Comparison of 1-Year Health Care Expenditures and Utilization Following Minimally Invasive vs Open Nephrectomy

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Abstract

**IMPORTANCE** Given the widespread adoption and clinical benefits of minimally invasive surgery approaches (MIS) in partial nephrectomy (PN) and radical nephrectomy (RN), assessment of long-term cost implications is relevant.

**OBJECTIVE** To compare health care utilization and expenditures within 1 year after MIS and open surgery (OS).

**DESIGN, SETTING, AND PARTICIPANTS** This cohort study was conducted using a US commercial claims database between 2013 and 2018. A total of 5104 patients aged 18 to 64 years who underwent PN or RN for kidney cancer and were continuously insured for 180 days before and 365 days after surgery were identified. An inverse probability of treatment weighting analysis was performed to examine differences in costs and use of health care services.

**EXPOSURES** Surgical approach (MIS or OS).

**MAIN OUTCOMES AND MEASURES** Outcomes assessed included 1-year total health care expenditure, health care utilizations, and estimated days missed from work.

**RESULTS** Of the 5104 patients, 2639 had PN (2008 MIS vs 631 OS) and 2465 had RN (1816 MIS vs 649 OS) and most were male (PN: 1657 [62.8%]; RN: 399 [63.1%]) and between 55 and 64 years of age (PN: 1034 [51.3%]; RN: 320 [55.7%]). Patients who underwent MIS had lower index hospital length of stay compared with OS (mean [95% CI] for PN: 2.45 [2.37-2.53] vs 3.78 [3.60-3.97] days; P < .001; for RN: 2.82 [2.73-2.91] vs 4.62 [4.41-4.83] days; P < .001), and lower index expenditure for RN ($28,999 [$28,243-$29,796] vs $31,977 [$30,729-$33,329]; P < .001). For PN, index expenditure was lower for OS than MIS (mean [95% CI], $27,480 [$26,263-$28,753] vs $30,380 [$29,614-$31,167]; P < .001). Patients with MIS had lower 1-year postdischarge readmission rate (PN: 15.1% vs 21.5%; odds ratio [OR], 0.65; 95% CI, 0.52-0.82; P < .001; RN: 15.6% vs 18.9%; OR, 0.79; 95% CI, 0.63-1.00; P = .05), and fewer hospital outpatient visits (mean [95% CI] for PN: 4.69 [4.48-4.90] vs 5.25 [4.84-5.66]; P = .01; RN: 5.50 [5.21-5.80] vs 6.71 [6.12-7.30]; P < .001) than those with OS. For RN, MIS was associated with 1.47 fewer missed workdays (95% CI, 0.57-2.38 days; P = .001). The reduction in health care use in MIS was associated with lower or similar total cumulative expenditures compared with OS (mean difference [95% CI] for PN: -$331 [$-3250 to $3912]; P = .85; for RN: -$11,265 [$-17,065 to $-5465]; P < .001).

**CONCLUSIONS AND RELEVANCE** In this cohort study, MIS was associated with lower or similar total cumulative expenditure than OS in the period 1 year after discharge from the index surgery. These findings suggest that downstream expenditures and resource utilization should be considered when evaluating surgical approach for nephrectomy.
Introduction

Minimally invasive surgery (MIS) approaches have had a major impact on the surgical management of kidney cancer. Although the laparoscopic approach was widely adopted, uptake of partial nephrectomy was slow owing to a challenging skillset and substantially steep learning curve for surgeons.1,2 With the introduction of the robotic platform, the adoption of the MIS has grown exponentially, contributing substantially to the overall trends and utilization of these techniques for both radical nephrectomy (RN) and partial nephrectomy (PN).

Compared with OS, MIS has been found to have a shorter length of hospital stay, reduced blood loss, lower rates of postoperative morbidity, reduced operative pain, improved cosmesis, and equivalent oncological outcomes.3-6 Despite the widespread adoption and the documented clinical benefits of MIS for PN and RN, its long-term cost-benefit is still heavily criticized. Most studies that have evaluated the cost implication of MIS have focused on the health care expenditures in the period during and immediately after surgery, and generally have shown higher expenditures with MIS due to the initial cost of acquisition and expenditures for maintenance and disposables.7-11 However, the benefits of MIS such as early recovery, reduced postoperative morbidity and health care utilization, early return to work, and improved work productivity may offset the higher expenditures for index surgery over time. A few studies have also compared the total health expenditures and health care use between both approaches over a long period of follow-up.12-14 Like the studies evaluating expenditures of index surgery, they are either antiquated or limited by their methodology.4 In this study, we aim to extend the period beyond surgery and compare total health care utilization and expenditures up to 1 year after MIS and OS for PN and RN.

Methods

Study Design

A retrospective cohort study was conducted to achieve the study objectives. Data were gathered from the IBM MarketScan Research Database (MarketScan), a large data set capturing deidentified employer-sponsored health insurance claims for inpatient, outpatient, and pharmacy services.15 Considering that this is an observational study using secondary deidentified data with no possibility of identification of patients, institutional review board was not required in accordance with 45 CFR §46. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies. The study population consisted of patients with kidney cancer aged 18 to 65 years who underwent PN or RN between July 1, 2013, and December 31, 2017. Procedure encounters and surgical approaches were identified using the International Classification of Diseases, Ninth Revision (ICD-9) codes, Tenth Revision (ICD-10) codes, and Current Procedural Terminology (CPT) codes (eTable 1 in the Supplement). For patients who had multiple surgical procedures, the first procedure identified based on admission date was considered index nephrectomy. We included patients with continuous health insurance enrollment from 180 days presurgery through 365 days postsurgery to ensure all health care utilizations and baseline comorbidities were captured. Exclusion criteria were inpatient cases without diagnosis-related group (DRG) code for neoplasm-related kidney and ureter procedures (code 656, 657, or 658), bilateral nephrectomy cases, secondary urinary cancer, metastatic cancer, severe or end-stage kidney disease, extreme total payment for index surgery (<1% or >99% percentiles), or nonpositive payments in the baseline and follow-up period.

Study Variables

Exposure Variables

Patients were categorized into MIS and OS groups. The MIS group included those who had robotic-assisted surgery or traditional laparoscopic surgery.
Outcome Variables
Three main outcomes were assessed including 1-year total health care expenditure, health care utilization, and missed days of work due to health care visits. To assess total health care expenditure, payments for inpatient services, outpatient services, and prescription drug claims during the index surgery and within 365 days after discharge were summed. Payments from patients’ out-of-pocket and payers’ reimbursements for health care services were included. For patients who did not have postdischarge health insurance claims, their postdischarge health care expenditure was assumed to be zero. All expenditures were adjusted for inflation to 2018 US dollars using midyear medical consumer price index. To assess postdischarge 1-year health care utilization, we estimated readmission rate, emergency department (ER) visit rate, mean per-patient number of health care visits by setting (inpatient, ER, hospital outpatient, and office-based clinician), and mean per-patient total inpatient days. Codes used to differentiate ER, hospital outpatient, and office-based clinician visits are shown in eTable 2 in the Supplement. Missed days of work were estimated based on count of health care visit dates. For the calculation, we assumed a one-half day of use for office-based clinician visit, a full day of use for hospital outpatient and ER visit, and total length of stay (LOS) for inpatient admissions.

Study Covariates
Patient characteristics included as covariates were age, sex, region, metropolitan residence status, area-level annual income status, insurance plan, year of surgery, Charlson Comorbidity Index score (excluding kidney cancer), and baseline health care expenditure. Insurance plans were classified into preferred provider organization (PPO), comprehensive insurance, health maintenance organization (HMO), point-of-service (POS) and other insurance plans. Baseline health care expenditure was calculated as sum of all payments for inpatient and outpatient services, and prescription drug payments during 180 days before surgery.

Statistical Analysis
To adjust for differences between groups and prevent potential sample selection bias, inverse probability of treatment weighting (IPTW) using stabilized weights was performed to compare outcomes between MIS and OS among PN and RN cohorts separately. A logistic regression model based on baseline characteristics described earlier estimated probability of surgical approach, and the inverse probabilities were assigned to patients. Adjustment with IPTW creates a synthetic sample which is independent of covariates allowing for estimation of unbiased average treatment effects. To ensure no residual differences exist between groups, baseline characteristics were compared before and after IPTW adjustment using χ² test for categorical variables and Wilcoxon rank-sum test for continuous variable.

Generalized linear model (GLM) with gamma or inverse-Gaussian distribution and log-link was used to estimate health care expenditures at index and 1-year after discharge. Modified Park test identified appropriate distribution family for the models. Binomial logistic regression model was used to estimate adjusted odds ratio (OR) of inpatient admission and ER visit. GLM with zero-inflated negative-binomial distribution and log-link was used to estimate incidence rate ratio (IRR) for health care service uses including number of admissions, hospital outpatient visits, and office-based clinician visits. Overdispersion test was performed to confirm appropriateness of negative-binomial model use. Missed workdays were estimated using GLM with zero-inflated Poisson regression and log-link. All regression models were weighted by the IPTW, and model fitness was assessed using the Hosmer-Lemeshow goodness-of-fit test.

Several sensitivity analyses were performed for estimating health care expenditures by excluding (1) patients who had no claims for inpatient or outpatient services during follow up, (2) patients who had multiple surgeries, (3) patients with less than 5% or greater than 95% index expenditures, (4) patients with lower than Medicare’s expected minimum payment. We used a $10 782 cutoff as proxy for Medicare’s minimum payment based on Golombos et al’s reported lower
quartile of expenditure among Medicare beneficiaries who had radical nephrectomy. All analyses were performed from August to November 2021 using R statistical software version 4.1.2 (R Project for Statistical Computing).18 P < .05 was considered statistically significant.

Results

Sample Characteristics

There were 27 086 patients identified who underwent nephrectomy between July 2013 and December 2017, of whom 5104 patients who underwent PN (2639 [51.7%]) or RN (2465, [48.3%]) (Figure) remained after applying inclusion and exclusion criteria. As shown in Table 1, most of the patients were male (PN: 1657 [62.8%]; RN: 399 [63.1%]), aged 55 to 64 years (PN: 1034 [51.3%]; RN: 320 [55.7%]), and had a PPO health plan (PN: 1161 [57.5%]; RN: 357 [59.6%]). Of the 2639 patients who underwent PN, 2008 (76.1%) received MIS and 631 (23.9%) received OS; of 2465 patients who underwent RN, 1816 (73.4%) received MIS and 649 (26.3%) received OS. Among PN, baseline health care expenditure was significantly greater for OS vs MIS (median [IQR], $9056 [$5564-$18 337] vs $8272 [$4690-$15 618]; P < .001). There were also significant differences between MIS vs OS groups in region of residence, year of surgery, and surgery setting (Table 1). Among RN, there were significant differences between MIS and OS group in year of surgery and surgery setting (Table 1). After applying IPTW, all baseline characteristics were balanced between MIS and OS groups for both PN and RN cohorts (eTable 3 in the Supplement).

Partial Nephrectomy

Results for IPTW-adjusted analysis for health care expenditure and uses following PN are shown in Table 2. The mean (95% CI) LOS for inpatient cases was lower among the MIS group compared with the OS group (2.45 [2.37-2.53] vs 3.78 [3.60-3.97] days; P < .001), whereas the index surgery expenditure was higher among the MIS group than the OS group (mean difference: $2901; 95% CI, $1434-$4367; P < .001). The mean 1-year health care expenditure after discharge for MIS was not significantly different when compared with OS (MIS: $17 116; 95% CI, $15 717-$18 640 vs OS: $19 686; 95% CI, $16 925-$22 898; P = .11), resulting in comparable total expenditure for the index period and 1-year postdischarge health care uses (MIS: $47 497; 95% CI, $45 760 to $49 299 vs OS: $47 166; 95% CI, $44 153 to $50 384; P = .86).
We observed a lower readmission rate among patients who underwent MIS (15.1%) compared with OS (21.5%) (OR, 0.65; 95% CI, 0.52–0.82, \(P < .001\)), and on average 0.32 times fewer readmissions (IRR, 0.68; 95% CI, 0.55–0.85, \(P = .006\)) during 1-year postsurgery. As compared with

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**Table 1. Baseline Patient Characteristics by Surgical Approach Before Inverse Probability of Treatment Weighting Adjustment**

| Variable | All (n = 5104) | Partial Nephrectomy (n = 2639) | Radical Nephrectomy (n = 2465) | \(P\) value |
|----------|----------------|--------------------------------|--------------------------------|-------------|
| Age, y   |                |                                |                                |             |
| 18-44    | 740 (14.5)     | 327 (16.3)                     | 103 (16.3)                     | .93         |
| 45-54    | 1636 (32.1)    | 647 (32.2)                     | 208 (33.0)                     |             |
| 55-64    | 2728 (53.4)    | 1034 (51.5)                    | 320 (50.7)                     |             |
| Sex      |                |                                |                                |             |
| Female   | 1891 (37.0)    | 750 (37.4)                     | 232 (36.8)                     | .79         |
| Male     | 3213 (63.0)    | 1258 (62.6)                    | 399 (63.2)                     |             |
| Income, $|                |                                |                                |             |
| <35 000  | 1414 (27.7)    | 485 (24.2)                     | 171 (27.1)                     | .12         |
| 35 000-39 999 | 1800 (35.3) | 707 (35.2)     | 191 (30.3)                     |             |
| ≥40 000  | 1492 (29.2)    | 653 (32.5)                     | 212 (33.6)                     | .13         |
| Unknown  | 398 (7.8)      | 163 (8.1)                      | 57 (9.0)                       |             |
| Region   |                |                                |                                |             |
| Northeast| 957 (18.8)     | 435 (21.7)                     | 150 (23.8)                     | .04         |
| North Central | 1112 (21.8) | 481 (24.0)     | 116 (18.4)                     |             |
| West     | 647 (12.7)     | 238 (11.9)                     | 83 (13.2)                      | .60         |
| South    | 2344 (45.9)    | 839 (41.8)                     | 274 (43.4)                     |             |
| Unknown  | 44 (0.9)       | 15 (0.7)                       | 8 (1.3)                        |             |
| Metro status |            |                                |                                |             |
| Metro    | 4277 (83.8)    | 1700 (84.7)                    | 523 (82.9)                     | .39         |
| Not metro| 726 (14.2)     | 264 (13.1)                     | 96 (15.2)                      |             |
| Unknown  | 101 (2.0)      | 44 (2.2)                       | 12 (1.9)                       |             |
| Insurance plan |          |                                |                                |             |
| Comprehensive | 227 (4.4) | 98 (4.9)                       | 36 (5.7)                       | .19         |
| PPO      | 2986 (58.5)    | 1161 (57.8)                    | 357 (56.6)                     |             |
| HMO      | 564 (11.1)     | 219 (10.9)                     | 85 (13.5)                      | .92         |
| POS      | 414 (8.1)      | 169 (8.4)                      | 46 (7.3)                       |             |
| Other    | 853 (16.7)     | 334 (16.6)                     | 104 (16.5)                     |             |
| Unknown  | 60 (1.2)       | 27 (1.3)                       | 3 (0.5)                        |             |
| Procedure year |          |                                |                                | <.001       |
| 2013     | 861 (16.9)     | 311 (15.5)                     | 143 (22.7)                     |             |
| 2014     | 1086 (21.3)    | 387 (19.3)                     | 151 (23.9)                     |             |
| 2015     | 1064 (20.8)    | 421 (21.0)                     | 120 (19.0)                     |             |
| 2016     | 1113 (21.8)    | 476 (23.7)                     | 115 (18.2)                     |             |
| 2017     | 980 (19.2)     | 413 (20.6)                     | 102 (16.2)                     |             |
| CCI score|                |                                |                                |             |
| 0        | 2045 (40.1)    | 799 (39.8)                     | 238 (37.7)                     | .65         |
| 1-2      | 2307 (45.2)    | 928 (46.2)                     | 301 (47.7)                     |             |
| >2       | 752 (14.7)     | 281 (14.0)                     | 92 (14.6)                      |             |
| Setting  |                |                                |                                |             |
| Inpatient| 3408 (68.1)    | 1704 (84.9)                    | 618 (97.9)                     | <.001       |
| Outpatient| 416 (10.9) | 304 (15.1)                       | 13 (2.1)                       |             |
| Baseline expense, $* |          |                                |                                | <.001       |
| Median (IQR) | 8345 (4621-15 805) | 8272 (4690-15 618) | 9056 (5564-18 337) |             |

Abbreviations: CCI, Charlson comorbidity index; HMO, health maintenance organization; MIS, minimally invasive surgery; OS, open surgery; PPO, preferred provider organization; POS, point of service.

* The baseline expenses are the baseline expenditures during the 180 days before surgery.
patients with OS, patients with MIS had approximately 10% fewer hospital outpatient visits (IRR, 0.90; 95% CI, 0.82-0.98; P = .01) and 14% more office-based visits (IRR, 1.14; 95% CI, 1.06-1.22; P < .001). The estimated mean number of days missed from work per patient was comparable between groups in the 1-year postdischarge period (mean [95% CI] for MIS, 12.9 [12.5-13.3] vs OS: 13.2 [12.5-14.0]; P = .43). However, the overall estimated missed workdays from the index surgery stay to 1-year postdischarge period was favorable to the MIS group (1.48 fewer days per-patient than OS [95% CI, 0.66-2.31; P < .001]).

In sensitivity analyses (eTable 4 in the Supplement), index total expenditure was no longer significantly higher for MIS as compared with OS when excluding patients with extreme index expenditure using 5% cutoff (mean difference: $518 [95% CI, –$752 to $1789]; P = .43), or when excluding patients with less than Medicare’s expected payment (mean difference: $1040 [95% CI, –$484 to $2564]; P = .19). Results for expenditures for health care during 1-year postdischarge, or from index to 1-year postdischarge remained consistent with the main analyses. Excluding patients with no claim for postdischarge care and excluding patients who had multiple surgical procedures did not change the study results.

**Radical Nephrectomy**

Results for the IPTW-adjusted analysis of total health care expenditure and use following RN are shown in Table 3. The mean (95% CI) LOS for inpatient cases was lower among MIS vs OS group (2.82 [2.73-2.91] vs 4.62 [4.41-4.83] days; P < .001) as well as the index surgery expenditure ($28 999; 95% CI, $28 243-$29 796 vs OS: $31 977; 95% CI, $30 729-$33 329; P < .001), resulting in mean difference of ~$2978 (95% CI, –$4490 to –$1466) favoring MIS. The MIS group also had a lower health care expenditure in 1-year postdischarge compared with OS (MIS: $22 505; 95% CI, $20 036-$25 667 vs OS: $30 792; 95% CI, $26 763-$36 248; P = .001). The total expenditure for the index procedure and 1-year post discharge health care use was $11 265 lower in favor of MIS (95% CI for mean difference: -$17 065 to -$54 656; P < .001).

### Table 2. Inverse Probability of Treatment Weighting–Adjusted Differences in Expenditure, Health Care Use, and Estimated Missed Days of Work Among Patients Who Had Partial Nephrectomy (N = 2465)

| Outcomes                      | Mean per patient (95% CI) | Adjusted estimates (OS as reference) |
|-------------------------------|--------------------------|---------------------------------------|
|                               | Overall                  | MIS                                   | OS                  |
|                               | (95% CI)                 | (95% CI)                              | Mean difference     |
|                               |                          | OR/IRR                                |                     |
| Index LOS, d                  | 2.83 (2.74 to 2.92)      | 2.45 (2.37 to 2.53)                   | 3.78 (3.60 to 3.97) | 0.65 (0.61 to 0.69) | –1.33 (–1.54 to –1.13) | <.001 |
| Index payment, $              | 29 680 (29 022 to 30 338)| 30 380 (29 614 to 31 167)             | 27 480 (26 263 to 28 753) | NA | 2901 (1434 to 4367) | <.001 |
| 1-y post–index                |                          |                                       |                     |
| Total payment, $              | 17 737 (16 415 to 19 059)| 17 116 (15 717 to 18 640)             | 19 686 (16 925 to 22 898) | NA | –2570 (–5884 to 744) | .11  |
| Readmission, No. (%)          | 441 (16.7)*              | 304 (15.1)*                           | 137 (21.5)*         | 0.65 (0.52 to 0.82) | NA | <.001 |
| Total inpatient days          | 0.90 (0.71 to 1.09)      | 1.37 (0.91 to 1.83)                   | 1.88 (1.15 to 2.62) | 0.85 (0.58 to 1.24) | –0.512 (–1.20 to 0.17) | .11 |
| ER visit, No. (%)             | 905 (34.2)*              | 905 (34.2)*                           | 687 (34.2)*         | 1.01 (0.84 to 1.22) | NA | .94 |
| No. hospital admitted         | 0.21 (0.19 to 0.24)      | 0.19 (0.17 to 0.22)                   | 0.26 (0.22 – 0.31)  | 0.68 (0.55 to 0.85) | –0.07 (–0.12 to –0.02) | .006 |
| No. ER visit                  | 0.70 (0.65 to 0.75)      | 0.68 (0.59 to 0.77)                   | 0.86 (0.65 – 1.07)  | 0.78 (0.62 to 0.99) | –0.18 (–0.39 to 0.02) | .05 |
| No. hospital OP visit         | 4.80 (4.58 to 5.02)      | 4.69 (4.48 to 4.90)                   | 5.25 (4.84 – 5.66)  | 0.90 (0.82 to 0.98) | –0.56 (–1.02 to –0.10) | .01 |
| No. office visits             | 11.20 (10.81 to 11.59)   | 11.5 (11.1 to 11.9)                   | 10.2 (9.50 – 10.8)  | 1.14 (1.06 to 1.22) | 1.36 (0.60 – 2.13) | <.001 |
| No. missed days of work       | 13.00 (12.56 to 13.44)   | 12.9 (12.5 to 13.3)                   | 13.2 (12.5 to 14.0) | NA | –0.35 (–1.22 to 0.52) | .43 |
| Index +1-y post               |                          |                                       |                     |
| Total payment, $              | 47 417 (45 883 to 48 951)| 47 497 (45 760 to 49 299)             | 47 166 (44 153 to 50 384) | NA | 331 (–3250 to 3912) | .86 |
| No. missed days of work       | 15.50 (15.04 to 15.96)   | 15.2 (14.7 to 15.6)                   | 16.6 (15.9 to 17.4) | NA | –1.48 (–2.31 to –0.66) | <.001 |

**Abbreviations:** ER, emergency department; LOS, length of stay; MIS, minimally invasive surgery; OP, outpatient; OR, odds ratio; OS, open surgery; IRR, incidence rate ratio; NA, not applicable.

* Overall total rather than mean per-patient estimate.
Although 1-year readmission rate was not statistically significantly different among patients with MIS compared with those with OS (15.6% vs 18.9%; OR, 0.79; 95% CI, 0.63-1.00; P = .05), we observed that patients with MIS had on average 0.24 times fewer readmissions than those with OS (IRR, 0.76; 95% CI, 0.60 to 0.96; P = .03), and ER visit rate (OR, 1.01; 95% CI, 0.83-1.22; P = .96). Overall reductions in health care use with MIS were associated with 1.47 fewer days missed from work post discharge (95% CI, 0.57-2.38; P = .001) and 3.20 fewer missed days (95% CI, 2.21-4.19; P < .001) when including index procedure stay.

Results for the sensitivity analyses on health care expenditures are presented in eTable 5 in the Supplement. None of the sensitivity analyses changed the conclusion of the main analysis results.

Discussion

In this study, we compared the 1-year total health care use and expenditures of 5104 patients who underwent MIS and OS for radical and partial nephrectomy from a commercial payer’s perspective. We found that patients with MIS had a shorter index length of stay than OS for both PN and RN and a lower index surgery expenditure for RN. For PN, the index surgery expenditure was lower for OS compared with MIS. The cumulative expenditure for index surgery and 1-year postdischarge health care use was comparable between MIS and OS for PN and lower in favor of MIS for RN. One-year health care use and readmission rate after discharge were comparable or significantly lower in favor of MIS. Specifically for RN, patients with MIS had lower resource utilization than OS, translating to mean (95% CI) 3.20 (2.21-4.19) fewer missed workdays and a mean (95% CI) cost savings of $11 265 ($5465-$17 065).

These findings imply that extending the period of analysis beyond the time of surgery allows us to assess the clinical advantages of using MIS as part of the cost estimate and cost-effectiveness analysis. A previous study comparing index surgery expenditures among Medicare beneficiaries

| Table 3. Inverse Probability of Treatment Weighting–Adjusted Differences in Expenditure, Health Care Use, and Estimated Missed Days of Work Among Patients Who Had Radical Nephrectomy (N = 2639) |
| Outcomes | Mean per patient (95% CI) | Adjusted estimates (OS as reference) (95% CI) | P value |
| --- | --- | --- | --- |
| **Index LOS, d** | Overall | MIS | OS | OR/IRR | Mean difference | P value |
| Total payment, $ | 3.3 (3.19 to 3.41) | 2.82 (2.73 to 2.91) | 4.62 (4.41 to 4.83) | 0.61 (0.58 to 0.65) | -1.8 (-2.02 to -1.57) | <.001 |
| **Index payment, $** | 29 784 (29 102 to 30 451) | 28 999 (28 243 to 29 796) | 31 977 (30 729 to 33 329) | NA | -2978 (-4490 to -1466) | <.001 |
| **1-y post-index** | | | | | | |
| Total payment, $ | 24 689 (23 694 to 25 663) | 22 505 (20 036 to 24 667) | 30 792 (26 763 to 36 248) | NA | -8287 (-13 688 to -2886) | .001 |
| **Readmission, No. (%)** | 407 (16.5) | 284 (15.6) | 123 (18.9) | 0.79 (0.63 to 1.00) | NA | .05 |
| **Total inpatient days** | 1.20 (0.99 to 1.40) | 4.03 (2.89 to 5.17) | 5.16 (3.41 to 6.92) | 0.78 (0.57 to 1.07) | -1.13 (-2.68 to 0.43) | .13 |
| **ER visit, No. (%)** | 762 (30.9) | 562 (30.9) | 200 (30.8) | 1.01 (0.83 to 1.22) | NA | .96 |
| **No. Hospital admitted** | 0.24 (0.21 to 0.27) | 0.22 (0.19 to 0.25) | 0.29 (0.23 to 0.35) | 0.76 (0.60 to 0.96) | -0.07 (-0.13 to -0.00) | .03 |
| **No. ER visit** | 0.70 (0.62 to 0.78) | 0.65 (0.58 to 0.71) | 0.72 (0.60 to 0.83) | 0.84 (0.65 to 1.10) | -0.07 (-0.20 to 0.06) | .27 |
| **No. Hospital OP visit** | 5.8 (5.46 to 6.14) | 5.50 (5.21 to 5.80) | 6.71 (6.12 to 7.30) | 0.82 (0.74 to 0.91) | -1.21 (-1.87 to -0.55) | <.001 |
| **No. Office visits** | 11.8 (11.41 to 12.19) | 11.6 (11.2 to 12.0) | 12.3 (11.6 to 13.1) | 0.94 (0.76 to 1.17) | -0.74 (-1.57 to 0.09) | .08 |
| **No. Missed days of work** | 14.5 (13.93 to 15.06) | 14.2 (13.6 to 14.7) | 15.6 (14.8 to 16.5) | NA | -1.47 (-2.38 to -0.57) | .001 |
| **Index +1-y post** | | | | | | |
| Total payment, $ | 54 472 (51 857 to 57 034) | 51 503 (48 688 to 54 663) | 62 768 (58 156 to 68 174) | NA | -11 265 (-17 065 to -5465) | <.001 |
| **No. missed days of work** | 17.7 (17.10 to 18.29) | 16.90 (16.4 to 17.4) | 20.10 (19.2 to 21.0) | NA | -3.20 (-4.19 to -2.21) | <.001 |

Abbreviations: ER, emergency department; IRR, incidence rate ratio; LOS, length of stay; MIS, minimally invasive surgery; NA, not applicable; OP, outpatient; OS, open surgery.

* Overall total rather than mean per-patient estimate.
reported that MIS and OS had comparable expenditures following RN. In contrast, we found that using employer-sponsored health insurance data, MIS had lower index expenditure than OS following RN. The cost-benefit of MIS in our study could possibly be more obvious due to the relatively younger and healthier population in the data. For PN, we found that index surgery expenditure was higher for MIS as compared with OS. Other studies comparing either robotic or laparoscopic surgery with OS for PN or RN were based on hospital cost or charge data, which hinders direct comparison with our study finding. The study findings were also mixed in that MIS was reported to have higher or comparable index expenditure as compared with OS. With increase in adoption and use of robotic surgery, complex cases requiring RN are now being managed with robotic surgery with a potential cost-saving benefit during the index surgery. The benefits of reduced complication rates, fewer readmission rates, reduced health care utilization, and better quality of life associated with the use of MIS may contribute to substantial reduction in expenditures over time. It is important to note that there is a potential for further cost-saving given the possibility of an increase in surgical volume over time, due to the rapid adoption of robotic technology, increase in patient demand, and shorter learning curve for physicians.

Similar to our study, previous studies have compared MIS and OS for expenditures in the periods after the index surgery. In a propensity score–matched cohort of Medicare patients who underwent RN, Golombos et al\(^4\) compared expenditures between MIS and OS for the periods of index surgery plus 30-day, and index surgery plus 90-day, and they reported that MIS had comparable expenditures with OS. In our study, the total expenditure for the index surgery and 1-year postdischarge period was significantly lower in favor of MIS for RN. To confirm whether the longer follow-up period in our analysis was the reason for the difference from the Golombos et al\(^4\) finding, we repeated our analysis with 30-day and 90-day periods and found still significantly lower expenditure with MIS as compared with OS. Perhaps, the difference in our findings could be source of payment and period of the study population. Our data came from the commercial payer’s perspective for patients who had nephrectomy between 2013 and 2018, whereas the Golombos et al\(^4\) data came from Medicare’s perspective for patients who had surgery between 2001 and 2012. Nabi and colleagues\(^21\) compared short-term and long-term expenditures between robotic-assisted surgery and OS using the MarketScan databases for patients who had RN or PN between 2012 and 2017. Looking at the perioperative period (−14 days to 28 days of index surgery) and extending the period of evaluation (29 days to 352 days after index surgery), Nabi et al\(^21\) found that robotic-assisted surgery had a significantly lower total expenditure compared with OS. Similarly, Hughes et al\(^14\) evaluated expenditures for PN in the 360 days and 1080 days after the index surgery using the National Health Services hospitals data in England. Hughes et al\(^14\) reported that robotic surgery had comparable total postdischarge expenditures with OS at 360 days (£778.96 vs £1241.93; \(P = .84\)) and at 1080 days (£2122 vs £2888; \(P = .57\)). The finding by Hughes et al\(^14\) is similar to our study finding that MIS and OS had comparable health care expenditures from index surgery to 1 year after surgery for PN.

Regarding health care use, several studies have reported a lower postoperative health care use among patients who have undergone MIS compared with OS. In our study, the length of hospital stay for index surgery was significantly lower in favor of MIS in both PN and RN groups. Prior studies have demonstrated similar results with MIS (RAP and LAP) compared with OS.\(^9,13,22,23\) Justifying this result, Golombos et al reported that MIS had a lower risk of adverse perioperative outcomes (eg, sepsis, deep vein thrombosis, acute kidney injury), and a low risk of ICU admissions compared with OS. Other studies have also reported fewer complication rates for MIS compared with OS.\(^13,24\) Lawson et al\(^25\) in a study assessing the implication of postoperative complications and readmissions on quality improvement and potential cost savings found a strong correlation between postoperative complication and readmission rates among patients who were readmitted in their study.\(^25\) They further elucidated that by reducing the complication rate by 5%, there is a potential cost savings of $31 million per year for the procedures that accounts for the most readmissions. From a policy perspective, improved outcomes and reduced readmissions associated with the use of robotics.
would help ensure that expenditures for robotic surgery would reduce substantially over the next few years following the implementation of quality improvement programs such as the Hospital Readmissions Reduction Program. In our current study, MIS had a lower readmission rate and fewer admissions 1-year post-surgery and may account for some of the cost benefits reported in this study. Hughes et al also reported that patients who had PN had fewer inpatient readmissions and hospital bed days at 360 and 1080 days. While assessing the breakdown of postoperative health care visits, MIS had fewer outpatient visits and comparable ER visits, translating into fewer missed workdays, especially when the length of stay during index surgery is taken into consideration. Elsewhere in patients undergoing radical prostatectomy, we have also reported that the use of the robotic approach is associated with fewer missed workdays and lower health care use with a potential bearing on the reduction in postoperative health care expenditures.

**Limitations**

Our study is based on analysis of a large database (MarketScan), that longitudinally captures patients' health care services, using inverse probability of treatment weighting technique, thereby enhancing generalizability of the study and reducing potential selection bias. Nonetheless, our study has some limitations.

Given the retrospective design of our study and that our data are from an administrative database, potential confounders may not be captured. While the IPTW reduces the risk for selection bias, it only accounts for known confounders and does not account for unknown confounders. The MarketScan database does not capture data on potential factors such as race and ethnicity, previous abdominal surgery, and tumor-related factors (eg, tumor stage and tumor size) that may influence the decision to undergo OS or MIS approach for PN or RN, or may account for the cost difference between the groups. Also, coding errors are possible with patient identification and data extraction. Given multiple tests performed, the lack of multiplicity adjustment in our analyses may be critiqued. Although multiplicity adjustment allows for minimizing false discovery rate, it also hinders discovery of important findings and prohibits further investigations. In post hoc multiplicity adjustment using Bonferroni method, results for 2 outcome variables (number of hospital admissions and number of hospital outpatient visits) for PN, and one outcome variable (number of hospital admissions) for RN changed from significant to nonsignificant. We suggest careful interpretation of these findings. Furthermore, the findings in this study may not be generalizable to older, Medicare, Medicaid, or uninsured patients because the database is an employer-sponsored health insurance claims database. Finally, missed workdays approximate the time spent out of work seeking follow-up care and are not a reflection of work productivity loss.

**Conclusions**

Considering longer follow-up time, MIS was associated with lower or similar total cumulative expenditure than OS in the 1-year postdischarge period including the index surgical expenditures. Several factors might contribute to cost savings after MIS in the postoperative period including reduction in readmission rate and number of outpatient visits. Our findings suggest that impact on downstream expenditures and resource utilization should be considered when evaluating surgical approach for both partial and radical nephrectomy.
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