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The Utility of the Area Deprivation Index in Assessing Complications After Total Joint Arthroplasty

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Background: Vulnerable populations, including patients from a lower socioeconomic status, are at an increased risk for infection, revision surgery, mortality, and complications after total joint arthroplasty (TJA). An effective metric to quantify and compare these populations has not yet been established in the literature. The Area Deprivation Index (ADI) provides a composite area-based indicator of socioeconomic disadvantage consisting of 17 U.S. Census indicators, based on education, employment, housing quality, and poverty. We assessed patient risk factor profiles and performed multivariable regressions of total complications at 30 days, 90 days, and 1 year.

Methods: A prospectively collected database of 3,024 patients who underwent primary elective total knee arthroplasty or total hip arthroplasty performed by 3 fellowship-trained orthopaedic surgeons from January 1, 2015, through December 31, 2021, at a tertiary health-care center was analyzed. Patients were divided into quintiles (ADI ≤20 [n = 555], ADI 21 to 40 [n = 1,001], ADI 41 to 60 [n = 694], ADI 61 to 80 [n = 396], and ADI 81 to 100 [n = 378]) and into groups based on the national median ADI, ≤47 (n = 1,896) and >47 (n = 1,128).

Results: Higher quintiles had significantly more females ($p = 0.002$) and higher incidences of diabetes ($p < 0.001$), congestive heart failure ($p < 0.001$), chronic obstructive pulmonary disease ($p < 0.001$), hypertension ($p < 0.001$), substance abuse ($p < 0.001$), and tobacco use ($p < 0.001$). When accounting for several confounding variables, all ADI quintiles were not associated with increased total complications at 30 days, but age ($p = 0.023$), female sex ($p = 0.019$), congestive heart failure ($p = 0.032$), chronic obstructive pulmonary disease ($p = 0.001$), hypertension ($p = 0.003$), and chronic kidney disease ($p = 0.010$) were associated. At 90 days, ADI > 47 ($p = 0.040$), female sex ($p = 0.035$), and congestive heart failure ($p = 0.001$) were associated with increased total complications.

Conclusions: Balancing intrinsic factors, such as patient demographic characteristics, and extrinsic factors, such as social determinants of health, may minimize postoperative complications following TJA. The ADI is one tool that can account for several extrinsic factors, and can thus serve as a starting point to improving patient education and management in the setting of TJA.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Social determinants of health, defined as the conditions in which people are born, grow, live, work, and age, have been associated with disparities in outcomes following total joint arthroplasty (TJA)[1-3]. Vulnerable populations, including patients from racial minorities and from a lower socioeconomic status, are at an increased risk for infection, revision surgery, mortality, and complications following TJA[4-10]. Decreased access to health care, implicit racial bias, an interplay of socioeconomic factors such as neighborhood wealth and education, and patient perceptions have been offered as possible but not definitive explanations for the perpetuation of these disparities[2,11-16].

One tool that has enabled quantification of socioeconomic status into a usable metric is the Area Deprivation Index (ADI). The ADI provides a composite area-based indicator of socioeconomic disadvantage consisting of 17 U.S. Census indicators, based on education, employment, housing quality, and poverty[17]. The national ADI provides normalized percentile scores ranging from 1 to 100, with higher scores suggesting increased

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social disadvantage. Several studies have examined the impact of ADI thresholds that may portend worse outcomes following TJA and have found mixed results overall. Grits et al.[18] and Khlopas et al.[19] both found that an ADI > 60 was associated with increased odds of nonhome discharge and prolonged length of stay. Mehta et al. showed that ADI > 75 was associated with discharge to an institution rather than home for postoperative care and rehabilitation after total hip arthroplasty (THA)[20]. One recent analysis found that the ADI did not predict 90-day postoperative emergency department visits after total knee arthroplasty (TKA)[21].

Given the lack of consensus with regard to the impact of the ADI on outcomes following TJA, we aimed to analyze patients who underwent TJA at a single institution to examine the potential differences on the basis of ADI represented as quintiles of ADI ≤ 20, ADI 21 to 40, ADI 41 to 60, ADI 61 to 80, and ADI 81 to 100, as well as ADI above and below the national median: ADI ≤ 47 and ADI > 47. We assessed patient risk factor profiles and performed multivariable regressions of total complications at 30 days, 90 days, and 1 year. We hypothesized that higher ADI quintiles would have disparate patient demographic characteristics as well as higher rates of total complications at all time points.

Materials and Methods

Patient Selection

This study involved a prospectively collected database of patients who underwent primary elective TKA or THA performed by 3 fellowship-trained orthopaedic surgeons from January 1, 2015, through December 31, 2021, at a tertiary health-care center. A total of 3,024 patients had complete data, including the ADI and demographic variables, and were included. Another 200 patients were excluded because of missing demographic variables and 50 were excluded because the ADI was not available because of changing living situations. Patients were divided into quintiles of ADI ≤ 20 (n = 555), ADI 21 to 40 (n = 1,001), ADI 41 to 60 (n = 694), ADI 61 to 80 (n = 396), and ADI 81 to 100 (n = 378). This distribution is consistent with a mean of 50 in the United States, which has also been shown to be consistent across geographic areas[18]. Institutional review board approval with exempt status was given because of the retrospective nature of the study.

ADI

The ADI is based on a measurement created by the U.S. Health Resources & Services Administration, which has been refined and validated down to the Census Block Group neighborhood level[21,22]. The ADI takes into account theoretical domains of education, income and/or employment, housing, and household characteristics. The variables carrying the most weight include the percentage of the population below 150% of the poverty level (0.1037), median family income (−0.0977), percentage of families below the poverty level (0.0977), percentage of the population ≥25 years of age with no high school education (−0.0970), income disparity (0.0936), and percentage of the population

TABLE I ADI Calculation Based on Singh Coefficients*,[23,24]

Category	Concept	U.S. Census Bureau ACS 5-Year Variable Group	2000 Singh Coefficient
Poverty	Median family income	B19113	−0.0977
	Income disparity	B19001	0.0936
	Percentage of families below the poverty level	B17010	0.0977
	Percentage of the population <150% of the poverty level	C17002	0.1037
	Percentage of single-parent households with dependents <18 years of age	B09002	0.0719
	Percentage of households without a motor vehicle	B25044	0.0694
	Percentage of households without a telephone	B25043	0.0877
	Percentage of occupied housing units without complete plumbing	B25016	0.0510
Housing	Percentage of owner-occupied housing units	B25003	−0.0615
	Percentage of households with >1 person per room	B25014	0.0556
	Median monthly mortgage	B25088	−0.0770
	Median gross rent	B25064	−0.0781
	Median home value	B25077	−0.0688
Employment	Percentage of employed persons ≥16 years of age in white-collar jobs	C24010	−0.0874
	Percentage of the civilian labor force (≥16 years of age) unemployed	B23025	0.0806
Education	Percentage of the population ≥25 years of age who did not graduate from high school	B15003	−0.0970
	Percentage of the population ≥25 years of age with at least a high school education	B15003	0.0849

*ACS = American Community Survey.

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TABLE II Baseline Characteristics by ADI Quintile

Variable	ADI				
	≤20 (N = 555)	21 to 40 (N = 1,001)	41 to 60 (N = 694)	61 to 80 (N = 396)	81 to 100 (N = 378)
Age* *(yr)*	64.2 ± 11.1	63.3 ± 11.6	62.1 ± 11.0	63.5 ± 11.0	61.7 ± 11.0
BMI group†					
<20 kg/m^2	8 (1.4%)	12 (1.2%)	9 (1.3%)	2 (0.5%)	7 (1.9%)
20 to <30 kg/m^2	176 (31.7%)	319 (31.9%)	189 (27.2%)	103 (26.0%)	106 (28.0%)
30 to <40 kg/m^2	244 (44.0%)	447 (44.7%)	310 (44.7%)	193 (48.7%)	183 (48.4%)
≥40 kg/m^2	48 (8.6%)	95 (9.5%)	105 (15.1%)	52 (13.1%)	48 (12.7%)
Unknown	79 (14.2%)	128 (12.8%)	81 (11.7%)	46 (11.6%)	34 (9.0%)
Sex†					
Female	305 (55.0%)	600 (59.9%)	438 (63.1%)	270 (68.2%)	253 (66.9%)
Male	250 (45.0%)	401 (40.1%)	256 (36.9%)	126 (31.8%)	125 (33.1%)
Race†					
American Indian or Alaska Native	3 (0.5%)	3 (0.3%)	1 (0.1%)	1 (0.3%)	0 (0.0%)
Asian	10 (1.8%)	12 (1.2%)	3 (0.4%)	0 (0.0%)	0 (0.0%)
Black or African American	100 (18.0%)	403 (40.3%)	490 (70.6%)	305 (77.0%)	348 (92.1%)
White	420 (75.7%)	552 (55.1%)	183 (26.4%)	79 (19.9%)	21 (5.6%)
Native Hawaiian, other Pacific Islander	1 (0.2%)	2 (0.2%)	0 (0.0%)	1 (0.3%)	0 (0.0%)
Declined to answer	6 (1.1%)	10 (1.0%)	5 (0.7%)	2 (0.5%)	1 (0.3%)
Multiracial	15 (2.7%)	19 (1.9%)	11 (1.6%)	8 (2.0%)	8 (2.1%)
Unknown	0 (0.0%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	0 (0.0%)
Alcohol abuse†	240 (43.2%)	398 (39.8%)	253 (36.5%)	137 (34.6%)	150 (39.7%)
Tobacco use†	137 (24.7%)	304 (30.4%)	222 (32.0%)	161 (40.7%)	186 (49.2%)
Substance abuse†	33 (5.9%)	83 (8.3%)	84 (12.1%)	57 (14.4%)	84 (22.2%)
Chronic obstructive pulmonary disease†	18 (3.2%)	31 (3.1%)	39 (5.6%)	32 (8.1%)	33 (8.7%)
Congestive heart failure†	19 (3.4%)	59 (5.9%)	39 (5.6%)	40 (10.1%)	31 (8.2%)
Hypertension†	258 (46.5%)	540 (53.9%)	418 (60.2%)	252 (63.6%)	260 (68.8%)
Chronic kidney disease†	27 (4.9%)	60 (6.0%)	53 (7.6%)	21 (5.3%)	14 (3.7%)
Diabetes†	68 (12.3%)	144 (14.4%)	132 (19.0%)	84 (21.2%)	103 (27.2%)
ASA class†					
1	11 (2.0%)	13 (1.3%)	8 (1.2%)	3 (0.8%)	3 (0.8%)
2	279 (50.3%)	477 (47.7%)	327 (47.1%)	195 (49.2%)	198 (52.4%)
3	255 (45.9%)	492 (49.2%)	350 (50.4%)	189 (47.7%)	174 (46.0%)
4	7 (1.3%)	13 (1.3%)	6 (0.9%)	6 (1.5%)	3 (0.8%)
2E	2 (0.4%)	3 (0.3%)	0 (0.0%)	2 (0.5%)	0 (0.0%)
3E	1 (0.2%)	2 (0.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
4E	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Unknown	0 (0.0%)	1 (0.1%)	3 (0.4%)	1 (0.3%)	0 (0.0%)

*The values are given as the mean and the standard deviation. †The values are given as the number of patients, with the percentage in parentheses.

without a telephone (0.0877) (Table I). The weights are based on the methodologies of 2 prior studies used to quantify the ADI[23,24]. These domains are then ranked from lowest (0) to highest (100), with higher scores suggestive of more disadvantaged groups in a region of interest at the state or national level.

Outcomes

The primary outcomes of the present study were 30-day, 90-day, and 1-year total complications, which comprised emergency department visits, readmissions, aseptic loosening, dislocations, deep venous thromboses, pulmonary

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TABLE III Multivariable Logistic Regression for 30-Day Outcomes Based on ADI Quintiles*

Predictor	OR†	P Value‡
ADI quintile§		
5 vs. 1	1.42 (0.80 to 2.52)	0.150
4 vs. 1	1.31 (0.75 to 2.29)	0.357
3 vs. 1	1.16 (0.69 to 1.94)	0.874
2 vs. 1	0.87 (0.53 to 1.42)	0.055
Race		
American Indian or Alaska Native vs. White	NA	0.977
Asian vs. White	0.91 (0.12 to 7.13)	0.934
Black or African American vs. White	1.38 (0.95 to 2.00)	0.927
Declined to answer vs. White	NA	0.959
Multiracial vs. White	0.26 (0.03 to 1.90)	0.954
Native Hawaiian, other Pacific Islander vs. White	NA	0.981
Age, per year	0.98 (0.97 to 1.00)	**0.023**
Male sex vs. female sex	0.69 (0.50 to 0.94)	**0.019**
ASA class#		
4 vs. 1	2.51 (0.25 to 24.69)	0.713
3 vs. 1	1.55 (0.20 to 11.89)	0.393
2E vs. 1	4.97 (0.25 to 98.50)	0.343
2 vs. 1	1.93 (0.25 to 14.59)	0.840
BMI group**		
3 vs. 0	NA	0.897
2 vs. 0	NA	0.910
1 vs. 0	NA	0.907
Presence vs. absence of health issue		
Alcohol use	1.28 (0.95 to 1.74)	0.106
Tobacco use	0.80 (0.58 to 1.11)	0.187
Substance abuse	1.33 (0.85 to 2.06)	0.210
Chronic obstructive pulmonary disease	2.37 (1.44 to 3.88)	**0.001**
Congestive heart failure	1.68 (1.05 to 2.71)	**0.032**
Hypertension	1.70 (1.20 to 2.40)	**0.003**
Chronic kidney disease	1.98 (1.18 to 3.31)	**0.010**
Diabetes	1.05 (0.73 to 1.49)	0.801

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, 5 = ADI 81 to 100, 4 = ADI 61 to 80, 3 = ADI 41 to 60, 2 = ADI 21 to 40, and 1 = ADI 0 to 20. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

emboli, manipulations under anesthesia, periprosthetic joint infections, periprosthetic fractures, and surgical site infections.

Patient Demographic Characteristics

Demographic variables included age, body mass index (BMI), sex, race, alcohol abuse, tobacco use, substance abuse, chronic obstructive pulmonary disease, chronic kidney disease, American Society of Anesthesiologists (ASA) class, hypertension, and congestive heart failure.

Statistical Analysis

Continuous variables were compared using Student t tests. Categorical variables were compared using Pearson chi-square tests. Significance was set at $p < 0.05$. Data analyses were performed using R software, version 4.1.1 (R Foundation for Statistical Computing).

Results

Patient Demographic Characteristics by ADI Quintile

BMI ($p = 0.060$), ASA class ($p = 0.800$), and chronic kidney disease ($p = 0.070$) were similar among the ADI quintiles.

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TABLE IV Multivariable Logistic Regression for 90-Day Outcomes Based on ADI Quintiles*

Predictor	OR†	P Value‡
ADI quintile§		
5 vs. 1	1.48 (0.82 to 2.66)	0.627
4 vs. 1	1.63 (0.93 to 2.86)	0.235
3 vs. 1	1.64 (0.98 to 2.75)	0.149
2 vs. 1	1.21 (0.74 to 1.98)	0.332
Race		
American Indian or Alaska Native vs. White	NA	0.969
Asian vs. White	0.86 (0.11 to 6.68)	0.954
Black or African American vs. White	1.36 (0.96 to 1.91)	0.946
Declined to answer vs. White	0.64 (0.09 to 4.90)	0.959
Multiracial vs. White	1.05 (0.36 to 3.02)	0.950
Native Hawaiian, other Pacific Islander vs. White	NA	0.975
Age, per year	0.99 (0.98 to 1.01)	0.417
Male sex vs. female sex	0.72 (0.53 to 0.97)	**0.033**
ASA class#		
4 vs. 1	3.39 (0.34 to 34.07)	0.952
3 vs. 1	2.44 (0.32 to 18.50)	0.959
2E vs. 1	NA	0.962
2 vs. 1	2.34 (0.31 to 17.52)	0.960
BMI group**		
3 vs. 0	3.34 (0.44 to 25.20)	0.303
2 vs. 0	3.66 (0.49 to 27.43)	0.166
1 vs. 0	3.23 (0.43 to 24.35)	0.359
Presence vs. absence of health issue		
Alcohol use	0.83 (0.61 to 1.11)	0.212
Tobacco use	1.32 (0.97 to 1.79)	0.082
Substance abuse	1.19 (0.78 to 1.82)	0.428
Chronic obstructive pulmonary disease	1.06 (0.60 to 1.86)	0.846
Congestive heart failure	1.92 (1.19 to 3.09)	**0.008**
Hypertension	1.05 (0.77 to 1.44)	0.748
Chronic kidney disease	0.82 (0.44 to 1.52)	0.522
Diabetes	0.79 (0.54 to 1.15)	0.211

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, 5 = ADI 81 to 100, 4 = ADI 61 to 80, 3 = ADI 41 to 60, 2 = ADI 21 to 40, and 1 = ADI 0 to 20. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

Higher quintiles had more females ($p = 0.002$) and higher incidences of diabetes ($p < 0.001$), congestive heart failure ($p < 0.001$), chronic obstructive pulmonary disease ($p < 0.001$), hypertension ($p < 0.001$), substance abuse ($p < 0.001$), and tobacco use ($p < 0.001$) (Table II).

Multivariable Regression for Total Complications by ADI Quintile

When accounting for several confounding variables, all ADI quintiles were not associated with increased total complications at 30 days, but age ($p = 0.023$), female sex ($p = 0.014$), congestive heart failure ($p = 0.032$), chronic obstructive pulmonary disease ($p = 0.001$), hypertension ($p = 0.003$) and chronic kidney disease ($p = 0.010$) were associated (Table III).

At 90 days, female sex ($p = 0.033$) and congestive heart failure ($p = 0.008$) were associated with increased total complications (Table IV).

At 1 year, only female sex ($p = 0.001$) and Black or African American race compared with White race ($p < 0.001$) were associated with increased total complications (Table V).

TABLE V Multivariable Logistic Regression for 1-Year Outcomes Based on ADI Quintiles*

Predictor	OR†	P Value‡
ADI quintile§		
5 vs. 1	1.24 (0.79 to 1.94)	0.289
4 vs. 1	1.11 (0.72 to 1.73)	0.829
3 vs. 1	1.18 (0.79 to 1.75)	0.428
2 vs. 1	0.92 (0.63 to 1.33)	0.115
Race		
American Indian or Alaska Native vs. White	NA	0.960
Asian vs. White	0.49 (0.06 to 3.72)	0.956
Black or African American vs. White	1.52 (1.15 to 2.02)	**<0.001**
Declined to answer vs. White	1.42 (0.41 to 4.95)	0.932
Multiracial vs. White	1.17 (0.51 to 2.67)	0.937
Native Hawaiian, other Pacific Islander vs. White	NA	0.968
Age, per year	0.99 (0.98 to 1.00)	0.082
Male sex vs. female sex	0.67 (0.53 to 0.86)	**0.001**
ASA class#		
4 vs. 1	4.83 (0.51 to 45.91)	0.941
3 vs. 1	3.98 (0.53 to 29.86)	0.946
2E vs. 1	NA	0.953
2 vs. 1	4.31 (0.58 to 32.10)	0.944
BMI group**		
3 vs. 0	1.63 (0.48 to 5.54)	0.463
2 vs. 0	1.69 (0.50 to 5.73)	0.325
1 vs. 0	1.52 (0.45 to 5.14)	0.742
Presence vs. absence of health issue		
Alcohol use	1.10 (0.87 to 1.39)	0.437
Tobacco use	1.20 (0.94 to 1.55)	0.151
Substance abuse	1.06 (0.74 to 1.50)	0.767
Chronic obstructive pulmonary disease	1.24 (0.78 to 1.96)	0.369
Congestive heart failure	1.44 (0.94 to 2.20)	0.090
Hypertension	1.18 (0.91 to 1.52)	0.212
Chronic kidney disease	0.82 (0.49 to 1.38)	0.461
Diabetes	1.11 (0.83 to 1.49)	0.469

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, 5 = ADI 81 to 100, 4 = ADI 61 to 80, 3 = ADI 41 to 60, 2 = ADI 21 to 40, and 1 = ADI 0 to 20. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

Patient Demographic Characteristics by ADI > 47 Versus ≤ 47

Compared with the ADI ≤ 47 cohort, the ADI > 47 cohort had higher incidences of BMI 30 to <40 kg/m^2 (52.15% compared with 44.99%; p = 0.001), BMI ≥ 40 kg/m^2 (15.38% compared with 10.23%; p < 0.001), female sex (66.13% compared with 59.07%; p = 0.001), Black or African American race (81.03% compared with 38.63%; p < 0.001), tobacco use (41.49% compared with 28.59%; p < 0.001), substance abuse (15.96% compared with 8.49%; p < 0.001), chronic obstructive pulmonary disease (8.60% compared with 4.01%; p < 0.001), and congestive heart failure (6.83% compared with 4.80%; p = 0.020) (Table VI).

Multivariable Regression for Total Complications by ADI > 47 Versus ADI ≤ 47

At 30 days, female sex (p = 0.019), congestive heart failure (p = 0.037), chronic obstructive pulmonary disease (p < 0.001), hypertension (p = 0.002), and chronic kidney disease (p = 0.010) were associated with increased total complications (Table VII). At 90 days, ADI > 47 (p = 0.047), female sex (p = 0.035), and congestive heart failure (p = 0.010) were associated with increased total complications (Table VIII). At 1 year, male sex (p = 0.002) was associated with increased total complications (Table IX).

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TABLE VI Baseline Characteristic by High Versus Low ADI

Variable	ADI > 47 (N = 1,128)	ADI ≤ 47 (N = 1,896)	P Value*
Age† *(yr)*	62.1 ± 10.88	64.2 ± 11.24	0.760
BMI group†§			
<20 kg/m^2	13 (1.30%)	25 (1.32%)	0.960
20 to <30 kg/m^2	312 (31.17%)	581 (30.64%)	0.760
30 to <40 kg/m^2	522 (52.15%)	855 (45.09%)	**0.001**
≥40 kg/m^2	154 (15.38%)	194 (10.23%)	**<0.001**
Sex§			
Female	746 (66.13%)	1,120 (59.07%)	**0.001**
Male	382 (33.87%)	776 (40.93%)	**0.001**
Race§			
American Indian or Alaska Native	2 (0.18%)	6 (0.32%)	0.470
Asian	2 (0.18%)	23 (1.21%)	**0.003**
Black or African American	914 (81.03%)	733 (38.66%)	**<0.001**
White	182 (16.13%)	1,073 (56.62%)	**<0.001**
Native Hawaiian, other Pacific Islander	1 (0.09%)	3 (0.16%)	0.610
Multiracial	19 (1.68%)	42 (2.22%)	0.310
Declined to answer	8 (0.71%)	16 (0.84%)	0.700
Health issues with available data§			
Alcohol abuse	415 (36.79%)	763 (40.24%)	0.060
Tobacco use	468 (41.49%)	542 (28.59%)	**<0.001**
Substance abuse	180 (15.96%)	161 (8.49%)	**<0.001**
Chronic obstructive pulmonary disease	97 (8.60%)	76 (4.01%)	**<0.001**
Congestive heart failure	77 (6.83%)	91 (4.80%)	**0.020**
Diabetes	266 (23.58%)	265 (13.98%)	0.900

*Significant values are shown in bold. †The values are given as the mean and the standard deviation. ‡In this category, there were 1,001 patients with data in the ADI > 47 group and 1,655 patients with data in the ADI ≤ 47 group. §The values are given as the number of patients, with the percentage in parentheses.

Discussion

The interplay of socioeconomic factors may contribute to disparate outcomes following TJA for patients from low socioeconomic status groups[15,16]. The ADI offers a reproducible way of capturing several components of socioeconomic disadvantage, with the potential to tailor management to patients who need additional support. A consensus on a threshold for the ADI following TJA has not yet been determined in the literature. Our major findings were that higher ADI quintiles were associated with worse behavioral risk factor profiles than lower ADI quantiles were and that higher ADI quintiles were not associated with increased risk of total complications at any of the time points, although ADI > 47 was associated with increased total complications at 90 days only.

We acknowledge the limitations that were present in the study. The ADI may have missed some components of an all-encompassing socioeconomic status metric, including health literacy, immigration status, racial segregation, area crime rates, green space, and transportation[19,22,23]. Because we studied only an American population, our results may not be generalizable globally. Other metrics such as the Social Vulnerability Index may be more useful for larger geographic areas but have an inability to target smaller areas at the level of neighborhoods, which is an advantage of the ADI[24]. Because the ADI is a composite of 17 elements of deprivation, we were limited in our ability to analyze the effects of individual factors, and, furthermore, such an analysis might not have accounted for overlapping determinants, such as insurance and race. Nevertheless, a breakdown of the individual components of the ADI has been presented in the interests of transparency. The small sample size may have missed potential associations. There were additional confounding variables that may have influenced postoperative outcomes but were not taken into account in our multivariable regression, such as health-care insurance, income, housing insecurity, transportation, education, and nutrition[25]. A lack of generalizability could have resulted from conducting the study in a single regional health-care system. Although discrepancies in TJA outcomes may exist among the surgeons, strict preoperative, perioperative, and postoperative protocols in our hospital, as well as similar training, mitigate the concern regarding

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TABLE VII Multivariable Logistic Regression for 30-Day Outcomes Based on High Versus Low ADI*

Predictor	OR†	P Value†
High vs. low ADI§	1.32 (0.97 to 1.80)	0.079
Race		
American Indian or Alaska Native vs. White	NA	0.977
Asian vs. White	0.91 (0.12 to 7.10)	0.934
Black or African American vs. White	1.44 (1.01 to 2.05)	0.926
Declined to answer vs. White	NA	0.959
Multiracial vs. White	0.26 (0.04 to 1.96)	0.953
Native Hawaiian, other Pacific Islander vs. White	NA	0.981
Age, per year	0.98 (0.97 to 1.00)	**0.025**
Male sex vs. female sex	0.69 (0.50 to 0.94)	**0.019**
ASA class#		
4 vs. 1	2.51 (0.26 to 24.63)	0.704
3 vs. 1	1.56 (0.20 to 11.95)	0.411
2E vs. 1	4.75 (0.24 to 94.69)	0.367
2 vs. 1	1.96 (0.26 to 14.81)	0.886
BMI group**		
3 vs. 0	NA	0.897
2 vs. 0	NA	0.911
1 vs. 0	NA	0.908
Presence vs. absence of health issue		
Alcohol use	1.28 (0.94 to 1.72)	0.115
Tobacco use	0.80 (0.58 to 1.11)	0.187
Substance abuse	1.35 (0.87 to 2.09)	0.178
Chronic obstructive pulmonary disease	2.42 (1.47 to 3.97)	**0.001**
Congestive heart failure	1.65 (1.03 to 2.66)	**0.037**
Hypertension	1.71 (1.21 to 2.42)	**0.002**
Chronic kidney disease	1.96 (1.18 to 3.28)	**0.010**
Diabetes	1.06 (0.74 to 1.51)	0.767

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, high = ADI > 47 and low = ADI ≤ 47. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

differences in management affecting postoperative outcomes. Another area of focus is the role of TJA access and TJA utilization as important factors in mediating disparities in outcomes following TJA, but that was not a goal of this study. The strength of this study is a single institution's novel inclusion of 2 different ADI categories (quintiles and the national mean cutoff) that, to our knowledge, have not been analyzed with regard to TJA.

Risk factors for patients from deprived neighborhoods have been well-described in the literature. In 1 analysis of

TABLE VIII Multivariable Logistic Regression for 90-Day Outcomes Based on High Versus Low ADI*

Predictor	OR†	P Value†
High vs. low ADI§	1.36 (1.00 to 1.83)	**0.047**
Race		
American Indian or Alaska Native vs. White	NA	0.969
Asian vs. White	0.84 (0.11 to 6.46)	0.954
Black or African American vs. White	1.40 (1.01 to 1.96)	0.946
Declined to answer vs. White	0.64 (0.08 to 4.86)	0.959
Multiracial vs. White	1.06 (0.37 to 3.03)	0.950
Native Hawaiian, other Pacific Islander vs. White	NA	0.975
Age, per year	1.00 (0.98 to 1.01)	0.444
Male sex vs. female sex	0.72 (0.54 to 0.98)	**0.035**
ASA class#		
4 vs. 1	3.51 (0.35 to 35.16)	0.952
3 vs. 1	2.51 (0.33 to 19.01)	0.959
2E vs. 1	NA	0.962
2 vs. 1	2.39 (0.32 to 17.94)	0.960
BMI group**		
3 vs. 0	3.38 (0.45 to 25.48)	0.292
2 vs. 0	3.68 (0.49 to 27.64)	0.163
1 vs. 0	3.23 (0.43 to 24.34)	0.369
Presence vs. absence of health issue		
Alcohol use	0.83 (0.61 to 1.11)	0.209
Tobacco use	1.30 (0.95 to 1.77)	0.098
Substance abuse	1.19 (0.78 to 1.82)	0.426
Chronic obstructive pulmonary disease	1.06 (0.60 to 1.87)	0.836
Congestive heart failure	1.88 (1.17 to 3.03)	**0.010**
Hypertension	1.06 (0.77 to 1.44)	0.739
Chronic kidney disease	0.84 (0.45 to 1.56)	0.573
Diabetes	0.79 (0.54 to 1.15)	0.211

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, high = ADI > 47 and low = ADI ≤ 47. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

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TABLE IX Multivariable Logistic Regression for 1-Year Outcomes Based on High Versus Low ADI*

Predictor	OR†	P Value†
High vs. low ADI§	1.20 (0.94 to 1.53)	0.148
Race		
American Indian or Alaska Native vs. White	NA	0.960
Asian vs. White	0.48 (0.06 to 3.71)	0.956
Black or African American vs. White	1.56 (1.19 to 2.05)	0.930
Declined to answer vs. White	1.42 (0.41 to 4.96)	0.932
Multiracial vs. White	1.18 (0.51 to 2.69)	0.937
Native Hawaiian, other Pacific Islander vs. White	NA	0.968
Age, per year	0.99 (0.98 to 1.00)	0.089
Male sex vs. female sex	0.67 (0.53 to 0.86)	**0.002**
ASA class#		
4 vs. 1	4.81 (0.51 to 45.65)	0.941
3 vs. 1	3.98 (0.53 to 29.84)	0.945
2E vs. 1	NA	0.952
2 vs. 1	4.33 (0.58 to 32.26)	0.943
BMI group**		
3 vs. 0	1.62 (0.48 to 5.48)	0.459
2 vs. 0	1.67 (0.49 to 5.64)	0.337
1 vs. 0	1.49 (0.44 to 5.05)	0.772
Presence vs. absence of health issues		
Alcohol use	1.10 (0.87 to 1.40)	0.426
Tobacco use	1.20 (0.93 to 1.54)	0.162
Substance abuse	1.07 (0.75 to 1.52)	0.708
Chronic obstructive pulmonary disease	1.26 (0.79 to 1.99)	0.330
Congestive heart failure	1.41 (0.93 to 2.16)	0.108
Hypertension	1.18 (0.92 to 1.53)	0.200
Chronic kidney disease	0.83 (0.50 to 1.39)	0.481
Diabetes	1.12 (0.84 to 1.50)	0.446

*NA = not applicable due to limitations in the database. †The values are given as the odds ratio (OR), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold. §In this category, high = ADI > 47 and low = ADI ≤ 47. #In this category, ASA 4 = a patient with severe systemic disease that is a constant threat to life, ASA 3 = a patient with severe systemic disease, ASA 2E = a patient with mild systemic disease who needs emergency surgery, ASA 2 = a patient with mild systemic disease, and ASA 1 = a normal healthy patient. **In this category, 3 = BMI ≥ 50 kg/m^2, 2 = BMI 40 to <50 kg/m^2, 1 = BMI 30 to <40 kg/m^2, and 0 = BMI 20 to <30 kg/m^2.

27,121 patients undergoing THA, the authors found that higher ADI was associated with increased risk of multimorbidity (≥2 chronic conditions) and that ADI may be a relevant proxy for socioeconomic status when an individual's socioeconomic status is not available[26]. Kamath et al. found that female sex, non-White race, education of high school or less, current smoking, BMI of >30 kg/m^2, more limitations in instrumental activities of daily living, and an ASA class of >2 were characteristics of patients from the most deprived neighborhoods, as represented by the highest quintile of the ADI (80 to 100)[27]. In our study, we found female sex and several risk factors associated with more deprived neighborhoods (including diabetes, congestive heart failure, chronic obstructive pulmonary disease, hypertension, substance abuse, and tobacco use) to be independent risk factors for total complications at 30 days, 90 days, and 1 year. We suggest that individual-level disadvantage and neighborhood-level disadvantage, as measured by the ADI, have a dynamic relationship in influencing perioperative health status and, ultimately, postoperative outcomes.

A similar, dynamic relationship can be found between intrinsic factors, such as female sex, BMI, and patient comorbidities, and extrinsic factors, such as socioeconomic status (including marital status), access to tobacco stores, and living in "food deserts." Both intrinsic and extrinsic factors have led to longer length of stay and worse outcomes following TJA[1,4,28-31]. This is consistent with our findings that patient demographic characteristics, namely female sex and congestive heart failure, and the ADI, a proxy for neighborhood socioeconomic status disadvantage, are both associated with increased total complications following TJA. Appropriate and effective intervention

may better serve patients by addressing both intrinsic and extrinsic factors, such as by nutritional support programs that could minimize the effect of BMI and living in a food desert in the same effort[32]. Additionally, we recommend clinical intervention in the form of preoperative risk factor management programs. A recent article reviewed the advantages and disadvantages of 10 different risk stratification tools to predict readmission and discharge status following TJA[33]. The authors concluded that individual metrics, such as race, insurance status, income, social support, housing status, and access to care, should be uniformly assessed in the preoperative setting. Our recommendation is the inclusion of multidimensional variables, such as the ADI, in risk assessment programs because of their unique ability to capture comprehensive measures of socioeconomic factors as well as more granular social determinants of health. Once high-risk patients are identified, clinicians can work toward better managing nonmodifiable and modifiable risk factors prior to TJA with the intent of minimizing postoperative complications. For instance, a reversal in differences between Black and White patients in the odds of readmission from 2009 to 2016 that resulted in a lower rate of readmission in 2015 occurred secondary to hospital-based quality improvement initiatives, including publicly available quality measures and efforts by surgeons and hospitals to prepare for value-based contracts and enhance physician cultural competency[34].

In several studies, authors have reported thresholds for the ADI that negatively influence outcomes following TJA, but the heterogeneity in study designs limits their generalizability and utility. Our analysis found ADI > 47 to be an independent risk factor for increased total complications at 90 days. Shaw et al. found that the ADI did not influence 90-day postoperative emergency department visit after TKA in a study with similar cohort sizes (3,024 in our cohort compared with 2,655 in their cohort). However, our patient population (in Baltimore, Maryland) was inherently different from that in the study by Shaw et al. (in Detroit, Michigan) and represented more disadvantaged neighborhoods (as indicated by the differences in male versus female sex, insurance type, ASA class, and congestive heart failure), which may have led to the dissimilar outcomes[21]. Similar to our study, Khlopas et al. also studied a more disadvantaged population, as shown by the number of female patients, patients who smoked, African American patients, and younger patients. They found that an ADI of 61 to 70 compared with an ADI of 31 to 40 was associated with higher odds of a ≥3-day length of stay and of nonhome discharge, but not with 90-day emergency department visits or reoperations[19]. Grits et al. showed that individuals in the ADI 61 to 80 quintile had higher odds of nonhome discharge compared with the ADI 21 to 40 group[18]. These findings are consistent with our finding that an ADI threshold of >47 was associated with a higher total rate of postoperative complications, albeit at different time intervals. In order to maximize patient care within this group with higher-than-average ADI, improvements can be made in better identifying vulnerable patient populations, prioritizing patient education, providing home health, and setting appropriate patient expectations[35-37].

Improving outcomes following TJA may be approached by better balancing intrinsic factors, such as patient demographic characteristics, and extrinsic factors, such as social determinants of health. The ADI is 1 tool that can account for several of the extrinsic factors and can be applied to different institutions. It can serve as a starting point to improving patient education and management in the setting of TJA. In a clinical setting, physicians can correlate patients' 9-digit ZIP code with their ADI in order to obtain the percentile into which these patients fall. Then patients can be risk-stratified on the basis of their ADI score, and physicians can discuss their individual level of risk based on previous data. If a vulnerable patient is identified, interventions can be identified to mitigate the risk associated with undergoing TJA. For this to occur, the 17 indicators within the ADI need to be assessed for each patient and discussed in order to provide the patient with the best possible care. The ease of use, reproducibility, and multidimensional nature of the ADI enable its effective implementation as a marker in patient optimization. The consistent use of a single tool to measure neighborhood disadvantage works toward achieving these goals. ■

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