

Comparative Analysis of Robotic-Assisted, Laparoscopic, and Open Radical Nephrectomy: Utilization, Costs, and Clinical Outcomes

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INTRODUCTION

- Renal cell carcinoma (RCC) is a significant public health concern, accounting for approximately 4.2% of adult malignancies globally and over 74,000 new cases each year in the United States.¹
- Radical nephrectomy is the established standard of care, traditionally performed via open radical nephrectomy (ORN), particularly for large tumors and T1–T2 tumors not suitable for nephron-sparing surgery.²
- However, the emergence of minimally invasive surgical techniques has led to increased adoption of laparoscopic radical nephrectomy (LARN) and, more recently, robotic-assisted radical nephrectomy (RARN).^{3–5}

OBJECTIVE

This contemporary study evaluates trends in RARN, LARN, and ORN use and compares their hospital costs, clinical complications, and mortality rates.



METHODS

- Data Source and Study Design:** This retrospective cohort study analyzed data from the 2016–2019 National Inpatient Sample (NIS), the largest all-payer inpatient database in the U.S., maintained by the Agency for Healthcare Research and Quality (AHRQ).
- Study Population:** Patients aged ≥18 years diagnosed with renal cancer undergoing radical nephrectomy were identified using ICD-10 codes. Surgical approaches compared included ORN, LARN, and RARN.
- Outcomes:** Primary outcomes assessed included postoperative complications (cardiac, respiratory, genitourinary, vascular, wound-related, bleeding), blood transfusions, mortality, length of hospital stay, and hospitalization costs.
- Statistical Analysis:** Multivariable logistic, negative binomial, Poisson regressions, and generalized linear models adjusted for patient demographics and hospital characteristics to evaluate differences in clinical and economic outcomes among surgical approaches. The data were analyzed using SAS® version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Table 1. Characteristics of patients undergoing radical nephrectomy by surgical technique

	LARN N = 60,855	RARN N = 39,590	ORN N = 53,670
Age, Mean ± SD	57.6 (16.7)	62.9 (14.9)	57.9 (18.2)
Age, No. (%)			
≤ 50	18,250 (30.0)	7,000 (17.7)	15,470 (28.8)
51–60	12,940 (21.3)	7,705 (19.5)	11,930 (22.2)
61–70	15,525 (25.5)	11,725 (29.6)	13,825 (25.8)
≥ 71	14,140 (23.2)	13,160 (33.2)	12,445 (23.2)
Sex, No. (%)			
Female	28,135 (46.2)	16,510 (41.7)	22,585 (42.1)
Male	32,685 (53.7)	23,060 (58.2)	31,065 (57.9)
Missing	35 (0.1)	20 (0.1)	20 (0)
No. race (%)			
White	40,565 (66.7)	29,205 (73.8)	35,905 (66.9)
Black	6,495 (10.7)	3,485 (8.8)	6,270 (11.7)
Other	11,770 (19.3)	5,710 (14.4)	8,860 (16.5)
Missing	2,025 (3.3)	1,190 (3.0)	2,635 (4.9)
No. primary payer (%)			
Medicare	25,155 (41.3)	20,130 (50.8)	23,185 (43.2)
Private	23,880 (39.2)	14,435 (36.5)	19,370 (36.1)
Medicaid	4,835 (7.9)	3,000 (7.6)	5,710 (10.6)
Other	6,765 (11.1)	1,950 (4.9)	5,235 (9.8)
Missing	220 (0.4)	75 (0.2)	170 (0.3)
No. Zip Code median income quartile (%)			
Q1	14,495 (23.8)	9,250 (23.4)	14,225 (26.5)
Q2	15,320 (25.2)	9,950 (25.1)	14,440 (26.9)
Q3	15,180 (24.9)	10,245 (25.9)	13,200 (24.6)
Q4	14,895 (24.5)	9,605 (24.3)	10,880 (20.3)
Missing	965 (1.6)	540 (1.4)	925 (1.7)
No. CCI (%)			
0	18,790 (30.9)	7,685 (19.4)	12,610 (23.5)
1	17,295 (28.4)	11,320 (28.6)	14,830 (27.6)
2	13,645 (22.4)	10,745 (27.1)	13,560 (25.3)
3 or greater	11,125 (18.3)	9,840 (24.9)	12,670 (23.6)

Abbreviations: LARN, Laparoscopic Radical Nephrectomy; RARN, Robotic-Assisted Radical Nephrectomy; ORN, Open Radical Nephrectomy; IQR, Interquartile Range; LOS, Length of Stay Notes: Percents may not add to 100 due to rounding.

Table 2. Intraoperative and postoperative outcomes during hospitalization by surgical technique

	LARN N = 60,855	RARN N = 39,590	ORN N = 53,670
No. blood transfusions (%)	18,250 (30.0)	7,000 (17.7)	15,470 (28.8)
No. complications (%)	12,940 (21.3)	7,705 (19.5)	11,930 (22.2)
Cardiac	15,525 (25.5)	11,725 (29.6)	13,825 (25.8)
Genitourinary	14,140 (23.2)	13,160 (33.2)	12,445 (23.2)
Respiratory	28,135 (46.2)	16,510 (41.7)	22,585 (42.1)
Vascular	32,685 (53.7)	23,060 (58.2)	31,065 (57.9)
Wound or Infection	35 (0.1)	20 (0.1)	20 (0)
Bleeding	40,565 (66.7)	29,205 (73.8)	35,905 (66.9)
Misc. Medical	6,495 (10.7)	3,485 (8.8)	6,270 (11.7)
Misc. Surgical	11,770 (19.3)	5,710 (14.4)	8,860 (16.5)
No. Any complication (%)			
0	56,495 (92.8)	36,430 (92.0)	45,140 (84.1)
1	3,680 (6.0)	2,565 (6.5)	6,205 (11.6)
2+	680 (1.1)	595 (1.5)	2,325 (4.3)
No. discharge status			
Routine	54,055 (88.8)	33,930 (85.7)	41,220 (76.8)
Non-Routine	6,575 (10.8)	5,540 (14.0)	10,820 (20.2)
Missing	225 (0.4)	120 (0.3)	1,630 (3.0)
No. deaths (%)	185 (0.3%)	90 (0.2%)	1,600 (3.0%)
Median days LOS [IQR]	2 [2, 4]	2 [2, 4]	4 [3, 7]
Median \$ total costs [IQR]	13,950 [10,628–18,924]	16,771 [12,794–22,794]	17,821 [12,703–28,516]

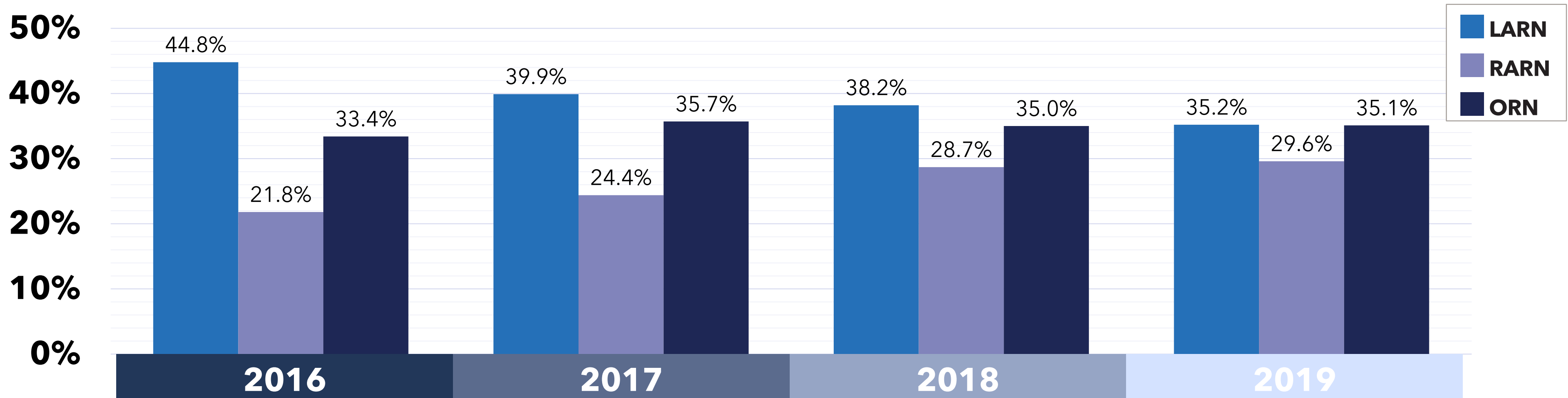
Abbreviations: LARN, Laparoscopic Radical Nephrectomy; RARN, Robotic-Assisted Radical Nephrectomy; ORN, Open Radical Nephrectomy; IQR, Interquartile Range; LOS, Length of Stay Notes: Percents may not add to 100 due to rounding.

Table 3. Results of regression analyses of LARN and RARN vs ORN for intraoperative and postoperative outcome, length of stay and cost

Surgery Type	Blood transfusions Adjusted OR (CI)	Complications Adjusted OR (CI)	Cardiac Adjusted OR (CI)	Genitourinary Adjusted OR (CI)	Wound/Infection Adjusted OR (CI)	Non-routine discharge Adjusted OR (CI)	Death Adjusted OR (CI)	LOS IRR (CI)	Total Costs e ^B (CI)
ORN Reference									
LARN	0.23 (0.20–0.27)	0.43 (0.40–0.47)	0.49 (0.35–0.69)	0.48 (0.40–0.57)	0.30 (0.24–0.36)	0.49 (0.45–0.53)	0.10 (0.07–0.15)	0.80 (0.76–0.84)	0.73 (0.72–0.74)
RARN	0.28 (0.24–0.32)	0.43 (0.39–0.48)	0.50 (0.34–0.74)	0.47 (0.38–0.57)	0.33 (0.27–0.41)	0.52 (0.48–0.57)	0.08 (0.05–0.14)	0.77 (0.73–0.80)	0.85 (0.84–0.87)

Abbreviations: e^B=anti-log transformation of the coefficient B from regressing LN(total costs) on covariates, yielding the multiplicative difference in the expected value of total cost associated with different covariate values; LARN, Laparoscopic Radical Nephrectomy; RARN, Robotic-Assisted Radical Nephrectomy; ORN, Open Radical Nephrectomy; IQR, Interquartile Range; IRR=incidence rate ratio; LOS, Length of Stay

Figure 1. Annual percentages of procedures using LARN, RARN, and ORN during 2016–2019



Discussion

- Minimally invasive techniques (LARN and RARN) were associated with better perioperative outcomes compared to ORN, including lower complication rates, reduced transfusions, and shorter hospital stays; however, RARN was significantly more costly than LARN despite similar clinical outcomes.
- RARN adoption increased while LARN declined, driven by factors such as surgeon training, institutional investment in robotics, and perceived technical advantages, even though cost considerations favor LARN.

Limitations

- The use of administrative data limits the ability to account for tumor-specific factors (e.g., stage, size, histology) and detailed clinical considerations that may influence surgical approach selection.
- Robotic surgery costs may be underestimated due to the inability to capture capital and maintenance expenses, and a full cost-effectiveness analysis was not conducted.

Conclusion

- Despite higher costs, the use of RARN continues to rise, offering comparable perioperative outcomes to LARN and demonstrating advantages over ORN, raising important economic and clinical considerations.
- Future research should assess long-term outcomes, cost-effectiveness, and patient-centered measures to better inform evidence-based surgical decisions for renal cancer management.

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