Minimally Invasive Techniques in Pediatric Surgical Oncology

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KEYWORDS

- Minimally invasive surgery • Laparoscopy • Thoracoscopy • Pediatric cancer
- Solid tumors

KEY POINTS

- Minimally invasive approaches to pediatric cancer surgery are increasingly used, not only for the benefits of smaller incisions, but also for better field visualization and precise dissection.
- Advances in technology and surgeon experience have facilitated this trend.
- However, the appropriate indications for its use remain to be determined, and oncologic principles should not be compromised.

INTRODUCTION

Classically, minimally invasive surgery (MIS) refers to surgical techniques that limit the size of incisions to access a body cavity or specific anatomic region. However, many other advantages of MIS are being appreciated. These advantages include better visualization of the surgical field, potentially more precise dissection, and less disruption of normal tissue.

MIS use has markedly increased over the last 2 decades and is now widely applied in adult and pediatric general surgery. More recently, MIS has been increasingly used in pediatric surgical oncology.[1,2] The traditionally espoused benefits of MIS include smaller incisions, resulting in a better cosmetic outcome; smaller wounds and therefore less postoperative pain, translating into shorter hospital stays; a more rapid return to regular activities; and, importantly for patients with cancer, the opportunity to begin adjuvant therapy more quickly. Another theoretic benefit of MIS is a decreased incidence of bowel adhesions, a surgical complication that can be quite problematic, particularly when surgery is combined with other treatment modalities such as

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radiation therapy. MIS may also provide immunologic advantages because there is less tissue trauma. Finally, visualization of the operative field with a laparoscope or thoracoscope is often enhanced for some locations, particularly deep in the pelvis and apex of the chest cavity. However, the advantage of tactile sense for localization is lost. Importantly, the conduct and goals of operations that are consistent with an open approach should not be compromised when using a minimally invasive approach.

Early reports described the use of MIS in pediatric patients with cancer for performing biopsies, staging solid tumors, assessing tumor resectability, and evaluating and potentially resecting metastatic disease.[3,4] Shortly thereafter, a randomized clinical trial sponsored by the National Institutes of Health was conducted to assess the efficacy and safety of MIS as compared with standard open approaches for surgical procedures in children with cancer. However, the trial closed early, primarily because of a lack of patient accrual. The reasons for poor accrual included a lack of buy-in by pediatric oncologists, a lack of surgical expertise with MIS procedures, and a preconceived surgeon bias toward either endoscopic or traditional open approaches.[5] Additional theoretic concerns, which were largely unfounded, regarding tumor cell disbursement with insufflation and port site recurrence also contributed to the poor accrual. In addition to these issues, performing MIS in pediatric patients without appropriately sized instrumentation was technically challenging. Finally, anesthesia had and still does introduce challenges, including the requirement for lung collapse for most thoracoscopic procedures, abdominal insufflation pushing the diaphragm up, and CO_2 diffusion from insufflation resulting in hypercapnia. Finally, the need to remove tumors intact often necessitates a large incision, negating some of the benefits of MIS. The limited tactile feedback of MIS may also be important when trying to locate small lesions, particularly for metastatic lesions in the lungs.

More recently, Cecchetto and colleagues,[6] representing the Italian Group of Pediatric Surgical Oncology, made recommendations on the use of MIS for pediatric solid tumors. The basic operative principles of open pediatric cancer surgery should be followed during the conduct of the operation. Tumor spill and positive margins should be avoided, particularly in tumor types in which an R0 resection is critical for good oncologic outcomes. Lymph node dissection or sampling should still be performed when indicated. Additionally, the authors discussed a number of histology-specific considerations, such as removing intact Wilms tumors intact (in contrast with neuroblastoma tumors, which can be removed piecemeal), and purpose-specific considerations for biopsies, staging, or therapeutic solid tumor resections.

Spurbeck and colleagues[7] described the early pediatric oncology experience with MIS at St. Jude Children's Research Hospital. This experience was updated more recently by Abdelhafeez and colleagues[8] Over nearly 20 years, more than 350 minimally invasive procedures were performed. Thirty-eight percent were laparoscopic and 62% were thoracoscopic. Of all abdominal procedures, only 15% were performed with a minimally invasive approach, whereas more than one-half of chest procedures were performed with a minimally invasive approach. The majority of these procedures (60%) were performed for diagnostic purposes. Approximately 25% of these procedures were performed to resect primary solid tumors and 17% were performed for adjuvant or supportive indications for disease or treatment-related complications (ie, cholecystectomy, gastrostomy tube placement or fundoplication, splenectomy, or oophoropexy for female patients before receiving pelvic irradiation). Of the therapeutic resections in the abdominal cavity, approximately two-thirds were performed for neuroblastic tumors and one-third were performed for germ cell tumors. Of the therapeutic resections performed with a thoracoscopic approach, most were for metastatic nodules in the lung; a few were for neuroblastic tumors in the chest and germ cell tumors.

THE ROLE OF MINIMALLY INVASIVE SURGERY IN SPECIFIC PEDIATRIC SOLID TUMORS

The usefulness and appropriateness of MIS in the management of pediatric solid tumors is very much tumor histology dependent. The following is an overview of the role of MIS in the most common pediatric solid tumors and scenarios (Table 1).

Adrenal Tumors

Most adrenal tumors in children are neuroblastic tumors, although differential diagnoses may include adrenocortical tumors and pheochromocytomas. The goals of surgery differ depending on the suspected histology. For neuroblastic tumors, the goals can be variable, but margin-negative, R0 resections are never required (and often not feasible). In most circumstances, even gross tumor can be left behind without compromising oncologic outcomes. MIS is commonly used for resection of L1 tumors (ie, no encasement of major blood vessels or other image-defined risk factors) (Fig. 1). For neuroblastic tumors with 1 or more preoperative image-defined risk

Table 1
Appropriate use of MIS for pediatric solid tumors

Tumor	Appropriateness of MIS
Adrenal	
Neuroblastic tumors	
Image-defined risk factors absent (L1)	Yes
Image-defined risk factor present (L2)	Depends on surgeon skill/experience
Adrenocortical tumors	
Likely malignant	Rarely
Likely benign	Yes
Renal tumors	
Nephrectomy	Rarely and usually only after neoadjuvant chemotherapy
Partial nephrectomy	Rarely and usually only after neoadjuvant chemotherapy or small lesion detected on screening
Ovarian tumors	
Likely malignant	Yes, oophorectomy
Likely benign	Yes, ovary sparing
Rhabdomyosarcoma	
Site dependent	Yes, for bladder dome primary, some retroperitoneal tumors
Retroperitoneal lymph node dissection	Yes
Lung metastases	
Diagnostic intent	Yes
Therapeutic intent	Uncertain

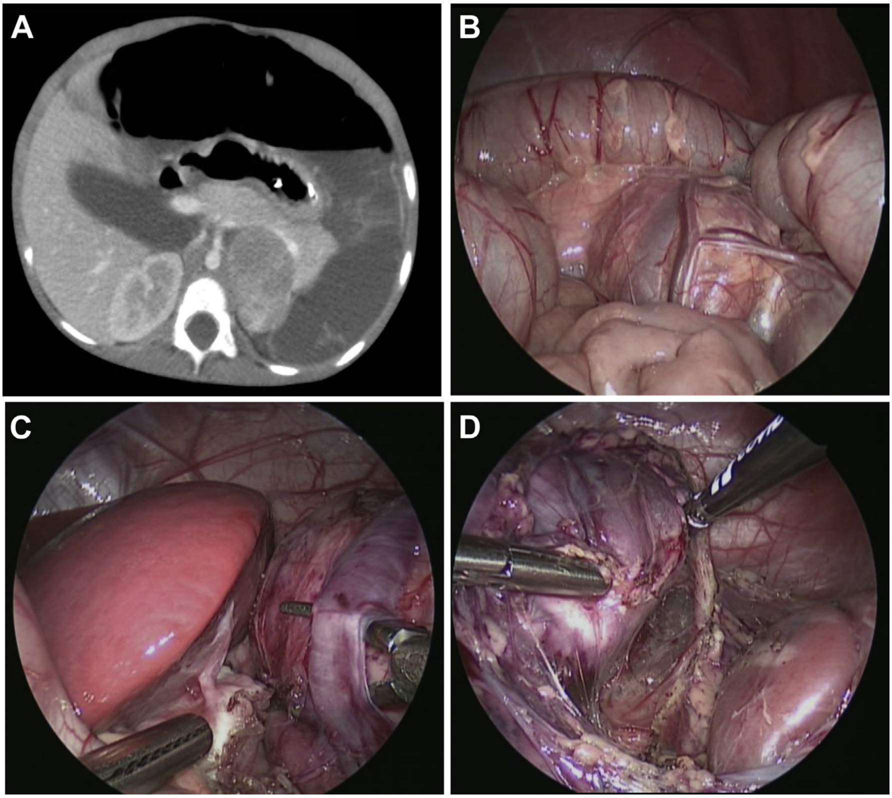

Fig. 1. Laparoscopic resection of a left adrenal neuroblastoma. (*A*) Preoperative computed tomography scan. (*B*) View of the tumor through the colon mesentery. (*C*) Isolation of the adrenal vein. (*D*) Elevation of the tumor from the left upper quadrant. (*Courtesy of* Harold N. Lovvorn, III, M.D).

factors (ie, L2 tumors), the role of MIS is uncertain because these tumors usually encase vital vascular structures. Because R0 resections are not required (or achievable) for L2 lesions, these tumors can be removed piecemeal and leave some residual disease behind. Therefore, some surgeons may undertake resections of L2 tumors, according to their experience and expertise, but most surgeons perform open resections of L2 tumors (**Fig. 2**).

Neuroblastic tumors can occur in the posterior mediastinum. These neoplasms are particularly well-suited for a thoracoscopic approach that avoids posterolateral thoracotomy, which, even with a muscle-sparing maneuver, may increase the risk of scoliosis development in pediatric patients. Tumors at the apex of the chest are particularly well-visualized with a thoracoscopic approach (**Fig. 3**). Thus, an increasing number of neuroblastic tumors are being removed with MIS.[9,10] Recently, Gurria and colleagues, along with the American Pediatric Surgery Cancer Committee published a comprehensive review of the role of MIS in the surgical management of neuroblastoma in children.[11]

Using MIS for neuroblastic tumors is in marked distinction to that for adrenocortical carcinomas (ACC) because adjuvant therapy is not very effective for ACC tumors and complete resection without spill or positive margins is critical for favorable oncologic

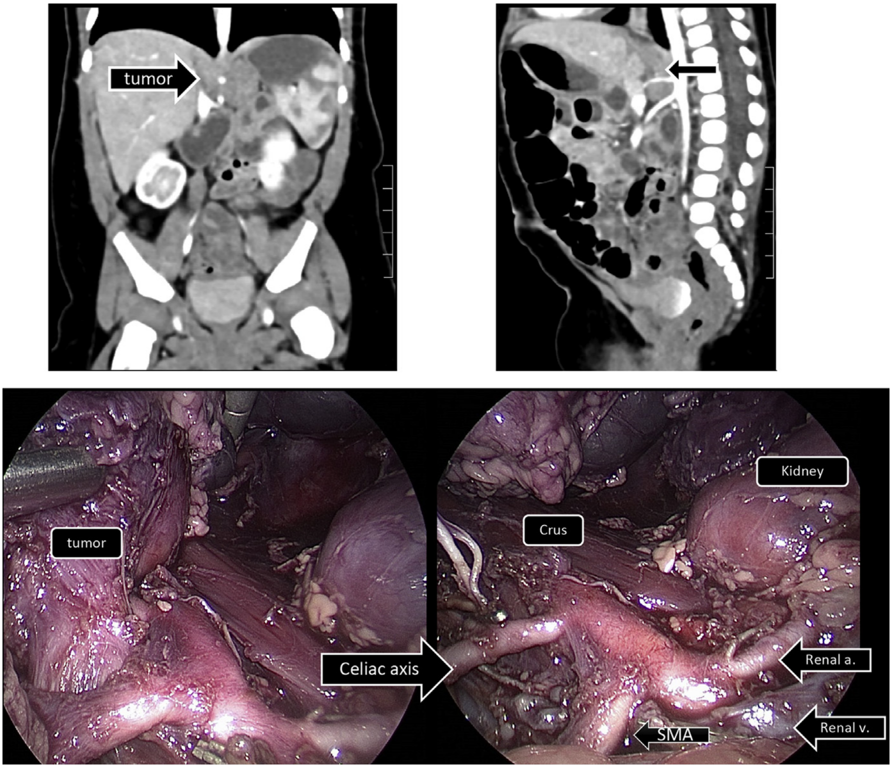

Fig. 2. Neuroblastoma with an image-defined risk factor (L2, encasement of the celiac axis) shown on coronal (*top*, *left*) and sagittal (*top*, *right*) views of the preoperative computed tomography scan. Laparoscopic mobilization of the tumor (*bottom*, *left*) and resection bed (*bottom*, *right*). (*Courtesy of* Harold N. Lovvorn, III, M.D.)

outcomes. Moreover, lymphadenectomy should be performed. Many studies now recommend that suspected ACC tumors should not be removed with a minimally invasive approach.[12,13] These are very friable tumors that can frequently rupture upon manipulation. Therefore, MIS should be discouraged when patients have an adrenal tumor and evidence of metastatic disease in the lung because such tumors are most likely ACCs. Other preoperative factors suggesting malignant tumors and thereby discouraging an MIS approach include large tumor size (>10 cm), local invasion, and lymph node involvement. However, minimally invasive approaches can generally be safely used for small, well-circumscribed, and most likely benign adrenal tumors. This approach can either be transperitoneal or retroperitoneal. MIS can also be used for the resection of pheochromocytomas after appropriate preoperative preparation and with careful intraoperative vascular control.

Renal Tumors

The most common renal tumor histology in children is a Wilms tumor, but other histologies include renal cell carcinomas, clear cell sarcomas of the kidney, rhabdoid tumors of the kidney, and mesoblastic nephromas. Uniformly, for all of these histologies the goal of surgery is complete resection, generally in the upfront setting, with negative margins and without tumor spill, and sampling of lymph nodes, even if

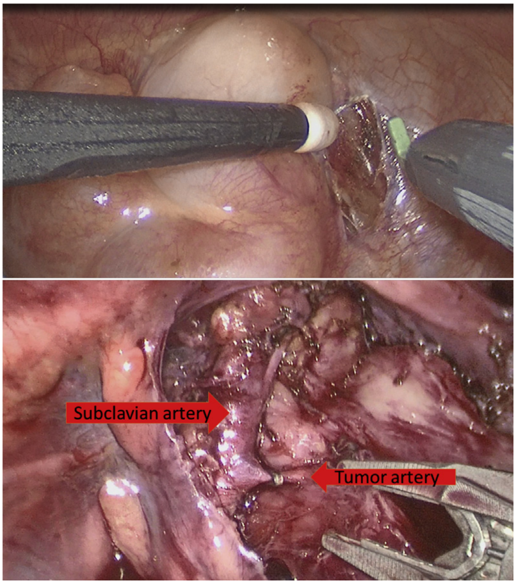

Fig. 3. Apical neuroblastoma before and after removal. (*Courtesy of* Hafeez Abdelhafeez, M.D.)

not apparently involved. This is especially important for Wilms tumor. Although not recommended by the Children's Oncology Group (COG) or the International Society for Pediatric Oncology, some surgeons elect to perform laparoscopic nephrectomies, particularly if the tumors are small and centrally located (and perhaps even surrounded by healthy kidney tissue).[14–16] A systematic review of MIS for pediatric renal tumors was published recently by Malek and the American Pediatric Surgical Association Cancer Committee.[17] Importantly, the recommended approach for treating Wilms tumors by the COG differs from that of the International Society for Pediatric Oncology. Specifically, the COG recommends upfront nephrectomy, whereas the International Society for Pediatric Oncology recommends nephrectomy after neoadjuvant chemotherapy. This difference affects the number of cases that may be amenable with a laparoscopic approach, with the International Society for Pediatric Oncology treatment strategy resulting in smaller, firmer tumors at the time of resection, which may be more suitable for an MIS approach.

Despite the enthusiasm for minimally invasive nephron-sparing surgery in adult patients with renal cell carcinoma, laparoscopic nephron-sparing surgery is rarely performed in children because of the risk of upstaging the tumors, thereby necessitating additional cytotoxic chemotherapy and radiation therapy.[18] Anatomically favorable (eg, polar or exophytic) pretreated tumors or small tumors found on surveillance imaging of syndromic patients may be the rare circumstance in which MIS may be attempted. However, Schmidt and colleagues[19] have suggested that, when a minimally invasive or open partial nephrectomy is considered, open partial nephrectomy should be favored to facilitate the preservation of long-term renal function.

Ovarian Tumors

The most common use for MIS in definitive solid tumor resection in children is for ovarian tumors, largely because of the favorable anatomic location of the ovary. The goals of surgery are different, however, depending on whether the tumor is malignant or benign. For malignant ovarian tumors, recommendations include performing a salpingo-oophorectomy on the ipsilateral side. For large tumors, a Pfannenstiel incision may be required to remove the tumor intact. In addition, inspection of the contralateral ovary, ipsilateral iliac lymph nodes, and omentum should be performed with biopsy of suspicious lesions in any of the sites and collection of ascites. This practice is distinct from the surgical management of benign ovarian tumors, in which ovarian-sparing tumor excision is now the standard of care (**Fig. 4**). Many investigators have found predictive criteria to assess the likelihood of whether a tumor is benign or malignant. The factors suggesting the likelihood of malignancy include tumor size greater than 10 cm, solid lesions (in contrast with cystic lesions), and elevated serum markers (alpha-fetoprotein and/or beta human chorionic gonadotropin).[20,21] For large cystic masses deemed benign, controlled drainage of the cyst can be performed to facilitate removal of the cyst wall through a very small incision. Other laparoscopic ovarian procedures include oophoropexy for girls or young women who will receive lower abdominal or pelvic radiation and ovarian tissue harvest for fertility preservation.

Lung Nodules

The most common use for MIS in pediatric patients with cancer is for the removal of lung nodules, most often to confirm the presence of metastatic disease or non-neoplastic etiologies, but occasionally as a therapeutic intervention. Because tactile sensation is lost during thoracoscopy, lesion localization may be required. The techniques for this include hook-wire, methylene blue, and ultrasound examination, among

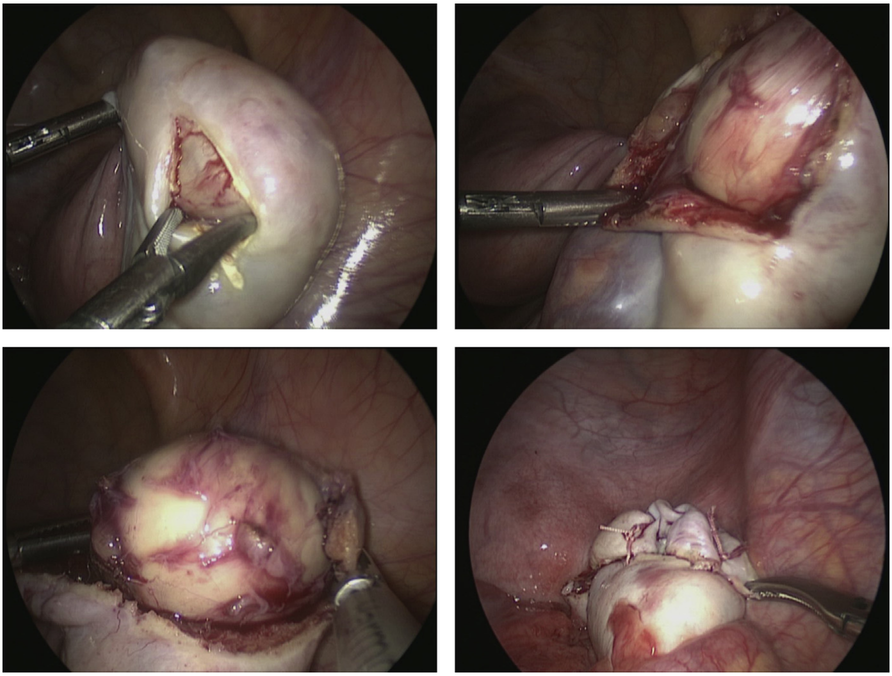

Fig. 4. Ovary-sparing laparoscopic resection of a benign ovarian tumor. The final view shows the edges of the normal ovary sewn over the raw surface at the site of tumor enucleation. (*Courtesy of* Harold N. Lovvorn, III, M.D.)

others. Occasionally, the removal of lung metastases may play a therapeutic role, particularly for tumor types that are relatively resistant to adjuvant therapies, such as osteosarcomas. However, whether thoracoscopy or thoracotomy should be used to manage pulmonary metastatic osteosarcoma is controversial because surgical clearance of all disease is required for potential cure. However, whether potentially delayed tumor clearance with multiple thoracoscopic procedures results in a survival disadvantage is unclear. To address this, COG surgeons plan to open a prospective, randomized trial of thoracoscopy versus thoracotomy for the resection of osteosarcoma metastases. Resection of solitary nodules with a thoracoscopic approach seems to be acceptable because additional metastases are unlikely to be present in this setting of minimal metastatic disease.[22]

Rhabdomyosarcomas

Rhabdomyosarcomas of the abdomen (eg, retroperitoneum or bladder) may be removed with a minimally invasive approach while maintaining the same surgical oncologic principles as for open resections. These procedures are usually performed after pretreatment with neoadjuvant chemotherapy and sometimes with radiation therapy. An additional indication is retroperitoneal lymph node dissection in boys older than 10 years with paratesticular rhabdomyosarcoma (**Fig. 5**). An MIS approach most likely spares the patient the postoperative discomfort associated with laparotomy and may prevent erectile dysfunction by providing a better visualization of pelvic nerves. New modifications to this approach, including limited lymph node sampling and sentinel lymph node biopsy, are currently being tested.[23]

ALTERNATIVE APPROACHES TO MINIMALLY INVASIVE SURGERY

Robotic-Assisted Surgery

Robotic surgeries are similar to laparoscopic and thoracoscopic surgeries because they both use small incisions through which specialized instruments are passed to enter a specific body cavity while monitoring the operation with a high-definition camera. In contrast with laparoscopic and thoracoscopic surgeries, robotic surgeries use instruments with a greater range of motion and precision. Laparoscopic and thoracoscopic instruments have only 4° of freedom, whereas robotic instruments typically have 7° of freedom, allowing a greater range of precise movements. Surgical robots also sense surgeon hand movements and translate and filter them electronically into smaller movements to manipulate the surgical instruments. The camera provides a stereoscopic picture transmitted to the surgeon's console. Although the first operative surgical robots in the United States were approved in 2000, they are not extensively

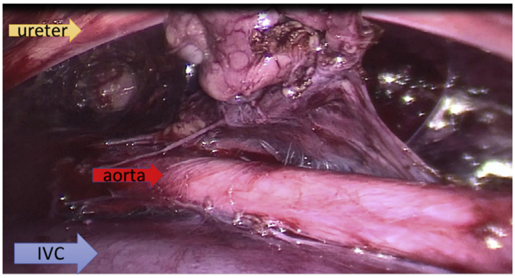

Fig. 5. Extraperitoneal exposure for retroperitoneal lymph node dissection in an older patient with paratesticular rhabdomyosarcoma. (*Courtesy of* Hafeez Abdelhafeez, M.D.)

used in pediatric surgical oncology because of the limited number of indications, cost, and instruments that are not well-suited for smaller patients.

Natural Orifice Transluminal Endoscopic Surgery

A relatively new approach to access the peritoneal cavity for performing surgery within the abdomen is via natural orifice transluminal endoscopic surgery, which accesses the abdominal cavity through a natural orifice under endoscopic visualization. Specifically, natural orifices are used to access intra-abdominal organs by passing an endoscope into the peritoneal space via a transgastric, transvaginal, transvesical, or transcolonic approach. Natural orifice transluminal endoscopic surgery is used in rare circumstances in adult surgical oncology for limited indications, including colorectal cancer, staging of gastrointestinal tumors, and splenectomy. However, to date, using natural orifice transluminal endoscopic surgery to manage solid tumors in children has not been reported.

ADJUVANTS TO MINIMALLY INVASIVE SURGERY

Three-Dimensional Visualization

Better visualization and preoperative planning using 3-dimensional (3D) imaging can improve surgical outcomes. Surgeons must mentally transform 2-dimensional images into 3D images, yet now this can be done by the imaging system, facilitating the surgeon's understanding of the tumor anatomy. Most radiology departments can provide 3D images during surgery, rotating the screen to improve anatomic understanding of the surgical field. With very limited resources, this process can be expanded to yield life-size 3D images and augmented reality images. The resection of renal tumors in which partial nephrectomy is warranted is a particularly useful application of 3D imaging. The incomplete resection rate is approximately 30%, and the resection rate of unilateral tumors with partial nephrectomy is less than 5%.[24–27]

With commercially available software and a 3D printer, life-sized models of the tumor, renal tissue, collecting system, and vessels in relation to each other can be rapidly produced (Fig. 6). Moreover, these models cost approximately $5 per model to print after a 3D printer is purchased.

The 3D Slicer software can create such 3D-printed surgical field models. This software package is free to use and reads MRI and computed tomography data. Either manual or semiautomatic segmentation techniques can be used to build the 3D models. The software allows for the export of standard 3D model formats, which are recognized by the 3D printer software. The dual extrusion Ultimaker S5 3D printer allows printing with multiple materials. The most common material (polylactic acid) is a

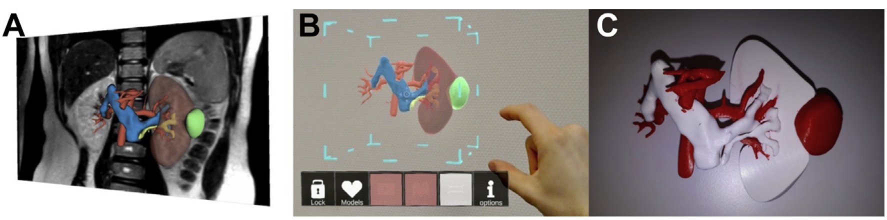

Fig. 6. (*Left*) The 3D model of a left sided renal tumor shown in 3DSlicer. (*Middle*) The same tumor visualized in augmented reality through a HoloLens. (*Right*) Again, the same patient's renal tumor as a life-size 3D printed model. (*From* Matthijs Fitski et al. MRI-Based 3-Dimensional Visualization Workflow for the Preoperative Planning of Nephron-Sparing Surgery in Wilms' Tumor Surgery: A Pilot Study; 2020: 2020; 3.)

standard plastic that facilitates printing without extensive knowledge. Other materials such as thermoplastic polyurethane (a flexible polymer) and polyvinyl alcohol (a soluble material) are more difficult to print, but are better for advanced 3D printing.

If 3D printing is not possible for a specific surgical field, 3D images can be used in a mixed reality device and viewed from all angles. This process permits the relation between the vessels and tumor to be assessed. Software can depict 3D anatomic images, and different anatomic and pathologic images can be switched on and off, or the transparency can be adjusted to yield various views of the surgical field. Additionally, MRI and computed tomography data can be shown in all 3 directions to correlate traditional imaging data with augmented reality images. This approach allows surgeons, patients, and families to more clearly understand the surgical process and goals.[28,29] The advantages of 3D printing are that it is reasonably inexpensive, has an acceptably short lead time for preoperative planning, is beneficial for advising patients and families when explaining procedures, and is real size, so that surgeons know the dimensions that can be expected. A disadvantage of the virtual modeling software is that the images can only be viewed by 1 person at a time, although multiple goggles can be synchronized. Another disadvantage of the virtual viewing technology is that some advanced knowledge of the hardware and software is needed; however, the hardware and software may become more accessible over time. In the near future, augmented reality may be used during operations by projecting augmented reality images of the kidney and overlaying them on the moving kidney of patients, making it possible to view the inside of the moving kidney during surgery.

Visual Field Augmentation

Another challenge that pediatric surgeons often face is that nearly all tumors are treated with preoperative chemotherapy, which makes it more difficult to discern malignant tumor tissue from scar tissue and benign tissue. To avoid unnecessary resection of healthy tissues and damage to vessels and organs, fluorescence-guided surgery improves the differentiation of tumors from the surrounding healthy tissue. Fluorescence-guided surgeries can be used in endoscopic and open surgery settings and may be used to determine the margins of resected tumors.[30,31]

The working mechanism of fluorescence is as follows. Characteristically, under the action of light, depending on wavelengths, the level of energy of the molecules increases; as soon as the level returns to its basal state, light is emitted. The difference between excitation and emission wavelengths is exploited thanks to cameras equipped with interferential filters to obtain the images. Fluorescent light emission is largely attenuated by hemoglobin and water as it traverses biological tissues. Hemoglobin strongly attenuates all wavelengths of light shorter than 700 nm, corresponding with the entire visible spectrum except deep red. Water is transparent in visible and near-infrared light, but attenuates wavelengths longer than 900 nm. Therefore, a window of wavelengths between the limits of deep red and near infrared (700–900 nm) wavelengths permits maximal tissue transparency. Because of this, indocyanine green (ICG) fluorescence can be detected as near-infrared light in tissues as deep as 10 mm from the surface.

Fluorescence can be used during sentinel lymph node resections in a similar method as conventional use of blue dyes. When using ICG for transecting lymph vessels, the whole operating field does not turn blue, as is the case with blue dyes, or green when the laser is switched off. Moreover, ICG does not permanently stain the skin, which can occur with blue dyes.[32]

However, using ICG during surgery does not preclude preoperative imaging with technetium, but may help in detecting lymph nodes that are superficially located.

ICG-guided near-infrared imaging has several advantages over that of other intraoperative detection methods. The maximum absorption (765 nm) and peak fluorescence emission (830 nm) wavelengths of ICG are in the near-infrared spectrum, permitting a depth of penetration of up to 10 mm and decreased background fluorescence. This factor enables the detection of tumor tissues even when obscured by blood or thin layers of tissue. In addition, ICG is relatively inexpensive and does not expose patients to ionizing radiation, in contrast with computed tomography scans or radiotracers. ICG is easy to use and does not interrupt the surgical workflow. The safety profile of ICG has been established in the pediatric population for other indications.

ICG can be administered intravenously to locate tumors and metastases in the lung, liver, and peritoneum. Because of the increased vascular permeability of ICG, it persists longer in tumor tissues than in healthy tissues. ICG injections are typically performed 24 hours before surgery to allow washout in healthy tissues and optimal tumor-to-background signal ratios. ICG use for hepatoblastoma tumor detection and resection is established, although the mechanism slightly differs from that of nonhepatic tissues. In hepatic surgeries, ICG is used to evaluate hepatic function and inform hepatectomy strategies for oncologic resections and transplants. After intravenous or direct intrabiliary injection of ICG, imaging allows for the visualization of the bile ducts and primary and metastatic liver tumors during surgery (**Fig. 7**).[33,34]

When ICG is administered intravenously before or during surgeries in variable time intervals, the liver surface is illuminated intraoperatively. Indeed, intravenous ICG administration of 0.25 to 0.50 mg/kg from 12 hours to 14 days before surgery helps to identify tumors by intraoperative fluorescence. After ICG injection, both healthy hepatocytes and tumor cells rapidly take up ICG. ICG is then excreted in the bile and dissipates from the healthy liver parenchyma within a few hours. In contrast, ICG persists in tumor cells and pathologic areas of the liver, particularly in the hypoactive hepatocytes located around nonhepatocellular tumors. Near-infrared cameras allow detection of hepatocellular (ie, tumor fluorescence) and nonhepatocellular tumors (ie, peritumoral fluorescence) because of retained ICG fluorescence. Similar to ICG, 5-aminolevulinic acid fluorescence can be used to discern glioma tumors from healthy brain tissue during neurosurgery.[35,36]

Intravenous ICG can also be used to visualize tissues at risk of hypoperfusion, such as difficult bowel anastomoses, free flap reconstructions, and extremity sarcoma surgeries in which 1 or more arteries are sacrificed.

Fig. 7. Near-infrared image showing accumulation of ICG of a lung metastasis in a child being treated for hepatoblastoma. (*Courtesy of* Hafeez Abdelhafeez, M.D.)

Fluorophore-labelled antibodies can also be used to assist surgical oncology techniques as immune therapy becomes more prevalent and more tumor-specific antibodies become available. Fluorophore-labelled antibodies can be used to visualize tumor cells after intravenous injection of the tumor-specific antibody used for treatment. Preclinical trials of the use of nanobodies for this purpose are also ongoing.

Before the use of fluorescence in surgical oncology becomes widely disseminated in practice, several aspects regarding tumor type and specific applications must be addressed. First, optimal injection times to achieve the best tumor-to-background ratio must be established for various tumor types. Second, the implication of residual fluorescence in tissues after resection must be determined for distinct tumor types. Third, different protocols must be established for various fluorophores and their surgical applications. The optimal dosing of each fluorophore and application, depending on patient weight, must also be determined. Nevertheless, intravenous ICG doses up to 4 mg/kg seem to be safe for children. Last, the cost, service, and availability of support for surgical imaging equipment are important considerations. The decision of whether to buy a single or dual wavelength laser and the possibility of endoscopic use are particularly important factors to consider.

Targeted fluorophores are promising and may improve the specificity and precision of fluorescence-guided surgeries. Although ICG is generally nonspecific beyond its perfusion and clearance kinetics, some fluorophores can be activated only in tumor-specific environments. For example, 5-aminolevulinic acid is administered orally and metabolized within glioma cells to yield a fluorescent molecule that remains nonfluorescent in surrounding tissues.[36]

Studies of fluorophore-conjugated monoclonal antibodies targeting tumor-specific antigens are also ongoing.[37] Indeed, a first-in-human, proof-of-concept study recently demonstrated the usefulness of a fluorophore conjugated to an epidermal growth factor receptor antibody for localizing glioblastoma tumors during resection. First-in-human intraoperative near-infrared fluorescence imaging of glioblastoma using cetuximab-IRDye800.[38] The opportunities to expand the field of theranostics (ie, using therapeutic agents for diagnostic purposes) are nearly limitless.

SUMMARY

MIS has advanced the field of surgical oncology. Many widely accepted uses for MIS in pediatric surgical oncology that are largely tumor type specific now exist. In some cases, however, the appropriateness of MIS is uncertain and should be discouraged. In all cases, when using an MIS approach, oncologic principles should be maintained, and the procedures should be performed by surgeons trained and experienced in these techniques. Newer technologies and surgical adjuncts are certain to further increase the role MIS plays in pediatric surgical oncology practice.

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DISCLOSURE

Authors have nothing to disclose.

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