Comparison of Robot-Assisted Nephrectomy with Laparoscopic and Hand-Assisted Laparoscopic Nephrectomy

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ABSTRACT

Objective: To compare the initial perioperative outcomes of our robot-assisted laparoscopic nephrectomies with laparoscopic and hand-assisted nephrectomies performed by 2 experienced laparoscopic surgeons.

Patients and Methods: We retrospectively evaluated all patients who underwent laparoscopic (LN), hand-assisted (HALN), and robot-assisted laparoscopic nephrectomy (RALN) for benign and malignant diseases between August 2006 and December 2008. Data collected included patient age, body mass index, operative times, estimated blood loss, complications, and hospital stay. Radical nephrectomy was performed for renal neoplasms, and simple nephrectomy was performed for suspected benign diseases. In addition, average direct costs and total costs were calculated for each laparoscopic approach.

Results: Forty-six patients underwent LN, 20 underwent HALN, and 13 underwent RALN. The median operative time was 171, 210, and 168 minutes, respectively. LN, HALN, and RALN groups had similar median EBL [(100mL (IQR=113mL), 100mL (IQR=150mL), and 100mL (IQR=125mL); P=0.695], length of hospital stay [2.0d (IQR=1.0d), 3.0d (IQR=2.0d), and 2.0d (IQR=3.0d); P=0.233], and postoperative morphine equivalent analgesic requirements [33mg (IQR=43mg), 45mg (IQR=50mg), and 30mg (IQR=16mg); P=0.766]. Three patients (6%) in the LN group had complications, 2 (10%) in the HALN group had complications, and 4 (30%) in the RALN group had complications. The average total direct operating room costs were $5,500, $6,979, and $6,869 for the LN, HALN, and RALN groups, respectively.

Conclusions: Early experience with robotic assistance for radical and simple nephrectomy offers no significant advantage over traditional laparoscopic or hand-assisted approaches. It was also more costly.

Key Words: Nephrectomy, Laparoscopy, Robotics, kidney problems

INTRODUCTION

Laparoscopic nephrectomy (LN) is commonly used in the management of renal masses and in patients in whom nephrectomy is indicated for nonmalignant pathologic processes.[1] Hand-assisted laparoscopic nephrectomy (HALN) was developed as an alternative to LN and provides the surgeon with the ability to use a hand for blunt dissection, retraction of surrounding structures, and tactile sensation.[2–6] Previous studies have shown similar surgical outcomes, pain scores, analgesic requirements, costs, and convalescence for both LN and HALN. With the introduction of new technologies, the surgeon has a broader range of tools at his or her disposal to assist in the operating room.[7–9]

Our institution acquired a da Vinci-S system in 2006, resulting in its use for laparoscopic nephrectomies, pyeloplasties, partial nephrectomies, nephroureterectomies, and radical prostatectomies. Reconstructive procedures requiring intracorporeal suturing, such as partial nephrectomies and pyeloplasties, are facilitated by robotic technology. However, there is little experience with the utilization of robotic assistance for radical and simple nephrectomy. The objective of our study was to retrospectively compare the perioperative outcomes of patients undergoing laparoscopic nephrectomy, hand-assisted laparoscopic nephrectomy, and robot-assisted laparoscopic nephrectomy.

METHODS

We performed a retrospective review for all patients undergoing a laparoscopic nephrectomy (LN), hand-assisted laparoscopic nephrectomy (HALN), and a robotic-assisted laparoscopic nephrectomy (RALN) on the da Vinci-S system between the August 2006 and December 2008. All patients presenting for nephrectomy for either benign or malignant pathologic processes were included in the review. All patients were evaluated preoperatively with ei-

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ther computed tomography or magnetic resonance imaging and a renal scan when deemed appropriate. All patients presenting for nephrectomy for either benign or malignant pathologic processes were included in the review. Patients presenting for living-related laparoscopic donor nephrectomy were excluded from the review.

Two experienced laparoscopic surgeons performed all LN, HALN, and RALN between 2006 and 2008. Both surgeons were experienced with robotic surgery for pelvic surgery and reconstructive renal surgery prior to starting RALN in 2006.

Data collected included age, body mass index (BMI), operative details, histopathology, length of hospital stay (LOS), postoperative morphine requirements, and complications. Operative time included the time from the first skin incision to the time of the skin closure. In the case of the RALN, the operative time included the time of the first skin incision, trocar placement, docking of the robot, and closure of the skin.

Patients undergoing a left LN had 4 trocars placed: two 12-mm trocars and two 5-mm trocars. Trocars were placed in a diamond configuration. Patients undergoing a right LN had a fifth trocar (5mm) placed in the subxiphoid area that was used for liver retraction. Patients undergoing HALN had the hand-assist device placed through an 8-cm periumbilical incision. Two 12-mm trocars and an assistant's 5-mm trocar were placed in addition to the hand port. A second 5-mm trocar was placed in the subxiphoid area for liver retraction on right-sided HALNs. All RALNs were performed on the da Vinci-S system that was acquired by our institution in May 2006. All patients undergoing RALN had a 12-mm assistant trocar placed at the umbilicus. The umbilical site was used to gain pneumoperitoneum and initial access into the intraabdominal space. A second 12-mm trocar was placed in the subcostal region in the anterior axillary line for the laparoscope, and two 8-mm da Vinci trocars were placed in a diamond configuration. At the surgeon's discretion, a third 8-mm trocar for the fourth arm of the robot was placed in the lower abdomen. For right-sided RALNs, a 5-mm trocar was placed in the subxiphoid area for liver retraction. All trocars used during LN, HALN, and RALN were bladeless dilating trocars.

All specimens were extracted intact in a specimen bag, except in patients with large autosomal dominant polycystic kidneys with no evidence of malignancy. Extraction sites were located in the midline periumbilical area for all patients undergoing HALN and RALN. Extraction sites included lower midline, periumbilical, Pfannenstiel, and flank for patients undergoing LN. The abdominal fascia was closed with a running 1 PDS or 0 PDS. In cases where the specimen was extracted from a flank site, the fascia was closed in 2 layers. Fascia closure at the trocar sites was performed at the surgeon's discretion with 0 PDS. Postoperative pain was measured by a visual analog scale, which is standard for all patients at our institution. Analgesic requirements were converted to morphine equivalents.

A cost analysis for the laparoscopic, hand-assisted, and robot-assisted groups was performed with the assistance of the financial services department at Indiana University Hospital. Patient outliers with unusually prolonged hospitalizations or with multiple surgical procedures while under the same anesthetic were excluded from the cost analysis. Average direct costs and average total costs were examined for all 3 groups.

Statistical analysis was performed using unpaired t tests, or Kruskal-Wallis and Mann Whitney U tests for nonparametric data, using commercially available statistical software [R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.]

RESULTS

Between August 2006 and December 2008, 79 patients presented for LN, HALN, or RALN. Forty-six patients underwent LN, 20 underwent HALN, and 13 underwent RALN. **Table 1** shows the patient characteristics of the 3 groups.

In the LN group, 35 patients presented with renal masses; 3 of these patients had metastatic renal cell carcinoma at the time of initial presentation. Eleven patients presented for nephrectomy for a nonfunctioning kidney that was complicated by nephrolithiasis, recurrent infections, or pain. In the HALN group, 7 patients presented with renal masses, and 2 of those patients had metastatic renal cell carcinoma at presentation. The remaining 13 patients presented for nephrectomy due to pain and recurrent infections secondary to autosomal dominant polycystic kidney disease (ADPKD). Twelve of the patients with ADPKD had a functioning renal transplant, and 1 patient was on hemodialysis prior to nephrectomy. Five of the patients with ADPKD underwent bilateral HALN. In the RALN group, 11 patients presented with renal masses. One of these patients had metastatic renal cell carcinoma at the time of initial

Table 1.
Preoperative Characteristics

Demographics	Laparoscopic Nephrectomy (N=46)	Hand-Assisted Laparoscopic Nephrectomy (N=20)	Robot-Assisted Laparoscopic Nephrectomy (N=13)
Sex	24 M, 22 F	11 M, 9 F	8 M, 5 F
Side			
Left	23 (50%)	6 (30%)	9 (69%)
Right	22 (48%)	9 (45%)	4 (31%)
Bilateral	1 (2%)	5 (20%)	-
Mean BMI	29	30	29
Mean Preop Creatinine (mg/dL)	1.2	1.5	1.0
Diagnosis			
Renal mass	35	7	11
ADPKD	2	13	-
Non functioning symptomatic renal unit	9	-	2
Renal mass size (cm)	5.8	7.2	4.8

presentation. Two patients had a nonfunctioning kidney complicated by recurrent infections and flank pain.

Table 2 shows perioperative results for the 3 laparoscopic approaches. The median operative time for the LN, HALN, and RALN groups was 171, 210, and 168 minutes, respectively. There was a statistically significant difference in operative times between the LN and HALN groups (P=0.020). When the groups are corrected for bilateral nephrectomies, there is no statistically significant difference between LN, HALN and RALN. There were no conversions to an open nephrectomy in any of the 3 groups; however, one patient

undergoing RALN required conversion to standard LN due to difficulties achieving hemostasis around a hypervascular mass. There was no statistically significant difference between the 3 groups in EBL, analgesic requirements in morphine equivalents, or length of hospital stay.

In the LN group, there were 3 major complications. A patient sustained a serosal injury to the cecum that was oversewn intraoperatively without postoperative sequelae. Another patient developed a partial small bowel obstruction that was managed conservatively with nasogastric decompression. There was a ureteral stump leak in

Table 2.
Perioperative Parameters

Parameter	Laparoscopic Nephrectomy (N=46)	Hand-Assisted Laparoscopic Nephrectomy (N=20)	Robot-Assisted Laparoscopic Nephrectomy (N=13)	P
Estimated blood loss (IQR) mL	100 (113)	100 (150)	100 (125)	0.695
Operating room time (IQR) min	171 (62)	210 (69)	168 (63)	0.060
Length of stay (IQR) d	2.0 (1.0)	3.0 (2.0)	2.0 (3.0)	0.233
Morphine Eq (IQR) mg	33 (43)	45 (50)	30 (16)	0.766
Complications	Partial small bowel obstruction, Cecal serosal injury, Ureteral stump leak (conduit)	Fascial dehiscence, Diaphragm injury	Pulmonary embolism (n=2), Pancreas injury Liver laceration	

a patient with ESRD and an ileal loop. The leak was managed conservatively with an abdominal drain and subsequently resolved. In the HALN group, 2 major complications occurred, a fascial dehiscence and a diaphragmatic injury. The fascial dehiscence occurred in a patient with a postoperative ileus and a history of alcoholism, both of which may have contributed to the dehiscence. The diaphragmatic injury occurred in a patient with an 11-cm mass. The diaphragm was repaired intraoperatively without a chest tube, and there were no postoperative sequelae. In the RALN group, 4 major complications occurred. Two patients acquired pulmonary embolisms; 1 of these patients had significant respiratory compromise requiring several days of ventilator support. One patient developed a pancreatic leak after a resection of an adherent upper pole renal mass. The pancreatic leak was managed conservatively with a drain and total parenteral nutrition until the leak resolved. One patient sustained an intraoperative liver laceration that was managed conservatively with no postoperative sequelae.

A detailed cost analysis was performed for each laparoscopic approach (**Table 3**). During the cost analysis, patients who underwent multiple surgical procedures (ie, laparoscopic cholecystectomy) while under the same anesthetic or who had unusually prolonged hospital courses were excluded. The average direct costs and average total costs were calculated for each group. The average direct costs included costs that were directly attributed to patient care, such as surgical instruments, anesthetic pharmaceuticals, nursing salaries, time-based operating room costs, and recovery room costs. The average total costs included direct costs and indirect costs that were allocated to patient care. Indirect costs included costs from Human Resources, Finance, Environmental Services, and other departments that are essential to the delivery of care but may be difficult to measure.

DISCUSSION

Since Clayman et al[1] first described laparoscopic radical nephrectomy, the procedure has commonly been used in the management of malignant and benign renal diseases of the kidney. HALN was developed as an adjunct to standard laparoscopic nephrectomy.[2] It allows surgeons to bridge the difficult learning curve between open surgery and standard laparoscopic surgery and provides the additional benefits of tactile sensation, retraction, and blunt dissection with the surgeon's hand.[3–6] LN and HALN have demonstrated improved convalescence and similar surgical outcomes compared with open radical nephrectomy. Both approaches have similar operative times, complication rates, length of hospital stay, time to ambulation, oral intake, and return to normal activities.[5–9]

LN and HALN are used at our institution with regularity. HALN is often reserved for cases that are deemed difficult by the operating surgeon, because of the theoretical added benefits of the surgeon's hand in the abdomen. The hand-assisted approach is most commonly used for patients with large polycystic kidneys, but the reduction in working abdominal space due to the enlargement of the kidneys can sometimes be prohibitive. When we accounted for the higher rate of bilateral nephrectomies in the HALN group, we found no difference between LN and HALN in operative times.

Previous studies have described the use of robot-assistance for pyeloplasties, partial nephrectomies, donor nephrectomies, simple nephrectomies, and radical nephrectomies.[10–17] Klingler et al[18] described the feasibility of robot-assisted radical nephrectomies. Later, that same group described a small cohort of 6 patients versus 33 patients who underwent standard laparoscopic nephrectomies and 18 patients who underwent open nephrectomies. There was no statistically significant difference in operative variables between robotic or laparoscopic nephrectomies, except for the opera-

Table 3.
Total Charges and Costs

	Mean Total Charges	Mean Direct Costs	Mean Total Costs	Median Hosp. Stay
Laparoscopic Nephrectomy	$29,916	$5,500	$10,635	2.0
Hand-Assisted Laparoscopic	$32,395	$6,979	$12,823	3.0
Robot-Assisted Nephrectomy	$25,5334	$6,869	$11,615	2.0

[a]Costs measured in US dollars. Outliers and multiple procedures were excluded.

tive times, 345 minutes vs 265 minutes, respectively. The differences in operative times may have been due to a learning curve, port placement, and docking of the robot.[19]

Rogers et al[20] described 42 patients who underwent robot-assisted laparoscopic nephrectomies for benign and malignant diseases. A transperitoneal approach was used in 39 patients, and a retroperitoneal approach was used on 3 patients. The mean operative console time was 158 minutes, mean EBL was 223mL, mean hospital stay was 2.4 days. A complication rate of 2.6% was reported.

In our series, we compared our initial cohort of patients[13] undergoing RALN against the last 2 years of HALN and LN at the hands of 2 experienced laparoscopic surgeons. Mean EBL, length of hospital stay, and mean analgesic morphine requirements were similar with no statistically significant difference between the 3 groups. The operative times between RALN and LN groups were also similar, which included the time from the first skin incision, trocar placement, console time, and skin closure. We had a higher complication rate in the RALN group (30%) compared with HALN (10%) and LN (6%) groups. The higher complication rate in the RALN group is not clinically significant given the small number of cases in the series. The pulmonary embolism is unlikely to be related to the approach used. The pancreatic injury was a result of dense adhesions from the tumor to the pancreas. While robotic assistance in this series did not offer any benefit, it could be of value for radical nephrectomies requiring a retroperitoneal nodal dissection. An experienced assistant is recommended at the patient's side during advanced robot-assisted renal surgery.

The longer hospital stay in 2 patients in the RALN group increased the dispersion of this outcome, which was influenced by the complications experienced in this group. One patient required ventilatory support due to a pulmonary embolism and had a prolonged hospitalization (18 days), and another patient required total parenteral nutrition for a pancreatic leak resulting in a longer than usual hospitalization (13 days).

Limitations of this study include the lack of prospective randomization and the small sample size of the robot-assisted group. A larger sample size in the robot-assisted group may have had a smaller incidence of perioperative complications and a shorter length of hospital stay.

A detailed cost analysis was performed for each laparoscopic approach. At our institution, the same equipment and instruments are used during both procedures with a few exceptions. Ultrasonic shears are used during both LN and HALN, and a hand-assist device is used during HALN. Costs for both of these devices are shown in **Table 4**. The difference in average direct costs between the groups undergoing laparoscopic nephrectomies and hand-assisted laparoscopic nephrectomies was approximately $1,400. The remaining difference in direct costs between the 2 groups can be explained by the increased average operating room time in the HALN group. The increased operating room time translates into longer anesthetic time, nursing time, and time-based operating room costs. Time-based operating room costs are $54/minute for the first 30 minutes and $11/minute thereafter.

The average direct costs for a robot-assisted laparoscopic nephrectomy were approximately $1,300 more than costs for the LN group. Purchase costs for the EndoWrist instruments used at our institution are shown in **Table 4**. These instruments are reusable 10 times, and then require replacement by the purchasing institution. The use of the EndoWrist curved scissors, PK forceps, and ProGrasp forceps translates into costs of approximately $830 per patient. Drapes and other disposables necessary for a robotic procedure cost $210. Additional costs for robot-assisted nephrectomies include the initial purchase of the da Vinci-S robotic system, approximately $1.65 million, and an annual maintenance contract of $139,000. These costs per patient depend on the institution's robotic procedure volume.

There is a considerable increase in the costs assumed by the patient and the hospital for robot-assisted laparoscopic nephrectomies. Per patient, the costs for a robot-assisted nephrectomy are similar to costs of a hand-assisted laparoscopic nephrectomy. In an institution in which an established robotics program is already in place, the addition of robot-assisted nephrectomies into patient care would not be cost prohibitive and may provide a bridge in training for renal reconstructive procedures. The additional costs of purchasing a robot and the annual maintenance required for the equipment might be prohibitive in a hospital without an established robotics program.

CONCLUSION

Early experience with robotic assistance for radical and simple nephrectomies offers no significant advantage over traditional laparoscopic or hand-assisted approaches. In fact, when considering all cases, the pa-

Table 4.
Comparison of Disposable Costs

Disposable Instruments	Laparoscopic Nephrectomy	Hand-Assisted Laparoscopic Nephrectomy	Robot-Assisted Laparoscopic Nephrectomy
Total Disposable Costs	$1,573.38	$2,078.49	$1,942.28
Harmonic ScalpelACE 36cm shaft	$482.04	$482.04	$0
Gel Port	$0	$575	$0
Robotic hot shears	$0	$0	$320
PK dissecting forceps	$0	$0	$290
ProGrasp Forceps	$0	$0	$220
Robotic drapes, cannula seals, tip cover	$0	$0	$210.50
Endocatch	$155	$155	$155
12mm trocar + sleeve	$158.38	$158.38	$158.38
Additional 12mm sleeve	$90.90	$90.90	$90.90
5mm trocar + sleeve	$119.67	$119.67	$0
Additional 5mm trocar + sleeve	$69.89	$0	$0
EndoGIA stapler	$187.50	$187.50	$187.50
Staple load x 1	$200	$200	$200
10mm Hemolok clip	$10	$10	$10
Suction irrigator	$100	$100	$100

[a]Assumes a left-sided cases. An additional 5mm trocar is required for right-sided cases. Costs in US dollars.

tients undergoing a robotic nephrectomy had a higher rate of complications, which suggests a detrimental effect from utilizing the robot. However, such differences may reflect a learning curve and the small number of patients. Additionally, robotic assistance adds about $1,300 in direct costs to surgery compared with the traditional laparoscopic approach but is comparable to the hand-assisted approach. Further comparison with a larger number of robotic cases is needed.

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