10 Robotic-Assisted Laparoscopic Heminephrectomy

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1. INTRODUCTION

Ehrlich et al. *(1)* first reported the use of laparoscopic nephrectomy in children, and Jordon and Winslow *(2)* reported the first laparoscopic partial nephrectomy (LPN) in a 14-year-old girl with bilateral duplicated systems. Since these reports, there has been a boom in the utilization of laparoscopy in pediatric urology, where it has been aggressively pursued as an alternative to traditional open surgery given its association with decreased postoperative pain, length of stay, and improved cosmesis. The recent advent of robotic-assisted laparoscopic surgery (RALS) allows for most heminephrectomy to be performed without needing to fully mobilize the kidney, a distinct contrast to open surgery. This helps minimize trauma and vascular compromise to the remnant pole *(3–5)*.

RALS has been shown to offer the same benefits of traditional free-hand laparoscopy, but with the added benefit of 3-dimensional, high-magnification optics, and fully articulating instrument arms. These added benefits, despite the initial financial investment have been credited with greatly reducing the learning curve associated with various surgeries, which is critical when the primary goal for most indications of heminephrectomy is to prevent infections, incontinence, and protect functioning renal and ureteral tissue. However, there is a lack of a consensus regarding the best surgical approach (i.e., transperitoneal, retroperitoneal (prone), or retroperitoneal (lateral) for a given indication. The utility of ureteral stenting and surgical bed drainage (i.e., Jackson-Pratt or Penrose) also remains undefined.

From: *Current Clinical Urology: Pediatric Robotic Urology*
Edited by: J. S. Palmer, DOI 10.1007/978-1-60327-422-7_10

2. EMBRYOLOGY OF DUPLICATED URETERAL SYSTEM

In a duplicated ureter, an accessory ureteral bud develops from the mesonephric duct. If the two ureteral buds are widely separated on the mesonephric duct, the accessory bud develops proximally and inserts into the bladder with an ectopic orifice inferiorly. The crossing of the duplicated ureters and their insertion explain why the upper pole is frequently linked to an obstructed system, thus causing dysplasia during fetal development (Weigert-Meyer rule). Ureteral ectopia is at least twice as common in females as males *(6)*. While ectopia of one or both ureters is possible, ectopia of only the upper pole ureter is usually present because its late migration results in an abnormal insertion outside the bladder (i.e., urethra or vagina) *(7)*.

3. INDICATIONS FOR HEMINEPHRECTOMY

By far, the most common indication for heminephrectomy in children is a non-functioning dysplastic pole secondary to obstructive uropathy, ureterocele, reflux, and/or ectopic/duplex ureter *(8)*. Multicystic dysplastic kidneys (MCDK) that have not involuted may be candidates for robotic-assisted laparoscopic heminephrectomy (RALH). Indications for RALH for MCDK are increasing cyst size, cyst infection, or hypertension *(9)*. Lastly, segmental mesonephric blastemia would be a good candidate for RALH if it was possible to better to be discerned from nephroblastoma preoperatively.

While partial nephrectomy and heminephrectomy are most commonly performed in adults for malignancies, the most common malignancy in children, nephroblastoma is rarely a candidate for a minimally invasive surgical intervention owing to its large, bulky size, frequent invasion of perirenal tissue, and risk of rupture with subsequent seeding during dissection. In children, peripheral, well-circumscribed lesions with enhancement on contrast imaging may be considered for a laparoscopic intervention. The maximal size that is considered safe to be managed laparoscopically is approximately 4 cm in adults, but is yet to be defined in the pediatric population.

4. PREOPERATIVE EVALUATION

Patients may present with incontinence, flank pain, hematuria, recurrent urinary tract infection, vaginal discharge, change in bowel habits, or abdominal masses. A thorough preoperative evaluation includes a voiding cystourethrogram (VCUG), renal ultrasound, and MAG-3 diuretic renogram *(10)*. Occasionally, cystoscopy with retrograde pyeloureterogram, abdominal CT with intravenous contrast or intravenous pyelogram (IVP) are useful in further defining the anatomy and assessing for common urological findings associated with ectopia (i.e., ureterocele, ureteropelvic junction obstruction, renal ectopia, renal dysplasia, and reflux) *(6,7)*. In cases where a neoplasm is suspected, a metastatic work up consisting of a chest and abdominal CT scan with intravenous contrast should be performed. A bone scan is primarily only useful in cases of nephroblastemia. Given the possibility for hemorrhage if the renal vessels are injured a blood type and cross is performed. Figure 1 demonstrates the results of typical preoperative imaging.

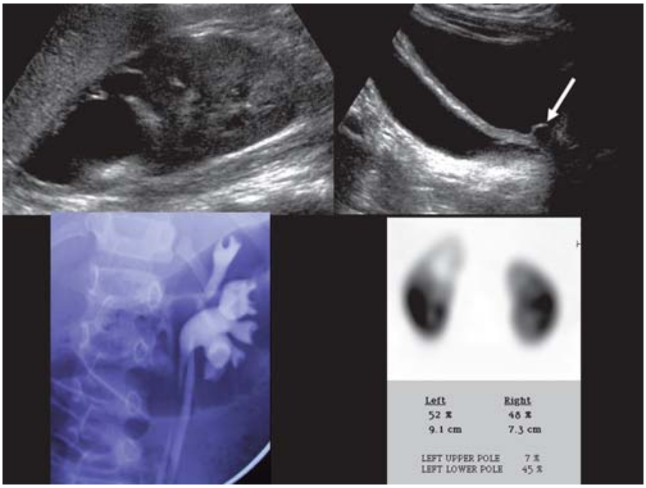

Fig. 1. Preoperative ultrasound, voiding cystourethrogram and nuclear medicine renogram demonstrating hydroureteronephrosis in a duplicated system with an ectopic ureter and mid-line ureterocele (*arrow*).

5. CONTRAINDICATIONS TO RALH

There are no specific contraindications for performing a RALH. Standard laparoscopic contraindications should be observed (i.e., hemodynamic instability, uncontrolled bleeding diathesis) *(11)*.

6. OPERATIVE CONSIDERATIONS

The night prior to surgery a mechanical bowel prep of polyethylene glycol and an enema is undertaken on either the inpatient or outpatient setting. Apply sequential compression devices to each calf for patients greater than 10 years of age. Subcutaneous anticoagulation is rarely indicated in patients without coagulopathy given the very brief period of postoperative bed rest.

Preoperatively, prophylactic a broad spectrum 3rd generation cephalosporin such as ceftriaxone is administered to cover skin flora and any specific urine organisms. Alternatively, clindamycin is also effective in those with penicillin or celphalosporin allergies. Robotic instruments and sutures typically needed are listed on Table 1.

Table 1
Typical Surgeon's Preference Card

Item	*Quantity*
Large gel rolls	2
Pillows	3
Instruments	
Minor pack	1
Prep pack	1
Foley 12 Fr	1
5 mm trocar	1
8 mm trocar	2
12 mm trocar	1
8 mm robotic microforcep	2
8 mm robotic Debakey forcep	1
8 mm robotic monopolar scissor	1
10 mm 30-degree robotic laparoscope	1
5 mm laparoscopic harmonic scalpel	1
10 mm laparoscopic specimen bag	1
Laparoscopic ultrasound (if neoplasm suspected)	1
Double-J stent (surgeon's preference)	1
Sutures	
2-0 Vicryl on UR-6 needle	3
5-0 Monocryl	2
Have available	
5 mm laparoscopic fan retractor	1
5 mm laparoscopic clip applier	1
Laparotomy kit	1
Dennis Brown retractor	1

Avoid nitrous-based inhalational anesthesia as this can cause bowel edema which can impact the size of the effective working field *(11)*. Children are more sensitive to the effects of carbon dioxide and the pressure of pneumoperitoneum or retropneumoperitoneum *(12)*, therefore recommended insufflation pressure is 10–12 mmHg *(13)*, lower than that is customarily used in adults. A transient modest decrease in intraoperative urine output is expected as a result of the pneumoperitoneum *(14)*. It is important not to increase the rate of intravenous fluid administration to overcome this as the minimization of insensible fluid losses in laparoscopy may result in fluid overload, especially in patients with cardiac comorbidities.

If the anatomy is uncertain, cystoscopy with retrograde ureterogram immediately prior to heminephrectomy can be both diagnostic and thera-

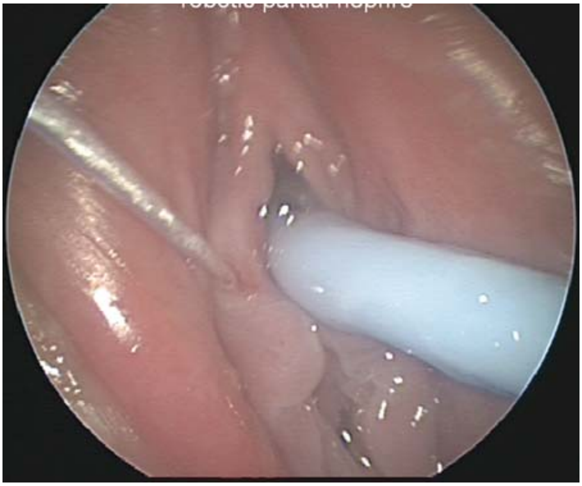

Fig. 2. Cystoscopy with stent placement into the normal ureter of a duplicated system with ectopia.

peutic (i.e., unroofing of an ureterocele). Some surgeons prefer to insert a Double-J ureteral stent into the normal ureter (Fig. 2) during cystoscopy to assist in identifying and protecting its vasculature during the laparoscopic excision of the duplicated ureter. Alternatively, a ureteral catheter can be placed in the normal ureter to inject methylene blue into the collecting system to identify inadvertent injury or confirm adequacy closure of an entered collecting system.

Occlusion of the main renal vessels is commonly performed during heminephrectomy in the adult population, since a relatively bloodless field greatly facilitates the proper identification and excision of a highly vascularized neoplasm, a far more common indication for surgery in this patient population. However, the most frequent indication of heminephrectomy in children involves operating on a poorly vascularized, non-functioning moiety; thus, clamping of the hilum is infrequently necessary.

When required, it is currently recommended that the renal vessels not be clamped for more than 30 minutes (warm ischemia) to maximize the recovery of renal function. Cooling the kidney to less than 20–25°C (cold ischemia) has been utilized to reduce cellular metabolism, allowing the surgeon 60–180 minutes of ischemic time while minimizing the risk of permanent tissue damage. In traditional open surgery, surgeons are readily able to cool the kidney by placing it on a bed of sterile saline slush. However, transferring this concept for cold ischemia to laparoscopic surgery has proven difficult.

Despite multiple published series on the methods to induce renal hypothermia, no system has proven to be either universally feasible or superior for use in laparoscopic partial nephrectomy. One proposed system is to use a laparoscopic specimen bag to completely cover the kidney and to deliver ice slurry via a laparoscopic port into the bag *(15)*. Unfortunately, the ice slush delivery mechanisms require extensive amounts of custom-built equipment or trocars larger than those traditionally used in pediatrics *(16–18)*. Another proposed method of cold ischemia is to directly administer cold saline into the renal artery *(19,20)*. However, this method is limited by the risk for whole body hypothermia, the need for interventional radiology's assistance in placing an intraarterial line, and the theoretical risk of damage to the renal artery (i.e., hematoma and thrombosis). More promising techniques of inducing renal hypothermia (<20°C) include (1) irrigating the kidney with cold saline using a standard laparoscopic irrigator/aspirator *(21)*; (2) infusing cold saline transureterally in a retrograde fashion *(22–24)*; and the use of medications such as inosine *(25)*, captopril *(26)*, and tetrodotoxin *(27)* to enhance renal protection from ischemia. Of note, none of these modalities has been used in the pediatric population.

Since the hypoplastic, parenchyma of the affected pole is poorly vascularized, simple electrocautery is often sufficient for obtaining hemostasis in most RALH cases. However, many surgeons prefer to use commercially available hemostatic devices such as an argon beam coagulator, ultrasound coagulator, fibrin glue, cellulose, or suture bolsters. It is the preference of the authors to use an ultrasound coagulator to facilitate a near bloodless dissection and excision of the affected renal moiety. It is critical to reduce the insufflation to less than 3 mmHg at the end of the surgery to evaluate for any low-pressure venous bleeding, which may have been masked by the pressure of insufflation.

7. PATIENT POSITIONING AND SURGICAL CART DOCKING

Trocar placement and robotic cart docking are two of the most important steps to enable the surgery to progress safely and efficiently. Ergonomic arrangements will make assistant port(s) readily assessable with minimal conflict with robotic instrument arms. Fine adjustments to positioning are usually more efficiently achieved by moving the bed rather than attempting to reposition the surgical cart. Extensive padding of all points of contact (i.e., knees and arms) is required to avoid nerve palsies and pressure ulcers, especially in young children who have little fat for protection. The patient must be secured to the table to prevent movement or injury when rotating the bed intraoperatively. Specific patient positioning and surgical cart docking is dependent on the operative approach: transperitoneal vs. retroperitoneal. Advantages and limitations of transperitoneal vs. retroperitoneal approach are listed on Table 2.

8. STEPS OF THE SURGERY

8.1. Transperitoneal Approach

1. The patient is placed on the operating table with the affected side up (Figs. 3 and 4), and all points of contact (i.e., knees and arms) are padded. Position

Table 2
Benefits and Limitations to Surgical Approaches

Approach	*Pros*	*Cons*
Transperitoneal	• Familiar anatomy • More working space, especially in young children • Can perform concurrent extravesical ureteral reimplantation or ureterocelectomy • Shortest distance to the kidney • Avoid pedicle	• Theoretical risk of postoperative intraperitoneal adhesions *(48,49)* • Often limited working space and unfamiliar layout of anatomy. • Risk of peritoneal tear and subsequent conversion to open surgery
Retroperitoneal (Lateral)	• Less risk of subjecting peritoneum to complications (i.e., urine leak, infection and seeding) • Less interference from surrounding organs (i.e., liver, spleen, bowel) • Greater working space and more access to distal ureter than prone retroperitoneal approach, but requires lateral retraction to expose hilum • Theoretical reduction in postoperative intraperitoneal adhesions and easy conversion to lumbodorsal approach	• The use of a balloon dilator to develop the retroperitoneal space carries a risk of balloon rupture which necessitates meticulous retrieval of fragments which is especially critical if a peritoneal tear is present

(Continued)

Table 2
(Continued)

Approach	*Pros*	*Cons*
Retroperitoneal (Prone)	• Shortest distance to the kidney • Avoid pedicle • Less risk of subjecting peritoneum to complications (i.e., urine leak, infection and seeding) • Less interference from surrounding organs (i.e., liver, spleen, bowel) • Kidney falls anteriorly with gravity, exposing the hilar vessels without retraction • Ureter and pelvis posterior for easier dissection. • Theoretical reduction in postoperative intraperitoneal adhesions and easy conversion to lumbodorsal approach	• Often limited working space and unfamiliar layout of anatomy • Inability to perform total ureterectomy without adjunct inguinal incision *(50)* • Risk of peritoneal tear and subsequent conversion to open surgery. The use of a balloon dilator to develop the retroperitoneal space carries a risk of balloon rupture which necessitates meticulous retrieval of fragments which is especially critical if a peritoneal tear is present

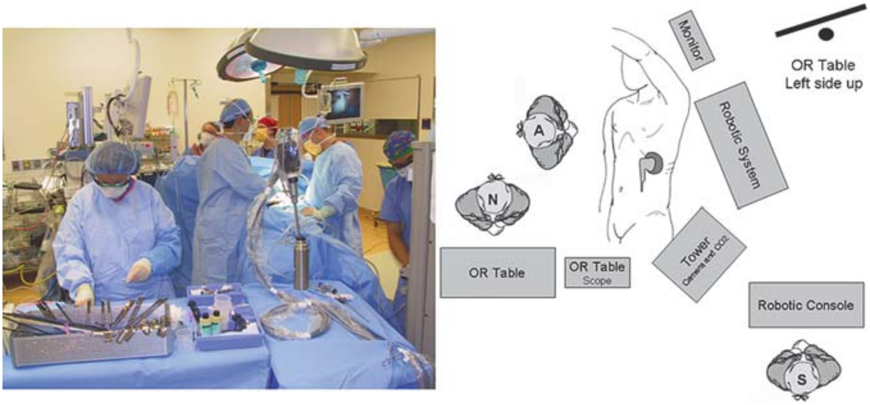

Fig. 3. Operating room set up.

Fig. 4. Patient positioning for a left transperitoneal heminephrectomy. Note the abundant padding for pressure points.

the patient on the edge of the table to provide amble room for the articulation of the camera arm over the side of the bed. This maneuver is essential in allowing for a full view of the abdomen. A combination of a roll under the nape of the back and rotation ("airplane") of the bed will put the patient approximately 45-degree angle off the table. Not enough angulation will prevent the bowel from sufficiently falling away from the kidney and hilum. Whereas too much rotation will cause the kidney to fall down upon the hilum, both obstructing the hilum and creating a difficult angle of approach for instruments.

2. Trocars are placed under direct visualization as indicated in Fig. 5. In most patients an angle of 120–150 degrees between the trocars facilitates a balance between being able to perform a distal ureterectomy, while still retaining the ability to excise the upper pole moiety.
3. To dock the surgical cart, the surgical cart arms and instruments are positioned so as to mimic a patient in lithotomy position (Fig. 6). This helps minimize interference between arms. Place Debakey forceps in the left

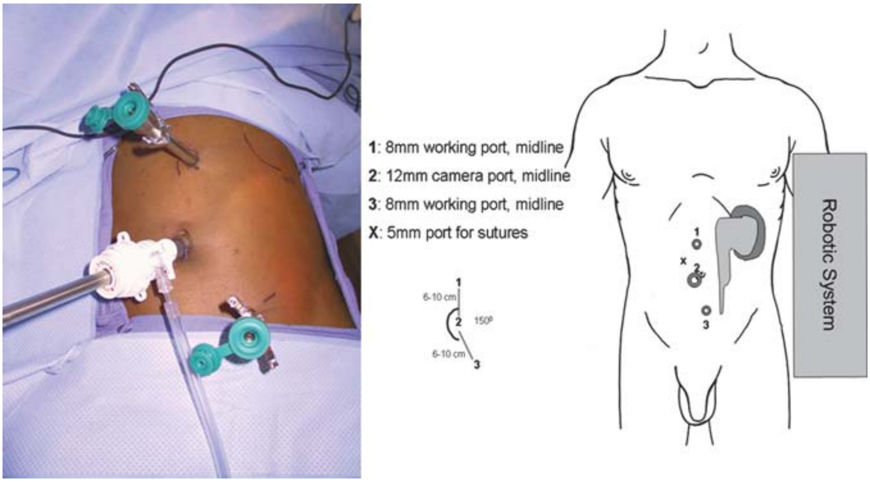

Fig. 5. Port placement for a left heminephrectomy.

Fig. 6. Docking of the robotic cart. Note the space between the surgical arms.

arm/hand (yellow) and monopolar scissors in the right arm/hand (green). Notice, the amble room available for camera movement as a result of positioning the patient close to the edge of the table.

4. Mobilize colon along white line of Toldt (Fig. 7).
5. Identify the kidney which is facilitated by the usually hydronephrotic affected pole (Fig. 8).
6. As a means to reduce postoperative pain and the need for postoperative narcotics, it is the authors' preference to aerosolize bupivacaine intraperitoneally prior to incising the perirenal fascia (Fig. 9) *(28)*.
7. Open the perirenal fascia to expose the kidney, ureters, and hilum (Fig. 10).

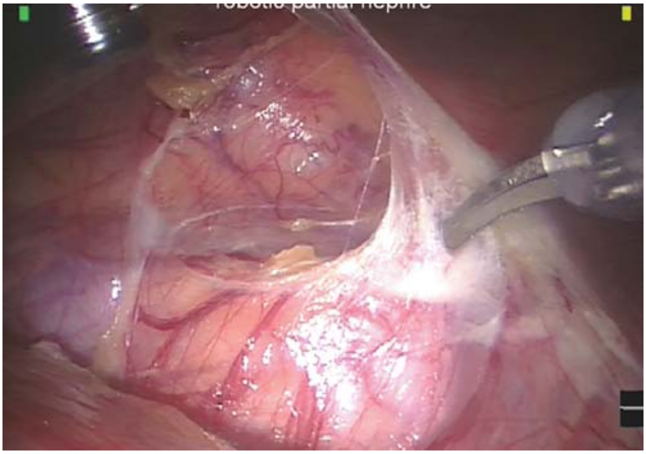

Fig. 7. Mobilization of the colon.

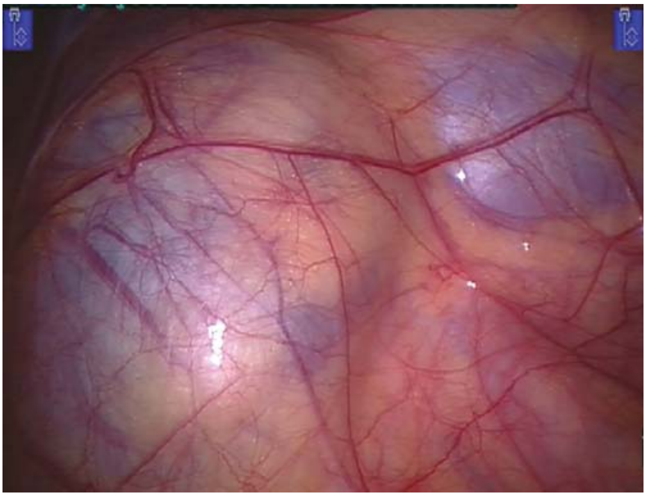

Fig. 8. Identification of the affected pole is facilitated by its dilatation.

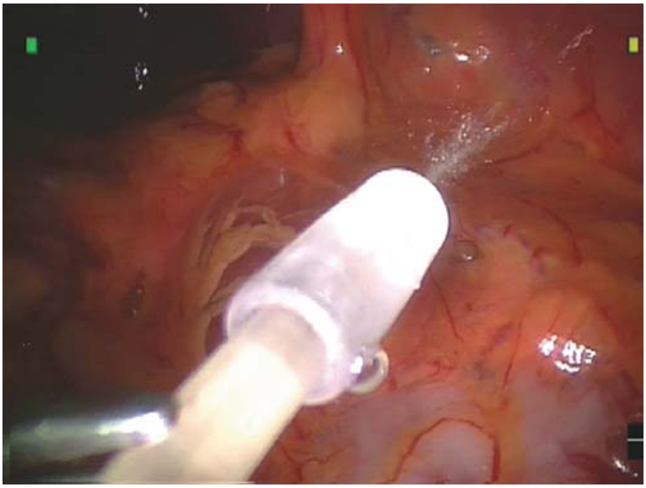

Fig. 9. Intraperitoneal aerosolization of bupivacaine.

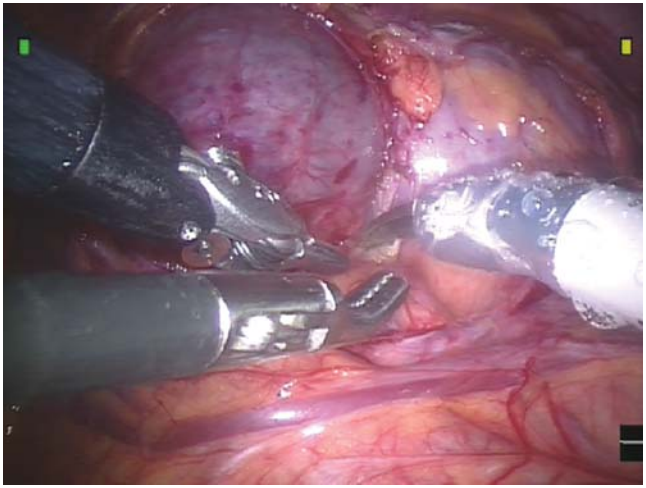

Fig. 10. Exposing the renal hilum.

8. Identify both ureters and trace the larger one to the upper pole (Fig. 11). Delay decompressing hydronephrotic pole until as late as possible to facilitate identification and dissection.
9. Mobilize the affected ureter distally while protecting normal ureter and its vasculature (Fig. 12). If possible, remove as much ureter as possible to prevent infection in the stump, which may require a subsequent surgery. However, it is reasonable to leave a small ureteral stump if no reflux is detected on the preoperative VCUG. In cases with an ureterocele/ectopic ureter the stump is left open.

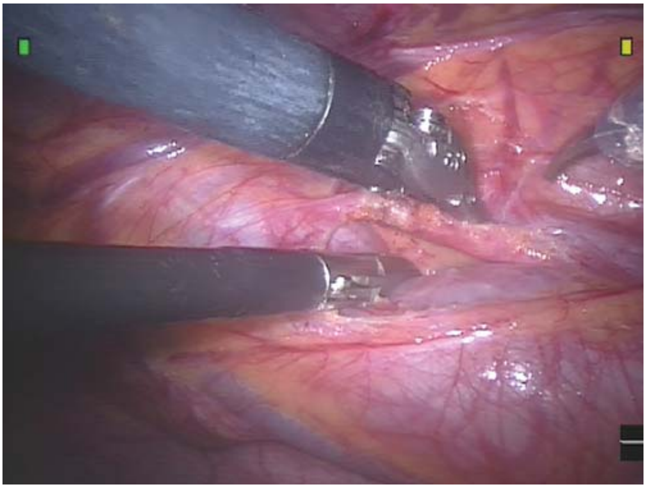

Fig. 11. Identification of the ureters.

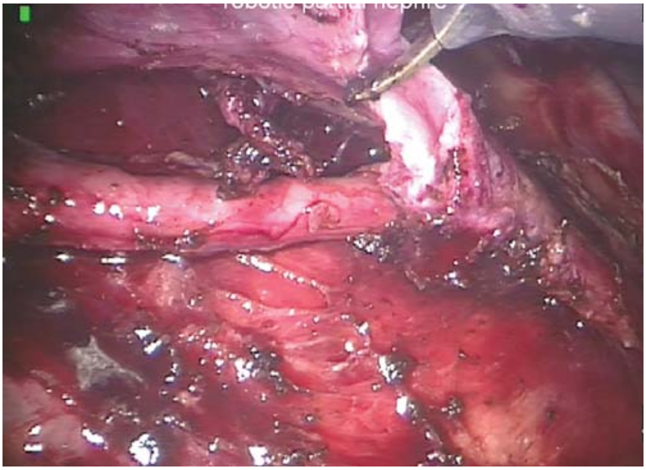

Fig. 12. Isolation of the ureter from the vasculature.

10. Use ureter to manipulate kidney for mobilization (Fig. 13). Be careful when reflecting upward as you may avulse small feeding branches to the kidney.
11. Identify and dissect the vasculature to the affected pole (Fig. 14). If the anatomy of the vasculature is not obvious, temporarily occluding the vessel will cause parenchymal blanching in the dependent tissue. It is rarely necessary to occlude the main vessels, but if needed administer mannitol intravenously 10 minutes prior to clamping. Renal ischemia and methods of achieving cold ischemia are previously discussed. Dissection of the lower pole is similar to that of the upper pole, but the vascular supply must be

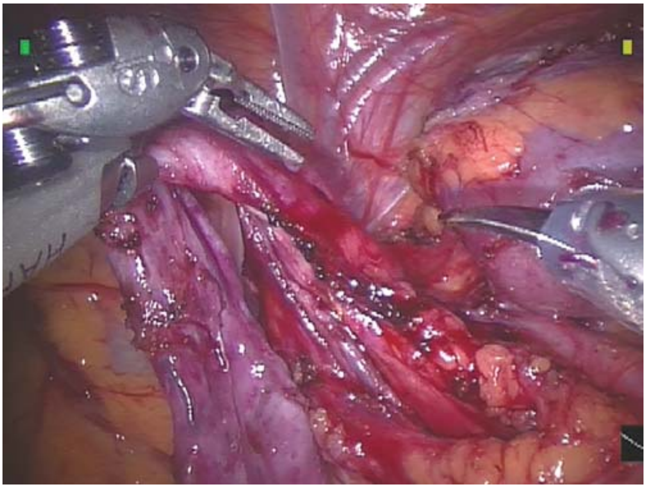

Fig. 13. Mobilization and dissection of the affected ureter.

Fig. 14. Identification of the vasculature.

definitively identified and protected as the upper pole vasculature usually branches from the main vessel to the upper pole.

12. Excise the affected pole along the concave plane (Fig. 15). Avoid entering the normal pole collecting system. If entered, close with 4-0 absorbable suture. Note the deep grove between the dysplastic and normal pole and the difference in thickness and color of the parenchyma.
13. Close the capsule over the exposed parenchyma with running 4-0 absorbable suture (Fig. 16). Place a mattress 3-0 suture over either a fat or gel foam bolster.
14. Because the unaffected pole is not mobilized, a nephropexy to avoid torsion to the remaining segment is not required.
15. Unlike the retroperitoneal approach the absorptive property of the peritoneum removes the need for a surgical bed drain. A ureteral catheter is left in the normal ureter and a Foley catheter is left to gravity.

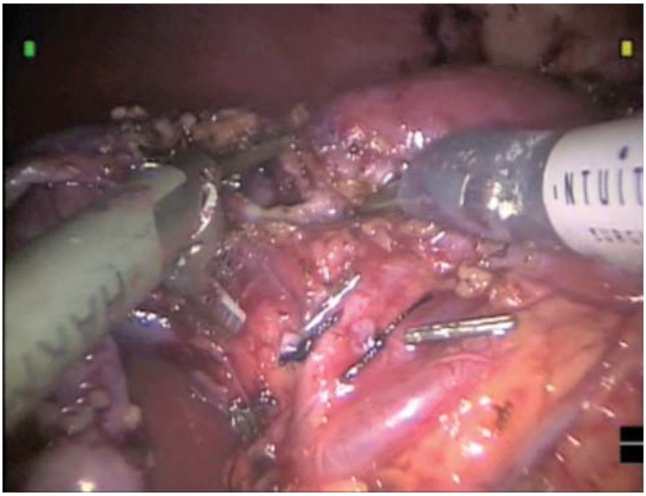

Fig. 15. Excising the affected pole.

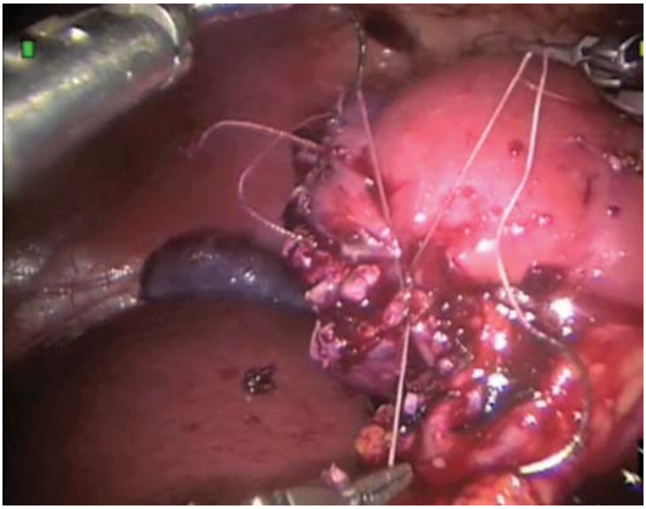

Fig. 16. Closure of the renal capsule.

8.2. Retroperitoneal-Lateral Approach

1. The patient is positioned on the operating table laterally with sufficient flexion to facilitate trocar placement between the last rib and iliac crest (Fig. 17). The authors prefer to use gel padding in young children and the kidney rest in young adults.
2. An open Hassen trocar is inserted 3 cm below the 12th rib. Gerota's is approached with a muscle splitting technique via blunt dissection along the lumbodorsal fascia. Anchoring this trocar with a purse string suture to

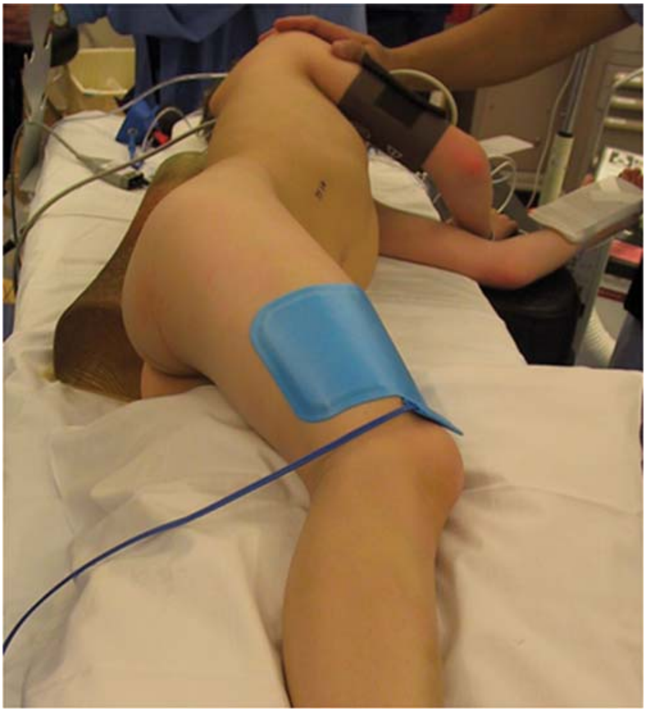

Fig. 17. Patient positioning for a retroperitoneal approach.

the fascia allows the trocar to be retracted, increasing the working space as needed. One must be careful to guide the dissection along the posterior wall to avoid violation of the peritoneum.

Fig. 18. Identification of the affected pole.

3. Identify the kidney which is facilitated by the usually hydronephrotic affected pole (Fig. 18).
4. A working space is developed with either gas insufflation, balloon dilator, or bluntly with a finger (Fig. 19) *(29)*. Maximizing and demarking the psoas muscle the working space prior to inserting the trocars is critical to assist in avoiding peritoneal tears, necessitating a conversion to a transperitoneal or open approach *(30,31)*.

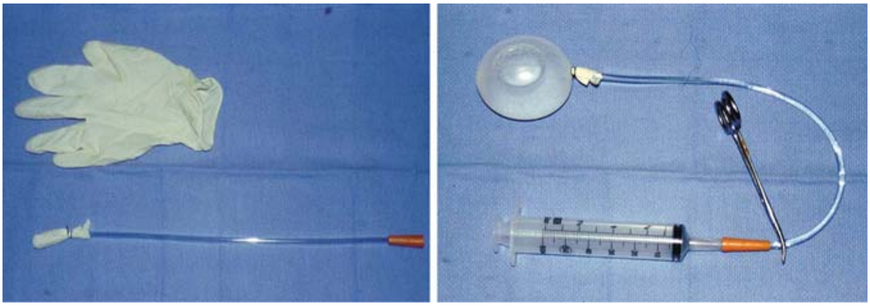

Fig. 19. Development of a retroperitoneal working space.

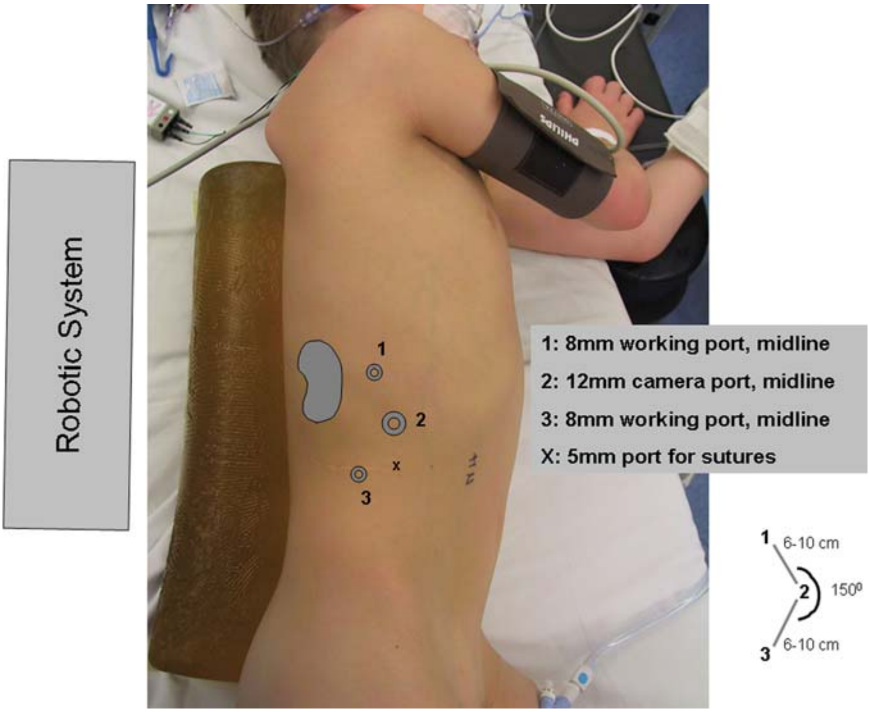

Fig. 20. Trocar placement for a left lateral retroperitoneal approach.

5. After the working space is developed a second trocar of 8 mm is inserted posteriorly in the costoverberal angle. The third trocar, the second 8 mm, is inserted along the anterior axillary line 10 mm superior to the iliac crest (Fig. 20).
6. The dilated, affected pole and ureter are identified and isolated along with the supplying vasculature (Fig. 21).

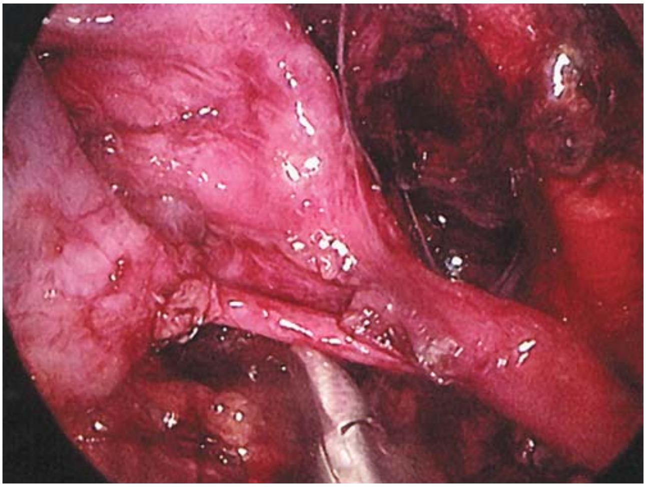

Fig. 21. Identification of the affected pole.

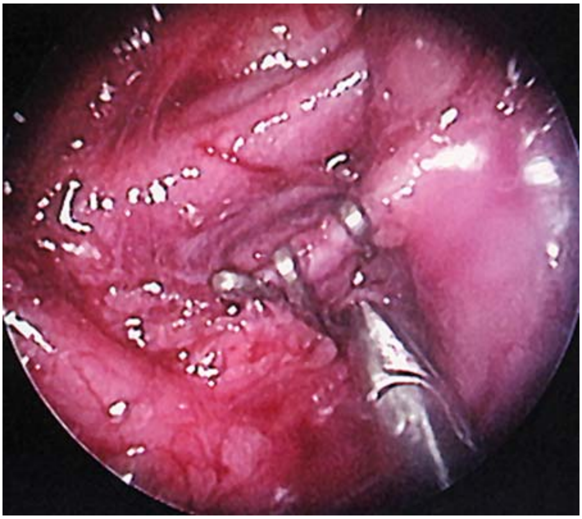

Fig. 22. Identification of the hilar vessels.

7. Identify renal pedicle and ligate the vessels supplying the affected pole (Fig. 22).
8. The distal ureter is transected and used to help manipulate the kidney (Fig. 23).

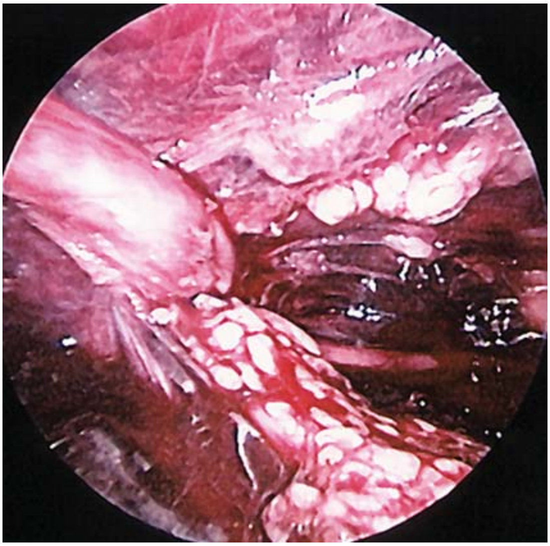

Fig. 23. Dissection of distal ureter.

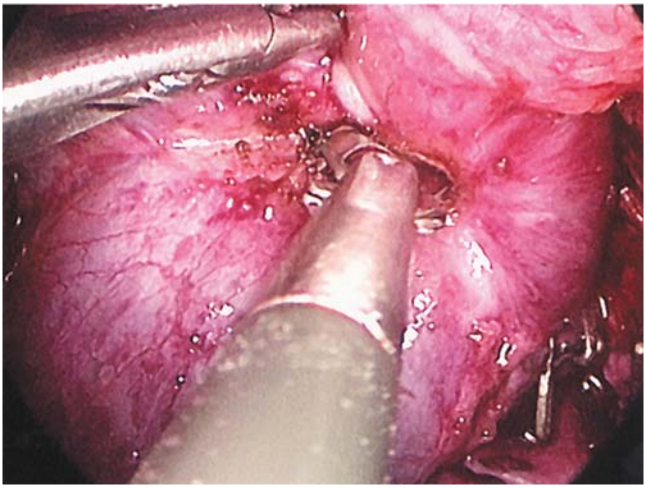

Fig. 24. Excision of the affected pole.

9. The affected pole is excised along a relatively avascular plain (Fig. 24). Great care must be taken to avoid entry into the collecting system of the normal pole.
10. The normal remaining kidney is checked for leaks and closed over bolsters (Fig. 25).
11. The authors recommend placing a penrose drain in the surgical bed due to the limited fluid absorptive ability of the retroperitoneum as compared to the transperitoneal approach. A Foley catheter is left to gravity drainage.

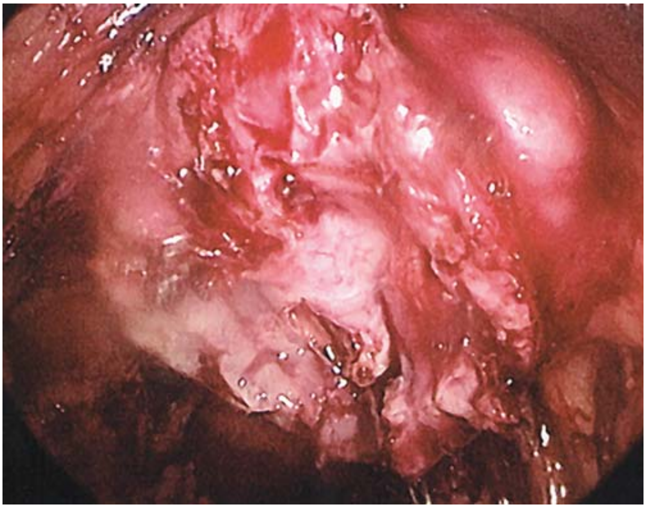

Fig. 25. Remaining normal pole prior to capsule closure.

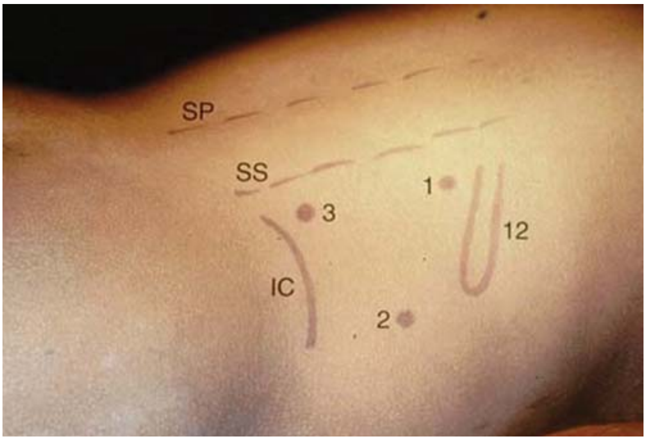

Fig. 26. Trocar placement for a left prone retroperitoneal heminephrectomy.

8.3. Retroperitoneal–Prone Approach

1. The patient is placed in the prone position with careful attention taken to pad all contact areas and protect the endotracheal tube.
2. The first trocar is inserted at the costovertebral angle at the edge of the paraspinous muscles (SS) and the 12th rib. The second trocar is placed laterally along the posterior clavicular line, also just above the iliac crest (IC). The third trocar is placed medially to the paraspinous muscles (SS), just above the iliac crest (Fig. 26).
3. The steps of dissection, development of a working space, identification and excision of the affected pole are the same as the lateral retroperitoneal approach.

9. COMPLICATIONS

There are few complications specific to performing a robotic-assisted laparoscopic heminephrectomy. One such complication is the failure of the robotic system (i.e., non-overridable fault) which necessitates either conversion to free hand laparoscopy or open surgery. Additionally, the undetected entry into the collecting system, damage to the normal parenchyma or ureter is possible. As with all intraperitoneal laparoscopic surgeries there is a risk, albeit low, of serious complications such as bowel perforation, trocar and Veress needle trauma to major blood vessels, spleen injury (left-side surgery), and liver laceration (right-side surgery). Pneumothorax secondary to diaphragmatic injury or transient bursts in pneumoperitoneum pressures using argon beam coagulation have been reported *(32)*. While rare, spleen injury (left-sided surgery) and liver laceration (right-sided surgery) are also possible.

10. POSTOPERATIVE MONITORING AND FOLLOW-UP

Immediate postoperative analgesia is achieved with ketorolac every 8 hours and morphine as needed. Codeine or equivalent per mouth is sufficient for most patients by postoperative day 1. A complete blood count (CBC) is obtained either intraoperatively or in the PACU. A follow-up CBC is obtained the morning after surgery. Typically, patients are started on a clear diet within 4 hours postoperative and advanced as tolerated to an appropriate "full" diet on the morning of postoperative day one. The Foley catheter is removed in the morning of postoperative day 1, unless otherwise indicated. Once patients are tolerating a diet, afebrile with no signs of wound infection, and able to void, they are deemed safe for discharge home. Of note, the authors do not require a return of bowel function as indicated by a bowel movement prior to discharge. Patients are discharged with antibiotics only if a vesicoureteral reflux is present or a catheter was left. Unless otherwise indicated, an ultrasound is performed at a month postoperatively

Table 3
Summary of Published Literature for Transperitoneal Approach

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
Castellan et al. *(34)*	Retroperiteonal (16) v. Transperitoneal (32) Upper/lower-pole heminephrectomy	TP: Ureterocele (16), Ectopic ureter (13), VUR (3). RP: Ureterocele (6), Ectopic ureter (8), VUR (1), Caliceal diverticulum (1)	48	RP: 3 months–17 years (Mean 6.1 years); TP 45 days–17 years (Mean 2.8 years)	RP: 90–180 minutes (Mean 133); TP: 80–170 minutes (Mean 125)	TP: 0.5-5 days (Mean 2.6); RP: 1–6 days (Mean 2.3) *5 patients undergoing concomitant surgeries	TP: 8 month old with pneumothorax secondary to diaphragm perforation requiring chest tube(1), 6 month old with postoperative HTN requiring medication likely due to small vessel injury(1), 11 month old requiring an excision of ureteral stump due to recurrent UTIs. RP: Peritoneal tear with conversion to transperitoneal approach (1), Conversion to open due to scarring and anterior pole vessels (1). 16 year old with urine leak(1), 12 month old with urinoma(1)	0.75–7.25 years (mean 3.5 years)	80% of complications in children <1 year. TP associated with increased difficulty identifying polar vessels, but RP avoids need for dissection of the main renal vessels. TP best approach when total ureterectomy required or patient <1 year.

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Table 3 (Continued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
Jordan Winslow *(2)*	Transperitoneal Upper-pole heminephroureterectomy (1)	Recurrent UTIs and incontinence with severe hydronephrosis and orthotopic ureterocele	1	14 years	Not Reported	POD #2	None.	6 months – "Both sides to be normal. No further incontinence or urinary tract infection"	
Janetschek et al. *(4)*	Transperitoneal Upper (9*)/Lower (5)-pole heminephrectomy. *(2) with concomitant ureterocelectomy and URI	Ectopic refluxing mega ureter (5), ectopic obstructed megaureter (2), reflux nephropathy (5), Obstructing ureterocele with non-functioning upper-pole (2)	14	5.4 years (0.6–14)	222 minutes (180–330) in group with no concomitant surgery	4.4 days (3–6) in group with no concomitant surgery	None	Not Reported	

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Table 3 (Continued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
Prabhakaran *(45)*	Transperitoneal Heminephroureterectomy	Duplex System with dysplastic upper pole moiety and VUR (1), Duplex kidney with dysplastic lower pole moiety and VUR (1)	2 of 6 (Combined series with nephroureterectomy)	3 months, 20 months (Mean 11.5 months)	20 months—225 minutes; 3 months—265 minutes	20 months—Not Specifically Reported, 3 months—7 days	Bleeding requiring transfusion(1)	Not Reported	Recommended the use of stay sutures "to elevate the abdominal wall, increase the anterior-posterior distance, and thus prevent intraperitoneal injury during trocar insertion."
Yao and Poppas *(47)*	Transperitoneal Upper (5)/Lower (1)-pole Heminephroureterectomy. Lower pole with concurrent open ipsilateral URI	Utereocele (2), ectopic ureter (1), reflux (1), non-fuctioning moiety with hydroureteronephrosis (2)	6 of 26 (Combined series with nephrectomy and nephroureterectomy)	1.6 years	200 minutes (90–315)	1 day (0.4-5*). *Concomitant open URI with ileus.	None	Not specifically reported	

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Table 3 (Continued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
Horowitz et al. *(3)*	Transperitoneal Upper-pole nephroureterectomy	12 ectopic ureters (1 bilateral, 2 with reflux), 2 ureteroceles	13	0.4-14 years (Mean 3.8 years)	70–135 minutes (Mean 100); 125 min for simultaneous bilateral LPN	2–4 days (Mean 2.4). Delays in hospitalization: fever (4), Not tolerating diet (1), Low HCT not requiring transfusion (1)	Decreased hematocrit (etiology not reported)(1)	"All reported overall satisfaction with medical and cosmetic results" via phone follow up	
Pedraza et al. *(43)*	Transperitoneal Bilateral Upper-pole Heminephroureterectomy (1)	Duplicated system with ectopic ureters (1)	1	4 years	440 minutes	2 day	None	Not Reported	
Mulholland et al. *(42)*	Transperitoneal Upper-pole heminephroureterectomy	Duplicated system with ectopia (1), Nonfunctioning upper pole with ureterocele (1)	2 of 17 (Combined series with nephroureterectomy)	3 months and 16 months	229, 165 (Mean 197)	<23 hours (Mean <23 hours)	Pneumothorax from diaphragmatic injury with intraoperative laparoscopic repair (1)	2 weeks	

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Table 3 (Continued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
Sydorak Shaul *(46)*	Transperitoneal Upper-pole nephroureterectomy	Duplex System with ureterocele (5), severe reflux (1), ectopic ureter (1)	7	5–15 months (Mean 10 months)	Mean 179 (including cystoscopy)	1-5 days (Mean 2.4 days)	"several years later"—Ureteral stump excision for treatment of recurrent stump infections. Incisional hernia (1) requiring repair. Conversion to transperitoneal due to lack of space (1)	4-51 months	"The retroperitoneal space may be too small a space to properly visualize the hilum and distal ureter in [infants]."
Piaggio et al. *(44)*	Transperitoneal Upper (11)/Lower (3) -pole heminephrectomy	Ectopic ureter (7), Ureterocele (3), VUR (3), UPJO (1)	14 of 34 (Combined series with LPN v. Open PN)	0.5 Years (0.34–13.3)	81–349 minutes (Mean 180); Last 7 LPN (Mean is 138)	2 days (1–6)	Omental hernia (1), Urinoma (1)	Not Reported	Not toradol since 2001 surgeon preference change. No benefit for RP v. TP. Preference for TP due to more working space and ability to completely excise ureter. Stressed the importance of learning curve upon operative time.

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Table 3 (Continued)

Author	Procedure	Urologic Findings	Patients	Mean Age (range)	Mean Operative Time (range)	Length of Hospitalization	Complications	Follow Up	Author's Comments
Breda et al. *(41)*	Transperitoneal Heminephroureterectomy	Upper-pole obstruction of duplicated system (3)	3	12, 13, 14 months (Mean 13 months)	120-160 (Mean 138 minutes)	1–4 days (Mean 2 days)	Postoperative UTI requiring IV antibiotics (1)	2 weeks	3 mm instruments may minimize approach-related trauma, improve cosmesis and recovery without increase in difficulty.
Chertin et al. (2007) *(40)*	Transperitoneal Upper-pole (5), Lower-pole (5) Hem-inephroureterectomy with concomitant STING (1)	Non-functioning moiety of a duplex kidney with ectopic ureter (4), ureterocele (1), VUR (5)	10 of 20 (Combined series with LPN v. Open PN)	3.6 years ± 1.3	Not Reported	2.7 ± 0.29 days	Conversion to open (1) due to injury to unaffected ureter	28 months (6–81 months)	Safe and recommended even for children <2 years of age
Miranda et al. (2007) *(51)*	Transperitoneal Upper-pole nephroureterectomy	Unilateral Duplex System(5) with ureterocele (1) ; Bilateral Duplex System with VUR (1) (Staged Surgery)	6	5–20 months (Mean 9.5)	120–160 min (Mean 135 min)	5–48 h; 2–24 h	None	Mean 18 months. DMSA showed stable or improved function in all infants.	Use retroperitoneal for >2 years for total nephrectomy

Table 4
Summary of Published Literature on Retroperitoneal Approach

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospitalization*	*Complications*	*Follow Up*	*Author's Comments*
El-Ghoneimi et al. *(38)*	Retroperitoneal upper-pole heminephroureterectomy (6) and ureteral reimplantation (2)	VUR (2)	8	1.2 years (mean 0.2 –3.7)	153 minutes (90–210)	3.4 days (2–5)	Conversion to open due to inability to identify polar vessels (3) also revealing duodenal tear (1/3), Renal vein injury requiring nephrectomy (1), peritoneal tear not requiring conversion to open (4)	Not Reported	
Borzi *(36)*	Randomized posterior RP (12) v. lateral RP (7) partial nephrectomy ± ureterectomy	Not Specifically Reported	19	pRP: 4.9 years (0.5–7); LRP: 5.2 years (0.5–12)	pRP: 75 minutes (55–135); LRP 85 (60–140)	Not reported	pRPA: UTI(2); LPRA: Renal vein tributary injury ->conversion to open (2), peritoneal tear which did not halt surgery (2)	pRPA with UTI likely secondary reflux into ureteral stump unable to fully excise with pRPA approach (2)	pRP less complete of a ureter excision in older kids as compared to LRP. Thus, >5 yoa preference for LRPA. pRPA "marginally safer", but treatment of choice for polar heminephrectomy due to excellent vascular control.

(Continued)

Table 4 (Continued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospital-ization*	*Complications*	*Follow Up*	*Author's Comments*
El-Ghoneimi et al. *(37)*	Retroperitoneal upper (13)/lower (2)-pole hem-inephroureterec-tomy	Ureterocele (8), Ectopic ureter (4), VUR (2)	15	Median 5.1 years (0.4–17.6)	152 minutes (75–240)	1.4 days (1–3)	Conversion to open due to peritoneal tear(1). Urinoma managed con-servatively(1)	3 months - all patients with "no abnormali-ties in the remaining renal moiety"	"The lower pole is more technically demanding. . .identifying the polar vessels requires a full dissection of the pedicle and the line of demarcation is less evident that that for an upper pole. . ."
Lee et al. *(39)*	Retroperitoneal-prone (11)/Flank (3) upper (8)/lower (6)-pole heminephrectomy	Ectopic ureter (5), Ureterocele (2), VUR (6), UPJO (1)	14	1.9 years (0.2–6.6)	194 minutes (116–325) Excluding cystoscopy and concomitant surgery.	1.2 days if no con-comitant surgery	Urinoma managed conserva-tively(1)	26 months. Ipsilateral renal growth by sonography in all patients	"The lower pole nephrectomy was considered to be more technically demanding because of the more extensive dissection required." For patients less than 2 years of age (9) operative time, narcotic usage, LOS was similar and without complications.

(Continued)

Table 4 (Coninued)

Author	*Procedure*	*Urologic Findings*	*Patients*	*Mean Age (range)*	*Mean Operative Time (range)*	*Length of Hospital-ization*	*Complications*	*Follow Up*	*Author's Comments*
Wallis *(35)*	Retroperitoneal upper (18)/lower (5)-pole hem-inephrectomy	Ureterocele (10), Ectopic ureter (7), VUR (5), Bilateral VUR (1) with staged surgeries	22	4.6 years (0.3–18)	174 minutes (105–300). Last 13 procedures 156 minutes (105–216). Excluding cystoscopy.	2.2 days (1–5)	Conversion to open due to peritoneal tear and inability to develop adequate working space (3). Not considered complications by the authors and were excluded from analysis. Transient urine leak (3), seroma requiring aspiration (1), and fever (1)	33 months (range 3-56). Functional loss of residual moiety in two patients less than 1 year of age: POD #3 normotensive and clinically asymptomatic (1), 3 months postoperative requiring nephrectomy to alleviate HTN(1)	"…the retroperitoneal approach [is] preferable for heminephrectomy because it more closely resembles the approach used in open surgery…RPA may place the residual unit at high risk for ischemia in infants." "An argument could be made for TPA being more appropriate in small children because it affords a greater working space and potentially decreases the risk of damage to the residual moiety…decreases the amount of manipulation required." "We have elected to perform open heminephrectomy in children younger than 12 months."

to assess renal growth, proper drainage of the remnant pole, and degree hydroureteronephrosis. If VUR was demonstrated preoperatively, a VCUG is also performed at 3–6 months. If no reflux is observed antibiotics are discontinued.

11. REVIEW OF THE LITERATURE*

A summary of the current published literature on the transperitoneal and retroperitoneal laparoscopic heminephrectomy is provided on Table 3 and Table 4, respectively.

Trocars: Regardless of approach (TPA or RPA), the majority of case series recommended a 10 mm camera port and two –5 mm, instrument ports with an additional 5 mm port, as needed for liver retraction. These port placements were recommended in the context of free-hand laparoscopy, some the surgeons find these trocar sizes and quantity to be sufficient for RALH, but we find the motion of the 8 mm robotic instruments to be smoother than that of the 5 mm instruments, thus justifying the negligible increase in trocar size. The size of the robotic camera necessitates a 12 mm trocar, as compared to the 10 mm (or smaller) camera used in free-hand laparoscopy.

Hemostasis: There is a significant variation in the preferred method of maintaining hemostasis from electrocautery only to the combined use of argon bean and ultrasonic coagulation in conjunction with cellulose. We feel that the majority of the case, including the excision of the poorly vascularized affected pole can be performed with electrocautery alone, but the use of ultrasonic coagulation provides excellent hemostasis while excising the affected pole. While there is an additional cost associated with using this equipment, we feel that the improved visualization from the hemostasis achieved and the efficiency of the ultrasonic coagulation excision reduces operative times, thus minimizing the cost associated with its utilization. Additionally, the use of fibrin glue as part of the closing bolster helps prevent leaks which would potentially extend the length of hospitalization postoperatively.

Ureteral stenting: Only one series (El-Ghoneimi et al. *(38)*) utilizing a retroperitoneal approach specifically commented on the use of a ureteral stent. In that study, El-Ghoneimi et al. placed a ureteral stent to identify the normal ureter. Conversely, among the transperitoneal approach series most authors did place a ureteral stent to facilitate the identification and thus protection of the unaffected ureter. However, multiple series felt that the grossly dilated affected ureter found in most patients sufficiently enabled proper identification, negating the need for stenting once a higher level of surgeon comfort with the surgery and anatomy was obtained.

*There is only one report of RALH in the English literature (Pedraza et al. *(43)*). All other data are from publications on free-hand laparoscopy.

Surgical bed drains: There was no consensus in the published literature. In our institution's experience the ability for the peritoneum to absorb fluid accumulation makes the placement of a surgical bed drain unnecessary in the transperitoneal approach. Conversely, due to the minimal absorptive abilities of the retroperitoneum, we routinely place either a penrose or bulb-suction drain during retroperitoneal approaches.

Postoperative narcotic utilization: Lee et al. *(39)* reported a mean postoperative morphine utilization of 0.4 mg/kg (0.1–2.5). Three patients required no postoperative narcotics and three had an epidural placed intraoperatively per surgeon preference in their series of 14 patients undergoing a laparoscopic retroperitoneal heminephrectomy. In the transperitoneal group, Chertin et al. *(40)* reported a mean narcotic requirement of 0.56 ± 0.29 mg/kg. Additionally, multiple authors advocated the use of ketorolac postoperatively. There were no reports of postoperative bleeding attributed to the use of ketorolac.

Return to eating/activity: In most transperitoneal series children were started on at least a clear diet within 6 hours postoperatively. No data were reported in the retroperitoneal literature.

12. COST ANALYSIS

There are no specific data specifically assessing the financial aspects of robotic-assisted laparoscopic surgery. However, Robinson et al. reported a mean charge of $6,123 for free-hand laparoscopic heminephrectomy as compared to $4,244 for that of the open surgery cohort *(5)*. Of note, the mean operative time in the laparoscopic group was significantly higher than that of the open (200.4 v. 113.5 min, $p < 0.005$). There was not a significant difference in the length of hospitalizations between the groups. While not specifically reported in the literature, the decreased operative times and learning curves associated with RALH as compared to free-hand laparoscopy will likely offset a portion of the cost associated with acquiring and utilizing the robotic system.

13. FUTURE DEVELOPMENTS/TOOLS/TECHNIQUE VARIATIONS

Intraoperative fluorescence imaging is an evolving, new technology which can help identify blood vessels, tissue perfusion, and urine flow in real-time (Fig. 27). This technology may be especially useful when assessing the often aberrant vasculature of the lower pole. Intraoperative imaging also has the potential to assist in protecting the normal pole and ureter, by early identification and minimization of tissue trauma.

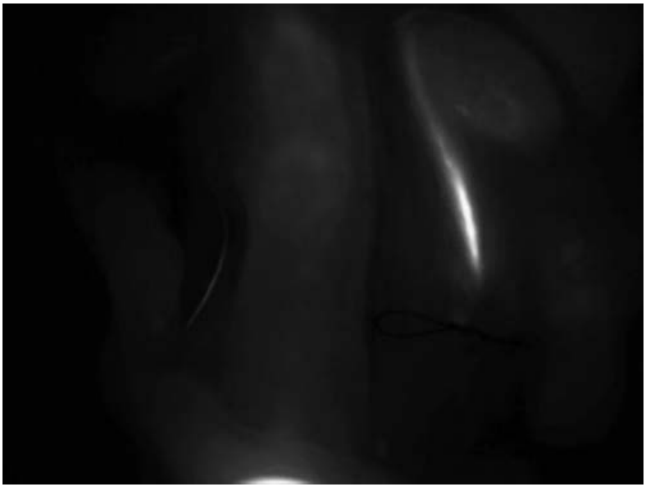

Fig. 27. Fluorescent imaging of a surgically induced left proximal ureteral obstruction in a mouse model. Note the normal peristaltic urine flow in the distal ureter of the right kidney.

14. CONCLUSIONS

Robotic-assisted laparoscopic heminephrectomy is superior to traditional open surgery in regard to cosmesis, postoperative length of hospitalization, and narcotic utilization. In comparison to free-hand laparoscopy, RALH offers the additional benefits of 3-dimensional, high-magnification optics, six degrees of instrument articulation, and a shorter learning curve.

While there are limited data directly assessing robotic-assisted laparoscopic heminephrectomy, the data for free-hand laparoscopy strongly supports a minimally invasive approach to heminephrectomy with or without ureterectomy. We feel that the added benefits of a robotic-assisted approach will further improve safety and the learning curve needed to achieve desired postoperative outcomes. RALH is safe even in the very young (2 months of age) *(33)*. While most authors recommend a transperitoneal approach in children less than 1–2 years of age due to the extra working space as compared to a retroperitoneal approach, there is no consensus on the age at which the working space afforded by a retroperitoneal approach is inferior to a transperitoneal approach *(34,35)*. The inability to reliably perform a distal ureterectomy in the prone RPA has limited its role in RALH as compared to a lateral RPA. As with many other surgical techniques for which there is not a definitive recommendation, the best approach is that which the surgeon feels most comfortable.

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