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Surgery in Motion

Zero-fragment Nephrolithotomy: A Multi-center Evaluation of Robotic Pyelolithotomy and Nephrolithotomy for Treating Renal Stones

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Abstract

Background: Robotic pyelolithotomy (RPL) and robotic nephrolithotomy (RNL) may be utilized for treating kidney stones as an alternative to percutaneous nephrolithotomy or flexible ureteroscopy.
Objective: To describe the techniques of RPL and RNL, and present multi-center outcome data for patients undergoing these procedures.
Design, setting, and participants: This study was a retrospective analysis of 27 patients undergoing RPL and RNL at five tertiary academic institutions between 2008 and 2014.
Surgical procedure: RPL and RNL without use of renal ischemia.
Measurements: We assessed stone clearance by visual assessment and postoperative imaging. We also examined other factors, including complications (Clavien grade), estimated blood loss, operative time, and length of stay.
Results and limitations: Twenty-seven patients underwent 28 procedures for a mean renal stone size of 2.74 cm (standard deviation: 1.4, range: 0.8–5.8). The mean stone volume was 10.2 cm^3. RPL accounted for 26 of these procedures. RNL was performed in one patient, while another underwent combined RPL-RNL. Indications included failed previous endourological management (13), staghorn calculi (five), gas containing stone (one), calyceal diverticulum (one), complex urinary tract reconstruction (two), and patient preference (four). The mean patient age was 35.6 yr and mean body mass index was 25.5 kg/m^2. Mean operative time/console times were 182 min and 128 min, respectively. The mean estimated blood loss was 38 ml. The mean length of stay was 1.7 d. There was no significant change in preoperative and postoperative serum creatinine levels. The overall complication rate was 18.5% (Clavien 1 = 3.7%; 2 = 7.4%; 3b = 7.4%). The complete stone-free rate was 96%.
Conclusions: RPL and RNL are safe and reasonable options for removing renal stones in select patients. In particular, RPL allows the removal of stones without transgressing the parenchyma, reducing potential bleeding and nephron loss.
Patient summary: The robotic approach allows for complete removal of the renal stone without fragmentation, thereby maximizing chances for complete stone clearance in one procedure.

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1. Introduction

Percutaneous nephrolithotomy (PCNL) is the standard of care for the management of large renal stones greater than 2 cm in size [1]. Contemporary multi-institutional registry data demonstrates that stone-free rates (SFR) for nonstaghorn and staghorn stones treated with PCNL range from 77% to 83%, and 33% to 57%, respectively [2,3]. Common complications from PCNL include postoperative fever (8.7–14.8%), bleeding (7.8%), sepsis (0.9-4.7%), blood transfusion (5–18%), and hydrothorax (2%) [2,4–6]. Recent studies have revealed that retreatment rates after PCNL can be as high as 30–40% in patients with residual fragments (RF) [7,8].

Open nephrolithotomy may be considered when the stone cannot be removed by a reasonable number of less invasive procedures. Patients in this group include those with extremely large staghorn calculi, unfavorable collecting system anatomy, extreme morbid obesity, and skeletal abnormalities [9]. However, open surgery is rarely performed for stones in the modern era, and instead laparoscopic approaches are utilized as alternatives to PCNL. In a meta-analysis comparing laparoscopic pyelolithotomy with PCNL, laparoscopy had significantly lower rates of bleeding and sepsis, as well as a trend towards a higher SFR [10]. More recently, robotic pyelolithotomy (RPL) and robotic nephrolithotomy (RNL) have been shown to be safe and feasible options for removing large renal stones in toto as a single specimen, without stone fragmentation [11–13]. Compared with a pure laparoscopic approach, RPL and RNL may have advantages of improved dexterity for suturing and reconstruction. With robotics or laparoscopy, the lack of fragmentation limits the risk of RFs, and may have long-term benefits in avoiding surgical retreatment.

Previous reports of RPL and RNL have been limited to small studies from single institutions [3,12,13]. The purpose of our study is to evaluate patient outcome data for RPL and RNL from a multi-center collaborative of robotic surgeons, and evaluate its efficacy and safety. We also describe the technique with an accompanying video in this article, including tips and tricks for successful surgery.

2. Material and methods

We performed a retrospective review in five surgical centers performing robotic renal surgery for stone disease (Ann Arbor Veterans Affairs Hospital, Ann Arbor, MI, USA; Wake Forest Baptist Hospital, Salem, NC, USA; Henry Ford Health System, Detroit, MI, USA; Medical College of Georgia, Augusta, GA, USA; Mount Sinai Hospital, New York, NY, USA). The institutional review boards of all centers approved retrospective data collection; data were collected on 27 patients undergoing RPL and RNL performed by K.R.G., R.M., A.H, J.S.E., and K.B. from 2008 to 2014. Only procedures without the use of renal ischemia were included in this series. Patients with intrarenal pelvis are not suitable for RPL, and were excluded for surgical consideration. One center from our group has already published results of robotic anatrophic nephrolithotomy using renal ischemia, and are not included in this series [12]. Procedures were performed using either a transperitoneal or retroperitoneal approach. The approach was based on surgeon preference or stone location. Posterior stones are suitable for a retroperitoneal approach.

2.1. Surgical technique

2.1.1. Patient preparation

Patients undergoing transperitoneal RPL were instructed to be on a clear liquid diet the day prior to surgery. No bowel preparation was needed for retroperitoneal surgery. All patients received a preoperative type and screen.

2.1.2. Patient positioning

Procedures performed transperitoneally utilized a standard robotic approach for kidney surgery. Patients were positioned in the lateral decubitus position with the affected side up. For the retroperitoneal approach, the patient is placed in the full flank position with the table fully flexed to increase the space between the 12th rib and iliac crest. The spine and hip is positioned in a straight line. In both approaches, the dependent arm is padded and secured to an armrest, which is tilted towards the head as much as possible to avoid clashing with the robotic arms.

2.1.3. Port placement

Transperitoneal: A 12-mm camera port is placed lateral and superior to the umbilicus and three 8-mm robotic working ports were placed under direct vision in the ipsilateral upper quadrant, lower quadrant, and lateral abdomen. A 12-mm assistant port is usually placed close to the midline, midway between the camera port and the robotic ports. Some centers used a fourth robotic arm port to aid with retraction of the kidney and exposure of the renal pelvis and hilum.

Retroperitoneal: The camera port is placed above the iliac crest, lateral to the triangle of Petit. A 12-mm incision is made in this area, and the lumbodorsal fascia pierced to enter the retroperitoneal space. A balloon-dilating device (OMSPDBS2; Covidien, Mansfield, MA, USA) is inserted and expanded under direct vision using a 30° laparoscope. This is swapped for a 12-mm camera port for the robotic camera. Two 8-mm robotic ports are inserted, the first being above the erector spinae muscles just under the 12th rib, and the second port 7–8 cm superior and medial to the camera port. A 12-mm assistant port is placed in the anterior axillary line cephalad to the anterior superior iliac spine, and 7–8 cm caudal to the medial robotic port.

2.1.4. Docking

For transperitoneal surgery, the patient side-cart is docked in a 30–45° angle from the flank as per standard for robotic renal surgery. For retroperitoneal surgery, the side-cart is docked over the patient's head parallel to the spine.

2.1.5. Instruments

Robotic instruments include monopolar shears, monopolar hook, bipolar fenestrated grasper, Prograsp forceps, and needle drivers. We also recommend use of a robotic ultrasound probe (Hitachi Aloka, Wallingford, CT, USA) and availability of a flexible nephroscope.

2.1.6. Surgical dissection

Transperitoneal: The kidney is mobilized and the renal hilum exposed in a similar fashion as for robot-assisted partial nephrectomy. While we do not clamp the vessels, it is important to have the renal vessels exposed in case of the need to clamp due to excessive bleeding at the time of the nephrotomy incision. After hilar dissection, the renal pelvis is dissected and mobilized being careful to protect the upper ureter and avoid excessive mobilization.

Retroperitoneal: The Gerota's fascia is incised just above the psoas muscle, exposing the perinephric fat and the kidney. Dissection is then carried out along the psoas muscle, elevating the kidney and perinephric fat until the hilum and renal pelvis is encountered.

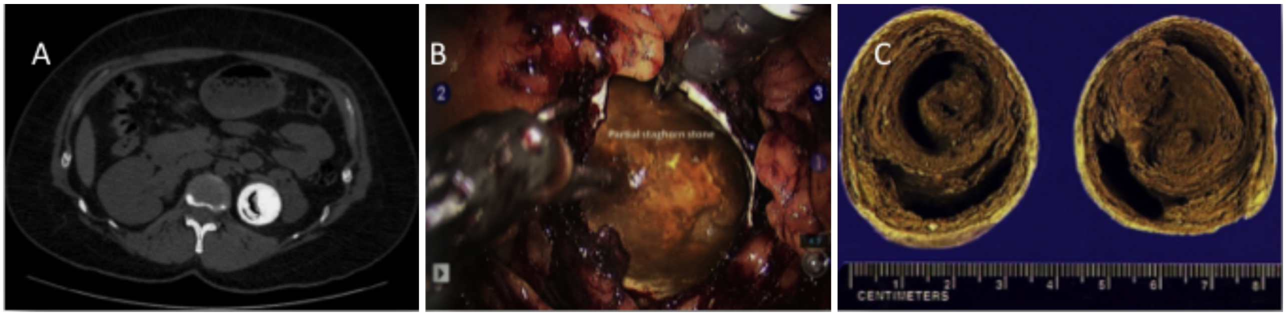

Fig. 1 – Robotic pyelolithotomy performed for a large pelvic stone. (A) Computed tomography scan demonstrating a 3.6-cm pelvic stone with possible gas in the stone. (B) Pyelolithotomy incision exposing the stone. (C) Sectioned large left gas-containing renal stone.

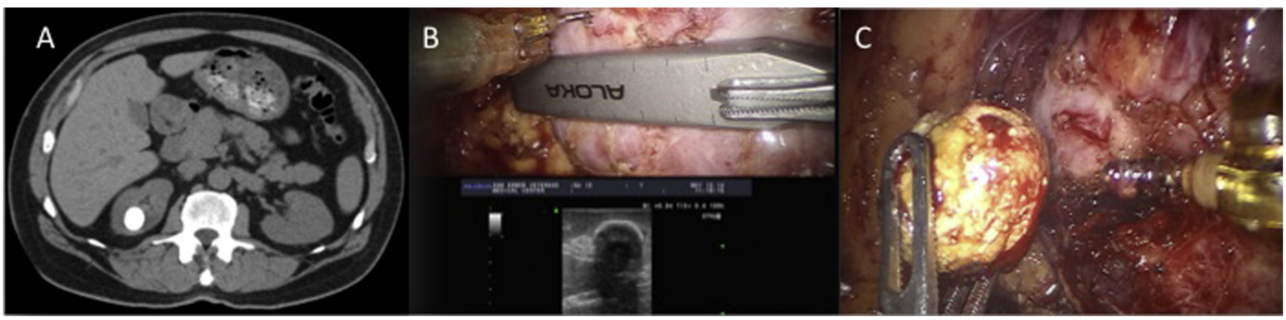

Fig. 2 – Robotic nephrolithotomy performed for an upper pole stone. (A) A 2-cm upper stone within a diverticulum noted on computed tomography scan. (B) A robotic ultrasound probe is utilized to identify and confirm the location of the stone and plan the incision. (C) A robotic ProGrasp forcep is then used to carefully extract and remove the stone in its entirety.

2.1.7. *Pyelolithotomy*

Once the pelvis is mobilized, the robotic ultrasound probe is utilized to identify and confirm the location of the stone, and plan the incision (Fig. 1A). A vertical incision is made in the pelvis, until the stone is exposed (Fig. 1B). A robotic ProGrasp forcep is then used to carefully dislodge and remove the stone/s (Fig. 1C).

2.1.8. *Nephrolithotomy*

The perinephric fat is cleared off the parenchyma overlying the location of the stone. Scanning with the robotic probe identifies the stone with presence of acoustic shadowing (Fig. 2A). The incision line is planned in the part of the parenchyma which is the thinnest. A linear nephrotomy incision directly over the stone is then made using the robotic monopolar hook (Fig. 2B). This is done without clamping the renal hilum, and if performed correctly, minimal bleeding is encountered. The stone is then removed using the Prograsp as a single piece without fragmentation (Fig. 2C). In case the cavity containing the stone is thought to be in a diverticulum, it is then ablated using argon beam or cautery.

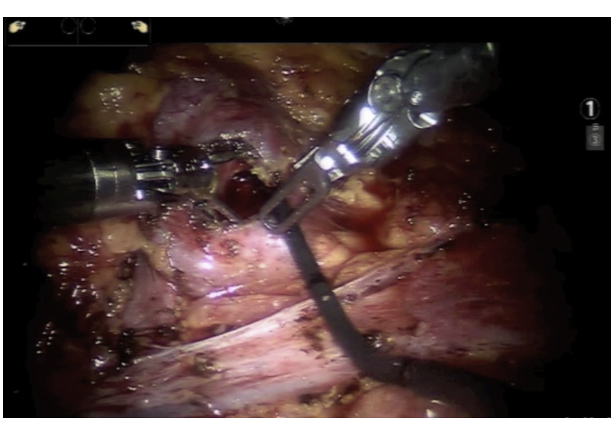

Fig. 3 – Flexible nephroscopy being performed at the time of robotic nephrolithotomy to inspect for residual stone.

2.1.9. *Flexible nephroscopy*

After removing the stone, the ultrasound probe is redeployed to assess for further stone(s) in the collecting system. If a stone is noted, and inaccessible via the robotic instruments, a flexible nephroscope can be inserted through an assistant port and manipulated into the renal pelvis for inspection of the collecting system (Fig. 3). This can be navigated by the bedside assistant with guidance from the console surgeon. If a stone is identified on nephroscopy, it is removed using a basket.

2.1.10. *Stent placement*

During pyelolithotomy, a ureteral stent is placed. A 14-gauge Angiocath needle is inserted by the bedside assistant and visualized by the robotic surgeon. The assistant passes a guidewire through the catheter, which is passed antegrade down the ureter. A double pigtail ureteral stent is then inserted over the wire and advanced in the ureter with the aid of a pusher until the mark on the stent indicates the proximal curl. The wire is then withdrawn and the proximal curl placed into the renal pelvis.

2.1.11. *Closure*

The pyelotomy is closed using a running 3-0 absorbable suture. For nephrolithotomy, the incised renal parenchyma is closed using sliding clip renorrhaphy technique with 1-0 vicryl absorbable sutures. Hemostatic agents may also be applied over the defect. At the end of the operation, the stone specimen is placed in an Endocatch bag and retrieved through the camera port.

Table 1 – Patient characteristics

No. of patients (no. of procedures)	27 (28)
Mean age, *n* (SD, range; yr)	35.6 (23.2, 1–77)
Laterality	16 right, 10 left, 1 bilateral
Sex	Men: 16, Women: 11
Mean BMI, *n* (SD, range; kg/m^2)	25.5 (4.6, 17–33.2)
Anticoagulation	2 patients; 1 Jehovah's Witness
Median ASA score, *n* (SD, range)	2 (0.9, 1–4)
Prior abdominal surgery	Partial gastrectomy (1); lap cholecystectomy (1); gastric bypass (1); umbilical hernia (1); hysterectomy (1); pyeloplasty (2); robotic pyelolihtotomy (1); augmentation cystoplasty/mitrof/malone (1)
Preoperative imaging	
Plain abdominal radiography	7
Plain abdominal radiography and US	2
CT	18
Maximum stone diameter, *n* (SD, range; cm)	2.74 (1.4, 0.8–5.8)
Mean stone volume, *n* (SD, range; cm^3)	10.6 (19.4, 0.18–92.7)

ASA = American Society of Anesthesiologists; BMI = body mass index; CT = computed tomography; SD = standard deviation; US = ultrasound.

3. Results

RPL accounted for 26 out of 28 of these procedures. Indications for RPL and RNL included patients who had failed endourological management (*n* = 13), staghorn calculi (*n* = 5, all partial staghorn), gas containing stone (*n* = 1), stone in the calyceal diverticulum (*n* = 1), and patients with renal stone in complex reconstructed urinary tract (*n* = 2). Reasons for unsuccessful endourological management included patients that failed ureteroscopy due to calyceal diverticulum or lower pole positioning. Two patients failed PCNL, including one who had difficult access due to a reconstructed urinary tract. Several patients also failed shockwave lithotripsy due to hard stones as well patients with abnormal anatomy (eg, cross fused ectopia). Four patients elected to proceed with a robotic procedure as the primary approach for their renal stone treatment; two of these patients were counseled by a fellowship-trained endourologist.

Table 1 provides demographic information on patient's undergoing RPL and RNL. Nine patients underwent radiography or ultrasound imaging, as these patients were <18 yr of age. Two patients were on anticoagulation, and one patient was a Jehovah's Witness. Prior abdominal surgery was noted in nine patients. The mean maximum stone diameter was 2.74 cm (standard deviation [SD]: 1.4 cm, range: 0.8–5.8 cm), with a mean stone volume of 10.6 cm^3 (SD: 19.4 cm^3, range: 0.18–92.7 cm^3). The patient with a 0.8 cm stone had multiple lower pole stones, and had previously failed shock wave lithotripsy.

Table 2 summarizes perioperative characteristics and patient outcomes data. Mean operative time was 182 min (SD: 61.6, range: 101–300), and mean robotic console time was 128 min (SD: 56.9, range: 48–245). Use of a retroperitoneal approach increased the preconsole operative time. The longest operation in our series was due to a bilateral procedure. Mean estimate blood loss was 38 ml (SD: 30.3, range: 5–100). Complications were recorded in five patients (18.5%). These included Clavien 1 (*n* = 1), Clavien 2 (*n* = 2), and Clavien 3b (*n* = 2) complications. No patients underwent a blood transfusion or developed a postoperative fever or sepsis.

Postoperative imaging was obtained in 23 patients. Ten patients had computed tomography (CT), 10 had plain abdominal radiographs, and three patients underwent an ultrasound. The complete SFR (ie, zero-fragment rate) after a single robotic procedure was 26/27 (ie, 96%). In one patient, a 3-mm RF was noted on postoperative imaging. Eighteen patients had stents placed intraoperatively, and 12 had intraoperative drains placed. All drains were removed on postoperative d 1. Stone composition was varied, including calcium oxalate monohydrate, calcium oxalate dehydrate, struvite, cysteine, calcium phosphate, calcium phosphate dihydrate, and carbonate apatatite stones. Stone composition of the staghorn stones included one cystine, one calcium oxalate dihydrate, two calcium oxalate monohydrate, and one calcium phosphate stone. All were partial staghorn stones.

Table 2 – Perioperative characteristics and patient outcomes

Mean operative time, min (SD, range)	182 (61.6,101–300)
Mean console time, min (SD, range)	128 (56.9, 48–245)
Mean EBL, ml (SD, range)	38 (30.3, 5–100)
Preop serum creatinine, mg/dl (SD, range)	0.94 (0.3, 0.5–2.0)
Postop serum creatinine, mg/dl (SD, range)	0.91 (0.3, 0.4–2.1)
Mean length of stay, d (SD, range)	1.7 (1.0, 1–4)
Stone-free rate (%)	96
Drain placement (no. of patients)	12
Intraoperative ureteral stent placement (no. of patients)	17
Follow up, d (SD, range)	275 (369, 12–1320)
Complications	5 (18.5%)
Clavien 1 = 1	Ileus (1)
Clavien 2 = 2	UTI: 2 wk post operatively (1);
	Dislodged Malecott catheter (1)
Clavien 3b = 2	Hydronephrosis requiring PCN + URS (1)
	Encrusted stent (1) requiring removal

EBL = estimated blood loss; PCN = percutaneous nephrolithotomy; postop = postoperative; preop = preoperative; SD = standard deviation; URS = ureteroscopy; UTI = urinary tract infection.

4. Discussion

In this study we provide multi-center outcome data for patients undergoing RPL and RNL for the management of renal stones. We found that the complete SFR after a single robotic procedure was 96%. Our overall complication rate was 18.5%, with only 7.4% of patients having a ≥Clavien 3 complication. None of the patients underwent a blood transfusion or developed sepsis after RPL or RNL. The procedures were done without the need for renal ischemia, and in patients undergoing RPL, there was no transgression of the renal parenchyma.

Robotic stone surgery has previously been shown to be a reasonable approach for removing large staghorn stones [3,13]. Badani and colleagues [13] described robotic extended pyelolithotomy in 13 patients, in which staghorn or partial staghorn stones were treated. All but one patient with a complete staghorn stone had removal of the entire stone specimen, providing a SFR of 92%. Hemal et al [14] performed eight cases of robotic-assisted laparoscopic surgery for primary stone removal, with a SFR of 93.2%. Ghani et al [3] presented results on three patients with complex staghorn stones who underwent robotic anatrophic nephrolithotomy with cold ischemia of the kidney. In this select group, however, two of the three patients had RFs following the procedure. Table 3 provides a summary of all studies to date assessing robot-assisted and laparoscopic approaches to pyelolithotomy and renal stone removal [11,13,15–25]. Our study is the largest series to date evaluating the safety and efficacy of a robotic approach to treat renal stones.

The advantage of RPL or RNL is that it results in complete stone removal in a minimally invasive fashion, reducing the risk of RFs. Fragments following PCNL have the potential for long-term morbidity due to need for surgical retreatment. Raman et al [7] evaluated 42 patients with RFs after PCNL confirmed on CT, and found that 43% of patients experienced a stone related event at a median of 32 mo, and 61% of these required a repeat surgical procedure. On multivariable analysis, RF size >2 mm was the only independent predictor associated with a repeat stone event. More recently, Portis and colleagues [8] assessed long-term outcomes in 129 patients undergoing PCNL with a mean follow-up of 5.4 yr. Patients who were completely stone-free had a lower rate of a repeat procedure (4%), whereas those with RF >2 mm or even <2 mm, had repeat procedure rates of 30% and 33%, respectively. This implies that even small RFs <2 mm may have significant consequences, and that a zero-fragment outcome has the most desirable result. Robotic minimally invasive surgery offers the possibility of a one-stop solution for the removal of large renal stones, and permits a *zero-fragment nephrolithotomy*, that is zero fragmentation with the aim of intact complete stone removal. The appeal of a single definitive procedure is strong and robotic pyelolithotomy may be the best option in some cases [15]. There are select indications when nephrolithotomy is feasible, such as when the overlying parenchyma for a peripherally located stone is thin or the stone is in a calyceal diverticulum.

RPL allows removal of stones through an incision of the renal pelvis without transgressing the parenchyma, which is a potential cause for bleeding and nephron loss. A select group of patients that one could consider RPL include patients with unfavorable anatomy, anticoagulated patients, concomitant ureteropelvic junction obstruction, ectopic kidney, and failed PCNL [26]. We acknowledge that robotic surgery should not be the initial treatment choice for most patients with renal stones, and that endourologic management is the standard of care. A further point regarding RPL is that in some patients, dissection of the renal pelvis can be challenging as the pelvis may be inflamed with adherent fat, making demarcation of planes difficult with bleeding encountered.

RNL may be the better option in cases where access to the collecting system through the renal pelvis is restricted. The robotic ultrasound probe is used to both locate the stone and plan the incision, which is best if performed in the thinnest part of the parenchyma. If done appropriately, bleeding is minimal and clamping not necessary. Further, as we have shown in the accompanying video, RNL is able to successfully treat calyceal diverticular stones, especially posterior lying stones via a retroperitoneal approach. One note on technique here should be addressed; if the diverticulum orifice is not well localized, or hydrocalyx is suggested as a differential diagnosis, we recommend ablation in order to avoid a urine leak from an unablated hydrocalyx [27]. The advantages of a retroperitoneal approach are that the bowel and peritoneal cavity are not transgressed, allowing quicker return of bowel function as well as a more rapid dissection to the hilum [28]. Disadvantages to this approach are that it requires greater expertise to develop the space, particularly in obese patients, as well as longer preconsole operative times for access and port placement as noted in our series.

Some shortcomings of robotic renal stone surgery compared with PCNL need to be noted. First, PCNL should be considered the least invasive approach, especially in a single access approach as there is only one skin incision. However, with complex stones, multiple tracts for PCNL may be needed which increases the number of incisions. Second, flexible nephroscopy is more easily performed during PCNL than via a laparoscopic port. Third, in patients who have soft stones, PCNL with an energy device incorporating suction may lead to easier stone clearance. RPL and RNL are more suited for hard stones that can be grasped and removed intact. Finally, data is not clear about the costs of robotic surgery for renal stones. A recent study by Hyams and Shah [29] calculated PCNL to cost $19 845 in the USA. Using robotic partial nephrectomy as a surrogate for the cost of RPL or RNL, a study by Mir and colleagues [30] estimates the cost of robotic partial nephrectomy to be $11 962. Charges and ancillary equipment used may vary between institutions, and comparing costs is difficult.

Limitations of our study include absence of postoperative imaging in four patients. However, these patients were assessed intraoperatively under robotic vision, and were patients who had solitary stones removed intact. Of 23 patients undergoing postoperative imaging, CT was used

Table 3 – Summary of studies evaluating the role of laparoscopic and robotic surgery in managing complex renal stones[a]

Study	Yr	*N*	Technique evaluated	Stone size (mean; cm)	Mean operative time (mins)	Mean ischemia time (mins)	Ischemia: none (N), warm (W), or cold (C)	EBL (mean; ml)	LOS (mean; d)	Clavien complication rate (%)	Stone-free rate (%)	Ancillary procedures (%)	Follow-up (mean; d)
Laparoscopic (L)													
Lee et al [15]	2014	45	L-PL	4.9	163.7	0	N	47.7	4.6	2.2 Grade 2 2.2 Grade 3 0.0 Grade 4	91.1	8.9	90
Li et al [16]	2014	89	L-PL	2.9	90.8	0	N	NA	4.5	3.4 Grade 2 0.0 Grade 3 0.0 Grade 4	98.0	NA	90
Basiri et al [17]	2014	30	L-PL	3.6	149.0	0	N	NA	3.4	3.3 Grade 2 3.3 Grade 3 0.0 Grade 4	90.1	9.9	90
Haggag et al [18]	2013	10	L-PL	6.5 cm^2	131.0	0	N	65.0	2.3	30.0 Grade 2 0.0 Grade 3 0.0 Grade 4	80.0	20.0	90
Singh et al [19]	2013	22	L-PL	3.0	91.8	0	N	54.2	NA	NA	95.5	4.5	90
Giedelman et al [20]	2012	8	L-ANL	5.3	142.5	20.8	W	315	3.5	0.0 Grade 2 12.5 Grade 3 0.0 Grade 4	63	NA	15
Zhou et al [21]	2010	11	L-ANL	5.2	139.0	31.0	W	<150	NA	27.3 Grade 2 0.0 Grade 3 0.0 Grade 4	90.9	9.1	365
Simforoosh et al [22]	2008	5	L-ANL	5.3	170	32.0	W	<100	5.4	0.0 Grade 2 0.0 Grade 3 0.0 Grade 4	60.0	40.0	90
Robotic (R)													
Atug et al [23]	2005	8	R-PL	10.7	275.8	0	N	48.6	1.1	0.0 Grade 2 0.0 Grade 3 0.0 Grade 4	100	0.0	374
Badani et al [13]	2006	13	R-PL	4.2	158.2	0	N	100.0	–	7.7 Grade 2 0.0 Grade 3 0.0 Grade 4	92.3	7.7	1
Lee et al [24]	2007	5	R-PL	3.84	315.0	0	N	19.0	3.8	NA	60.0	20.0	467
Mufarrij et al [25]	2008	13	R-PL	NA	235.9	0	N	60.8	2	0.0 Grade 2 0.0 Grade 3 0.0 Grade 4	100	0.0	855
Ghani et al [11]	2014	4	R-PL/NL	NA	216.0	NA	N	37.5	2	25.0 Grade 2 0.0 Grade 3 0.0 Grade 4	100	0.0	NA
King et al [12]	2014	7	R-NL	NA	222	35	W	121	3	14.3 Grade 2 0.0 Grade 3 0.0 Grade 4	28.6	28.5	153

ANL = anatrophic nephrolithotomy; EBL = estimated blood loss; LOS = length of stay; NA = not available; NL = nephrolithotomy; PL = pyelolithotomy.
[a] Case reports were not included.

in 10 (44%) patients. While routine use of CT may expose the patient to unnecessary radiation exposure, it remains the most sensitive study to determine complete stone clearance, and it is possible that in patients undergoing ultrasound, a small RF could have been missed. In the one patient where stone clearance was incomplete (3 mm lower pole RF detected on CT), it was when a concomitant lower pole stone could not be identified and retrieved with the flexible nephroscope. While it is important to assess the kidney for residual stones with ultrasound, and flexible nephroscopy can be used to retrieve stones, we consider RPL and RNL better suited for patients with single stones to avoid these issues. Further, this was a retrospective study, and as such has the potential for reporting bias. Finally, our follow-up is not long enough to assess repeat stone episodes or interventions, which is an important marker for outcomes. We also emphasize that the indication to perform robotic surgery needs to take into account factors such as risk of recurrence, and consequences of any re-do surgery in the future. However, even in pediatric patients, robotic surgery for kidney stones has been found to be safe and effective [24].

It is yet to be fully determined whether the da Vinci system will have a significant role to play in the management of complex stone disease. For the individual urologist, utilization is likely to be based on the relationship between three specific factors: skillset, logistics, and cost [26]. Obtaining percutaneous access can be quite challenging, and is one reason why the majority of urologists rely on radiologists to get access [31]. It is likely that the next generation of urologists will be more comfortable and skilled with robotics than at gaining percutaneous access. Regarding logistical factors and access to equipment—especially if the urologist has to rely on a radiologist—the urologist is self-sufficient with robotics. However, there is no doubt that robotics has high capital and instrument costs, and in some centers which are not high-volume robotic centers or do not have a robot it will be more sensible to perform laparoscopy in these select patients. Finally, further studies are required to determine the efficacy of robotic surgery in comparison to the standard of PCNL. A randomized controlled trial assessing the comparative effectiveness of each procedure in respect to SFR, morbidity and long-term retreatment may help define future treatment algorithms.

5. Conclusion

RPL and RNL are safe and reasonable options for removing large renal stones in select patients and for surgeons experienced and comfortable with robotic kidney surgery. RPL is ideal for single pelvic or partial staghorn stones, whereas RNL is suitable for calyceal stones if the overlying parenchyma is thin, providing a bloodless window into the kidney. Advantages of both techniques include low risk of sepsis and bleeding. More importantly, the robotic approach permits zero-fragment nephrolithotomy where the stone is removed in toto thereby maximizing chances for complete stone clearance, and avoiding the pitfall of future retreatment due to retained fragments.

Author contributions: Khurshid R. Ghani had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Ghani, Madi, Elder, Hemal, Badani.
Acquisition of data: Swearingen, Sood, Madi, Klaassen, Badani, Elder, Wood, Hemal, Ghani.
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Appendix A. Supplementary data

The Surgery in Motion video accompanying this article can be found in the online version at http://dx.doi.org/10.1016/j.eururo.2016.10.021 and via www.europeanurology.com.

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