Chapter 9
Nephrectomy: Minimally Invasive Surgery

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Introduction

For decades pediatric urologists have been performing laparoscopy for non-palpable testis. The passage from diagnostic to therapeutic indications has been a long and hesitating course for pediatric urologists. During the 1990s minimally invasive renal surgery was limited to ablative indications and used only in a limited number of centers, with the first laparoscopic pediatric nephrectomy performed in 1992. In the early experience, the indications for laparoscopy in pediatric urology were unclear and unproven compared to the advantages of open procedures. It is only in the last several years that minimally invasive surgery has taken a foothold in practice and research in pediatric urology. Since that time, laparoscopic and robotic approaches to pediatric nephrectomy have become an essential part of the pediatric urologist's armamentarium.

This chapter will address first the established technique of laparoscopic nephrectomy and second the development of robotic-assisted laparoscopic nephrectomy including particular applications, complications and outcomes.

Surgical Technique

Patient Preparation

Patient preparation is not different from the conventional pediatric urology preparation. Usually, no specific diet measures are prescribed before surgery. Usual

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recommendations for general anesthesia preparations are followed. All patients are screened for blood type. Serum electrolytes, creatinine, and coagulation studies should be performed, and all patients should have preoperative sterile urine cultures, as indicated. The child is on strict NPO diet for a period between 4 and 8 hours depending on his/her age, and premedicated before going to the operating theatre. Some surgeons recommend fluid diet and enema on the night preceding surgery [1]. A nasogastric tube may be placed after the endotracheal general anesthesia. Noninvasive hemodynamic and ventilatory monitoring is needed during laparoscopic nephrectomy in either trans- or retroperitoneal approach. Cephalosporin is often administered intravenously in the operating room.

Renal Access

The kidney can be safely accessed by during laparoscopy by either a retroperitoneal or a transabdominal transperitoneal approach. Additionally, there are several patient positioning options and newer approaches utilizing a single surgical site.

Retroperitoneal

Lateral

The patient is placed lateral, with enough flexion of the operating table to expose the area of trocar placement, between the last rib and the iliac crest. In infants and young children (under 6 years), the use of a lumbar padding to laterally flex the patient without flexing the operating table may be needed. Retroperitoneal access is achieved through the first incision, 15 mm in length, and one finger width from the lower border of the tip of the 12th rib. The use of narrow retractors with long blades allows a deep dissection despite a short incision. Gerota's fascia is approached by a muscle splitting blunt dissection, then it is opened under direct vision and the first blunt trocar (5 mm, 0° lens) is introduced directly inside the opened Gerota's fascia. A working space is created by gas insufflation's dissection, and the first trocar is fixed with a purse-string suture that is applied around the deep fascia to ensure an airtight seal and to allow traction on the main trocar if needed to increase the working space. This suture is preferably done before putting the trocar as the small incision is too tight around the trocar. A second trocar (5 mm) is inserted posteriorly in the costovertebral angle, in front of the lumbosacral muscle. A third 5-mm trocar is inserted, in the anterior axillary line, a finger width from the top of the iliac crest. To avoid transperitoneal insertion of this trocar, the working space is fully developed, and the deep surface of the anterior wall muscles is identified before trocar insertion. Insufflation pressure should not exceed 12 mm Hg, and the CO_2 flow rate is progressively increased from 1L to 3L/min. Access to the retroperitoneum and creation of the working space are the keys to success in retroperitoneal renal surgery.

Age is not a limiting factor for this approach [2]. Young children have less fat and the access is even easier.

Prone Posterior

The access begins with an incision in the costovertebral angle at the edge of the paraspinous muscles. The secondary trocars are placed just above the iliac crest, one medially at the edge of the paraspinous muscles, and one laterally at the posterior clavicular line [1, 3, 4]. This approach gives the advantage of excellent exposure of the pedicle with spontaneous traction on the pedicle by the gravity. The difficulty in this approach is to go to the distal part of the ureter. Borzi et al. compared in a randomized prospective study the lateral to the posterior retroperitoneal approach in children undergoing laparoscopic nephrectomy and found no significant difference in the operative time [5].

Other Tips for Access

Since the description by Gaur et al., balloon dissection has been the method applied by most urologists [6]. Disadvantages of the balloon are the cost of the disposable material and the possible complications related to rupture of the balloon [7]. On the other hand, balloon dissection allows creating a working space without opening Gerota's fascia, which is important for radical removal of malignant tumors in adults. Capolicchio et al. [8] described a modification of lateral access [8]. They recommend the insertion of the first trocar through the costovertebral angle. This modification helped them to avoid an accidental peritoneal tear during access through the first lateral incision and allowed a smaller incision for the laparoscope. One of the possible disadvantages of the use of this device is that the placement of the device can be incorrectly inserted and the Gerota's fascia would be approached more anteriorly. This common mistake may lead to downward release of the kidney and makes the retroperitoneal approach more difficult with the need to retract the kidney upwards. Micali et al. reported the use of the VisiPort© (Medtronic, Minneapolis, MN, USA) visual trocar to access directly to the retroperitoneal space, which was originally described by Cadeddu et al. [9, 10]. The advantage of this method is the possibility to use a small incision for the first trocar, which is helpful in reconstructive surgery but not in ablative surgery as the first incision is needed for organ retrieval.

Transperitoneal

Several options exist in terms of patient positioning. The most frequently described is the flank position [1]. The pneumoperitoneum is created through an open umbilical approach. The child is positioned with the surgeon standing in front of the abdomen (opposite side of the kidney). The most frequent configuration has been with the umbilical port and two operating ports in the midline above and below the umbilicus. A fourth trocar may be placed in the mid-clavicular line if needed for exposure. The kidney is exposed by medial mobilization of the colon. One significant advantage of a transperitoneal approach is clear identification and dissection of the distal part of the ureter as well as navigation by familiar intraabdominal landmarks.

Single-Site Access

Johnson et al. published in 2009 the first pediatric single-port-access nephrectomy for a multicystic, dysplastic kidney [11]. With the patient in a right lateral decubitus position, a semicircular infra-umbilical incision was made. A R-port was utilized to establish laparoscopic access. It is a unique single-access port consisting of two components: a fascial retractor containing an inner and an outer ring with an intervening plastic sleeve and a multichannel valve. Each component is covered with a thermoplastic elastomer that maintains pneumoperitoneum while allowing the introduction of flexible or rigid instruments. A 2-cm rectus fasciotomy was made, and the R-port was secured. Mobilization of the spleen and left colon allowed identification of the left kidney and ureter. A harmonic scalpel can be used to take the renal artery, renal vein and ureter. After complete mobilization, the kidney is secured in an entrapment bag, morcellated and removed through the single infra-umbilical incision. Beyond the initial hurdles and learning curve, this technique is promising and has the potential to be extended to other procedures in pediatric urology [12–16]. The use of adjacent fascial puncture sites for instrumentation can obviate the need for a commercial port or multiple trocars [17].

Technique of Laparoscopic Nephrectomy

Laparoscopic Retroperitoneal Approach

First described by Diamond et al. and Valla et al. in 1995 [18–20], patients are placed in a modified lateral decubitus position with table flexion and kidney rest elevation and the procedure is performed via the lateral retroperitoneal approach [21–23]. The retroperitoneal access is achieved via the first incision, 15–20 mm in length, and one finger width from the lower border of the tip of the 12th rib. The Gerota's fascia is approached by a muscle-splitting blunt dissection and is then opened under direct vision. The first blunt trocar (5 or 10 mm) is introduced directly inside the opened Gerota's fascia. A working space is created by gas insufflation dissection. A second trocar (5 mm) is inserted posteriorly in the costovertebral angle and a third trocar (5 mm) is inserted, in the anterior axillary line, a finger width from the top of the iliac crest. The renal pedicle is identified and approached posteriorly and dissected close to the junction with the aorta and vena cava. On the left side the vein is ligated distal to the genital and adrenal branches. After dissecting the renal artery then the vein, the vessels are clipped, ligated or coagulated. The choice of method depends on the vessel diameter. In general, small arteries of MCDK can be coagulated by bipolar cautery or harmonic scalpel, while the most common method is to double ligate the artery proximally by two clips and distally by one. The vein is generally clipped in the same way, if the diameter is bigger than the length of the clip, the vein is first ligated by a resorbable intracorporeal knot; the diameter is thus reduced, and the ligature is secured by juxtaposed clips. The ureter is then identified and dissected as far as necessary. In the absence of reflux, the ureter is coagulated and sectioned at the level of the lumbar ureter (especially in pretransplant nephrectomy, the native ureter might be used for the transplantation). In the presence of reflux, the dissection is distally followed, the vas deferens is identified in males, and the ureter is ligated as close as possible to the ureterovesical junction. The last part of dissection is the anterior surface of the kidney. The kidney is dissected from the peritoneum very close to its capsule in the cleavage plan of areolar tissue. Usually no hemostasis is necessary in this plane, but in inflammatory adherent kidneys a sharp dissection with bipolar coagulation may be necessary. The kidney is usually retrieved through the main incision at the tip of the 12th rib. A 5-mm telescope is inserted through the accessory port, and a toothed grasping forceps is introduced through the first port to extract the kidney. The kidney is grasped at one of the poles, and pulled in this axis, to pull on the smallest diameter of the kidney. In most cases, the kidney can be divided under vision during extraction through the muscle wall. In cases of severe pyelocaliceal dilation or MCDK, direct evacuation by puncture helps in organ retrieval. An extraction bag is used for infected or large kidneys, and the kidney is morcellated inside the bag.

Laparoscopic Transperitoneal Approach

The child is placed, supported, and strapped in the semilateral position with a degree of contralateral flexion of the spine to open the renal angle. This position allows the intestine to fall medially by gravity. The surgeon stands in front of the patient. In the traditional kidney position three trocars are inserted after creation of a pneumoperitoneum: 10 mm periumbilical (port I), 10/12 mm subcostal (port II) and 12/10 mm above the iliac spine (port III) in the mamillary line [24, 25]. Although a 0° laparoscope may be used successfully in some cases, a 30° laparoscope gives better visibility and versatility. After laterocolic incision the colon is reflected away from the lateral wall. Thereafter two 5-mm trocars (ports IV, V) are inserted into the lateral abdominal wall parallel to ports II and III. Following clipping and dissection of the gonadal vein, the ureter is isolated and divided. Then the cranial part of the ureter is used as a retractor exposing the renal hilum for dissection of the renal vessels. The main renal artery and vein are dissected separately by use of an endoscopic stapling device. Finally, the kidney including Gerota's fascia is isolated from the adrenal and the upper peritoneum. Entrapment of the organ is performed with a specially designed bag. The neck of the bag is brought out onto the surface of the abdomen (via port II/III) allowing digital morcellation with index finger inside the bag and removal of the organ in several pieces can be performed if necessary [26]. After a final inspection of the operative field and evacuation of the pneumoperitoneum, incisions >3.5 mm are closed using absorbable sutures. The cannula sites are infiltrated with local anesthetic agents.

Technique of Robot-Assisted Nephrectomy

Nephrectomy is a valuable tool in the armamentarium of the pediatric urologist to treat a wide variety of conditions. While robotic procedures have increased dramatically recently, most focus by pediatric urologists on the upper tracts has been on reconstructive or minimally ablative procedures such as pyeloplasty, ureteroureterostmy and partial nephrectomy [27]. A robotic approach to nephrectomy will replicate similar approaches used in reconstruction applied to a purely extirpative procedure. The surgeon must select the appropriate approach for the patient based on the case particulars, even with acknowledgement of higher reported total costs, but shorter hospitalization [28]. Additionally, a robotic approach may be advantageous such as in bilateral procedures, where a nephrectomy/nephroureterectomy may combined with a contralateral procedure such as a ureteral reimplant as Lee et al. reported in four patients with concurrent contralateral extravesical ureteral reimplantation [29, 30]. A mixed pure-laparoscopic and robotic approach for bilateral upper pole heminephrectomies has also been reported for non-functional moieties [31]. Lastly, while current robotic ports are 8 mm in size, they offer not only articulated instruments, but a wide variety of instruments that the surgeon may find useful. Smaller sized ports and instruments exist, but their adoption is not as widespread.

Patient preparation is similar for a robotic assisted approach. Appropriate blood work, including type and screen, CBC, and BMP should be considered. Should entry into the urinary tract other than ligation of the ureter be anticipated, or in cases or recurrent infections, obtain a urine culture and treat prior to proceeding. Besides a standard NPO period prior to surgery, a bowel preparation is not necessary, unless the surgeon expects significant constipation that may hinder dissection. Antibiotic prophylaxis should be guided by best-practices including any expected entry into the urinary system or the presence of long-standing infection. In the absence of this, the procedure may be treated as a clean procedure with common antibiotic prophylaxis choice such as cefazolin. The surgeon may consider a neuraxial block or regional block to be performed by the anesthesiologist (such as a transversus abdominis plane, i.e., TAP block) versus local anesthetic infiltration into the port sites, with reported similar pain control [32].

Patient positioning is surgeon-dependent, however should at least initially be undertaken with the anesthesiologist to ensure careful padding and avoid compression or hyperextension that may lead to neuropraxia. Patients should be secured a multiple points, and the bed rotation tested for stability. As with a pure laparoscopic approach, renal access may proceed in a retroperitoneal or transperitoneal fashion. A retroperitoneal approach is taken with similar position to an open surgery with the patient in the lateral decubitus position, with the head well-supported and the arms either both forward in a neutral position, or with the ipsilateral arm tucked to the side if space permits. The legs are placed in a neutral, well-padded position and the table may be slightly flexed, either with or without the kidney rest deployed, just enough to open the space between the iliac crest and the inferior border of the ribs.

For a transabdominal approach, the patient may be placed in one of three different positions: pure flank, modified flank or supine. Flank position is similar as described above for a retroperitoneal approach. In a modified flank approach the patient is placed with approximately 45 degrees of lift of the operative side via the use of gel rolls and gentle padding. The ipsilateral hip and back are bumped in the fashion with the legs slightly flexed. In this position the ipsilateral arm is most easily tucked at the side. In a supine position, arms may be tucked or folded over the chest, and a X-pattern of tape over the chest often works well the secure the arms at the side. We favor the supine in older children for its ease of position with the ability to replicate a modified flank position internally simply tilting the operative table.

With a retroperitoneal approach, ports may be placed in a fashion similar to a pure laparoscopic depending on a prone posterior versus flank approach and dilation of the potential retroperitoneal space. The first port may either be placed at the tip of the 12th rib, or in the costovertebral angle at the lateral boarder of the paraspinous muscles. The potential space is developed, and two more working ports placed as above. Rarely are more than three ports necessary with a robotic setup, although placement of a fourth arm or an assistant port is possible, usually inferior to the camera, though a superior placement may be done if needed for creating space under the liver.

Port placement for a transabdominal approach may depend on the robotic platform being used (Fig. 9.1). With the Si series of Da Vinci robots, side docking was necessary which required certain port placement with triangulation of the operative field. Currently, with the Xi series, port placement may proceed in standard triangulation or in a straight line in the midline using the umbilicus for the camera port. This has been reported for use in bilateral procedures where midline placement obviates the need for replacing or adding new trocar sites [33]. This approach easily allowed for five midline ports in a 14 kg child as reported by Sala et al. for a bilateral Wilms nephrectomy. Three port placement may be accomplished with an umbilical camera port and ipsilateral ASIS and infracoastal ports to triangulate the kidney. If needed, a fourth port for either the third robotic arm or an assistant port may be added at a suprapubic location or midway between the superior ports at the lateral edge of the rectus muscle. Recently popularized, the HiDES technique can be used to place two of the ports other than the umbilical incision below the waistline [34]. After standard access through the umbilicus, ports can be placed just medial the ipsilateral ASIS and at the midline suprapubic, both with a transverse incision. The skin and facial ports entry sites may be slid along each other to allow for a lower skin incision while still maintaining reasonable access and working room. Using an

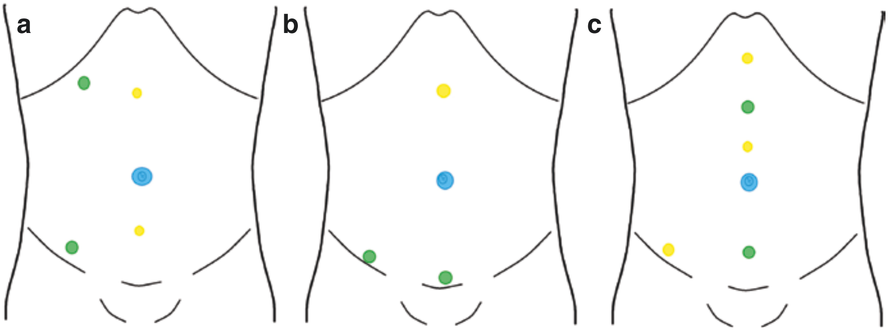

Fig. 9.1 Port placement for a robotic setup will depend on platform and number of ports needed. (**a**) Standard three-port triangulation with the camera (blue) in the umbilicus and working ports (green) in a sub-costal location and off of ASIS. Additional ports (yellow) may be placed as need for retraction, dissection or for an assistant. (**b**) Three-port placement for a HiDES approach to the kidney. (**c**) Midline port placement possible with the Xi DaVinci system. The inferior working port may be placed in a HiDES position

Si platform, the robot is brought over the patient's should at approximately 45 degrees to allow for the instruments to triangulate on the kidney. With standard or inline placement using the Xi system the boom may be rotated to the correct orientation. Multiple instruments are available, with robotic hem-o-lock appliers, and robotic articulating stapling instruments now available on standard 8 mm sizes [35].

Dissection of the kidney may then proceed from several approaches. Via a retroperitoneal approach the space has already been created and careful dissection around the kidney will allow access to the vessels at the hilum. In a transabdominal approach, obtain access to the retroperitoneum by reflecting the colon along the white line of Toldt on the operative side. If bleeding is a concern early vascular control may first be obtained with dissection and vascular control of the hilum. The kidney may be dissected away from surrounding tissues with a bottom-to-top approach utilizing the ureter as the initial landmark and lifting the kidney away from the psoas muscle. Release of the kidney from the lateral attachments may be delayed as needed or order to perform the medial dissection including hilar control. Often the superior dissection is performed at last, usually leaving the adrenal unless dictated by oncologic concerns.

Special Situations

Non-orthotopic kidneys, such as pelvic kidneys, horseshoe kidneys and those with expected deviations in anatomy, especially vascular, require careful workup prior to extirpation.

Horseshoe kidney occurs in approximately 1 of every 400 individuals. Cross-sectional imaging should identify relevant vasculature. Previously reported case series in laparoscopy are immediately applicable to a robotic approach, with the added ease of a third robotic arm being able to substitute for an assistant to provide traction and positioning in the peritoneum. Agrawal reported three cases of laparoscopic nephrectomy for non-functioning moieties in two and a renal mass requiring radical right nephrectomy [36]. The small vessels and isthmus were taken with a hook cautery, 10 mm Ligasure™, or using hem-o-lock clips for hemostasis. Recently, Lottman reported a left retroperitoneoscopic nephrectomy for nephrotic syndrome [37]. Care should be taken to identify the true line of fusion, as complications from incomplete resection have been reported as up to 60% of lower pole fusion may be lateral and not midline [38]. Kumar reported a case of robot-assisted heminephrectomy for chromophobe renal cell carcinoma in a case of fused ectopic kidneys [39]. Indocyanine green (ICG)-aided near infrared fluorescence has been reported for selective atrial mapping during heminephrectomy to prevent inadvertent injury to non-operative moiety, and may be useful for determining isthmus blood supply during dissection of a horseshoe kidney [40].

Pelvic kidneys offer a unique challenge given location with the pelvis and aberrant arising vessels that may descend directly from the aorta or lateraling from the iliac arteries. Oyinloye reported a Wilms tumor a of a left pelvic kidney in a 10-year old girl, treated with open nephrectomy [41]. As to date there are no reports of robotic removal of a pelvic kidney, although we would expect case series soon.

Tips and Tricks

Ligation of the Ureter

As previously described, ureteral ligation may be accomplished using a number of tools but will depend on the reason for removal. Simple transection with cautery may be acceptable for non-refluxing units, but refluxing units may require further ureteral dissection and transection of the ureter at the ureterovesical junction with further plication of the ureter to prevent urine leak. The ureteral stump may ligated with a hem-o-lock clip, and may be over sewn robotically if large and a concern for reflux. Care should be taken to dissect as close as possible to the ureterovesical junction if excision for reflux, without injury to the vas deferens in a male or uterine vessels in a female.

Kidney Retrieval

Retrieval of the kidney will depend on any oncologic concerns and size of the organ. A multicystic kidney or large hydronephrotic kidney may be decompressed prior to removal to facilitate removal without much need to enlarge ports. The robot is well-suite toward removal of a MCDK, and increased use of the robot for this despite a decrease in overall nephrectomies has been reported [42]. Numerous commercial laparoscopic retrieval bag systems exist, with various port sizes (5–25 mm) and bag volumes (150–4000 mL). Previous laparoscopists have reported no increased risk of surgicalsite infection and a 1% rate of retrieval site hernias among 373 elective cholecystectomies without the use of a bag for organ retrieval [43]. Surgeons have also devised homemade retrieval systems at the bedside in order to reduce cost and facilitate removal. The finger of a sterile glove may be used for small dysplastic kidneys, with a hem-o-lock clip on a string used to close the finger bag and retrieve the specimen. Kao et al. reported on 135 patients undergoing laparoscopic adrenalectomy or prostatectomy using the palmer portion of a sterile glove, 2-0 nylon for a drawstring and 1-0 Vicryl to secure the bottom of the bag, with no reported perioperative complications or evidence of leak in the form of wound metastases [44]. A further retrieval system, the Nadiad bag, constructed from a plastic sheet, nylon thread and a 5-Fr ureteral catheter has been reported [45] with a 4-min retrieval time in 100 nephrectomies [46] and no saline leak. In-bag morcellation systems are available, but should only be considered for extremely large, non-malignant kidneys that cannot be decompressed with any of the above techniques.

Role of Prophylactic Antibiotics

According to the WHO and the EAU, surgical antibiotic prophylaxis is not recommended for laparoscopic nephrectomy in children. However, AUA guidelines recommend the use of a single use of cefazolin or TMP-SMX injection after induction [47].

Lymph Node Dissection

In an oncologic setting, the lymph node samples can be picked up along the aorta above the level of the mesenteric artery and this sampling is very important for accurate staging, and decreases the risk of undertreating the child in case of malignant renal tumors [48]. There has been controversy regarding the impact on survival of the number of lymph nodes examined in. Among 1340 Wilms' tumors reported by Zhuge et al. with lymph node data available following surgery, the 5-year survival was significantly lower for patients with no lymph nodes sampled (87%) or one to five lymph nodes sampled (91%), versus 6–10 lymph nodes (93%) or more than 10 lymph nodes (95%) [49]. However, Kieran et al. demonstrated recently that the number of lymph nodes sampled did not predict 5-year event-free survival variations from 3409 patients; the effect of lymph node positivity was greater only for patients with anaplastic tumors [48]. Nevertheless, although this study confirmed the great importance of sampling at least some lymph nodes, allowing an accurate staging, extensive lymph node dissection seems unnecessary as no patient had positive distant lymph nodes in the setting of negative hilar lymph nodes. Thus, radical nephrectomy with lymph node sampling can be performed under laparoscopy as in open surgery. Bouty et al. published in 2020 a large study including 50 transperitoneal laparoscopic total nephrectomies [50]: lymph node sampling is recommended for all patients, with an ideal number of seven nodes sampled [51, 52]. It is often reported that MIS does not allow for as good a lymph node picking as open surgery [53]. However, Bouty et al. demonstrated the contrary [50, 54].

Indication and Outcome

Laparoscopy

Renal Cancer

In the International Society of Pediatric Oncology (SIOP) protocol, the old standard for therapy is open total nephrectomy, preceded by neoadjuvant chemotherapy [55]. However, increased morbidity, such as the risk of adhesion-related complications and the presence of scars altering the quality of life of long-term survivors, is not uncommon [56, 57]. It is now well established that these risks are lower with minimally invasive surgery (MIS) [56]. Therefore, modern protocols now focus on reducing these risks, while maintaining excellent oncological outcomes. First described in 2004 by Duarte et al., the use of MIS for WT has been reported in the literature in approximately 100 cases [58, 59]. The first series of minimally invasive surgery for unilateral WT by laparoscopy in children was reported by Duarte et al. in 2006 in eight cases with good results [60]. They showed that LRN was feasible after preoperative chemotherapy, including for rather large tumors, even if the follow-up was short. Local control was achieved, as only a 1/8 tumor had microscopic residual disease and required flank radiotherapy. Varlet et al. first reported five cases (mean age: 4 years; mean renal tumor diameter: 50 mm) in 2009 [61]. All tumors and lymph node samples were removed completely by laparoscopy without rupture. No conversion to laparotomy was necessary and there was neither intraoperative bleeding nor complications. The mean operative time was 90 min (60–117). No recurrence was reported after a mean follow-up of 18 months. Varlet et al. concluded that LRN in children for renal cancer was feasible after preopretavive chemotherapy by experiment surgeons in oncology and laparoscopic procedures, with the same oncologic strategies as open surgery, giving the advantage that the tumor needs less mobilization before vessel coagulation, and leads to less blood loss [61]. The laparoscopic approach not only improves the convalescence, the pain, the hospital stay, and the cosmetic outcome in these patients, but also allows planned postoperative chemotherapy or radiation therapy to proceed at an earlier date than open procedure.

The criteria for selection to allow performed LRN in unilateral renal tumors include unilaterality, size of tumors post chemotherapy without crossing the midline, and absence of the thrombus in the renal or cava vein. The tumors beyond the midline after chemotherapy, thrombus of the renal and cava vein, and primary tumors not treated with preoperative chemotherapy should serve as contraindications, as the open surgical procedure is still the standard care. The size of the tumor may also be a contraindication but depending on the size and age of the child, if a large tumor can be extracted by a suprapubic incision without rupture, the size is not a problem; however this incision must be large enough to avoid this complication. It seems reasonable that a low suprapubic incision for removal of the tumor is not only more cosmetic than flank incision but probably better tolerated by patients.

A retrospective multicentric study of children having undergone laparoscopic radical nephrectomy for a malignant renal tumor in the pediatric surgery institutions of the French Society of Pediatric Oncology was published in 2014, including 17 patients with unilateral small malignant tumors at the time of surgery, with or without neoadjuvant chemotherapy, whose medial edge did not cross the lateral edge of the vertebra, allowing an easy approach to the renal pedicle [62]. None of these tumors had preoperative suspicion of extrarenal extension, vena cava thrombosis, preoperative rupture, or large lymph node involvement around the vena cava and the aorta. Median age at surgery was 26 months (5 months–11 years). After chemotherapy, only three tumors were more than 51 mm and 14 were less than 50 mm. The tumor did not cross the lateral edge of the vertebra in 16 but crossed it in one case (the largest one was 8 cm in diameter), the medial edge of the tumor being on the midline. Tumors were located as follows: seven in the upper pole, three in the lower pole, and seven in the medial part of the kidney. Two conversions were necessary for difficult dissection of the renal artery, especially for the largest tumor (8 cm) crossing the lateral edge of the vertebra. No tumoral rupture occurred and the median operative time was 124 min (70–210). The immediate follow-up was uneventful for 16 children. Local staging was stage I in eight patients, stage II in six, and stage III in one. This stage III right WT was not related to spillage or incomplete resection, but to the presence of a vascular tumoral thrombus on the margins of the renal vein division. With a median follow-up of 42 months [12–77], 88.2% children were in complete remission without evidence of disease. None of them had oncological complications (port site or retroperitoneal recurrence, secondary pulmonary metastasis) and no small bowel obstruction occurred. One stage I intermediate-risk left upper pole nephroblastoma relapsed locally 9 months after surgery in the kidney area and was treated by second-line chemotherapy and open surgery; he was in second complete remission at 6 months. The child with the *TFE3* renal cell carcinoma had a local needle biopsy site recurrence 13 months after the biopsy, treated by a parietectomy, but she died 4 years and 2 months after laparoscopic nephrectomy because of pulmonary and cerebral metastases; she had no evidence of port site or retroperitoneal or parietal recurrence.

The indications of laparoscopic radical nephrectomy in children can be summarized, for trained laparoscopic surgeons, as small tumors that do not cross the lateral edge of the vertebra at the time of surgery (Fig. 9.2). Thus, the indications will be probably more frequent in the SIOP protocol with preoperative chemotherapy than in COG protocols without adjuvant chemotherapy [63]. Contraindications include cava or renal thrombosis at time of surgery, adhesions to other organs and initial tumoral rupture to avoid peritoneal spillage, and diffusion by the pneumoperitoneum, even if peritoneal metastases could be removed under laparoscopy, as in one case disease-free at 19 months after surgery [64]. A difficult question remains

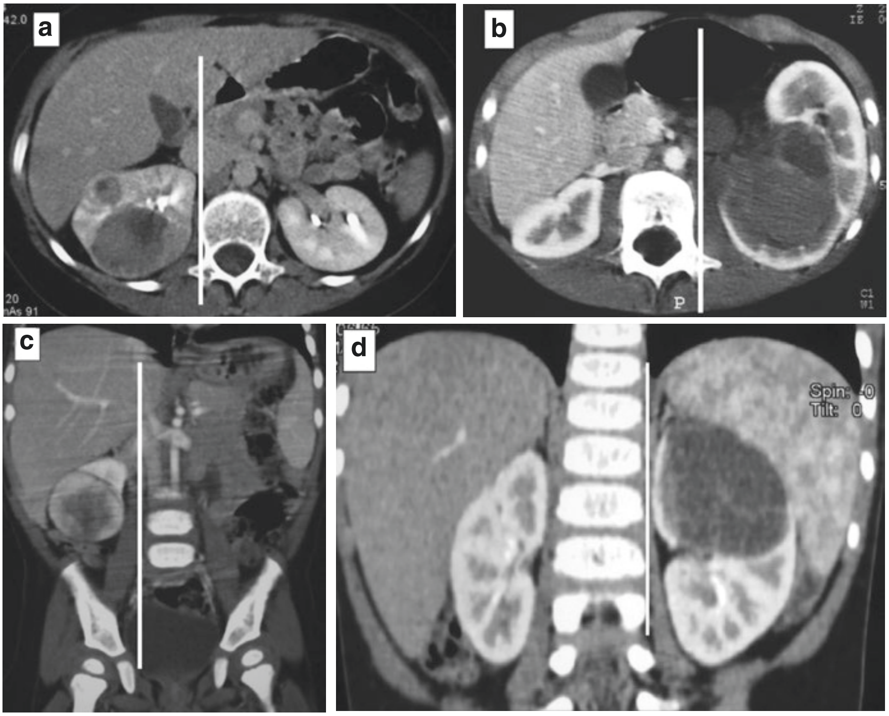

Fig. 9.2 The medial edge of the tumor does not cross the lateral edge of the vertebra (white line). (**a**) TFE3 renal cell carcinoma. (**b**) Wilms' tumor after chemotherapy. (**c**) Clear cell sarcoma. (**d**) Cystic Wilms' tumor (from Varlet et al.) [62]. (*Reprinted with permission from Elsevier*)

concerning the choice between laparoscopic radical nephrectomy and partial open nephrectomy for small polar tumors, that is the choice between the risk of possible renal failure in the long term, about 1% with radical nephrectomy in non-syndromic patients, versus the risk of local recurrence with partial nephrectomy, increased from 3% with radical nephrectomy up to 7–8% in unilateral Wilms' tumor with a poor prognosis in spite of intensive chemotherapy [49, 65–67].

If the surgeon has appropriate training in both endosurgery (nephrectomy, pyeloplasty, or other complex abdominal and thoracic procedures) and surgical oncology, we believe the risk of rupture is similar to open radical nephrectomy in carefully selected cases of renal tumor. Imaging magnification and modern coagulating devices allow safe dissection and little movement of the instruments in the abdominal cavity, avoiding any damage to the tumor [62].

Other articles have been published on the feasibility and satisfactory oncological outcomes for malignant renal tumors:

- Romao et al. in 2014 compared the outcomes of laparoscopic nephrectomy (LN) with open radical nephrectomy (ORN) in the management of consecutive pediatric neoplasms [68]. Demographics from the 45 patients (13 LN, 32 ORN) were similar, and tumors in the LN group were significantly smaller (6.6 ± 1.8 cm *vs*. 11 ± 3 cm ORN). No tumor ruptures occurred with either technique. Wilms tumor (seven LN, 24 ORN) was the most common diagnosis, followed by renal cell carcinoma (four LN, four ORN). Mean length of stay was significantly shorter for LN (3 vs. 6 days). Postoperative narcotic requirements and use of nasogastric tube were higher in the ORN group. After a median follow-up of 18 (LN) and 33 months (ORN), 1 and 4 recurrences occurred, respectively.

- Warmann et al. in 2014 included 24 children undergoing MIS for tumor nephrectomy in the SIOP 2001 trial [52]. Median age at operation was 40 months [14–65]. All patients received preoperative chemotherapy. Median tumor volume was 178 mL at diagnosis (47–958) and 73 mL at surgery (4–776). There was one surgical complication (splenic injury), no intraoperative tumor rupture occurred. Abdominal stage was I in 14, II in 7, and III in 3 patients. Adequate lymph node sampling was performed in only 2 patients. One local relapse occurred. Event-free survival was 23/24, overall survival was 24/24, median follow up was 47 months (2–114).
- Bouty et al. in 2018 analyzed the risk of local recurrence [59]. One hundred and four LTRNs have been performed for WT with neoadjuvant chemotherapy in 93 cases. Tumor was ruptured preoperatively in three cases but never intraoperatively. The median volume of the tumor was 229 mL (4–776 mL). Local stage was specified in 86 cases: 49 stage I, 28 stage II, and nine stage III. Lymph nodes were sampled in 48 patients (median 2.3 [0–14] nodes). Three tumors were initial local stage I (2 intermediate and 1 high risk) and one stage III. With a median follow-up of 20.5 months (1–114), there were four local recurrences (3.8%) at a median of 8.5 [7–9] months after surgery. This local recurrence incidence is lower than previously reported after open resection. However, tumors amenable to minimally invasive surgery are smaller, with higher numbers of low stage and standard histology. Additionally, the quality of the reports is suboptimal, and follow-up is relatively short. However, LTRN does not seem to increase the incidence of local recurrence in WT.
- Harris et al. in 2018 focused on the size of the tumor. Tumors in the laparoscopic group were significantly smaller, but it was possible to excise tumors more than 300 mL. A ratio of tumor to contralateral kidney may be a better guide to safe excision than an overall volume cutoff [69].
- Flores et al. in 2018 described preliminary results of laparoscopic nephrectomies (LN) for the treatment of unilateral Wilms tumors (WT) [70]. Among 105 patients with WT, 14 underwent LN. Median tumor volume for the patients undergoing LN was 72 mL (7–169). Estimated 5-year overall survival for all patients with WT during this period was 88.7%. Two patients underwent conversion. No recurrence or related death was found at a mean 32-month follow-up period.
- Schmidt et al. in 2019 presented their experience (N = 9) with special regard to patient selection and technical aspects [71]. Median tumor volume at surgery, maximal diameter, and specimen weight was 74 mL (15–207), 6.5 cm (3.5–9.3), and 125 g (63–310), respectively. No intra- or postoperative complications

occurred. Overall survival and event-free survival was 9/9, median follow up was 48 months [24–78]. These data were used to propose a patient selection algorithm. Technical aspects derived from our experience include usage of the ureter as leading structure, usage of a transabdominal traction suture around the ureter, and lymph node sampling before tumor nephrectomy.

- Bouty et al. in 2020 underlined the concerns with this approach, in particular with regard to the difficulty of lymph node sampling and the risk of local recurrence [50, 59]. Hence, the UMBRELLA SIOP – RTSG 2016 Wilms tumor protocol has defined criteria for the use and contraindications of MIS in WT [51]. Contraindications include infiltration of extrarenal structures, extension beyond the lateral border of the spinal column, presence of a venous thrombus, and little experience in laparoscopic nephrectomy. During the study period, 50 patients underwent transperitoneal MIS total nephrectomies. The median age at diagnosis was 38 months (6–181). All tumors were unilateral. Renal vein thrombus and preoperative rupture was present in three cases each (6%). Seven patients (14%) presented with lung metastases at diagnosis (stage IV). Twenty-one patients (42%) underwent a percutaneous biopsy prior to initiating treatment. The median volume of the tumors at diagnosis was 2336 mL (66–12,811). Neoadjuvant chemotherapy was vincristine – actinomycin D in 43 cases (86%) with localized disease, vincristine – actinomycinD – doxorubicin in six patients with stage IV WT and a combination of etoposide – carboplatin – cyclophosphamide and doxorubicin in the remaining patient, where WT developed on a previously treated nephroblastomatosis. Lymph node sampling was performed in 42 cases (84%), with a median of four lymph nodes [1–11] present on the pathology report. There were three perioperative complications (6%): one bowel, one splenic vein, and one renal vein injury. There were four diaphragmatic resections, of which two were repaired laparoscopically. Six (12%) patients were converted to an open approach: two for diaphragmatic tears with patients not tolerating insufflation, one for the splenic vein injury, one for the renal vein injury, one due to difficulty in dissecting the renal artery, and one because of an inability to perform the thrombectomy of the vena cava robotically for a thrombus not visible on preoperative CT. Conversions occurred more frequently at the beginning of the experience. There were no intraoperative tumor ruptures. After a median follow-up of 34 months (2–138), 47 patients (94%) were in complete remission, two (4%) presented with local relapse at 7 and 9 months after surgery (both stage I, intermediate risk) and one presented with metastatic relapse to the lungs 4 months after surgery (stage III, high risk). In conclusion, MIS can be used safely in about 20% of cases of WT, with no intraoperative rupture and a 3-year EFS of 94%. Although these tumors are smaller and of lower stages than usually reported, there was only 4% local relapse.

In conclusion, data suggest that laparoscopic nephrectomy for WT is feasible and has promising results in terms of event-free and overall survival [70]. In patients undergoing pre-operative chemotherapy the correct selection for LN is crucial. Following the basic oncological precepts and in experienced centers, LN represents a plausible modality in the care of these patients. One of the major advantage of MIS in WT are lower morbidity especially intestinal obstruction. Even though it is difficult to properly evaluate, the other benefits of laparoscopy likely include a more comfortable postoperative course, quick discharge at day 2 or 3 and a better cosmetic result on the abdominal wall, with three or four small scars on the abdomen and one suprapubic scar instead of a large abdominal scar [14]. This last point was discussed in a recent report providing prevalence data relating to scarring, disfigurement, and persistent hair loss in adult survivors of childhood cancer; they can affect psychological function and quality of life, especially chest or abdominal scars [57]. Minimal invasive surgery should also result in more rapid recovery of patients and immune function [72].

Finally, the risk-benefit balance for laparoscopic radical nephrectomy for Wilms' tumor when feasible seems favorable: the theoretical risks of tumoral rupture, peritoneal diffusion, and port site metastasis, not uncommon in open surgery, remain present with laparoscopy, but do not seem to be significantly increased in carefully selected indications. The benefits are more comfortable postoperative course, decreased hospital stay, improved hospital cost saving, better cosmetic results, and probably a decrease in the incidence of small bowel obstructions.

A prospective registration of performed cases seems mandatory to allow evaluation of the technique and its indications and longer follow-up is mandatory to confirm comparable oncological outcomes to ORN. Multicenter prospective studies are necessary to evaluate and compare the results of the laparoscopic approach with open surgery.

Benign Conditions: Nonfunctioning Kidney and End Stage Renal Disease (ESRD)

The majority of benign indications, e.g., renal dysplasia, non-functioning kidneys secondary to obstructive or refluxing uropathy, or ectopic ureter, or UPJO or MCDK, pretransplant nephrectomy for arterial hypertension, nephrotic syndrome or uremic hemolytic syndrome and nephrolithiasis is suitable for laparoscopic nephrectomy [19, 20, 23, 73, 74]. Same-day discharge after surgery is even feasible and safe for laparoscopic nephrectomy in children [75]. Several studies even indicate that laparoscopic nephrectomy for congenital benign disease in children is achieved safely and that the modality offers additional advantages in children as compared to adults in terms of blood loss, transfusion and perioperative complication [76]. Non-functioning kidneys are generally of small size, so they can be extracted via a 10- or 12-mm cannula site without morcellation [20].

The first article comparing open, transperitoneal and retroperitoneal laparoscopic nephrectomy in children for benign renal diseases was published in 1998 by Rassweiler et al. [24]. Analgesic medication requirement per patient and length of hospital stay were lower in case of MIS. They were the first team to conclude that their results demonstrated an overall clear advantage of a laparoscopic approach when compared to open surgery. The literature provides crystal-clear data: very low complications or conversions in well-trained hands are reported [20].

Furthermore, nephrectomy may be indicated in children with ESRD before transplantation. This procedure through a retroperitoneal laparoscopic approach is feasible in this high-risk group of pediatric patients. El Ghoneimi et al. in 2000 reported his series of 12 nephrectomies in nine children with ESRD performed at a mean age of 7 years (7 months–13 years) through three trocars [22]. Cases were classified as American Society of Anesthesiologists grade III and presented with ESRD, hypertension, thrombocytopenia and/or nephrotic syndrome. The renal artery and vein were ligated separately with endocorporeal knots and clips. No conversion nor intraoperative complications were recorded. The same conclusion was reported by Szymanski et al. in 2010 stating that retroperitoneoscopic nephrectomy for ESRD is a safe and effective technique that preserves peritoneal integrity in children who require immediate postoperative peritoneal dialysis [77]. Avoiding post-nephrectomy hemodialysis decreases patient morbidity, preserving vessels for future vascular access. Moreover, en-bloc removal of horseshoe kidney for ESRD is feasible through retroperitoneoscopy with early postoperative reinitiating peritoneal dialysis [78].

The introduction of laparoscopic procedures has allowed the development of techniques that reduce patient morbidity, hospital stay, and analgesia requirement. Steven et al. also reported a series of 13 children who underwent elective laparoscopic nephrectomy for unilateral multicystic dysplastic kidney and emphasized the advantages this procedure has to offer for their management [79].

Severe Urinary Tract Infections

A total of 23 successful retroperitoneoscopic nephrectomies for pyonephrosis were first performed by Lucan et al. and published in 2004 [80]. Although technically difficult, retroperitoneoscopic nephrectomy for pyonephrosis is feasible. The extraperitoneal approach allows direct access to the renal hilum and helps avoid spillage of pus into the peritoneum. Even if the operative time is longer than in classic lumbotomy, blood loss, hospital stay, wound complications and time of return to school are significantly in favor of laparoscopy.

Nephrectomy for xanthogranulomatous pyelonephritis (XGP) can be extremely challenging. Josh et al. published three laparoscopic nephrectomies performed at 1, 5 and 9 years for this severe and chronic infection [81]. Creation of retroperitoneal space was easier than anticipated despite the perinephric inflammation. Excellent visualization of renal pedicle was obtained. The renal vessels were divided using the ultrasonic dissector. Postoperative pain and morbidity were greatly reduced. However, in case of XGP, retroperitoneoscopy may be contraindicated according to Esposito et al. [74].

In conclusion, there is no data showing any superiority of retroperitoneal (RP) to transperitoneal (TP) and to posterior prone retroperitoneoscopic (PRP) approach for laparoscopic nephrectomy in children. Kim et al. published in 2009 a systematic review including 51 articles that reported the outcomes of 689 pediatric nephrectomies [82]. Of these, 401 were RP and 288 were TP laparoscopic renal surgeries in children. The mean patient age for RP and TP was 5.4 years and 4.8 years, respectively. The mean operative time was 129 min for RP and 154 min for TP. The hospital stay was 2.5 days for RP and 2.3 days for TP. The overall complication rate for RP was 4.3% and for TP was 3.5% ($p > 0.05$). The number of vascular injuries for RP was 2 and for TP was 0 ($p > 0.05$). The number of bowel injuries for RP was 2 and for TP was 1 ($p > 0.05$). Gundetti et al. also concluded in his series of 100 consecutive nephrectomies performed by MIS that both the TP and PRP approaches for nephrectomy are equally applicable in children [83]. It is also safe and feasible in infants younger than 12 months and weighing 10 kg or less [84].

Moreover, nephrectomy via laparo-endoscopic single site (LESS) surgery (also known as single incision laparoscopic surgery or SILS) is associated with shorter lengths of hospital stay and decreased postoperative pain medication use when compared with open surgery [14]. LESS nephrectomy in children is associated with similar surgical times, lengths of hospital stay and postoperative pain medication use as the other minimally invasive modalities (TP and RA) [16].

Complication rate is relatively low. Nephrectomy had a significantly lower frequency of grade III complications (1.2%) compared to pyeloplasty (3.6%), ureteral reimplantation (6.7%) and complex reconstruction (11.8%) ($p < 0.05$) in the largest systematic review of 5864 pediatric patients who had minimally invasive surgery [85]. Conversion rate is globally low too [85, 86]. Need for reoperation is often associated with the underlying diagnosis and the natural sequelae of the disease process.

Only Baez et al. reported the operating time may be slightly shorter and postoperative recovery significantly longer for transperitoneal nephrectomy (TP) in comparison to retroperitoneal nephrectomy (RP) [87]. TP may be associated with minimal paralytic ileus within the first 24 h, meanwhile RP requires a different surgical skillset, but the patient may have a postoperative tolerance. Esposito et al. in 2016 concluded that LN (N = 101) is easier and faster to perform compared to RN (N = 48) and complication rate was higher after RN compared to LN [74]. Eight complications (5.3%) were recorded: 3 small bleedings (2 RN, 1 LN) during dissection, 2 peritoneal perforations during RN requiring conversion in LN, 1 abdominal abscess in case of XGP after LN requiring a redo surgery to drain the abscess, 1 instrumentation failure (LN) and 1 refluxing ureteral stump after RN requiring a redo surgery to remove it. Moreover, they concluded that LN is better in case of nephroureterectomy for VUR as the symptoms related to a refluxing distal ureteral stump (DUS) occurred only in patients undergoing retroperitoneoscopic nephroureterectomy, where the DUS was longer than the DUS detected in laparoscopic patients [88].

In conclusion, retroperitoneal, prone posterior and transperitoneal have no clear sono significant advantage is gained by a RP, PPR or TP approach for laparoscopic nephrectomy. MIS is associated with a lower postoperative complication rate than for open procedures [89]. The management of renal pathologies using laparoscopy is now currently the approach of choice for most pediatric renal diseases [90]. The incidence of vascular and bowel injuries is rare for all approaches. Therefore, the choice of approach should be determined by surgeon preference, patient anatomy, or the procedure to be performed. Higher-volume MIS centers also reach a lower complication rate than lower-volume centers [89].

Robot-Assisted

As robotics continue to grow in use and applications we expect to see further reports of successful adoption of above laparoscopic success now applied with robotic assistance. This follows lateral spread of skills from existing laparoscopy in pediatric urology and surgery as well as transfer of techniques first implemented in adult robotic surgery. In this vein, Varda and colleagues reports on a series of eight pediatric urologic oncology cases done in collaboration with their adult colleagues, including one nephrectomy with pericaval lymph node dissection [91]. In the field of renal transplantation, successful donor nephrectomies have been reported in a small series [92]. A meta-analysis of adult patients comparing robotic and laparoscopic partial nephrectomy found similar operative time and EBL. Patients treated with robotic partial nephrectomy has larger tumors with higher mean R.E.N.A.L. nephrometry scores and had a decreased likelihood of conversion to open surgery, lower any and major (Clavien 1 or greater and Clavian 3 or greater) complications with shorter warm ischemia time [93]. Partial nephrectomies of both upper and lower pole non-functional moieties have been reported. Bansal et al. reported on 24 patients undergoing pediatric robotic-assisted laparoscopic nephroureterectomy versus a laparoendoscopic single-site approach [94]. There was no difference in age, weight, hospital stay and pain medication use. There was a longer operative time with a robotic approach (mean 227 min versus 174 min). In the question of robotic versus open surgical approaches, a comparison by Ballouhey of 28 pediatric patients undergoing heminephrectomy for duplex kidney found lower length of stay and total narcotic use, but similar operative time, renal outcomes and complication rate (drain-site omental hernia and an asymptomatic fluid collection in the robotic group) [95]. While further literature examining only pediatric robotic-assisted laparoscopic nephrectomies are fewer in the literature, this is likely due to the well-established role that laparoscopic nephrectomies have already been shown, with practice following and adopting robotics. Newer literature now focuses on complex reconstruction and partial nephrectomies in the pediatric urologic literature.

Conclusion

Indications for minimally invasive surgery in pediatric urology are expanding, with more centers being involved in the evolution of various procedures. To avoid a discouraging learning curve, we recommend that pediatric urologists acquire their experience in a progressive pattern. Nephrectomy for multicystic dysplastic kidney or hydronephrosis is a relatively safe and easy procedure which acquaints the surgeon with laparoscopic exposure to the upper tract. When the surgeon is familiar with this exposure, he/she can proceed to more difficult nephrectomies (pre-transplant, partial nephrectomy). Time can only be limited by training. Today, training is easily available in many centers of adult and pediatric surgery. Experienced peers are also available to accompany the surgeon during the initial experience, especially in the era of robotic surgery. This might improve the results during the initial experience with laparoscopy and encourage its development among larger number of pediatric urologists. Minimal access procedures emphasize our goals of improving patient comfort and safety while adapting the laparoscopic procedures as closely as possible to conventional surgical techniques with respect to the operative time, cost, and surgical principles.

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