Practice Patterns and Outcomes of Open and Minimally Invasive Partial Nephrectomy Since the Introduction of Robotic Partial Nephrectomy: Results from the Nationwide Inpatient Sample

Khurshid R. Ghani,*† Shyam Sukumar,† Jesse D. Sammon, Craig G. Rogers,‡ Quoc-Dien Trinh‡ and Mani Menon

From the Department of Urology, University of Michigan (KRG), Ann Arbor and Vattikuti Urology Institute, Henry Ford Health System (CGR, MM), Detroit, Michigan, Department of Urology, University of Minnesota (ISS), Minneapolis, Minnesota, and Department of Surgery, Division of Urology, Brigham and Women's Hospital/Dana-Farber Cancer Institute, Harvard Medical School (QDT), Boston, Massachusetts

Purpose: We determined practice patterns and perioperative outcomes of open and minimally invasive partial nephrectomy in the United States since the introduction of a robot-assisted modifier in the Nationwide Inpatient Sample.

Materials and Methods: We identified all patients with nonmetastatic disease treated with open, laparoscopic or robotic partial nephrectomy in the Nationwide Inpatient Sample between October 2008 and December 2010. Utilization rates were assessed by year, patient and hospital characteristics. We evaluated the perioperative outcomes of open vs robotic and open vs laparoscopic partial nephrectomy using binary logistic regression models adjusted for patient and hospital covariates.

Results: In a weighted sample of 38,064 partial nephrectomies 66.9%, 23.9% and 9.2% of the procedures were open, robotic and laparoscopic operations, respectively. In 2010 the relative annual increase in open, robotic and laparoscopic partial nephrectomy was 7.9%, 45.4% and 6.1%, respectively. Compared to open partial nephrectomy patients treated with minimally invasive partial nephrectomy were less likely to receive blood transfusion (robotic vs laparoscopic OR 0.56, p < 0.001 vs OR 0.68, p = 0.016), postoperative complication (OR 0.63, p < 0.001 vs OR 0.78, p < 0.009) or prolonged length of stay (OR 0.27 vs OR 0.41, each p < 0.001). Only patients who underwent the robotic procedure were less likely to experience an intraoperative complication (robotic vs laparoscopic OR 0.69, p = 0.014 vs OR 0.67, p = 0.069). Excess hospital charges were higher after robotic surgery (OR 1.35, p < 0.001).

Conclusions: The dissemination of robotic surgery for partial nephrectomy in the United States has been rapid and safe. Compared to open partial nephrectomy the robotic procedure had lower odds than laparoscopic partial nephrectomy for most study outcomes except hospital charges. Robotic partial nephrectomy has now supplanted laparoscopic partial nephrectomy as the most common minimally invasive approach for partial nephrectomy.

Key Words: kidney, nephrectomy, robotics, laparoscopy, complications

CURRENT American Urological Association and European Association of Urology guidelines recommend PN as the standard of care for renal masses less than 4 and less than 7 cm.1,2 While OPN is the traditional standard, the
last decade has seen significant advances in minimally invasive PN. LPN is equivalent oncologically to OPN with lower blood loss and LOS after LPN at some centers. More recently, the adoption of robot-assisted surgery has popularized RPN. Although recent population level studies assessed PN compared to RN, studies evaluating the different approaches to PN have been mostly limited to institutional series with few population level studies. A reason was the difficulty of discriminating RPN from LPN in administrative data sets.

As of October 1, 2008, Food and Drug Administration approved a RM to identify robot-assisted procedures. We determined practice patterns and perioperative outcomes of open and minimally invasive PN (LPN and RPN) since the introduction of RM using the NIS.

MATERIALS AND METHODS

Data Source
We abstracted NIS data between 1998 and 2010 to determine long-term trends in PN. To assess the impact of RM the data were narrowed to October 1, 2008 to December 31, 2010. This was the cohort for all subsequent analysis. The NIS contains inpatient discharge data collected by the Agency for HCUP (Healthcare Research and Quality Healthcare Cost and Utilization Project). As of 2010, it held 8 million hospital stays from more than 1,000 hospitals in a total of 44 states, representing approximately 20% of American hospitals, including public and academic hospitals. It is the only American database with charge information on all patients regardless of payer.

Study Cohort
Patients 18 years old or older with a primary diagnosis of kidney cancer were identified using the ICD-9-CM diagnostic code 189.0. Secondary diagnostic codes (ICD-9-CM 197.0, 197.7 and 198.x) were used to identify those with metastasis, who were excluded from further analysis. We abstracted data on patients who underwent PN (ICD-9-CM 55.4). As recognized by the National Center of Health Statistics, and Centers for Medicare and Medicaid Services, beginning October 1, 2008 the RM code (ICD-9-CM 17.4x) was used to identify RPN. Patients with the minimally invasive modifier code (ICD-9-CM 54.21) without RM were classified as having undergone LPN. The remaining patients were determined to have undergone OPN. Hospital sampling weights were used to estimate the total number of these procedures.

Patient and Hospital Characteristics
For all patients the available variables were age, race, CCI and insurance status, ie private, Medicare, Medicaid or other (self-pay). Baseline CCI was calculated and adapted according to Deyo et al as 0, 1, 2, or 3 or greater. All demographic characteristics were weighted according to HCUP discharge level estimates. Hospital characteristics included hospital region (Northeast, Midwest, South or West) obtained from the AHA (American Hospital Association) Annual Survey of Hospitals, as defined by the United States Census Bureau. Hospitals were divided into academic and nonacademic institutions and status was obtained from the AHA. Hospital case load was defined according to the number of PNs performed annually, as previously described.

Complications, LOS and In-Hospital Mortality
The NIS records up to 15 diagnoses and procedures per stay. The presence of any complication was defined using ICD-9 diagnoses 2 to 15 and previously published methodology. Intraoperative complications consisted of surgical laceration of the bowel, ureter and nerves, and/or vessels during a procedure (ICD-9 998.2). Blood transfusion recipients were identified using the ICD-9 procedure codes 99.02 and 99.04. Seven groups of postoperative complications were identified, consisting of cardiac, respiratory or vascular events, as well as other events, such as genitourinary, digestive, neurological, operative wound and postoperative infection. Perioperative mortality was coded from patient disposition. LOS was calculated by subtracting the hospital admission date from the date of discharge. We defined pLOS as hospitalization beyond the 75th percentile. Excess charges were calculated as overall hospital charges beyond the 75th percentile after adjusting for inflation in 2012 dollars.

Statistical Analysis
The median and IQR were generated for continuously coded variables, and the frequency and proportion were generated for categorical variables. The Mann-Whitney and chi-square tests were used to assess the statistical significance of medians and proportions, respectively. Binary logistic regression analysis was done to compare perioperative outcomes of OPN vs RPN and OPN vs LPN. Evaluated outcomes included the odds of 1) blood transfusion, 2) intraoperative complication, 3) postoperative complication during hospitalization, 4) pLOS and 5) in-hospital mortality. Models were adjusted for age, race, gender, baseline CCI, hospital teaching status, region, location, hospital case load, surgery year and insurance status. All tests were 2-sided with statistical significance considered at p <0.05. R, version 2.15.2 (http://www.r-project.org/) was used for all analysis.

RESULTS
A weighted national estimate of 118,330 PNs was performed from 1998 to 2010, of which 84.7%, 7.7% and 7.5% were OPN, RPN and LPN, respectively. From October 1, 2008 to December 31, 2010 a weighted estimate of 38,064 PNs was performed, of which 66.9%, 23.9% and 9.2% were OPN, RPN and LPN, respectively. The figure shows changes in the number of PNs done from 1998 to 2010 with notable increases in RPN from 2009. In 2010 the relative annual increase in OPN, RPN and LPN was 7.9%, 45.4% and 6.1%, respectively.

The supplementary table (http://jurology.com/) lists the characteristics of the patient populations.
that underwent OPN, RPN and LPN. The populations differed. In particular, fewer RPNs were done in Hispanic and black patients than in their white counterparts. Comorbidity varied among the groups. Of patients with a CCI of greater than 2 11.4% and 10.1% underwent OPN and RPN, respectively, while 9.1% underwent LPN. Although 73.6% of PNs were performed at a teaching hospital, more minimally invasive PN was done at an urban location, including 98.1% of RPNs and 97.7% of LPN compared to 94.3% of OPNs. There was also marked regional variability. RPN was more common in the Midwest (36.8%) while LPN and OPN were more common in the Northeast (40.4%) and South (33.6%), respectively. Finally, more patients with private insurance underwent RPN (59.1%) than OPN (53.2%) or LPN (56.4%).

Table 1 lists unadjusted rates of outcomes, pLOS and excess hospital charges stratified by surgical technique. The overall postoperative complication rate after OPN was 30.5% compared to 22.1% and 24.9% for RPN and LPN, respectively. The intraoperative complication rate was greater after OPN (5.3%) but similar for RPN (3.7%) and LPN (3.5%). The blood transfusion rate was 10.6%, 5.8% and 7.1% after OPN, RPN and LPN, respectively. More patients treated with OPN also had pLOS than those who underwent PRN and LPN (34.8% vs 23.6% and 29.4%, respectively). On multivariable logistic regression analysis patients undergoing minimally invasive PN were significantly less likely than those with OPN to receive blood transfusion (RPN vs LPN OR 0.56, p < 0.001 vs OR 0.68, p = 0.016), or have a postoperative complication (OR 0.63, p < 0.001 vs OR 0.78, p = 0.009) or pLOS (OR 0.27 vs 0.41, each p < 0.001, table 2). Specifically, patients treated with RPN were significantly less likely to have respiratory, digestive, genitourinary or vascular complications. Furthermore, only those who underwent RPN were less likely to experience an intraoperative complication (RPN vs LPN OR 0.69, p = 0.014 vs OR 0.67, p = 0.069). However, the excess hospital charge rate was greater after RPN (RPN vs LPN OR 1.35, p < 0.001 vs OR 0.97, p = 0.759).

### Table 1. Intraoperative and postoperative outcomes during hospitalization by surgical technique from NIS, October 2008 to December 2010

<table>
<thead>
<tr>
<th>Outcome</th>
<th>OPN</th>
<th>RPN</th>
<th>LPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. pts</td>
<td>25,461</td>
<td>9,095</td>
<td>3,508</td>
</tr>
<tr>
<td>No. blood transfusion (%)</td>
<td>2,703 (10.6)</td>
<td>527 (5.8)</td>
<td>250 (7.1)</td>
</tr>
<tr>
<td>No. intraop complication (%)</td>
<td>1,338 (5.3)</td>
<td>333 (3.7)</td>
<td>124 (3.5)</td>
</tr>
<tr>
<td>No. postop complication (%)</td>
<td>7,776 (30.5)</td>
<td>2,007 (22.1)</td>
<td>873 (24.9)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>1,367 (5.4)</td>
<td>287 (3.2)</td>
<td>129 (3.7)</td>
</tr>
<tr>
<td>Digestive</td>
<td>2,522 (9.9)</td>
<td>596 (6.6)</td>
<td>271 (7.7)</td>
</tr>
<tr>
<td>Genitourinary</td>
<td>1,488 (5.8)</td>
<td>307 (3.4)</td>
<td>174 (5.0)</td>
</tr>
<tr>
<td>Cardiac</td>
<td>886 (3.5)</td>
<td>346 (3.8)</td>
<td>92 (2.6)</td>
</tr>
<tr>
<td>Vascular</td>
<td>438 (1.7)</td>
<td>97 (1.1)</td>
<td>29 (0.8)</td>
</tr>
<tr>
<td>Neurological</td>
<td>239 (0.9)</td>
<td>48 (0.5)</td>
<td>51 (1.5)</td>
</tr>
<tr>
<td>Operative wound</td>
<td>892 (3.5)</td>
<td>242 (2.7)</td>
<td>96 (2.7)</td>
</tr>
<tr>
<td>Infection</td>
<td>374 (1.5)</td>
<td>21 (0.2)</td>
<td>15 (0.4)</td>
</tr>
<tr>
<td>Other</td>
<td>3,104 (12.2)</td>
<td>754 (8.3)</td>
<td>260 (7.4)</td>
</tr>
<tr>
<td>LOS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median days (IQR)</td>
<td>4 (3–5)</td>
<td>3 (2–4)</td>
<td>3 (2–4)</td>
</tr>
<tr>
<td>No. pLOS (%)*</td>
<td>25.0</td>
<td>23.6</td>
<td>29.4</td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>73 (0.3)</td>
<td>Data</td>
<td>Data</td>
</tr>
<tr>
<td>Excessive hospital charges*</td>
<td>25.0</td>
<td>23.6</td>
<td>29.4</td>
</tr>
</tbody>
</table>

* Greater than 75th percentile.
† According to NIS for 0 < number of patients < 11.
‡ Model did not converge due to too few events.

### Table 2. Multivariable logistic regression analysis of RPN and LPN vs OPN intraoperative and postoperative outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Adjusted OR</th>
<th>(95% CI)*</th>
<th>p Value</th>
<th>Adjusted OR</th>
<th>(95% CI)*</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood transfusion</td>
<td>0.56 (0.44–0.70)</td>
<td>&lt;0.001</td>
<td>0.68 (0.50–0.93)</td>
<td>0.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraop complication:†</td>
<td>0.69 (0.52–0.93)</td>
<td>0.014</td>
<td>0.67 (0.44–1.03)</td>
<td>0.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postop complication:†</td>
<td>0.63 (0.55–0.72)</td>
<td>0.001</td>
<td>0.78 (0.64–0.94)</td>
<td>0.009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>0.60 (0.44–0.83)</td>
<td>0.001</td>
<td>0.77 (0.51–1.19)</td>
<td>0.224</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestive</td>
<td>0.65 (0.52–0.81)</td>
<td>0.001</td>
<td>0.83 (0.62–1.11)</td>
<td>0.216</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genitourinary</td>
<td>0.56 (0.42–0.75)</td>
<td>0.001</td>
<td>0.82 (0.56–1.19)</td>
<td>0.296</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac</td>
<td>1.17 (0.87–1.57)</td>
<td>0.301</td>
<td>0.79 (0.48–1.31)</td>
<td>0.364</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular</td>
<td>0.54 (0.32–0.92)</td>
<td>0.023</td>
<td>0.50 (0.22–1.16)</td>
<td>0.107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative wound</td>
<td>0.83 (0.59–1.16)</td>
<td>0.264</td>
<td>0.88 (0.53–1.43)</td>
<td>0.594</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>1.04 (0.35–4.80)</td>
<td>0.001</td>
<td>0.86 (0.39–0.86)</td>
<td>0.042</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0.61 (0.50–0.75)</td>
<td>0.001</td>
<td>0.67 (0.42–0.77)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pLOS (greater than 75th percentile)</td>
<td>0.27 (0.23–0.31)</td>
<td>&lt;0.001</td>
<td>0.41 (0.33–0.51)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess hospital charges</td>
<td>1.35 (1.18–1.55)</td>
<td>0.001</td>
<td>0.97 (0.79–1.19)</td>
<td>0.759</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>0 (0.00–0.19)</td>
<td>†</td>
<td>0.68 (0.08–5.33)</td>
<td>0.703</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Model adjusted for age, race, gender, baseline CCI, surgery year, and hospital status, region and case load.
† For neurological complications model did not converge due to too few events.
‡ Model did not converge due to too few events.
DISCUSSION
This population based study reveals that RPN has now overtaken LPN as the minimally invasive procedure of choice for PN in the United States. Although OPN remains the most common technique, there was a sharp increase in RPN in a relatively short time. When each minimally invasive PN was compared to OPN, after adjusting for patient and hospital characteristics RPN was associated with the lowest odds of blood transfusion, postoperative or intraoperative complication and pLOS.

Our findings serve as evidence of the growing popularity of RPN for nephron sparing surgery. Proponents of RPN advocated that robotic surgery may help overcome the technical challenges of LPN and result in an easier transition to minimally invasive PN. This may be a reason for increased RPN and account in part for the overall increase in PN in our series. While RARP lately increased significantly, a similar phenomenon for RPN was not noted. RPN has been performed since 2004, but the significant increases that we observed in RPN in 2009 and especially in 2010 cannot be attributable only to a change in data capture. The increase in LPN from 2004 to 2008 was steady and remained so, although at a slightly slower rate after 2008. The increase in RPN more likely represents a substantial dissemination of this technique and possibly even a direct shift from OPN to RPN.

We also found more favorable outcomes after RPN. Previous institutional series comparing RPN to OPN demonstrated lower blood loss, complications and LOS after RPN. A recent multi-institutional series showed similar postoperative complication rates after RPN and LPN. Studies assessing RPN in the framework of the NIS are limited. Yu et al assessed robotic, laparoscopic and open urological procedures performed in the last quarter of 2008. RPN accounted for 11.5% of PNs compared to 9.5% for LPN. RPN was significantly associated with the lowest LOS, and genitourinary, vascular and wound complications. Costs were higher between RPN and OPN but failed to achieve statistical significance, probably due to limited analysis.

In another NIS study Anderson et al found decreased LOS for RPN compared to OPN but no differences in hospital charges. Again, this study was also limited to a 3-month period with small cohort sizes, ie 41 patients treated with RPN. In a further study the same group compared patient safety indicators for LPN and OPN using NIS data on 1998 to 2009. In a subset comparison of OPN and RPN using RM for a 1-year period (2009) there was no significant difference in the patient safety indicator rate. In 2009 30% of all PNs were LPN, of which 72% were RPN. Using NIS data from 2009 Sun et al found a decrease in complications after LPN compared to OPN. Despite attempts by previous investigators to balance groups using propensity matching, such results may be biased against OPN due to the possibility of more complex cases in this group. We did not attempt propensity matching among our 3 study groups since the methodology is poorly suited to 3-way analysis and subject to further feasibility studies.

The NIS has served as a useful source for establishing renal cancer surgery utilization patterns and outcomes in the United States, especially PN. To our knowledge our results represent the most generalizable source of evidence of RPN compared to LPN and OPN. At the least we established that RPN is not associated with unfavorable outcomes, unlike other specialties, in which recent population level data demonstrated no difference in morbidity between laparoscopic and robotic procedures.

However, we identified significant health care disparities in RPN utilization. Minority and underinsured patients were less likely to undergo RPN than white and privately insured patients. These findings are concerning since they corroborate previous studies suggesting unequal access to care for nonwhite and nonprivately insured patients. Moreover, others described decreased access to RARP for black and nonprivately insured patients. Taken together, these findings suggest that access to RPN could be a target for improving health care disparities.

In our study RPN showed a 35% increased risk of excess hospital charges compared to OPN. While we did not assess actual costs, the relationship between charges and costs is often complex. Charges may fluctuate independently from costs, especially in regard to insurance type. One may hypothesize that the difference in charges between RPN and OPN may be related to insurance type since more patients who underwent RPN were privately insured. Moreover, we did not use inflation adjusted charges in a linear regression model because the distribution of charges was not normal. However, the association of increased charges after RPN emphasizes the need for further evaluation of the economic benefit of robotic surgery, especially in a time of increasing constraints on health care spending.

While population based studies can provide useful information on the dissemination of minimally invasive treatments, conclusions regarding outcomes may be limited due to inherent differences in patient and hospital characteristics among groups. In our study LPN was predominantly performed in
REFERENCES

19. Anderson JE, Parsons JK, Chang DC et al: Hospital costs and length of stay related to

the Northeast while RPN was more common in the Midwest. Interestingly, RPN (25.3%) was similar to OPN (27.5%) in its distribution at nonteaching hospitals compared to LPN (19.8%). PN can be highly regionalized and the lack of surgical expertise can impact the type of PN performed. Taken together, our findings corroborate the hypothesis that the diffusion of LPN has not been uniform and could be influenced by characteristics such as hospital volume and teaching status. Conversely, RPN might have a different dissemination pattern since it has already been adopted at more nonteaching hospitals than LPN. The introduction of RPN may possibly accelerate overall PN use as patients and surgeons seek to capitalize on minimally invasive approaches to PN. Indeed, in a recent study of Maryland data an increase in RPN from 2008 to 2011 was significantly associated with an increase in the overall volume of PN.

The limitations of our study include its retrospective design and reliance on administratively coded data. The dramatic increase in RPN may in part be due to coding practices, which may likely include the laparoscopic modifier. Also, because the RM code may not be associated with increased surgeon reimbursement, it may have been underused by those using the LPN code. This introduces bias and robotic use might even be greater than that coded so that some LPN cases may actually have been RPN. Since the NIS lacks information on hospital readmission, the true complication rates may be underestimated, especially since bleeding complications often develop after discharge home.

A further limitation is the lack of pathological characteristics. Specifically, it is not known which approach may be used for more complex cases. The inability to match for tumor complexity remains a major limitation of studies using the NIS. The lack of adjustment for such characteristics may have contributed to residual differences among the groups.

Finally, we could not classify complications according to accepted standards such as the Clavien classification due to the nature of the data set. However, to our knowledge our study is the most comprehensive analysis of RPN in the NIS and includes data up to its most recent release.

CONCLUSIONS

RPN has now overtaken LPN in the United States as the minimally invasive approach of choice for PN. While we noted lower odds of adjusted complications in patients treated with RPN compared to OPN, these findings must be considered in the context of the limitations of the NIS in providing case complexity. Nonetheless, our study reveals that the recent dissemination of robotic surgery for PN in the United States has been rapid, broad and safe.


EDITORIAL COMMENT

The authors performed a thorough, population based cohort analysis of robot-assisted PN in the United States. Their findings, which expand on prior NIS outcome studies (references 11 and 19 in article), confirm that robot-assisted PN is associated with superior perioperative safety outcomes and decreased LOS compared to OPN.

The NIS data highlight 2 important issues regarding the dissemination of surgical innovations through the urological community. 1) In contrast to robotic prostatectomy, which encountered considerable problems with preventable adverse events during its initial adoption, RPN diffused safely into broader clinical practice. Further elucidation of factors promoting the safe diffusion of surgical innovations would improve the assimilation of future innovations. 2) The persistence of substantial health care disparities in the allocation of surgical innovations with minority and lower income populations less likely to benefit from them is an unfortunate, shameful circumstance that merits urgent remediation.

J. Kellogg Parsons
Moores Comprehensive Cancer Center
University of California-San Diego
San Diego, California

REFERENCE


REPLY BY AUTHORS

With the widespread adoption of RARP and recent studies demonstrating superior outcomes after RARP (reference 14 in article) it appears that the learning phase of the robotic surgical platform has been overcome. The difference in RPN diffusion patterns may have been due to the fact that by the time urologists adopted RPN they were already experienced robotic surgeons.

Moving forward, the safe dissemination of any new surgical intervention might be best achieved by following IDEAL recommendations. Users of new robotic surgery techniques should adopt this framework for surgical innovation and reporting. Patient safety may be monitored during the learning phase in a prospective manner using statistical process control techniques. This would provide real-time learning curve analysis to prevent adverse events.

Finally, significant health care disparities remain in the allocation of robotic surgery. Differences in income, race and access to insurance are not the only means by which they exist. Efforts to examine the causes and reduce these gaps should be applauded and supported.
REFERENCES


