Original Article

Differential effects of obesity on perioperative outcomes in renal cell carcinoma patients based on race and ethnicity and neighborhood-level socioeconomic status

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Background: Obesity is a well-established risk factor of renal cell carcinoma (RCC), however the impact of obesity on surgical outcomes for racial and ethnic minority patients with RCC is unclear. This study investigated whether a higher body mass index (BMI) or obesity (BMI ≥30 kg/m^2) was associated with worse perioperative outcomes and if there were heterogeneous effects based on race, ethnicity, and neighborhood-level socioeconomic factor.

Methods: In this single-center cross-sectional study, medical records of patients who underwent partial or radical nephrectomy between 2010 and 2022 were retrospectively reviewed. Logistic regression analysis was performed to assess associations of BMI and perioperative outcomes [ischemia time, estimated blood loss (EBL), and length of hospital stay].

Results: A total of 432 patients, including 49.8% non-Hispanic White (NHW), 35.0% Hispanic, and 6.9% American Indian (AI) patients, were included. Median [interquartile range (IQR)] BMI was 30.2 (26.3–35.2) kg/m^2, and Hispanic (31.5) and AI (32.5) patients had higher median BMI than NHW (29.1) patients (P=0.006). Median ischemia time, EBL, and length of hospital stay were 18.5 (IQR, 15.0–22.4) minutes, 150 (IQR, 75.0–300.0) mL, and 3 (IQR, 2–5) days. BMI ≥35 kg/m^2 was associated with a longer ischemia time [>18.5 minutes; odds ratio (OR), 5.17; 95% confidence interval (CI): 1.81–14.76; P=0.002], and the association was stronger in NHW than Hispanic patients (BMI continuous OR, 1.13; 95% CI: 1.04–1.22; P=0.004 in NHW and OR, 1.07; 95% CI: 0.98–1.17; P=0.12 in Hispanics). Class I and II/III obese patients had over two-fold increased odds of a larger EBL (>150 mL) than patients with normal weight (OR, 2.17; 95% CI: 1.03–4.59; P=0.04 for class I and OR, 2.24; 95% CI: 1.04–4.84; P=0.04 for class II/III obese patients). This association was stronger in patients from neighborhoods with high social deprivation index (SDI) and in NHW patients (BMI ≥30 *vs.* <30 kg/m^2, OR, 3.53; 95% CI: 1.57–7.97; P=0.002 in high SDI

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neighborhoods and OR, 2.38; 95% CI: 1.10–5.14; P=0.03 in NHW). BMI was not associated with a longer hospital stay.

Conclusions: In this study, obesity increased likelihood of worse perioperative outcomes, and the associations varied based on race and ethnicity and neighborhood-level socioeconomic factors.

Keywords: Cancer health disparities; social deprivation; surgical outcomes; Hispanics

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Introduction

Kidney cancer is one of the top 10 common cancers in the United States (U.S.) (1). Obesity is well-established risk factor for renal cell carcinoma (RCC), a major histologic subtype of kidney cancer, and RCC incidence rates increased over several decades with increase in obesity rates in the U.S. (2-6). Patients with a localized RCC are generally treated with surgery. Compared to radical nephrectomy, partial nephrectomy provides better outcomes by preserving kidney function and with reduced risk of cardiovascular event and better survival after surgical treatment (7-9). Robot-assisted partial nephrectomy is equally beneficial for normal weight and obese patients (10,11).

RCC is recognized as a metabolic disease characterized by metabolic reprogramming (12,13). In RCC, glycolysis, lipid, and other metabolic pathways are dysregulated, but the biologic roles of obesity and adiposity are still under investigation (14,15). Obesity and metabolic disorders, however, may complicate the surgical procedure leading to poor perioperative outcomes. In particular, prior studies of partial nephrectomy have shown that obesity increase ischemia time (16), estimated blood loss (EBL) (16-19), acute kidney injury (20), and rate of conversion to open surgery (21). Studies in patients who underwent laparoscopic radical nephrectomy have also shown that obesity increases operative time (22), rate of conversion to open surgery (23), and length of hospital stay (24). Many studies, on the other hand, have reported a better survival of obese patients than patients with normal weight after surgical treatment (25,26). Nonetheless, a larger EBL prolongs hospital stay and increases financial burden with loss of income, especially for patients with socioeconomic challenges and racial and ethnic minority populations (27,28) and investigating impacts of obesity on perioperative outcomes in diverse patients is necessary to reduce RCC health disparities.

One of limitations of prior studies on obesity and perioperative outcomes in the U.S. is that they mainly included non-Hispanic White (NHW) patients or did not account for racial and ethnic differences. Hispanic and American Indian (AI) populations that have high rates of RCC mortality and obesity are previously underrepresented in RCC studies, and they should be included in studies of impact of obesity on nephrectomy outcomes (29-32). Studies using hospital-based database and population-based registry data have shown that racial and ethnic minority groups, including Hispanics and AI, in the U.S. were more likely to forgo nephrectomy and undergo radical rather than partial nephrectomy for treatment of RCC (33-36). These disparities potentially contribute to disparities in survival, but these databases and registries lacks data on obesity. Moreover, neighborhood socioeconomic characteristics impact obesity rates and healthcare access, but no RCC study has investigated this complex relationship to our knowledge (37-40).

The current study examined whether high body mass index (BMI), obesity (BMI ≥30 kg/m^2), and severe obesity

Highlight box

Key findings
- Obesity increased likelihood of worse perioperative outcomes after nephrectomy.

What is known and what is new?
- Obesity increases estimated blood loss during partial nephrectomy.
- Relationships between obesity and perioperative outcomes vary based on neighborhood characteristics and race and ethnicity.

What is the implication, and what should change now?
- Patient-centered care through understanding patient's sociocultural backgrounds and addressing social needs may improve kidney cancer care.

(BMI ≥35 kg/m^2, class II/III) impacted perioperative outcomes for patients who underwent nephrectomy for treatment of RCC. We also examined whether there were heterogeneous effects based on race and ethnicity and neighborhood-level socioeconomic factors. We hypothesized that obesity has negative impacts on perioperative outcomes, but the associations differ based on race and ethnicity as well as neighborhood-level socioeconomic characteristics. Our academic hospital is a major regional hospital located in the Southwest U.S., and we were able to good representation of Hispanic and AI patients to evaluate impact of obesity on nephrectomy outcomes including these under-studied populations. We present this article in accordance with the STROBE reporting checklist (available at https://tau.amegroups.com/article/view/10.21037/tau-23-421/rc).

Methods

Patient data

This cross-sectional study used a database of kidney cancer patients maintained by the University of Arizona Department of Urology. Medical records of patients who underwent partial and radical nephrectomy to remove renal tumors between 2010 and 2022 at Banner University Medical Center Tucson/University of Arizona were retrospectively reviewed. Patients for which BMI data as well as data for ischemia time, EBL, or length of hospital stay was available were included. RCC patients with a prior diagnosis of other cancer were excluded. For patients with bilateral RCC who had two surgeries, we used treatment and pathology information from only the first nephrectomy. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the University of Arizona Institutional Review Board (Protocol #1912228839) and individual consent for this retrospective analysis was waived.

This study evaluated the impact of obesity on three outcomes: (I) ischemia time (both warm and cold) among patients who underwent partial nephrectomy; (II) EBL; and (III) length of hospital stay for all the patients. Obesity was defined according to the World Health Organization criteria based on BMI (≥30.0 kg/m^2) and was further categorized into class I (BMI 30.0–34.9 kg/m^2) and class II/III (BMI ≥35.0 kg/m^2). Comorbidities were coded based on presence of either diabetes mellitus or hypertension, having both diabetes and hypertension, or having neither. Social deprivation index (SDI) was used to measure neighborhood-level socioeconomic challenges (40). SDI scores were calculated from the 2017 American Community Survey data, including poverty, high school graduation, unemployment rates, housing, household characteristics, and transportation. SDI scores range from 1 to 100, and higher SDI scores indicate increased social and economic challenges in the neighborhood. The calculated scores were linked to zip code of patients' residence.

Statistical analysis

RCC patients were characterized with the use of percentage and median with interquartile range (IQR). Differences across racial and ethnic groups were tested using the Kruskal-Wallis test for continuous variables and chi-square test for categorical variables. Logistic regression analysis was performed to assess associations of BMI and perioperative outcomes (ischemia time, EBL, and length of hospital stay) adjusting for potential confounders. Median ischemia time, EBL, and length of hospital stay as well as different cutoff values of EBL (500, 700, and 1,000 mL) were used to define binary outcomes. BMI was used as a continuous variable as well as categorical variable because the relationship between BMI and perioperative outcomes may not be linear. Stratified analysis was performed based on radical *vs.* partial nephrectomy, high *vs.* low SDI and for two major race and ethnic groups, NHW and Hispanics. Sub-analyses were also conducted in patients with pathological tumor (pT)1a tumors for ischemia time, patients who had robotic or open surgery for EBL, and patients who had partial nephrectomy for EBL and length of hospital stay. IBM SPSS Statistics Version 28.0 (IBM Corp., Armonk, NY, USA) was used.

Results

A total of 432 eligible patients, including 49.8% NHW, 35.0% Hispanics, and 6.9% AI patients, were included (*Table 1*). Of total patients in this study set, available patients included were 202 for ischemia time, 346 for EBL, and 426 for length of hospital stay. Median BMI was 30.2 (IQR, 26.3–35.2) kg/m^2. Compared to NHW patients, Hispanic and AI patients had significantly higher BMI (median BMI of 29.1, 31.5, and 32.5, respectively; P=0.006 for overall difference, P=0.03 for NHW *vs.* Hispanic patients; P=0.002 for NHW *vs.* AI patients). Nearly half of AI patients (46.7%) had class II/III obesity. BMI was higher among

Table 1 Clinical characteristics of RCC patients by race and ethnicity

Characteristics	All	NHW	Hispanic	AI	Other	P
Total	432 (100.0)	215 (49.8)	151 (35.0)	30 (6.9)	36 (8.3)	
Age (years)	60 [50–68]	62 [53–70]	57 [49–64]	56 [46–65]	60 [53–68]	<0.001
Sex						0.08
Male	269 (62.3)	141 (65.6)	85 (56.3)	23 (76.7)	20 (55.6)	
Female	163 (37.7)	74 (34.4)	66 (43.7)	7 (23.3)	16 (44.4)	
BMI (kg/m^2)	30.2 [26.3–35.2]	29.1 [25.2–33.9]	31.5 [26.6–35.5]	32.5 [29.8–41.3]	20.3 [25.9–36.2]	0.006
≥30, <35	110 (25.5)	48 (22.3)	46 (30.5)	8 (26.7)	8 (22.2)	
≥35	111 (25.7)	48 (22.3)	39 (25.8)	14 (46.7)	10 (27.8)	
Have hypertension	277 (64.1)	136 (63.3)	99 (65.6)	19 (63.3)	24 (66.7)	0.96
Have diabetes	144 (33.3)	56 (26.0)	66 (43.7)	15 (50.0)	7 (19.4)	<0.001
Have both hypertension and diabetes	128 (29.6)	50 (23.3)	59 (39.1)	13 (43.3)	6 (16.7)	0.006
Smoking history	n=430	n=214	n=151	n=29	n=36	0.001
Never smoked	234 (54.4)	98 (45.8)	98 (64.9)	15 (51.7)	23 (63.9)	
Former smoker	119 (27.7)	68 (31.8)	39 (25.8)	5 (17.2)	7 (19.4)	
Current smoker	77 (17.9)	48 (22.4)	14 (9.3)	9 (31.0)	6 (16.7)	
Marital status						0.004
Married/widowed	249 (57.6)	127 (59.1)	91 (60.3)	10 (33.3)	21 (58.3)	
Single/divorced	157 (36.3)	75 (34.9)	54 (35.8)	19 (63.3)	9 (25.0)	
Unknown	26 (6.0)	13 (6.0)	6 (4.0)	1 (3.3)	6 (16.7)	
Insurance						0.21
Private	111 (25.7)	61 (28.4)	35 (23.2)	4 (13.3)	11 (30.6)	
Public	267 (61.8)	123 (57.2)	103 (68.2)	23 (76.7)	18 (50.0)	
No insurance	19 (4.4)	9 (4.2)	6 (4.0)	1 (3.3)	3 (8.3)	
Unknown	35 (8.1)	22 (10.2)	7 (4.6)	2 (6.7)	4 (11.1)	
High SDI (>70)	212 (49.1)	66 (30.7)	101 (66.9)	30 (100.0)	15 (41.7)	<0.001
Clear cell subtype	364 (84.3)	171 (79.5)	141 (93.4)	27 (90.0)	25 (69.4)	<0.001
pT stage						0.41
pT1 (all)	275 (63.7)	139 (64.7)	100 (66.2)	18 (60.0)	18 (50.0)	
pT1a[†]	174 (64.0)	87 (63.0)	66 (67.3)	11 (61.1)	10 (55.6)	
pT1b[†]	98 (36.0)	51 (37.0)	32 (32.7)	7 (38.9)	8 (44.4)	
pT2	21 (4.9)	13 (6.0)	5 (3.3)	0 (0.0)	3 (8.3)	
pT3	130 (30.1)	59 (27.4)	45 (29.8)	12 (40.0)	14 (38.9)	
pT4	6 (1.4)	4 (1.9)	1 (0.7)	0 (0.0)	1 (2.8)	
Advanced stage	138 (31.9)	64 (29.8)	47 (31.1)	12 (40.0)	15 (41.7)	0.40

Table 1 (*continued*)

Table 1 (*continued*)

Characteristics	All	NHW	Hispanic	AI	Other	P
High grade	212 (49.1)	109 (52.7)	70 (46.4)	17 (56.7)	16 (44.4)	0.66
Radical nephrectomy	188 (43.5)	87 (40.5)	68 (45.0)	14 (46.7)	19 (52.8)	0.51
Surgical approach						0.26
Robotic	249 (57.6)	117 (54.4)	94 (62.3)	16 (53.3)	22 (61.1)	
Laparoscopic	45 (10.4)	21 (9.8)	14 (9.3)	3 (10.0)	7 (19.4)	
Open	138 (31.9)	77 (35.8)	43 (28.5)	11 (36.7)	7 (19.4)	
Ischemia time (min)	n=202	n=102	n=71	n=13	n=16	0.95
≤18.5	101 (50.0)	53 (52.0)	34 (47.9)	6 (46.2)	8 (50.0)	
>18.5	101 (50.0)	49 (48.0)	37 (52.1)	7 (53.8)	8 (50.0)	
EBL (mL)	n=346	n=167	n=129	n=25	n=25	0.04
≤150	194 (56.1)	87 (52.1)	70 (54.3)	18 (72.0)	19 (76.0)	
>150	152 (43.9)	80 (47.9)	59 (45.7)	7 (28.0)	6 (24.0)	
Length of hospital stay (days)	n=426	n=211	n=149	n=30	n=36	0.71
≤3	260 (61.0)	124 (58.8)	92 (61.7)	20 (66.7)	24 (66.7)	
>3	166 (39.0)	87 (41.2)	57 (38.3)	10 (33.3)	12 (33.3)	

Data are presented as n (%) or median [IQR]. NHW *vs.* Hispanic (P=0.05); NHW *vs.* AI (P=0.002) for BMI. †, the number of pT1a + pT1b patients in all, NHW, Hispanic, AI, and other groups are 272, 138, 98, 18, and 18, respectively. RCC, renal cell carcinoma; NHW, non-Hispanic White; AI, American Indian; BMI, body mass index; SDI, social deprivation index; pT, pathological tumor; EBL, estimated blood loss; IQR, interquartile range.

patients from neighborhoods with higher SDI compared than patients from low SDI neighborhoods (Table S1). Compared to NHW patients, Hispanic and AI patients were more likely to have diabetes and public insurance and come from high SDI neighborhoods. Hispanic and AI patients were also more likely to have both hypertension and diabetes together (P=0.006), and obesity and high SDI each increased this likelihood (Table S2). Hispanic patients were more likely to be non-smokers and married compared to NHW and AI patients. There were no racial and ethnic differences in nephrectomy type, surgical approach, pathological stage, grade, ischemia time, and length of hospital stay. EBL was significantly different across racial and ethnic groups (P=0.04), and AI and others were less likely to have a larger EBL.

Regarding operative outcomes, the median ischemia time during partial nephrectomy was 18.5 (IQR, 15.0–22.4) minutes. Patients with pT1a tumor had a significantly shorter ischemia time compared to pT1b tumor (P<0.001) with median ischemia time of 17.1 and 21.1 minutes respectively for pT1a and pT1b. Class II/III obesity (BMI ≥35 kg/m^2) was more common in patients who had a longer ischemia time (>18.2 minutes, 30.7%) than patients who had a shorter ischemia time (21.8%), but the difference was not statistically significant (*Table 2*). Class II/III obesity was associated with a longer ischemia time [odds ratio (OR), 5.17; 95% confidence interval (CI): 1.81–14.76; P=0.002; *Table 3*] and this association was similar in stratified analysis (Table S3). One increment increase in BMI was associated with 5% increased odds of a longer ischemia time. BMI had a linear association with a longer ischemia time in NHW patients (OR, 1.13; 95% CI: 1.04–1.22; P=0.004) but not in Hispanic patients (OR, 1.07; 95% CI: 0.98–1.17; P=0.12), although this interaction was not statistically significant. In the pT1a patient subset, class II/III obesity was associated with a longer ischemia time (OR, 4.87; 95% CI: 1.20–19.54).

Median EBL was 150 (IQR, 75.0–300.0) mL. Obesity was slightly more common in patients who had a larger EBL (>150 mL) than patients with a smaller EBL. In logistic regression analysis, higher BMI was associated with a larger EBL. Class I and II/III obese patients had over two-fold

Table 2 Rates of obesity stratified by ischemia time, EBL, and length of hospital stay

BMI (kg/m^2)	Longer ischemia time (min)			Larger EBL (mL)			Longer length of stay (days)		
	≤18.5	>18.5	P	≤150	>150	P	<4	≥4	P
<25	26 (25.7)	18 (17.8)	0.33	43 (22.2)	22 (14.5)	0.19	56 (21.5)	26 (15.7)	0.17
≥25, <30	21 (20.8)	24 (23.8)		55 (28.4)	39 (25.7)		67 (25.8)	58 (34.9)	
≥30, <35	32 (31.7)	28 (27.7)		46 (23.7)	46 (30.3)		70 (26.9)	40 (24.1)	
≥35	22 (21.8)	31 (30.7)		50 (25.8)	45 (29.6)		67 (25.8)	42 (25.3)	

Data are presented as n (%). Chi-squared test. EBL, estimated blood loss; BMI, body mass index.

increased odds of a larger EBL than patients with normal weight (OR, 2.17; 95% CI: 1.03–4.59; P=0.04 for class I and OR, 2.24; 95% CI: 1.04–4.84; P=0.04 for class II/III obese patients). When analysis was performed stratifying based nephrectomy type, obesity increased odds of a larger EBL in patients who underwent partial nephrectomy but not in patients who underwent radical nephrectomy (BMI ≥30 *vs.* <30 kg/m^2, OR, 2.77; 95% CI: 1.43–5.35; P=0.002 in partial nephrectomy and OR, 1.03; 95% CI: 0.39–2.76; P=0.95 in radical nephrectomy group). BMI was associated with a larger EBL even after adjusting for ischemia time (BMI ≥30 *vs.* <30 kg/m^2, OR, 3.63; 95% CI: 1.68–7.76; P<0.001). Patients who had a robotic partial nephrectomy had similar OR for larger EBL (BMI ≥30 *vs.* <30 kg/m^2, OR, 3.34; 95% CI: 1.42–7.87; P=0.006). BMI was not associated with a larger EBL in patients who had an open surgery.

Obesity was associated with a larger EBL in patients from high SDI neighborhood (OR, 3.53; 95% CI: 1.57–7.97; P=0.002), but not in patients from low SDI neighborhood. Analysis among patients who underwent partial nephrectomy showed a similar pattern of association (Table S4). Obesity was associated with a larger EBL in NHW patients (OR, 2.38; 95% CI: 1.10–5.14; P=0.03), but not in Hispanic patients. Interaction was not significant in these analyses. Obesity increased odds of larger EBL in both racial and ethnic groups among patients who underwent partial nephrectomy. We also explored the impact of obesity on EBL using different cutoffs (Table S5). Although not significant, BMI increased odds of EBL ≥700 mL.

The median length of hospital stay was 3 (IQR, 2–5) days. There was no difference in BMI between patients with a longer and shorter length of hospital stay. BMI was not associated with a longer hospital stay in our logistic regression analysis. Stratified analysis based on nephrectomy type, race and ethnicity, SDI, also yielded similar results. Race and ethnicity and SDI were not associated with ischemia time, EBL, and length of hospital stay.

The relationships among ischemia time, EBL, and length of hospital stay were assessed because BMI may impact the length of hospital stay indirectly through increased ischemia time and EBL. Ischemia time, EBL, and length of hospital stay were highly correlated. Patients who had a longer ischemia time had a larger EBL and a longer hospital stay (Table S6). Patients who had a larger EBL had longer hospital stay. In logistic regression analysis among patients who underwent partial nephrectomy, longer ischemia time was associated with larger EBL (Table S7). Longer ischemia time had 16-fold increased odds of EBL ≥700 mL, but the CI was large due to very small number of patients who had EBL ≥700 mL. Then, we assessed if ischemia time and EBL predict length of hospital stay. A longer ischemia time increased odds of longer hospital stay, but the association was not statistically significant (OR, 3.46; 95% CI: 0.59–20.43). Larger EBL and having both hypertension and diabetes increased odds of longer hospital stay, but ORs were extremely large and CIs were wide due to small sample size (OR, 32.53; 95% CI: 3.42–309.60 and OR, 19.18; 95% CI 1.56–236.53, respectively for a larger EBL and having both hypertension and diabetes).

Discussion

This study examined impacts of obesity on perioperative outcomes and heterogenous associations based on race and ethnicity and neighborhood-level socioeconomic challenges. Obesity was associated with a longer ischemia time and larger EBL. The associations varied based on race and ethnicity and neighborhood-level socioeconomic status. Specifically, obese NHW patients had a longer ischemia time, but we did not observe such pattern in Hispanic patients. Obese patients from a high SDI neighborhood had a greater EBL, but not obese patients from a low SDI

Table 3 Logistic regression analysis assessing impact of obesity on ischemia time, EBL, and length of hospital stay

BMI (kg/m^2)	Longer ischemia time†		Larger EBL‡		Longer length of stay§	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
All						
<25	Reference		Reference		Reference	
≥25, <30	2.29 (0.88–5.93)	0.09	1.11 (0.54–2.28)	0.77	2.13 (0.90–5.01)	0.09
≥30, <35	2.05 (0.79–5.30)	0.14	2.17 (1.03–4.59)	0.04*	0.93 (0.37–2.30)	0.87
≥35	5.17 (1.81–14.76)	0.002*	2.24 (1.04–4.84)	0.04*	0.83 (0.33–2.10)	0.70
Continuous	1.05 (1.002–1.10)	0.04*	1.02 (0.99–1.05)	0.22	0.99 (0.96–1.04)	0.81
Partial nephrectomy						
<30			Reference		Reference	
≥30			2.77 (1.43–5.35)	0.002*	1.11 (0.35–3.45)	0.86
Continuous			1.03 (0.99–1.08)	0.14	1.00 (0.94–1.08)	0.93
Radical nephrectomy						
<30			Reference		Reference	
≥30			1.03 (0.39–2.76)	0.95	0.51 (0.23–1.16)	0.11
Continuous			1.01 (0.96–1.07)	0.61	1.00 (0.95–1.05)	0.96
Low SDI						
<30	Reference		Reference		Reference	
≥30	1.58 (0.63–4.01)	0.33	1.18 (0.57–2.47)	0.66	0.97 (0.36–2.65)	0.97
Continuous	1.07 (0.99–1.15)	0.10	0.99 (0.94–1.05)	0.78	1.07 (0.99–1.16)	0.08
High SDI						
<30	Reference		Reference		Reference	
≥30	1.86 (0.66–5.26)	0.24	3.53 (1.57–7.97)	0.002*	0.45 (0.19–1.05)	0.06
Continuous	1.04 (0.97–1.10)	0.28	1.04 (0.99–1.09)	0.06	0.98 (0.93–1.03)	0.39
NHW						
<30	Reference		Reference		Reference	
≥30	2.81 (0.97–8.09)	0.06	2.38 (1.10–5.14)	0.03*	0.69 (0.26–1.82)	0.45
Continuous	1.13 (1.04–1.22)	0.004*	1.05 (0.99–1.10)	0.10	1.03 (0.97–1.10)	0.33
Hispanic						
<30	Reference		Reference		Reference	
≥30	2.44 (0.72–8.31)	0.15	1.85 (0.80–4.29)	0.15	0.85 (0.30–2.43)	0.76
Continuous	1.07 (0.98–1.17)	0.12	1.01 (0.96–1.06)	0.70	0.99 (0.93–1.07)	0.88

†, model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage (I/II *vs.* III/IV), grade (1/2 *vs.* 3/4), and RCC subtype; ‡, model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage, grade, nephrectomy type, and surgical approach; §, model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage, insurance, nephrectomy type, and surgical approach; *, P<0.05. EBL, estimated blood loss; BMI, body mass index, OR, odds ratio; CI, confidence interval; SDI, social deprivation index; NHW, non-Hispanic White; RCC, renal cell carcinoma.

neighborhood. Moreover, a longer ischemia time and larger EBL were associated with a longer length of hospital stay.

Our findings on impacts of obesity on EBL and length of hospital stay were consistent with literature showing that obesity increases blood loss during partial nephrectomy but no effect on length of hospital stay (16-20). However, unlike our study, previous studies focused on evaluating safety of minimally invasive surgical approach (laparoscopic or robotic partial nephrectomy) among obese patients and found no association between obesity and warm ischemia time (18-20). Obesity was associated with length of hospital study in a study of patients who underwent laparoscopic radical nephrectomy (24), but obesity was not associated with EBL or length of hospital stay in others studies of patient who underwent laparoscopic radical nephrectomy and studies including both nephrectomy types (22,23,41,42). In addition to potential differences in patients' racial and ethnic and socioeconomic backgrounds, this study has several differences from previous studies. This study included patients with all surgical approaches and both warm and cold ischemia time. After stratifying based on nephrectomy type, association between obesity and EBL was statistically significant only in patients who underwent partial nephrectomy, and sub-analysis with patients who underwent robotic-assisted partial nephrectomy yield similar results. Also, this study did not use RENAL (radius, exophytic/endophytic properties, nearness of tumor to the collecting system or sinus in millimeters, anterior/posterior location relative to polar lines) nephrometry, the Preoperative Aspects and Dimensions Used for an Anatomical (PADUA), or American Society of Anesthesiologists (ASA) scores. Including these scores in the regression models likely change the results. Obesity may also impact on length of surgery, post-surgical complications, or 30 days readmission (43). Future studies need to evaluate these aspects of nephrectomy outcomes in diverse patient populations.

We further examined whether race and ethnicity and neighborhood level socioeconomic challenges modified associations between obesity and perioperative outcomes because obesity rates vary across racial and ethnic groups and neighborhood factors are associated with obesity rates. Although we did not observe statistically significant interaction, we showed that the associations between obesity and perioperative outcomes may vary based on patients' race and ethnic and neighborhood-level socioeconomic backgrounds. The reasons for different associations based on race and ethnicity and neighborhood factors are not clear. We did not find significant association for Hispanic patients, potentially due to a small sample size and small variation in BMI with many of them having high BMI. Also, there are great variation in body composition across racial and ethnic groups (44,45), and body composition variation and perinephric fat thickness may better explain the relationships between obesity and perioperative outcomes (46,47). More detailed clinical information, including comorbidities and tumor characteristics assessed with computed tomography (CT) or magnetic resonance (MR) scans, is also necessary to further investigate the differences based on race and ethnicity and neighborhood-level socioeconomic characteristics.

These patterns have not been fully explored for RCC, but a previous study did not find association between race and ethnicity and postoperative complications among patients who underwent radical or partial nephrectomy (48). The studies looking at disparities in perioperative outcomes for treatment of other cancer types are still scarce, but current evidence shows that patients from racial and ethnic minority and low socioeconomic backgrounds are more likely to have perioperative and post-operative complications. Compared to NHW patients, non-Hispanic Black and Hispanic patients are more likely to have post-operative complications and prolonged hospital say after surgical treatment of urologic cancers and other cancer types (49-51). Among patients who received surgical treatment for colon cancer, racial and ethnic minority patients from small town or rural areas are more likely to have post-operative complications (52). High neighborhood socioeconomic deprivation and low household-level socioeconomic status was also associated with likelihood of having complications and longer length of hospital stay after surgical treatment of colon cancer (52,53). In a study among patients who underwent robotic-assisted pulmonary lobectomy for lung cancer treatment, Jermihov *et al.* demonstrated that length of hospital stay was significantly longer for patients from neighborhoods from below 300% Federal Poverty level (54). Other studies, on the other hand, showed that race and ethnicity and neighborhood-level socioeconomic deprivation do not affect quality of surgical care (55,56). More studies are needed to identify areas within healthcare systems to reduce disparities in surgical treatment and outcomes.

Obesity may not have major effects on nephrectomy outcomes in general populations. With use of minimally invasive surgical treatment, length of hospital stay can be reduced resulting in equivalent or lower cost than open surgery (57,58). However, the relationship between obesity, race and ethnicity, socioeconomic challenge, and perioperative outcomes is very complex, and patients from racial and ethnic minority backgrounds and neighborhoods with elevated socioeconomic challenges may be unevenly impacted. Obesity is more prevalent in racial and ethnic minority groups and patients from socioeconomically disadvantaged neighborhoods (32,37,38). Obesity increases the likelihood of more comorbidities and a larger EBL during the surgery, especially patients from neighborhoods with elevated socioeconomic challenges. Then, a larger EBL and having comorbidities prolong hospital stay (27,28). There is also a link between RCC outcomes and metabolomic syndrome defined as being obese and having hypertension, diabetes, and hyperlipidemia. Previous studies have shown that metabolic syndrome is associated with complications, transfusion, conversion to open surgery, and poor survival (21,59-61). Furthermore, racial and ethnic minority patients and patients with comorbidities are more likely to undergo radical rather than partial nephrectomy (33-36,62). These all together may have a synergetic effect resulting in a greater financial burden in racial and ethnic minority patients and patients from elevated socioeconomic challenges, their family, and communities (e.g., reduced income from a longer time off from work, a larger medical debt, and loss of economic productivity). Unfortunately, relationships between race and ethnicity or neighborhood-level socioeconomic challenge and length of hospital stay are not clear due to these mediating or confounding factors. The long-term consequences of these disparities are unknown. Given the complex relationship among race and ethnicity, socioeconomic challenges, comorbidities, and obesity, it is necessary to further investigate how this relationship affects surgical and oncologic outcomes. It is also important to consider a larger societal context to assess individual risk of negative surgical treatment outcomes, relationships between obesity and surgical outcomes, and financial burden among patients with socioeconomic challenges.

There are several limitations for this study. First, the data was obtained from a single academic institution. While racial and ethnic minority patients were well represented, patients included in our study may not be representative of the population in the area. The findings from this study may not be generalizable. Second, the sample size was small. Our study was underpowered to show moderate or small effect of obesity on perioperative outcomes, and we were not able to show significant associations when stratified analysis was performed for a specific clinical stage and nephrectomy type. Samples size for some of BMI categories were also small and resulted in large CIs for both statistically significant and non-significant categories. Our study is unique to include AI patients. However, we had only 30 AI patients, and we were not able to perform any AI patient specific analysis. Third, this was a retrospective study, and we did not have potentially important data that may have affected the association, such as urologists' experience as well as RENAL nephrometry, PADUA, and ASA scores. Future studies need to include RENAL nephrometry, PADUA, and ASA scores in diverse patient populations. Also, ischemia time data was missing 17.2% of patients who underwent partial nephrectomy, and EBL data was missing for 19.9% of patients. Selection bias may have affected the results even though BMI was not statistically significant different between those with and without missing data. Finally, we used neighborhood-level socioeconomic status. Use of individual-level socioeconomic status may yield different results.

Conclusions

This study evaluated impacts of obesity on ischemia time, EBL, and length of hospital stay including previously underrepresented patient populations that have higher rates of kidney cancer mortality and obesity. Race and ethnicity and neighborhood-level socioeconomic factors potentially impact the relationship between obesity and perioperative outcomes. A larger EBL and having comorbidities were associated with prolonged hospital stay.

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Footnote

Reporting Checklist: The authors have completed the

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the University of Arizona Institutional Review Board (Protocol #1912228839) and individual consent for this retrospective analysis was waived.

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Supplementary

Table S1 Correlations between SDI and BMI and increasing median BMI (IQR) with SDI (quartile)

Race and ethnicity	N	Spearman's correlation		SDI (quartile)				P†	Mann-Whitney *U* test P value		
		Spearman's rho	P	Q1 (≤35)	Q2 (>35, ≤70)	Q3 (>70, ≤88)	Q4 (>80)		$P_{Q1\ vs.\ Q2}$	$P_{Q1\ vs.\ Q3}$	$P_{Q1\ vs.\ Q4}$
All	432	0.132	0.006*	29.4 (26.0–32.8)	30.3 (25.7–34.2)	30.5 (26.6–36.9)	31.4 (27.0–37.2)	0.054	0.38	0.03*	0.02*
NHW	215	0.047	0.49	29.2 (25.8–32.8)	28.7 (26.6–34.1)	29.1 (25.1–34.7)	31.4 (23.7–37.8)	0.73	0.51	0.96	0.32
Hispanic	151	0.124	0.15	29.8 (26.5–34.0)	31.5 (24.8–34.0)	32.8 (27.4–36.9)	30.5 (27.3–35.6)	0.27	0.65	0.18	0.32
AI	30	−0.01	0.61	–	–	37.9 (27.1–42.3)	32.4 (29.8–40.0)	0.62	NA	NA	NA
Other	36	−0.15	0.93	29.3 (24.1–34.1)	35.1 (25.8–40.3)	29.3 (28.0–37.8)	25.9 (23.9–31.6)	0.33	0.27	0.38	0.51

†, P value from Kruskal-Wallis test; *, P<0.05. SDI, social deprivation index; BMI, body mass index; IQR, interquartile range; NHW, non-Hispanic White; AI, American Indian; NA, not available.

Table S2 Correlation of having hypertension and diabetes with BMI and SDI (quartile)

Categories	None	Hypertension or diabetes	Both hypertension and diabetes	P
BMI (kg/m^2)	n=141	n=173	n=132	<0.001
<25	40 (28.4)	31 (17.9)	14 (10.6)	
≥25, <30	48 (34.0)	55 (31.8)	29 (22.0)	
≥30, <35	26 (18.4)	47 (27.2)	40 (30.3)	
≥35	27 (19.1)	40 (23.1)	49 (37.1)	
SDI	n=138	n=166	n=128	0.007
Q1	31 (22.5)	52 (31.3)	25 (19.5)	
Q2	40 (29.0)	48 (28.9)	24 (18.8)	
Q3	38 (27.5)	33 (19.9)	35 (27.3)	
Q4	29 (21.0)	33 (19.9)	44 (34.4)	

Data are presented as n (%). BMI, body mass index; SDI, social deprivation index.

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Table S3 BMI is associated with a longer ischemia time and a larger EBL (>150 *vs.* ≤150 mL) stratified by SDI and race and ethnicity

BMI (kg/m^2)	Longer ischemia time		Larger EBL	
	OR (95% CI)	P	OR (95% CI)	P
Low SDI				
<25	Reference		Reference	
≥25, <30	4.01 (1.06–15.12)	0.04*	0.88 (0.32–2.42)	0.81
≥30, <35	2.24 (0.61–8.23)	0.23	1.99 (0.69–5.72)	0.20
≥35	5.82 (1.35–25.12)	0.02*	1.37 (0.43–4.34)	0.60
High SDI				
<25	Reference		Reference	
≥25, <30	1.34 (0.25–7.24)	0.74	1.05 (0.29–3.73)	0.95
≥30, <35	1.44 (0.27–7.57)	0.67	1.99 (0.54–7.30)	0.30
≥35	4.12 (0.72–23.52)	0.11	3.32 (0.93–11.87)	0.07*
NHW				
<25	Reference		Reference	
≥25, <30	2.41 (0.61–9.44)	0.21	0.94 (0.34–2.61)	0.90
≥30, <35	2.25 (0.55–9.28)	0.26	2.10 (0.70–6.30)	0.19
≥35	11.74 (2.34–59.01)	0.003*	3.10 (1.01–9.54)	0.048*
Hispanic				
<25	Reference		Reference	
≥25, <30	4.08 (0.48–34.61)	0.20	1.14 (0.28–4.64)	0.85
≥30, <35	4.64 (0.58–37.23)	0.15	2.64 (0.66–10.48)	0.17
≥35	16.72 (1.48–189.23)	0.02*	2.03 (0.48–8.65)	0.34

*, P<0.05. Model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage, grade, nephrectomy type, and surgical approach. BMI, body mass index; EBL, estimated blood loss; SDI, social deprivation index; OR, odds ratio; CI, confidence interval; NHW, non-Hispanic White.

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Table S4 Logistic regression analysis assessing impact of obesity and comorbidities on EBL, and length of hospital stay stratified based on SDI and race and ethnicity in patients underwent partial nephrectomy

BMI (kg/m^2)	Larger EBL[†]		Longer hospital stay[‡]	
	OR (95% CI)	P	OR (95% CI)	P
Low SDI				
<30	Reference		Reference	
≥30	2.28 (0.89–5.86)	0.09*	0.53 (0.09–3.00)	0.47
Continuous	1.01 (0.94–1.08)	0.88	1.05 (0.91–1.21)	0.49
High SDI				
<30	Reference		Reference	
≥30	3.75 (1.33–10.60)	0.01*	3.15 (0.37–27.02)	0.30
Continuous	1.07 (0.99–1.14)	0.053	0.97 (0.88–1.08)	0.63
NHW				
<30	Reference		Reference	
≥30	3.10 (1.18–8.20)	0.02*	0.36 (0.05–2.81)	0.33
Continuous	1.05 (0.98–1.12)	0.18	1.01 (0.89–1.14)	0.87
Hispanic				
<30	Reference		Reference	
≥30	3.57 (1.004–12.68)	0.049*	2.28 (0.34–15.41)	0.40
Continuous	1.03 (0.95–1.11)	0.44	0.98 (0.88–1.09)	0.64

[†], model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage, grade, nephrectomy type, and surgical approach; [‡], model includes BMI, comorbidity, age, sex, race and ethnicity, SDI, stage, insurance, nephrectomy type, and surgical approach; *, $P<0.05$. EBL, estimated blood loss; SDI, social deprivation index; BMI, body mass index; OR, odds ratio; CI, confidence interval; NHW, non-Hispanic White.

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Table S5 Association between BMI and EBL using different cutoff for EBL

BMI/obesity by different EBL cutoffs	EBL1	EBL2	OR (95% CI)	P
EBL >150 *vs.* ≤150 mL	>150 mL	≤150 mL		
Obesity	n=199	n=155		
Non-obese	99 (49.7)	64 (41.3)	Reference	
Obese	100 (50.3)	91 (58.7)	2.07 (1.24–3.48)	0.006*
Continuous	31.4 (8.0)	32.0 (7.3)	1.03 (0.99–1.06)	0.11
EBL ≥500 *vs.* <500 mL	≥500 mL	<500 mL		
BMI (kg/m^2)	n=296	n=58		
<25	55 (18.6)	10 (17.2)	Reference	
≥25, <30	83 (28.0)	15 (25.9)	0.70 (0.27–1.86)	0.48
≥30, <35	80 (27.0)	14 (24.1)	1.02 (0.38–2.75)	0.97
≥35	78 (26.4)	19 (32.8)	1.84 (0.68–5.02)	0.23
Obesity	n=296	n=58		
Non-obese	138 (46.6)	25 (43.1)	Reference	
Obese	158 (53.4)	33 (56.9)	1.66 (0.84–3.27)	0.15
Continuous	31.6 (7.6)	32.3 (8.3)	1.03 (0.99–1.07)	0.16
EBL ≥700 *vs.* <700 mL	≥700 mL	<700 mL		
BMI (kg/m^2)	n=323	n=31		
<25	62 (19.2)	3 (9.7)	Reference	
≥25, <30	86 (26.6)	12 (38.7)	1.91 (0.46–7.99)	0.37
≥30, <35	86 (26.6)	8 (25.8)	2.21 (0.48–10.21)	0.31
≥35	89 (27.6)	8 (25.8)	2.26 (0.46–11.03)	0.31
Obesity	n=323	n=31		
Non-obese	148 (45.8)	15 (48.4)	Reference	
Obese	175 (54.2)	16 (51.6)	1.41 (0.56–3.54)	0.47
Continuous	31.7 (7.8)	31.5 (7.0)	1.02 (0.96–1.08)	0.59
EBL ≥1,000 *vs.* <1,000 mL	≥1,000 mL	<1,000 mL		
BMI (kg/m^2)	n=340	n=14		
<25	63 (18.5)	2 (14.3)	Reference	
≥25, <30	92 (27.1)	6 (42.9)	1.31 (0.19–9.98)	0.78
≥30, <35	92 (27.1)	2 (14.3)	1.20 (0.10–14.88)	0.89
≥35	93 (27.4)	4 (28.6)	1.78 (0.20–16.19)	0.61
Obesity	n=329	n=14		
Non-obese	150 (45.6)	8 (57.1)	Reference	
Obese	179 (54.4)	6 (42.9)	1.27 (0.28–5.70)	0.75
Continuous	31.7 (7.7)	31.2 (8.5)	1.02 (0.94–1.11)	0.60

Data are presented as n (%) or mean (SD). *, P<0.05. BMI, body mass index; EBL, estimated blood loss; OR, odds ratio; CI, confidence interval; SD, standard deviation.

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Table S6 Ischemia time and EBL by length of hospital stay

Outcomes	Length of hospital stay (days)			Ischemia time (min)		
	≤3 (n=231)	>3 (n=122)	P	≤18.5 (n=98)	>18.5 (n=99)	P
Ischemia time (min)	n=152	n=53	0.007			
≤18.5	83 (54.6)	18 (34.0)				
>18.5	69 (45.4)	35 (66.0)				
EBL1 (mL)			<0.001			0.002
≤150	152 (65.8)	47 (38.5)		65 (66.3)	44 (44.4)	
>150	79 (34.2)	75 (61.5)		33 (33.7)	55 (55.6)	
EBL2 (mL)			<0.001			<0.001
≤500	210 (90.9)	85 (69.7)		94 (95.9)	79 (79.8)	
>500	21 (9.1)	37 (30.3)		4 (4.1)	20 (20.2)	
EBL3 (mL)			<0.001			0.02
≤700	223 (96.5)	99 (81.1)		97 (99.0)	90 (90.9)	
>700	8 (3.5)	23 (18.9)		1 (1.0)	9 (9.1)	
EBL4 (mL)			<0.001			0.25
≤1,000	230 (99.6)	109 (89.3)		98 (100.0)	96 (97.0)	
>1,000	1 (0.4)	13 (10.7)		0 (0.0)	3 (3.0)	

Data are presented as n (%). EBL, estimated blood loss.

Table S7 A longer ischemia time is associated with a larger EBL

EBL cutoffs	Smaller EBL	Larger EBL	OR (95% CI)	P
EBL >150 *vs.* ≤150 mL	n=109	n=88		
Shorter ischemia time	65 (59.6)	33 (37.5)	Reference	
Longer ischemia time	44 (40.4)	55 (62.5)	3.51 (1.70–7.26)	<0.001*
EBL ≥500 *vs.* <500 mL	n=173	n=24		
Shorter ischemia time	94 (54.3)	4 (16.7)	Reference	
Longer ischemia time	79 (45.7)	20 (83.3)	9.58 (2.56–35.92)	<0.001*
EBL ≥700 *vs.* <700 mL	n=187	n=10		
Shorter ischemia time	97 (51.9)	1 (10.0)	Reference	
Longer ischemia time	90 (48.1)	9 (90.0)	16.14 (1.41–185.09)	0.03*
EBL ≥1,000 *vs.* <1,000 mL	n=194	n=3		
Shorter ischemia time	98 (50.5)	0 (0.0)		
Longer ischemia time	96 (49.5)	3 (100.0)		

Data are presented as n (%). *, P<0.05. EBL, estimated blood loss; OR, odds ratio; CI, confidence interval.

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