3) Fever (1) Weakness (1) Pain (1) Anesthesia-related (1) Neuro-dural injury (7)
Surgical complications (11)	Durotomy (2) Nerve root injury (3) Dural injury (1) Nerve cord injury (1) Spinal fluid Leak or dural tear (3) Peripheral nerve injury (1) Spinal cord injured (1) Hardware related (4) Device complication (2) Hardware failure (1) Displaced fixation device (1) Prosthesis failure (1) Other surgical (6) Dysphagia (4) Vascular injury (1) Disc Herniation or Listhesis (1) Carotid or vertebral injury (1) Adjacent level disease (1) Pseudoarthrosis (2) Fusion rate (1) Radicular finding (1)

(n) reflects the number of studies each complication was included in. For categories of complications (i.e., Medical), the (n) denotes the number of studies in which the complication category or any of the sub-complications in that category was included.

Due to the inconsistent methods used to report complications in the available literature, a systematic survey of all included studies was performed. All complications reported within 90 days of surgery were gathered using the most granular data provided by the authors. We recorded each complication as it was described by the original authors. Complications were excluded if they were (1) not a medically relevant complication as determined by the senior author (MSF); or (2) iatrogenic complications (i.e., dural tears or hardware malposition). Included and excluded complications and their categorizations are summarized in Tables 2 and 3, respectively. The remaining complications were grouped into 8 medical (Cardiovascular, DVT/PE, Gastrointestinal, Genitourinary, Systemic Infection, Neurologic, Respiratory, Other) sub-categories and one surgical sub-category (Wound Complications). If a study reported more than one complication in a single sub-category, the incidence of all associated complications was ascribed to that category. If studies presented both matched and un-matched cohorts, matched data was preferentially extracted. For studies published by the same author in the same year, (a) and (b) in the author's name was used to distinguish between studies. Appendix A2 shows cases where exceptions in data extraction occurred.

Quality Assessment and Strength of Evidence

The Newcastle-Ottawa Scale was used to evaluate retrospective cohort studies (Appendix A3). Authors IA and NK independently judged the quality of all eligible studies, with disagreements settled by the senior author (MSF).

Statistical Analysis

Statistical analyses were performed using RStudio 4.1.2.[21] Pooled outcomes and complication rates were calculated for AA and White cohorts. Eleven comparative meta-analyses were performed based on the categories of peri-operative outcomes and post-operative complications detailed above.

Odds ratios (OR) and 95% confidence intervals (CI) were calculated as pooled metrics using the Mantel-Haenszel method. For medical complications, one analysis was performed each for cardiovascular, DVT/PE, genitourinary, neurologic, and respiratory complications. A general analysis was done for all medical complications, which included the above and gastrointestinal, systemic infectious, and other complications that had too few member studies to merit their own sub-

category analysis. An additional sub-analysis was performed for wound complications.

Heterogeneity was assessed using I^2 statistics. If there was no evidence of substantial heterogeneity ($I^2 \leq 50\%$), a fixed-effect model was used. The risk of publication bias was evaluated using a funnel plot analysis on the 4 peri-operative events, all medical complications, and wound complications. (Appendix B1).

Due to the significant variability in the sample sizes of the included works, which ranged from hundreds to hundreds of thousands of patients, each analysis was run in 3 different ways: (1) all studies, (2) studies with <100,000 patients, and (3) studies sourced from a single institution (SI). This ensured that large cohort sizes did not drown out the pooled effects of comparatively smaller studies and that the inter-reliability of different data sources could be investigated. Forest plots showing "all studies" were used as our primary finding and are presented in the text. Forest plots for analyses with <100,000 patients and SI subsets of data are shown in Appendix B2 and B3.

Results

Search Results

Database queries retrieved a total of 1023 results. No further studies were identified through other sources or via direct reference list review. After abstract and full-text screening, a total of 59 studies and 5,746,520 patients (9.6% AA) were included in the present review (Table 1). Figure 1 details our PRISMA screening process. All studies were retrospective cohort studies, 10 were SI, and 12 had more than 100,000 patients. Only 3 studies provided propensity-matched data.[22-24]

Overview of Findings

Table 4 shows a summary of the OR values, *P*-values, number of studies (k), and heterogeneity (I^2) from each of the 3 data source subsets across the 11 meta-analyses that were performed. When comparing across studies with different sample sizes, SI studies had less heterogeneity, with all 11 meta-analyses employing a fixed effects model ($I^2 \leq 50\%$) compared with just 3/11 meta-analyses that included all studies. All meta-analyses (and subset analyses) showed OR values favoring White patients except for All Medical (SI), DVT/PE (SI), Neurologic (SI), and Respiratory (SI). The smallest and largest significant OR values were 1.16 (GU) and 2.2 (DVT/PE). The Forest plots of the subset analyses for the <100,000 patient and SI subsets are shown in Appendix B2 and B3.

Re-Admission

Twenty-one studies comprising 331,399 patients were included in our meta-analysis for 90-day re-admission, of whom 9.0% were AA (Figure 2). Pooled analysis showed that AA patients were more likely to have a 90-day re-admission than White patients (OR 1.27, $P < .0001$), a difference that persisted across all subset-analyses. OR values ranged from 1.27 to 1.77, with smaller sample size studies reporting greater OR values.

Non-Routine Discharge

Eighteen studies comprising 570,611 patients (8.5% AA) were considered when pooling results for NRD (Figure 3). Results showed a significant difference favoring Whites (OR 1.71, $P = .0001$). This difference persisted across all data subsets, with OR values ranging between 1.69 and 1.80.

Table 4. Summary of OR Values, *P*-values, Number of Studies (k), and Heterogeneity (I^2) for 11 Outcomes and Across 3 Subsets of Included Studies: All studies, <100,000, and Single Institution (SI).

	OR	*P*-value	k (studies)	I^2 (%)
	All/<100,000/SI			
Peri-Op events				
Re-admission	**1.27/1.42/1.77**	0/0/0	21/19/8	47/27/13
Non-routine discharge	**1.71/1.8/1.69**	0/0/0.01	18/16/2	92/69/45
Re-operation	1.16/1.08/1.08	.17/0.35/0.76	8/7/2	72/50/0
Post-Op complications				
Mortality	**1.56**/1.24/—	0/0.08/—	10/5/—	82/26/-
All medical	**1.38/1.38**/0.95	0/0/0.80	27/21/4	94/69/35
Cardiovascular	**2.11**/1.48/1.31	.01/0.05/0.61	12/10/4	64/65/0
DVT/PE	**1.44/2.2**/0.39	.01/0.02/0.07	12/11/2	60/66/0
Genitourinary	**1.16/1.16**/1.31	.04/0.04/0.61	10/10/4	0/0/0
Neurologic	1.36/1.48/0.65	.21/0.32/0.35	11/7/1	97/81/-
Respiratory	**1.38**/1.33/0.41	.04/0.25/0.20	11/8/2	77/70/0
Wound	**1.47/1.38**/1.35	0/0/0.34	16/15/4	0/0/0

OR values with significance ($P < .05$) are bolded.

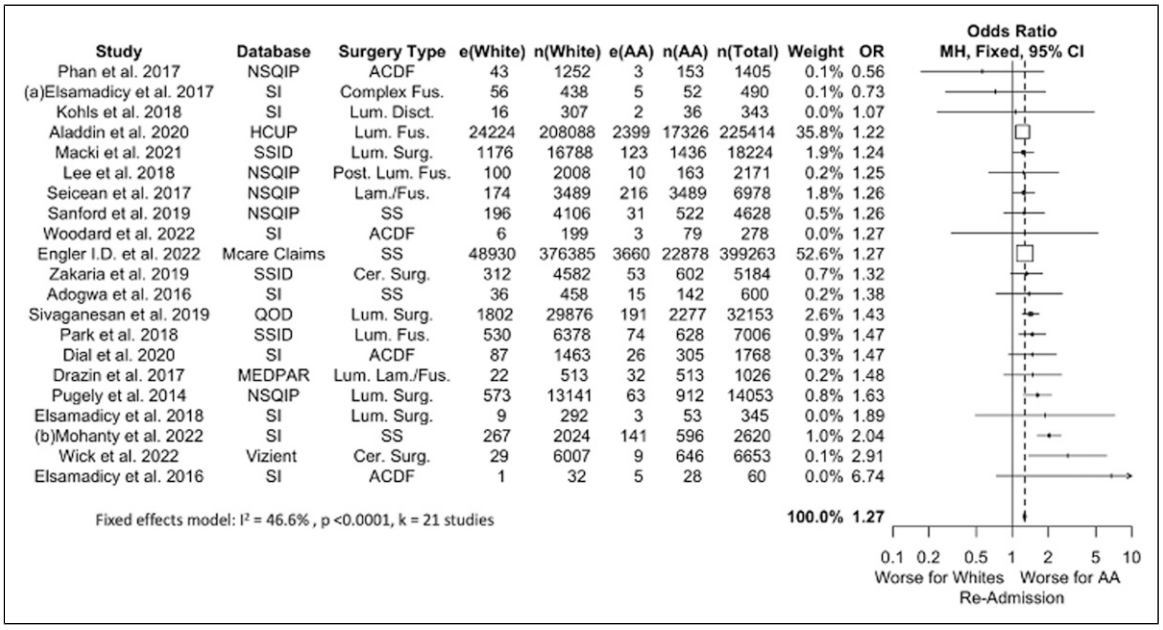

Figure 2. Meta-analysis with a fixed effects model of all studies reporting re-admission complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. Cer. = Cervical, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, Post. = Posterior, SS = Spine Surgery, Surg. = Surgery.

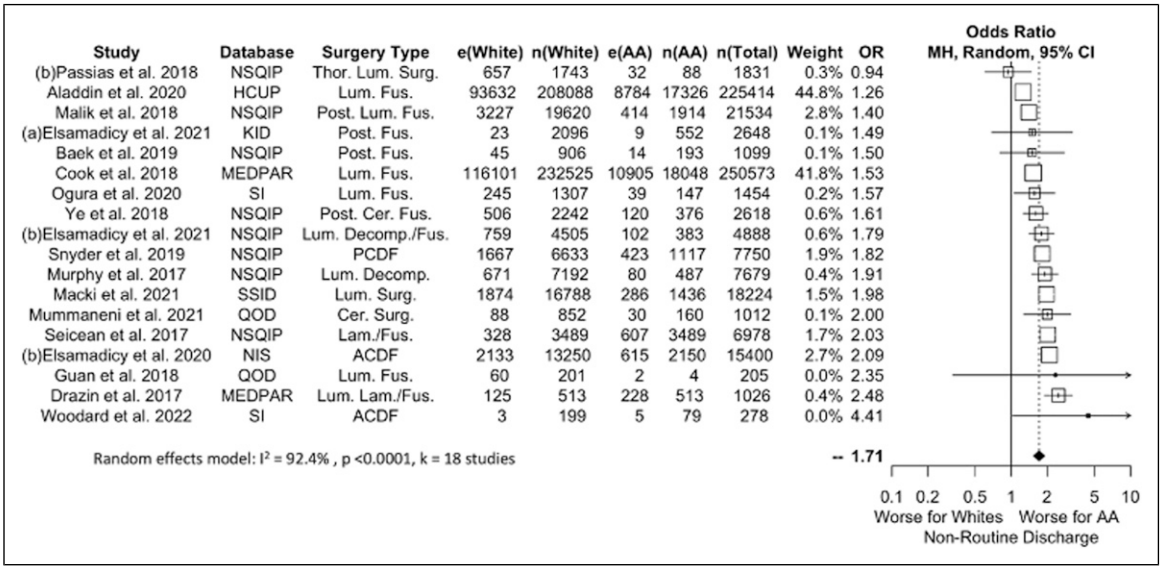

Figure 3. Meta-analysis with a fixed effects model of all studies reporting non-routine discharge complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. Cer. = Cervical, Decomp. = Decompression, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, Post. = Posterior, SS = Spine Surgery, Surg. = Surgery, Thor. = Thoracic.

Re-Operation

A pooled analysis of re-operation rates is shown in Figure 4. Eight studies were included, with data from 201,107 patients (11.3% AA). No significant differences were detected between AA and White patients (OR 1.16, P = .1354), an effect that persisted when considering different data subsets (OR range: 1.08-1.16).

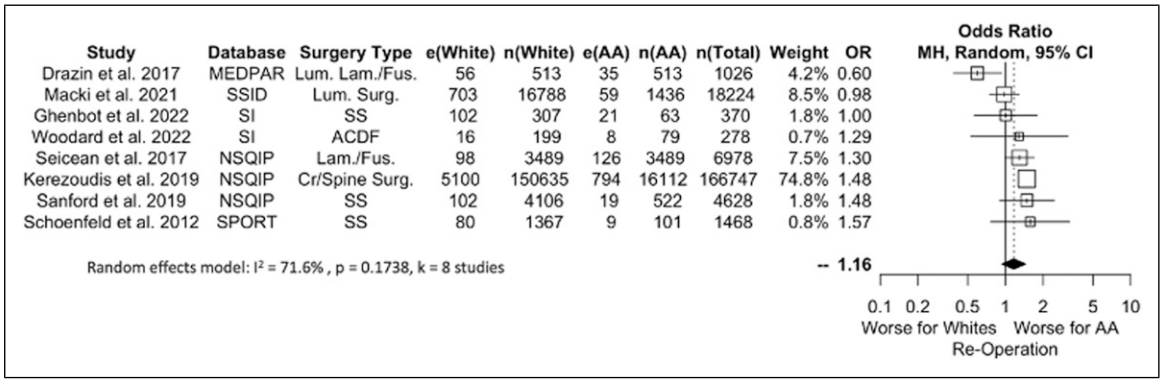

Figure 4. Meta-analysis with a fixed effects model of all studies reporting re-operation complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. Cr. = Cranial, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, SS = Spine Surgery, Surg. = Surgery.

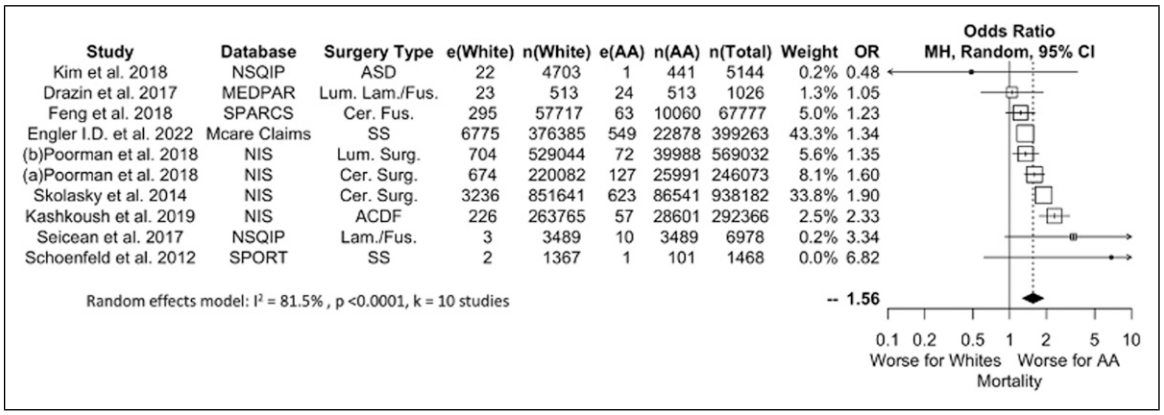

Figure 5. Meta-analysis with a fixed effects model of all studies reporting mortality complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. ASD = Surgery for Adult Spinal Deformity, Cer. = Cervical, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, SS = Spine Surgery, Surg. = Surgery.

Mortality

Ten studies comprising 1,559,014 patients (10.0% AA) considered mortality (Figure 5). AA patients were 1.56 times more likely to die following elective spine surgery ($P < .0001$). This finding was not significant when considering the 5 studies that included <100,000 patients. No analysis of SI findings could be performed due to a lack of SI studies. OR values ranged from 1.24 to 1.56.

Post-Operative Complications

Medical Complications. The pooled analysis for patients experiencing a medical complication is shown in Figure 6. Twenty-seven studies were included for a total of 3,863,527 patients (9.8% AA). Medical complications were significantly more common in AA vs White patients (OR 1.38, $P = .0001$).

A complication sub-analysis identified significant differences between AA and White patients in the incidence of Cardiovascular (12 studies, OR 1.44, $P = .0126$), DVT/PE (12 studies, OR 2.11, $P = .0103$), Genitourinary (10 studies, OR 1.16, $P = .0399$), and Respiratory (11 studies, OR 1.38, $P = .0407$) complications. Neurologic (11 studies, OR 1.36, $P = .2081$) complications failed to show a difference between AA and White patients. Forest plots of individual medical complications are shown in Appendix B2 and B3.

When studies with <100,000 patients were considered alone, only DVT/PE and GU complications were significantly different between White and AA patients. The non-significance in Cardiovascular and Respiratory complications in this sub-analysis is likely because both analyses included small sample size studies with OR values favoring AA patients.[13,25-27] (See Appendix B2). Neurologic and Respiratory complications were not significant regardless of data source.

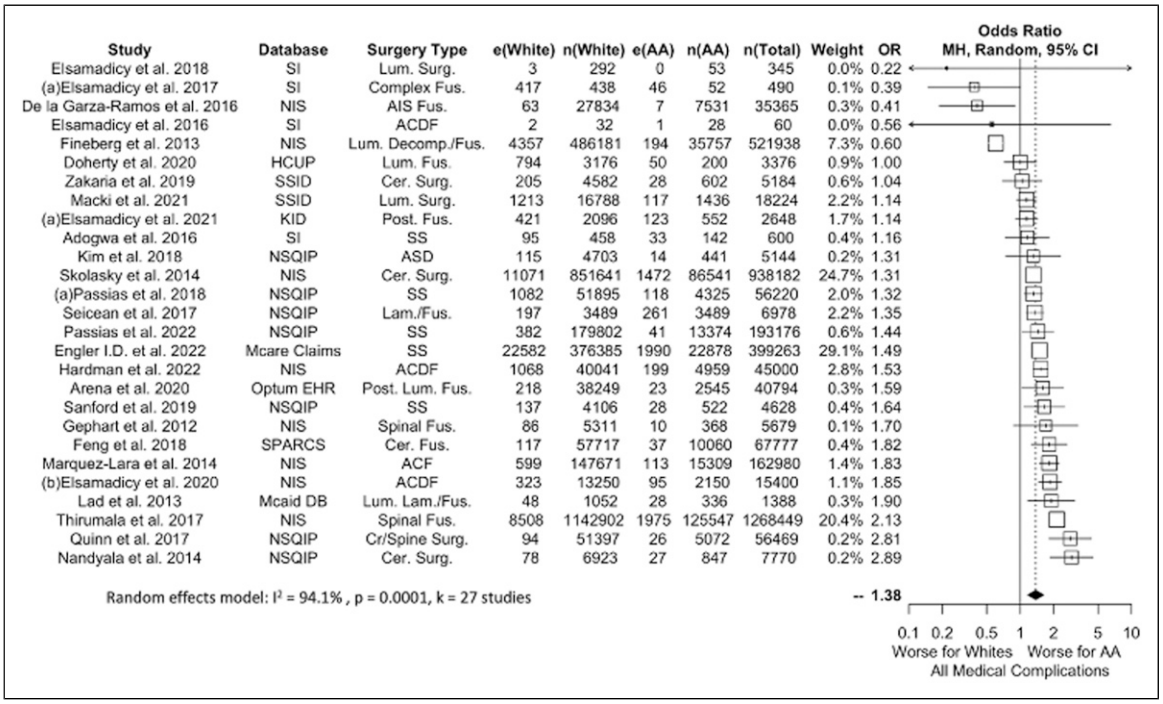

Figure 6. Meta-analysis with a fixed effects model of all studies reporting all medical complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. ASD = Surgery for Adult Spinal Deformity, Cer. = Cervical, Cr. = Cranial, Decomp. = Decompression, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, Post. = Posterior, SS = Spine Surgery, Surg. = Surgery.

Surgical Complications. Sixteen studies reported surgical complications related to wound healing, comprising a total of 1,057,538 patients (9.2% AA, Figure 7). Results favored White patients (OR 1.47, P = .0001), and this significance persisted across all data sources except for SI. This was likely due to the small number of SI studies (k = 4). OR values ranged from 1.38-1.47 across significant results.

Discussion

The goal of this review was to quantify the relative risk of perioperative events and post-operative complications in AA patients compared with White patients after elective spine surgery in the United States. Our systematic review and meta-analysis showed that AA patients were more likely to experience a re-admission, a non-routine discharge, and mortality during the perioperative period. AA patients were also more likely to have medical (All Medical, Cardiovascular, DVT/PE, Genitourinary, and Respiratory) and surgical (Wound) complications. Our analyses did not show any significant difference in neurologic complications, nor did the increased rate of wound complications translate into an increased rate of re-operation. Based on funnel plot analysis, our results indicate minimal publication bias.

It was our goal to determine whether race is a vulnerability factor in the setting of spine surgery in the AA community. The meta-analysis by Schoenfeld et al[15] reported that AA patients had a higher likelihood of having an unfavorable outcome than White patients, which is consistent with the findings of the present work. We found that the greatest differences in complication rates between White and AA patients were for those complications that are likely attributable to aspects of post-operative management that are most affected by socioeconomic factors. Non-routine discharge can be the result of an inability to afford or be covered by insurance for adequate at-home care, or of the lack of family and community support during the postoperative period.[28] Wound complications can arise from improper home-management and have been associated with minority race.[29] DVT/PE has been associated with reduced mobility and poor adherence to post-operative physical therapy,[30] which has been shown correlate with socioeconomic factors, namely AA vs White race.[31] DVT/PE complications were particularly notable in our analysis, with AA patients 2.11 times more likely to experience a thromboembolic event than White patients. Socially associated risk factors, such as hypertension and diabetes, were more incident in minority patients and have been shown to delay wound healing and increase the risk of a DVT/PE.[32] Re-admission can also result from an inability to manage post-operative care at home, which may be a challenge in lower-income households due to the lack of community resources.[33] Patients sent to rehabilitation centers are

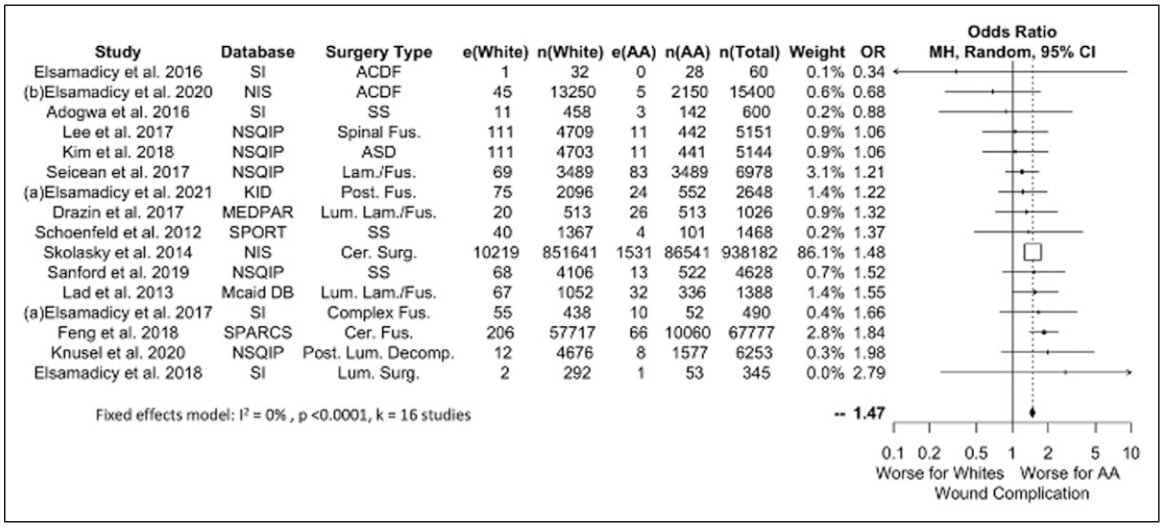

Figure 7. Meta-analysis with a fixed effects model of all studies reporting would related complications for AA versus White cohorts. OR=odds ratio. e(AA) = number of adverse events in AA patients. n(AA) = sample size of AA patients. e(White) = number of adverse events in White patients. n(White) = sample size of white patients. N(Total) = total sample size in study. Cer. = Cervical, Decomp. = Decompression, Fus. = Fusion, Lam. = Laminectomy, Lum. = Lumbar, Post. = Posterior, SS = Spine Surgery, Surg. = Surgery.

also more likely to be sent to the ER for complications that could have otherwise been managed at home with close observation (such as transient fevers without hemodynamic instability).

Despite differences in re-admission and wound complication rates, it is notable that re-operation rates between AA vs White patients were equivalent despite higher adverse event rates in the former. This finding was echoed by Lad et al and Khan et al,[16,34] although our finding persisted even when iatrogenic complications (such as dural tears and hardware malposition) were omitted from our analysis. This work's exclusion of iatrogenic peri-operative re-operations we believe makes it more reflective of patient socioeconomic support and peri-operative optimization.

Differences between AA and White patients after elective spine surgery are more reflective of the social disparities that exist between these groups rather than any genetic predisposition towards complication. Haider et al[7] found that contributing factors to racial disparities included socioeconomic status, insurance status, provider factors, access to care, hospital volume, and hospital patient population. Feng et al[35] and Schoenfeld et al[36] have shown that AA patients were more likely to undergo spine surgery at low-volume centers, which have been consistently shown to be associated with worse outcomes compared with high volume centers due to factors that likely include limited resources, fewer specialists, and slower adaptation of new technology.[37-39] Jancuska et al[40] demonstrated that AA patients face significant barriers to being treated at larger and higher-quality centers, highlighting a systematic pitfall in our current healthcare system.

AA patients are more likely to be either uninsured[41] or on Medicaid in the United States.[42] Safety-net hospitals predominantly treat these patients and have been shown to have worse post-operative outcomes.[43] Aladdin et al[33] illustrated this association, reporting that AA patients were more likely to have undergone surgery at safety-net hospitals and had higher odds of 30-day and 90-day re-admissions. These differences are likely the result of a combination of factors that impact the quality of safety-net hospital care, which include limited resources, staff shortages, a higher incidence of failure to rescue, and a general lack of specialized coordinated care.[44,45]

Patient-specific factors are important contributors to outcomes after spine surgery. Obese patients have been shown to have an increased incidence of complications after spine surgery (DVT and surgical site infection),[46,47] as have people with diabetes.[48,49] Drazin et al[22] reported a higher incidence of both of these comorbidities among AA patients undergoing spine surgery, and Aladdin et al[33] similarly showed a higher comorbidity burden among minority groups.

Such disparities may also influence how minority racial groups interact with the health care system.[50] Arega et al[51] reported that AA patients are less likely to choose operative management compared with other racial groups. Although the ratio of White to AA people in the United States is 5.74:1,[52] most of the studies in this present review had a lower subset of AA patients (Table 1). There is thus a concern that AA patients experience greater delays in obtaining treatment, which in the setting of degenerative spine disease can lead to a higher risk of disability.[53,54]

Forest plot analyses utilizing studies stratified by data origin and sample size largely yielded consistent results with small deviations in effect size. However, SI studies were not able to replicate the same significance seen when database-

derived papers were also included. This was likely because (1) relatively fewer studies were included when only SI studies were considered, making them less likely to achieve significance, and (2) SI studies are likely to be underpowered for reliably detecting rare complications. This is evidenced by the fact that many outcomes and complication categories had an incidence of 0 in SI studies. Our findings on mortality in particular highlighted this discrepancy. When larger sample size studies were included (all studies), the data showed a significant difference between White and AA patients in agreement with prior evidence in the field.[55-58] Smaller sample studies (<100,000) failed to show this difference.

The studies included in our analysis do not control for the socioeconomic determinants examined above or other systemic parameters such as area deprivation, which is associated with negative outcomes following spine surgery.[59,60] One study showed that the effect of race on outcomes following spine surgery is negligible after controlling for systemic factors such as social vulnerability.[61] This suggests that different post-operative outcomes between White and AA patients are rooted in structural differences in access and barriers to healthcare. Changes in policy, education and representation of healthcare staff, and childhood development are among the systemic changes that are required to address these spine surgery outcome differences.[62,63] Surgical care changes that can also be implemented to improve this outcome disparity include enhanced recovery after surgery (ERAS) protocols. ERAS is a multidimensional approach for promoting recovery after surgery, and included counseling and optimization during the pre-admission period, avoidance of prolonged fasting, pre-operative multimodal analgesia, prevention of hypothermia, appropriate fluid management, antimicrobial prophylaxis, blood conservation during surgery, early oral nutrition, thromboembolism prophylaxis, and early post-operative mobilization.[64] ERAS principles have only recently been applied to spine surgery due to barriers such as cultural and institutional reluctance to change and increased demands on workforces and resources.[65] Introductory studies demonstrate that spine ERAS protocols can reduce lengths of stay, reduce post-operative complications, accelerate return of function, minimize post-operative pain, and save money.[66] Patients who had greater compliance with ERAS items had fewer post-operative complications, regardless of whether or not the center had an established ERAS protocol.[67]

Beyond ERAS, increased patient engagement through patient portals, mobile health applications, and chatbots can provide post-operative benefits.[68] A study by Eastwood et al. found that a single 2-hour educational session prior to spinal fusion surgery can reduce emergency room utilization, improve patient satisfaction, and alleviate back pain[69] Furthermore, text messages or digital applications designed to facilitate smoking cessation, modify physical activity, and better manage hypertension and diabetes can optimize the preoperative physical readiness, which is a major determinant of post-operative outcome. Activity trackers and wearable devices (e.g., pedometers, pulse oximeter, blood pressure monitors) may also be useful for monitoring early mobilization, and electronic checklists can be used to reinforce compliance with early recovery protocol elements.[70]

Limitations

It should primarily be noted that this study is based on a meta-analysis of studies from a single nation (the United States of America). Racial data is unlikely to be generalizable to other nations around the globe for myriad historical, social, economic, and political reasons. An additional key limitation of this review comes from the source of the underlying data, which was all collected retrospectively. Most studies were judged to be "good" by the Newcastle-Ottawa grading scale. All included studies were retrospective in design, which creates a susceptibility to residual confounding and allocation bias. Our results also show significant heterogeneity in most measures. This finding is likely a result of the scope of the review, which included all elective spine surgeries for degenerative disorders, which include a wide range of pathologies. Second, we did not perform sub-analyses for elective surgeries of differing intensity or in different spinal regions. This is another confounder because certain procedures might incur a higher risk of a poor outcome compared with others. Additionally, we did not select for studies focusing on adults only. Given that adolescents are susceptible to different complication risks, this created further heterogeneity in our pooled analyses. However, only 6 studies included adolescent patients.[71-76] A further weakness is that we included studies with various sample sizes, which likely had differing levels of controlled variables, assuming that a single institution is exposed to fewer confounding variables than a million patient database. Many studies also drew data from the same databases, for example NSQIP was used in 20 studies. Although each paper had different criteria for patient selection, it is likely that the same patients were counted more than once in our pooled analysis. Finally, other racial groups were not included in our analysis. Although several studies have reported disparities in Hispanic, Asian, Native American, and other racial groups, the available data was not consistent and did not allow for a robust analysis, precluding effective pooling. Our results are therefore not generalizable to other racial minorities. Patients in "Other" or "Not Reported" racial groups might introduce a selection bias, as race is a self-reported metric and some patients might have chosen not to identify themselves.[77,78]

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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