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The Impact of Neighborhood Socioeconomic Disadvantage on Operative Outcomes after Single-Level Lumbar Fusion

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■ INTRODUCTION: **The relationship between socioeconomic status and neurosurgical outcomes has been investigated with respect to insurance status or median household income, but few studies have considered more comprehensive measures of socioeconomic status. This study examines the relationship between Area Deprivation Index (ADI), a comprehensive measure of neighborhood socioeconomic disadvantage, and short-term postoperative outcomes after lumbar fusion surgery.**

■ METHODS: **1861 adult patients undergoing single-level, posterior-only lumbar fusion at a single, multihospital academic medical center were retrospectively enrolled. An ADI matching protocol was used to identify each patient's 9-digit zip code and the zip code-associated ADI data. Primary outcomes included 30- and 90-day readmission, emergency department visits, reoperation, and surgical complication. Coarsened exact matching was used to match patients on key demographic and baseline characteristics known to independently affect neurosurgical outcomes. Odds ratios (ORs) were computed to compare patients in the top 10% of ADI versus lowest 40% of ADI.**

■ RESULTS: **After matching (n = 212), patients in the highest 10% of ADI (compared to the lowest 40% of ADI) had significantly increased odds of 30- and 90-day readmission (OR = 5.00, $P < 0.001$ and OR = 4.50, $P < 0.001$), ED visits (OR = 3.00, $P = 0.027$ and OR = 2.88, $P = 0.007$), and reoperation (OR = 4.50, $P = 0.039$ and OR = 5.50, $P = 0.013$). There was no significant association with surgical complication (OR = 0.50, $P = 0.63$).**

■ CONCLUSIONS: **Among otherwise similar patients, neighborhood socioeconomic disadvantage (measured by ADI) was associated with worse short-term outcomes after single-level, posterior-only lumbar fusion. There was no significant association between ADI and surgical complications, suggesting that perioperative complications do not explain the socioeconomic disparities in outcomes.**

INTRODUCTION

There has been increasing awareness that health outcomes are strongly affected by social determinants of health (SDOH).[1] The World Health Organization (WHO) defines SDOH as "the conditions in which people are born, grow, live, work and age,"[2] including factors such as socioeconomic status, education, neighborhood and physical environment, employment, and social support.[3,4] These SDOH operate at the preoperative, perioperative, and postoperative phases of care to effect surgical disparities.[4]

Key words
- Area deprivation index
- Health disparities
- Lumbar fusion
- Socioeconomic status
- Social determinants of health
- Spinal fusion

Abbreviations and Acronyms
ADI: Area Deprivation Index
ASA: American Society of Anesthesiologists
BMI: Body mass index
CCI: Charlson Comorbidity Index
CEM: Coarsened exact matching
ED: Emergency Department
IRB: Institutional Review Board
OR: Odds Ratio
SDOH: Social Determinants of Health

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Across neurosurgical procedures, prior work has shown disparities in patient outcomes (e.g., readmission rate, postoperative complications, and postoperative mortality) according to gender,[5-7] race,[8-16] and measures of socioeconomic status such as insurance status[9,11,12,17] and median household income.[5,18] Much of this literature examined the impact of individual SDOH, but it is important to recognize that multiple SDOH often interact in complex and interconnected causal pathways[2]; for example, several studies show that socioeconomic differences may explain a large part,[16,19-21] but perhaps not all,[2] of the black-white disparity in health outcomes. To capture the effect of complex interactions between SDOH, Figueroa et al. (2020) argue that we should not examine individual SDOH separately, but rather, examine multiple SDOH in aggregate through the development of polysocial risk scores.[22]

To this end, the Area Deprivation Index (ADI) considers 17 education, employment, housing quality, and poverty measures to formulate a single index of neighborhood socioeconomic disadvantage,[23] thus capturing many SDOH at the area/neighborhood level.[24] The ADI for any given patient can be identified simply with a zip code, thus providing locally sensitive information about SDOH[25] without requiring researchers to acquire large datasets with granular social information for each patient.

Across many fields of medicine[26,27] and surgery,[28,29] higher ADI (i.e., greater socioeconomic disadvantage) has been shown to be associated with worse health outcomes. However, there has been limited study of ADI within the neurosurgery literature. Prior work showed an association between high ADI and worse patient-reported outcomes,[30] and longer length of stay (LOS)[31,32] after cervical and lumbar spine surgery, as well as increased loss to follow-up after acute subdural hematoma evacuation.[33] There is a need to study the relationship between ADI and other neurosurgical outcome measures, such as the outcomes commonly assessed in value-based care models (e.g., 30 and 90-day readmissions, complication rate).[34] Prior work has shown that appropriately selected patients experience an increase in healthcare-related quality of life (QOL) after spine surgery.[35,36] In order to improve equity and increase access to the benefits of spine surgery, ADI could be used to develop and test interventions aimed at improving outcomes for socioeconomically disadvantaged populations.

This study examines the relationship between ADI and surgical outcomes among patients undergoing single-level, posterior-only lumbar fusion at a single, multihospital academic medical center. Coarsened exact matching (CEM) is performed to minimize confounding while comparing patients with the greatest socioeconomic disadvantage and patients with the least, as measured by ADI.

METHODS

Sample Selection

Consecutive patients undergoing single-level, posterior-only, nonrevision lumbar fusion surgery across a single, multihospital academic medical center from June 7, 2013 to April 29, 2019, were retrospectively enrolled. This study was approved by the Institutional Review Board (IRB) at the University of Pennsylvania. The IRB considered this study to be of minimal risk to patients and granted a waiver of informed consent. All ethical guidelines and rules were followed to protect patient privacy.

We included single-level, posterior-only, nonrevision lumbar fusion cases that were performed under general anesthesia and excluded nonelective emergency cases, resulting in a total of n = 1879 cases (**Figure 1**). An ADI matching protocol was developed that used each subject's home longitude and latitude to identify the corresponding 9-digit zip code, which was then cross matched to the ADI data associated with that zip code. 18 subjects were excluded due to missing ADI data because they lived in a Census Block Group with a high population living in group quarters[23] (group living arrangements such as group homes or nursing homes) resulting in a study population of n = 1861. ADI was measured in percentiles (from 1–100) at the national level, with higher ADI signifying increased socioeconomic disadvantage.

Data Collection and Matching

Patient data were acquired with the EpiLog tool and subsequently extracted and pushed into defined spreadsheets. EpiLog is a nonproprietary data acquisition system created by the senior author of the paper and is layered on top of the existing electronic health record to facilitate charting, workflow, and quality improvement.[37] Extracted data included patient demographic information, baseline health characteristics, and postoperative outcomes.

Coarsened exact matching (CEM) was utilized to mitigate the effects of confounding variables and isolate the effect of high versus low ADI on the outcomes of interest. With CEM, an exact match requires that the value of each matching covariate be the same between the 2 subjects.

The CEM analysis compared patients with high ADI (defined as top 10%) and low ADI (defined as lowest 40%). The top 10% cutoff was selected in accordance with prior studies examining ADI in other medical specialties,[38-40] as well as policies from the Centers for Medicare and Medicaid Services (CMS) that provide payment adjustments for beneficiaries in the top ADI decile of the Accountable Care Organization Realizing Equity, Access, and Community Health (ACO REACH model).[41,42]

The high and low ADI groups were matched on the following criteria: age, gender, insurance type, body mass index (BMI), smoking status, American Society of Anesthesiologists (ASA) grade, Charlson Comorbidity Index (CCI) score, presence of any prior surgical intervention, and presence of any surgical intervention in the 30 days preceding the index operation. Matching characteristics were carefully selected based on literature demonstrating that race,[13] smoking status,[43] BMI,[44] CCI score,[45] and ASA grade[46] independently predict morbidity following surgery. Age was matched according to five categories (<50, 50–59, 60–69, 70–79, or ≥80). Gender, insurance type, and smoking status were matched in a binary fashion based on being male or female, having private insurance or non-private insurance, and being a smoker or nonsmoker, respectively. BMI and CCI scores were matched in a ternary fashion based on having a BMI that was <18.5, 18.5–29.9, or ≥30, and having a CCI score that was 1–4, 5–6, or 7–33. All other covariates were exactly matched. Unmatched patients were removed from the dataset and were not included in the matched analysis.

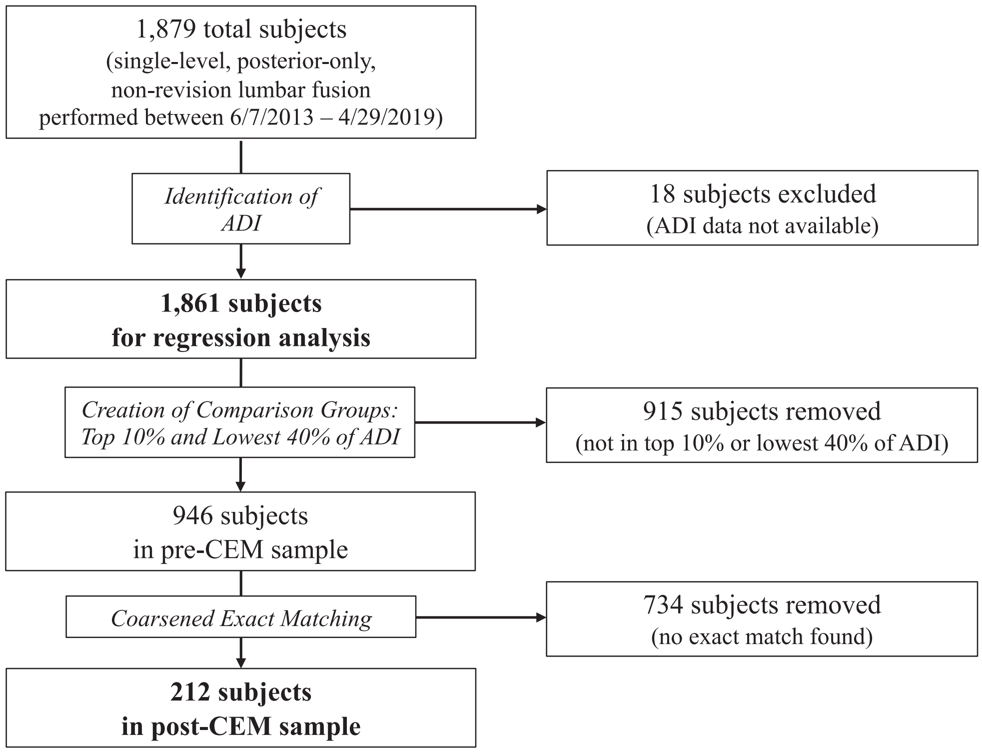

Figure 1. Flowchart of patients selected for analysis and matching.

Statistical Analysis

Primary outcome measures were readmissions, emergency department (ED) visits, and reoperations within 30- and 90-days after the index operation, as well as surgical complications. The secondary outcome measures were mortality within 30- and 90-days after the index operation, as well as discharge disposition (home vs. nonhome destinations).

Before matching, univariate logistic regression was used to compute ORs (with confidence intervals (CIs)) to estimate the effect of ADI on all primary and secondary outcomes. Then, for CEM, binning of the matching variables and removal of missing values was performed using SAS version 9.4 (SAS Institute Inc.). Matching was completed using the MatchIt programming package in R Statistics (R Core Team, 2017), with subsequent analysis executed through SAS version 9.4. After matching, McNemar's test was used to compare all primary and secondary outcomes between the 2 exact-matched groups. Significance for all analyses was set as $P < 0.05$.

RESULTS

Patient Characteristics—Entire Study Sample

Patients undergoing single-level, posterior-only, nonrevision lumbar fusion during a 6-year period (June 7, 2013 to April 29, 2019) who met the inclusion criteria and had ADI data available were included for analysis (n = 1,861, Figure 1).

Patient Characteristics—Prematch and Postmatch Samples

We analyzed n = 946 patients who either had high ADI (defined as ADI in the top decile) or low ADI (defined as ADI in the lowest 4 deciles). Before CEM, patients with high ADI (high socioeconomic disadvantage), compared to patients with low ADI (low socioeconomic disadvantage), were younger (mean age 56.9 vs. 62.6, $P < 0.001$), less likely to be white (21.32% vs. 91.86%, $P < 0.001$), less likely to be privately insured (29.95% vs. 52.34%, $P < 0.001$), more likely to be obese (58.88% vs. 36.98%, $P < 0.001$), and more likely to smoke (25.38% vs. 8.54%, $P < 0.001$) (Table 1).

Using CEM, the high ADI patients were matched with low ADI patients based on characteristics that were previously shown to independently affect neurosurgical outcomes. After CEM, 106 matches (n = 212) were generated. Among these exact matches, there was no significant difference between the 2 groups (high ADI vs. low ADI) across factors known to impact postoperative outcomes, including age, gender, insurance type, BMI, smoking status, ASA grade, CCI score, presence of any prior surgical intervention, and presence of any surgical intervention in the 30 days preceding the index operation (Table 2).

Patient Outcomes—Entire Study Sample

ADI was measured in percentiles based on national data; higher ADI signified increased socioeconomic disadvantage. Each percentile increase (0—100) in ADI was significantly associated with increased odds of 30- and 90-day readmission (OR = 1.02, P

Table 1. Prematch patient characteristics. Characteristics describing the prematch sample of patients in the lowest 40% or highest 10% of area deprivation index (ADI) (n = 946)

Variable	Lowest 40% of ADI (n = 749)	Highest 10% of ADI (n = 197)	*P*-Value*
Age, mean (range)	62.6 (25—88)	56.9 (24—83)	**<0.001**
Gender, n (%)			**0.005**
Male	349 (46.60)	70 (35.53)	
Female	400 (53.4)	127 (64.47)	
Insurance type, n (%)			**<0.001**
Private insurance	392 (52.34)	59 (29.95)	
Nonprivate insurance	357 (47.66)	138 (70.05)	
Body mass index (kg/m^2), mean			**<0.001**
<18.5	2 (0.27)	0 (0.00)	
18.5—29.9	470 (62.75)	81 (41.12)	
>30.0	277 (36.98)	116 (58.88)	
Smoking status, n (%)			**<0.001**
Smoker	64 (8.54)	50 (25.38)	
Non-smoker	683 (91.19)	146 (74.11)	
Unknown	2 (0.27)	1 (0.51)	
American Society of Anesthesiologists Grade, mean (range)	2.41 (1—4)	2.51 (1—4)	**0.015**
Charlson Comorbidity Index score, n (%)			**0.048**
Score 0—4	610 (81.44)	148 (75.13)	
Score 5—6	97 (12.95)	29 (14.72)	
Score 7—33	42 (5.61)	20 (10.15)	
Lifetime surgical interventions prior to the index operation, n (%)			**<0.001**
0	465 (62.08)	77 (39.09)	
1+	284 (37.92)	120 (60.91)	
Surgical interventions 30 days prior to the index operation, n (%)			0.06
0	736 (98.26)	189 (95.94)	
1+	13 (1.74)	8 (4.06)	

Bolded P-values are statistically significant ($P < 0.05$).
*Continuous variables were compared via nonparametric tests, while discrete variables were compared by Chi squared or Fisher's exact tests.

< 0.001 and OR = 1.02, P < 0.001, respectively), 30- and 90-day ED visits (OR = 1.02, P < 0.001 and OR = 1.02, P < 0.001), and 30- and 90-day reoperation (OR = 1.02, P < 0.001 and OR = 1.02, P < 0.001). High ADI was associated with decreased surgical complications (OR 0.99, P = 0.027) and no difference in mortality (30- or 90-day mortality; OR 0.99, P = 0.70; OR 1.02, P = 0.25). Likelihood of postprocedure discharge to home, over nursing facilities and rehab, was reduced among those with elevated ADI (OR = 0.99, P < 0.001) (**Figure 2**).

Patient Outcomes—Exact-Matched Patients

After CEM, patients with high ADI (top decile), compared to patients with low ADI (lowest 4 deciles), had significantly increased odds of 30- and 90-day readmission (OR = 5.00, P < 0.001 and OR = 4.50, P < 0.001, respectively), 30- and 90-day ED visits (OR = 3.00, P = 0.027 and OR = 2.88, P = 0.007), and 30- and 90-day reoperation (OR = 4.50, P = 0.039 and OR = 5.50, P = 0.013). High ADI was not associated with surgical complication (OR = 0.50, P = 0.63) and mortality (30- and 90-day) could not be assessed due to the lack of patient deaths in the exact-matched sample. Likelihood of postprocedure discharge to home, over nursing facilities and rehab, was reduced among those with elevated ADI (OR = 0.26, P = 0.002) (**Figure 3**).

DISCUSSION

Socioeconomic disadvantage, as measured by elevated ADI, was associated with worse outcomes for patients undergoing single-level, posterior-only lumbar fusion. This study assessed outcomes for patients with high socioeconomic disadvantage (high

Table 2. Prematch patient characteristics. Characteristics describing the exact-matched patients (n = 212) who are in the lowest 40% or highest 10% of area deprivation index (ADI)

Variable	Lowest 40% of ADI (n = 106)	Highest 10% of ADI (n = 106)	*P*-Value*
Age, mean (range)	60.7 (29—84)	59.1 (29—83)	0.28
Gender, n (%)			1.00
Male	41 (38.68)	41 (38.68)	
Female	65 (61.32)	65 (61.32)	
Insurance type, n (%)			1.00
Private insurance	43 (40.57)	43 (40.57)	
Nonprivate insurance	63 (59.43)	63 (59.43)	
Body mass index (kg/m^2), mean			1.00
<18.5	0 (0.00)	0 (0.00)	
18.5—29.9	49 (46.23)	49 (46.23)	
>30.0	57 (53.77)	57 (53.77)	
Smoking status, n (%)			1.00
Smoker	13 (12.26)	13 (12.26)	
Non-smoker	93 (87.74)	93 (87.74)	
Unknown	0 (0.00)	0 (0.00)	
American Society of Anesthesiologists Grade, mean (range)	2.42 (1—3)	2.42 (1—3)	1.00
Charlson Comorbidity Index score, n (%)			1.00
Score 0—4	88 (83.02)	88 (83.02)	
Score 5—6	11 (10.38)	11 (10.38)	
Score 7—33	7 (6.60)	7 (6.60)	
Lifetime surgical interventions Prior to the index operation, n (%)			1.00
0	64 (60.38)	64 (60.38)	
1+	42 (39.62)	42 (39.62)	
Surgical interventions 30 days prior to the index operation, n (%)			1.00
0	104 (98.11)	104 (98.11)	
1+	2 (1.89)	2 (1.89)	

*Continuous variables were compared via nonparametric tests, while discrete variables were compared by Chi squared or Fisher's exact tests.

ADI, defined as top decile) versus low socioeconomic disadvantage (low ADI, defined as lowest 4 deciles) whom were otherwise matched based characteristics known to be associated with risk of negative outcomes. Increased ADI was significantly associated with increased odds of 30- and 90-day readmission, ED visits, and reoperation. Increased ADI was not significantly associated with surgical complication. Increased ADI was associated with a reduced likelihood of postsurgical discharge to home.

In this study, CEM was utilized to control for the confounding influence of various patient characteristics (e.g., age, gender, insurance type, and baseline health characteristics reflected in BMI, smoking status, ASA grade, CCI score, and prior surgical history) that have previously been shown to affect neurosurgical outcomes.[43-46] We chose to utilize CEM over other matching methods to ensure that each individual covariate was balanced and thus adequately controlled. By comparison, other statistical matching techniques like propensity score matching involve summarizing all covariates into a single propensity score, and thus may result in larger standard mean differences and worse balance for covariates compared to CEM.[47] CEM allowed us to isolate ADI from other confounders to specifically evaluate its role on short-term postoperative outcomes.

The results from this study suggest that higher socioeconomic disadvantage is associated with worse short-term postoperative outcomes for several quality measures: 30- and 90-day readmission, ED visits, and reoperation. These findings corroborate prior work showing that socioeconomic disadvantage, as measured by nonprivate insurance status and lower median household income, is associated with worse postoperative outcomes.[5,9,11,12,17,18] However, insurance status and median household income do not capture the multidimensional nature

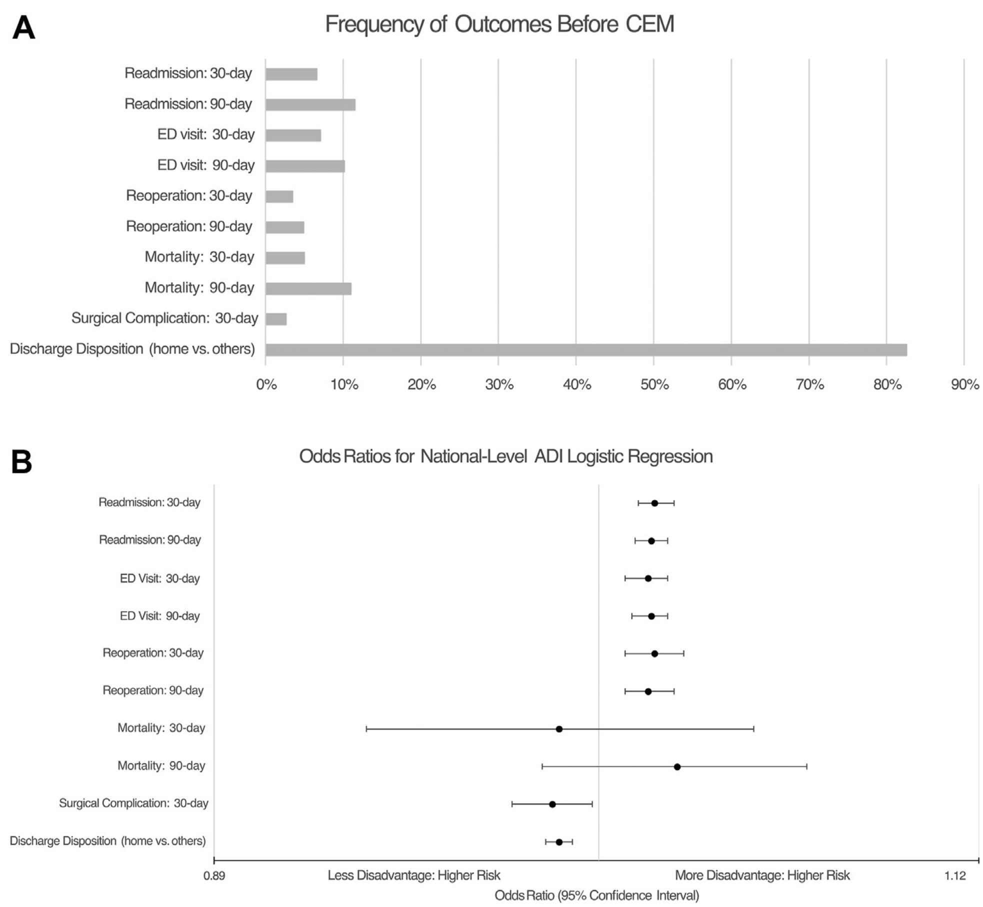

Figure 2. Outcomes before CEM. (**A**) Frequency of primary and secondary outcomes among all cases included in the prematch univariate analysis (n = 1861). (**B**) Odds ratios (ORs) and 95% confidence intervals from the univariate logistic regression analyses estimating the effect of ADI on all primary and secondary outcomes.

of socioeconomic status, such as the interactions between income and education,[48] or between income and housing quality.[49] By contrast, ADI summarizes aggregate data about multiple socioeconomic SDOH at a granular neighborhood level, and is easily obtained using the patient's zip code. Thus, ADI may be useful for social risk adjustment[50] under value-based care models,[34] and/or for identifying high-risk patients who may benefit from targeted interventions. For example, CMS' ACO REACH model utilizes ADI to provide upward and downward payment adjustments for the top 10% and bottom 30—50% of underserved beneficiaries according to ADI.[41,42]

The prior neurosurgical literature about ADI examined patient-reported outcomes and length of stay (LOS),[30-32] but did not examine outcomes such as complications and readmissions, which are central to many value-based care models such as Medicare's Bundled Payments for Care Improvement program.[51] This study quantified the relationship between high ADI and several 30- and 90-day outcome measures that are commonly evaluated by health systems. Our findings suggest that ADI may be used to identify at-risk patients who may ultimately benefit from interventions aimed at mitigating disparities and reducing healthcare costs. For example, patients with high ADI could be enrolled in pilot studies and randomized control studies evaluating the use of transportation vouchers to facilitate attendance at postoperative follow-up appointments,[52] or pre-operative navigation services that ensure patients have adequate social support during the post-operative recovery period.[53] In this manner, ADI may serve as a low-cost and easily accessible risk stratification tool that guides interventions to improve health equity. While ADI has only been analyzed in the United States thus far, high ADI groups may share similar education, income, employment, and housing characteristics with socioeconomically disadvantaged populations in low- and middle-income countries. Thus, the development and implementation of ADI-informed risk-mitigation strategies could have implications for international populations.

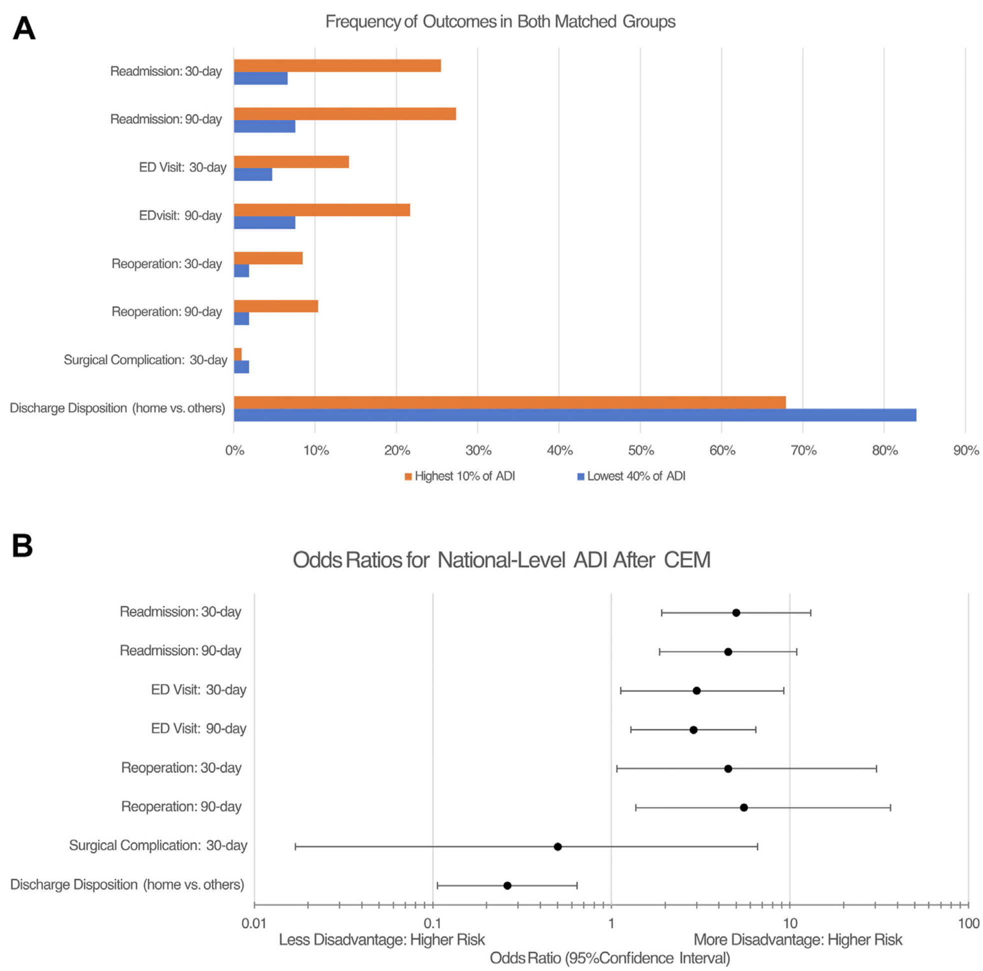

Figure 3. Outcomes after CEM. (**A**) Frequency of primary and secondary outcomes among all cases included in the post-match analysis (n = 212). (**B**) Odds ratios (ORs) and 95% confidence intervals (CIs) from the postmatch analyses comparing risk of adverse events between exact-matched patients in the top 10% versus lowest 40% of ADI.

Although high ADI was associated with higher 30- and 90-day readmission, ED visits, and reoperation, it notably was not associated with higher surgical complications. This finding demonstrates that perioperative surgical complications (e.g., cerebrospinal fluid leak, nerve damage) do not occur at a greater frequency in socioeconomically disadvantaged patients. Thus, the worse postoperative outcomes (30- and 90-day readmission, ED visits, and operation) of high ADI patients cannot be explained by an increased frequency of perioperative surgical complications. Surgeons may offer equal quality of surgery to patients with varying degrees of socioeconomic disadvantage, as evidenced by the lack of difference in complication rates, but social and structural factors beyond the operating room may give rise to the observed disparities in postoperative outcomes. The leading causes of short-term postoperative hospital readmissions include uncontrolled pain, surgical site infections, and wound dehiscence, which may not be related to intraoperative complications but may be associated with socioeconomic status.[54,55] Overall, our findings corroborate the existing literature about SDOH and neurosurgical outcomes disparities.[5]

Limitations

This study is limited by its retrospective cohort design; it is vulnerable to biases from data omission and confounding variables. To minimize such bias, we employed coarsened exact matching to control for many patient demographic variables and characteristics known to affect short-term neurosurgical outcomes. Another limitation was that the patients were enrolled from a single academic medical center, thus potentially limiting the generalizability of the findings. However, the medical center was multihospital and included large academic hospitals as well as smaller community hospitals. Furthermore, while this study analyzed the presence of postoperative outcome measures like ED visits, readmissions, and reoperation, our dataset did not have the granularity to determine specific causes of ED visits, readmissions, and reoperations (e.g., wound dehiscence). Follow-up work should focus on characterizing the etiology of specific postoperative events in relation to ADI. Future studies should also examine the relationship between ADI and postoperative outcomes in other patient populations and practice settings. Further, due to the low incidence of mortality in this study, no conclusions about death and ADI can be drawn. The low mortality rate in the study population is comparable to that reported in the literature.[56] To examine the relationship between ADI and postoperative mortality, future studies should study ADI in the context of other neurosurgical procedures with higher mortality rates.

CONCLUSION

Socioeconomic disadvantage, as measured by ADI, is associated with increased 30- and 90-day readmissions, ED visits, and reoperations. Furthermore, patients with high ADI are less likely to be discharged to home after single-level posterior-only lumbar spinal fusion. ADI may serve as a simple yet powerful index for preoperative risk prediction and identifying patients who may benefit from targeted interventions aimed at reducing disparities and long-term healthcare costs.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Grace Y. Ng: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Approved the manuscript as it is written. **Ritesh Karsalia:** Writing – original draft, Writing – review & editing, Approved the manuscript as it is written. **Ryan S. Gallagher:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Data curation, Approved the manuscript as it is written. **Austin J. Borja:** Writing – review & editing, Visualization, Formal analysis, Data curation, Approved the manuscript as it is written. **Jianbo Na:** Methodology, Software, Formal analysis, Data curation, Writing – review & editing, Approved the manuscript as it is written. **Scott D. McClintock:** Methodology, Software, Formal analysis, Data curation, Writing – review & editing, Approved the manuscript as it is written. **Neil R. Malhotra:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Data curation, Resources, Supervision, Project administration, Approved the manuscript as it is written.

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