Review Article

Robotic-assisted laparoscopy in pediatric surgical oncology: a narrative review

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Background and Objective: Robotic surgical oncology in children calls for experienced surgeons in minimally invasive surgery (MIS) and a solid oncological background. The aim of this review was to analyze the current state of robotic-assisted laparoscopy in pediatric tumor resection, assess the necessary framework of minimally invasive surgical oncology and describe future developments of the robotic technology.

Methods: A literature search of the MEDLINE/PubMed database was conducted, using the terms "robotic surgery", "pediatric" or "children" and "oncology" or "tumor". All relevant English-language studies published between 2008 and 2022 were reviewed.

Key Content and Findings: Although concerns have been raised regarding the use of MIS in surgical oncology, current literature reports similar oncological outcome if surgeons comply with the oncologic principles. The benefits of MIS have been established for robotic surgery in adult studies, including a shorter time to adjuvant chemotherapy. Surgical feasibility should be assessed based on tumor characteristics, preoperative imaging focusing on vascular involvement and surgeon's experience until clear guidelines are issued. The difficulties in establishing eligibility criteria for robotic resection of pediatric tumors lie in the great variability of indications, heterogeneity in tumor histology with their own surgical specificities, and wide range of age and weight, as shown by the literature review we performed. Between 2008 and 2022, 31 studies reported 171 cases with three studies including at least ten patients. The most reported procedure was adrenalectomy (41 cases). Current research in pediatric surgical oncology focuses on intraoperative locoregional treatment, improved vision with fluorescence and dyed-loaded specific probes and the many possibilities of enhancement software using the robotic console.

Conclusions: The robotic technology allows the surgeon to push the boundaries of conventional laparoscopy. Specific surgical guidelines are necessary.

Keywords: Robotic surgery; minimally invasive surgery (MIS); pediatric tumor; surgical oncology; pediatric surgery

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Introduction

The use of robotic surgery has spread in the pediatric population as precision and stability offered by the technology allow for minimally invasive treatment of more and more complex cases (1). Surgical oncology in children encompasses a wide range of surgical morbidity and difficulty, from simple organ removal to large tumors with vascular involvement and adjacent-organ invasion. All these procedures are to follow the oncologic principles to ensure the best possible oncologic outcome, keeping in mind that

Table 1 The search strategy summary

Items	Specification
Date of search	May 21st, 2022
Databases and other sources searched	MEDLINE/PubMed
Search terms used	Robotic surgery, pediatric/children, oncology/tumor
Timeframe	2008 to 2022
Inclusion and exclusion criteria	English-language studies included. Reviews, meta-analyses and studies with patients' overlap excluded; neurosurgery, orthopedics, ophthalmology and cardiac surgery excluded.
Selection process	Performed by N.V. (author)

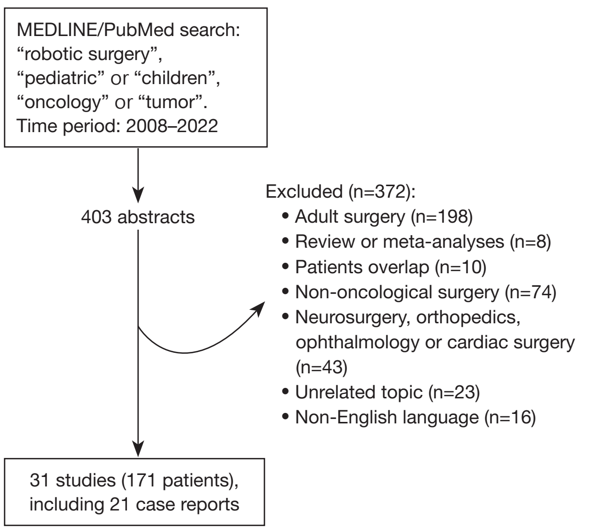

Figure 1 Flowchart of the reviewing process conducted on robotic-assisted surgical oncology in children.

our patients have a long life ahead of them. Managing these cases calls for experienced surgeons in minimally invasive surgery (MIS) and a solid oncological background (2).

The aim of this review is to analyze the current state of robotic-assisted laparoscopy in pediatric tumor resection, show the pitfalls in establishing clear guidelines in minimally invasive surgical oncology and describe future developments of the robotic technology. We present this article in accordance with the Narrative Review reporting checklist (available at https://tp.amegroups.com/article/view/10.21037/tp-23-251/rc).

Methods

A literature search of the MEDLINE/PubMed database was conducted, using the terms "robotic surgery", "pediatric" or "children" and "oncology" or "tumor". All relevant English-language studies published between 2008 and 2022 were retrieved. All types of studies regarding thoracic, abdominal or oral robotic surgery were sought, including case reports. Literature reviews, meta-analyses or studies with patients' overlap were excluded.

The search strategy summary is shown in *Table 1*.

Robotic surgical oncology in children

The difficulties in establishing eligibility criteria for robotic resection of pediatric tumors lie in the great variability of indications, heterogeneity in tumor histology with their own surgical specificities, and wide range of age and weight (3,4). The literature search we conducted on robotic-assisted surgical oncology (*Figure 1*) yielded a total of 31 studies reporting 171 cases between 2008 and 2022, including 21 (68%) case reports (*Table 2*). Only three studies counted ten patients or more. The five most reported procedures were partial or radical adrenalectomy (41 cases), partial or radical nephrectomy (30 cases), anterior or posterior mediastinal mass excision (17 cases), partial or radical ovariectomy (15 cases) and retroperitoneal lymph node dissection (14 cases).

The scarcity and great diversity of pediatric tumors are a serious impediment in building the large series needed to establish robotic surgery oncologic guidelines.

Initially intended for damage control surgery on the battlefield, robotic surgery was first reported in 1998 by Himpens *et al.* (5). Meininger *et al.* (6) were then the first to borrow this adult-designed surgical technology and use it in children in 2001. Seven years later, robotic surgery was first used for pediatric tumor resection (7).

Table 2 Results of the literature search on cases of robotic-assisted surgical oncology in children between 2008 and 2022

Authors	Year	Surgical procedure	Tumor pathology	Total # cases (N=171)	# cases (N=171)	Age at surgery (years)	Conversion rate	Complications
Meehan *et al.*	2008	Mediastinal mass excision	Neuroblastic tumor	5	2	9.8 [2–17]	0	0
			Mature teratoma		1			
			Germ cell tumor		1			
			Inflammatory mass of unclear etiology		1			
Rogers *et al.*	2008	Partial adrenalectomy	Pheochromocytoma	1	1	14	0	0
Meehan *et al.*	2008	Radical ovariectomy	Mature teratoma	10	1	NA	40% (4/10)	Incomplete resection (neuroblastoma)
		Partial ovariectomy	NA		1			
		Unilateral adrenalectomy	Neuroblastoma		6			
			Pheochromocytoma					
		Resection of pancreatic tumor	NA		1			
		Retroperitoneal tumor resection	Ganglioneuroma		1			
Cost *et al.*	2012	RPLND	Paratesticular embryonal rhabdomyosarcoma	2	1	15	0	0
			Malignant non-seminomatous germ-cell tumor		1			
Cost *et al.*	2012	Partial nephrectomy	Clear cell renal carcinoma	1	1	14	0	0
Kokot *et al.*	2013	TORS	Synovial sarcoma	1	1	15	0	0
Cost *et al.*	2015	Radical nephrectomy	Wilms tumor (prechemotherapy)	1	1	14	0	0
Glaser *et al.*	2017	RPLND	Non-seminomatous germ cell tumor	2	1	15 and 17	0	0
			Ectomesenchymoma with a spindle-cell rhabdomyosarcoma component		1			
Hu *et al.*	2017	Distal pancreatectomy	Insulinoma	1	1	9	0	0
Yadav *et al.*	2018	Partial nephrectomy	Wilms tumor	1	1	1.5	0	Lymphorrhea
Agarwal *et al.*	2018	Radical prostatectomy	Embryonal rhabdomyosarcoma	1	1	7	0	0
Hagendoorn *et al.*	2018	Pancreatoduodenectomy	Solid pseudopapillary tumor	1	1	10	0	Delayed gastric emptying
Arnold *et al.*	2018	TORS	Neurofibroma	1	1	6	0	Incomplete resection

Table 2 (*continued*)

Table 2 (*continued*)

Authors	Year	Surgical procedure	Tumor pathology	Total # cases (N=171)	# cases (N=171)	Age at surgery (years)	Conversion rate	Complications
Liang *et al.*	2018	Pancreatic enucleation	Insulinoma	1	1	9	0	0
Varda *et al.*	2018	Partial nephrectomy	Papillary renal cell carcinoma	4	1	3–17	0	0
		Unilateral adrenalectomy	Ganglioneuroma		1			
		RPLND	Paratesticular rhabdomyosarcoma		2			
			Non-seminomatous germ-cell tumor					
Lalli *et al.*	2019	Distal pancreatectomy	Solid pseudopapillary tumor	1	1	17	0	0
Llorens de Knecht *et al.*	2019	Radical prostatectomy	Primitive prostatic carcinoid tumor	1	1	3	0	Two febrile episodes, death due to local recurrence and bone metastasis
Xie *et al.*	2019	Ovarian tumorectomy	Mature teratoma	4	3	7.5 [1–13]	0	0
			Mucinous cystadenoma		1			
Navarrete Arellano *et al.*	2019	Unilateral adrenalectomy	Pheochromocytoma	4	1	4.8 (average)	25% (1/4)	0
		Radical nephrectomy	NA		1			
		Mediastinal mass excision	Mature teratoma		1			
		Retroperitoneal mass excision	Lipoma		1			
Canevari *et al.*	2020	TORS	Base-tongue Ewing sarcoma	1	1	16	0	0
Brown *et al.*	2020	RPLND	Testicular or paratesticular cancer (NA)	4	4	NA	NA	NA
Mitra *et al.*	2020	Unilateral adrenalectomy	Ganglioneuroblastoma	3	2	2–13	0	0
			Pheochromocytoma		1			
Silveri *et al.*	2020	Partial nephrectomy	Perivascular epithelioid cell tumor	1	1	14	0	0
Nishio *et al.*	2020	Radical cystectomy	Embryonal rhabdomyosarcoma	1	1	6	0	0
Nota *et al.*	2021	Distal pancreatectomy	Neuroendocrine tumor	1	1	11	0	0
van Ramshorst *et al.*	2021	Central pancreatectomy	Solid pseudopapillary tumor	1	1	16	0	Grade B pancreatic fistula
Schulte Am Esch *et al.*	2021	Pancreatic enucleation	Insulinoma	1	1	10	0	Pancreatic pseudocyst

Table 2 (*continued*)

Table 2 (*continued*)

Authors	Year	Surgical procedure	Tumor pathology	Total # cases (N=171)	# cases (N=171)	Age at surgery (years)	Conversion rate	Complications
Lowrey *et al.*	2021	Unilateral adrenalectomy	Adrenocortical tumor	1	1	4	0	0
Li *et al.*	2021	Partial or radical cystectomy	Bladder/prostate rhabdomyosarcoma	8	8	NA	NA	NA
Vatta *et al.*	2022	Radical ovariectomy	Mature teratoma	13	4	13.2 [8–16.9]	0	0
		Partial ovariectomy	Mature teratoma		5			
			Serous cystadenoma					
			Mucinous cystadenoma					
			Seromucinous cystadenoma					
		Pelvic mass excision	Serous papillary cystadenofibroma of the fallopian tube		2			
		Mediastinal mass excision	Ganglioneuroblastoma		1			
		Perirenal mass excision	Neuroblastoma recurrence		1			
Blanc *et al.*	2022	Unilateral adrenalectomy	Neuroblastic tumor	93	18	8.2 [3.6–13]	8% (7/93)	Pneumothorax (n=2), postoperative collection (n=1), anastomotic stenosis (n=1), bowel adhesion (n=1)
			Pheochromocytoma					
			Adrenocortical adenoma					
		Bilateral adrenalectomy	McCune Albright		5			
			Carney complex					
			Pheochromocytoma					
		Radical nephrectomy	Wilms tumor		17			
			Undifferentiated renal sarcoma					
		Radical nephrectomy with caudal splenopancreatectomy	Wilms tumor		1			
		Partial nephrectomy	Wilms tumor		6			
			Tubular papillary carcinoma					
			Metanephric adenoma					
			Nephrogenic rest					
		Central pancreatectomy	Focal congenital hyperinsulinism		3			

Table 2 (*continued*)

Table 2 (*continued*)

Authors	Year	Surgical procedure	Tumor pathology	Total # cases (N=171)	# cases (N=171)	Age at surgery (years)	Conversion rate	Complications
			Somatostatinoma					
		Distal pancreatectomy	Focal congenital hyperinsulinism		1			
		Mediastinal mass excision	Neuroblastic tumor		10			
			Mature teratoma					
		Thymectomy	Thymoma		4			
			Myasthenia					
			Prophylactic thymectomy for MEN1					
		Partial gastrectomy	Inflammatory myofibroblastic tumor		1			
		Radical gastrectomy (totalization)	Inflammatory myofibroblastic tumor		1			
		Pulmonary lobectomy	Bronchial carcinoid tumor		1			
		Pelvic mass excision	Lipoma		9			
			Embryonal rhabdomyosarcoma					
			Neurofibroma					
			Inflammatory myofibroblastic tumor					
			Mature teratoma					
			Germ cell tumor					
			Neuroblastic tumor					
			Paraganglioma					
		Omentectomy	Inflammatory myofibroblastic tumor		1			
		Mesenteric mass excision	Leiomyoma		1			
		RPLND	Seminomatous or Non-seminomatous germ cell tumor		4			
		Retroperitoneal tumor resection	Neuroblastic tumor		10			
			Paraganglioma					

In the "Age at surgery" column, data are presented as median [range], number, or range unless otherwise specified. NA, not available; RPLND, retroperitoneal lymph-node dissection; TORS, transoral robotic surgery; MEN1, multiple endocrine neoplasia type 1.

Contrary to adult surgery, the development of a new technology in children cannot wait for randomized control trials. This was the case with laparoscopy and robotic surgery is no exception. Potential benefits and pitfalls are inferred from retrospective studies (8). Pediatric robotic-assisted surgical oncology has spread without ironclad proof of safety and effectiveness (9), hence the initial skepticism that surrounded its initial use.

The use of MIS in surgical oncology has long been debated. The main concern was the risk of incomplete resection and recurrence (10,11). When performing such procedures, abiding by the oncologic principles is paramount: avoid tumor spillage, *en-bloc* macroscopically complete resection, optimal lymph node resection and preserving adjacent organs (3,12,13). MIS does not worsen the oncologic outcome as long as the above-mentioned principles are respected, as shown by Bouty *et al.* (14) or Blanc *et al.* (15) for the resection of Wilms tumor using laparoscopy or robotic-assisted surgery, respectively. Furthermore, MIS is associated with a shorter time to adjuvant chemotherapy in large adult series (16,17) and might, therefore, improve the oncologic outcome in selected cases.

Several other concerns have been addressed in the literature: the greater risk of port-site tumor recurrence, which has been disproven by adult series (18,19); the lack of haptic feedback as a possible cause of tumor rupture, which has been replaced by an enhanced visualization of the tension applied to the tissue and limited tumor manipulation (20); and the need for a larger scar to extract the tumor since the latter can be concealed and reduced to the minimum to allow safe extraction (21,22).

While the benefits of MIS on postoperative outcome are being reported in children (23,24), they have been established for robotic surgery in adult studies. For adult pancreatic resection, MIS has been shown to decrease intraoperative blood loss and postoperative complications, reduce time to oral intake and length of hospital stay, without any difference on mortality and reoperation rate compared to an open approach in a meta-analysis by Nigri *et al.* (25). Robotic pancreatic resection has also been shown to decrease the conversion rate compared to laparoscopy in adults with benign or malignant lesions of the distal pancreas (26), decrease the rate of postoperative fistula compared to open Whipple's procedure in adults (27) and significantly improve spleen preservation in pancreatic caudal resections compared to laparoscopy in adult benign or malignant pancreatic lesions (28). A randomized control trial on robotic versus laparoscopic oncologic gastrectomy in adults has also yielded great results with a higher Clavien ≥II complication rate in the laparoscopic group, no difference regarding the number of retrieved lymph nodes or surgical curability and an improved postoperative recovery in the robotic group (29). A comparative study on robotic versus open thymectomy in adult myasthenia and thymoma has shown a significant decrease of postoperative pain and hospital stay without any difference in operative time and postoperative complications (30). In retroperitoneal lymph node dissection, a large cohort study of testicular and para-testicular cancer, including pediatric patients, reported a significantly shorter length of hospital stay using the robotic technology compared to a non-robotic approach (31). MIS retroperitoneal lymph node dissection is also associated with a lower rate of retrograde ejaculation and bowel complication compared to an open approach, although the risk of vascular injury and chylous ascites was greater (32).

Vascular involvement remains one the greatest challenges of minimally invasive pediatric surgical oncology (15). Surgical feasibility should be assessed based on tumor characteristics, preoperative imaging possibly with tridimensional reconstruction and surgeon's experience until clear guidelines are issued.

The growing number of cases entails the development of surgical guidelines for robotic surgery, similar to the use of image-defined risk factors in the laparoscopic treatment of neuroblastic tumors (33,34). Robot-specific guidelines are required as robotic technology has pushed the boundaries of laparoscopic surgery in terms of surgical complexity (3). Robotic surgery is closer to open surgery than laparoscopy with a less steep learning curve, allowing for the resection of larger and more complex tumors than laparoscopy (7,15). The substantial experience of Blanc *et al.* (3) in robotic surgical oncology led to a primary set of guidelines in patient selection based on tumor location and pathology, as shown in *Table 3*.

The widespread use of robotic surgery paved the way for future technologic advancements. Current research in pediatric surgical oncology focuses on intraoperative locoregional treatment, improved vision with fluorescence and dyed-loaded specific probes and the many possibilities of enhancement software using the robotic console (35). A case of pediatric pancreatic enucleation using a robotic ultrasound probe with dual visual and ultrasound images integrated in the robotic console was recently reported (36). Tridimensional image overlay can be implemented in the console to guide the

Table 3 Guidelines on patient selection in robotic surgical oncology published by Blanc *et al.* (3)

Tumor type	Robotic surgery may be considered	Relative contraindications	Formal contraindications
Thoracic tumors	Paravertebral neuroblastoma	Age <2 years old (limited access)	Encasement of vessel
	Tumor limited to the thymic bed (teratoma, thymoma)		Mediastinal extension (pericardium, esophagus, trachea)
	Lung resection (single metastasis)		
Renal tumors	Tumor not crossing the ipsilateral border of the spine AND	Tumor with a thin rim of normal parenchyma	Tumor crossing the midline
	Tumor with a thick rim of normal parenchyma AND	Tumor crossing the ipsilateral border of the spine (but not the midline)	Tumor infiltrating extrarenal structures (liver, diaphragm)
	Tumor without any sign of infiltration of extrarenal structures AND		Tumor with encasement of renal vessels (e.g., sarcomas, carcinomas)
	ETV/EPBV <1.5%	ETV/EPBV 1.5–2%	ETV/EPBV >2%
Neuroblastic tumors	Paravertebral (thoracic, abdominal or pelvic) neuroblastoma without foramen extension	One or two IDRFs	>2 IDRFs
	Adrenal tumor	Paravertebral neuroblastoma with foramen extension but without spinal component	Any IDRF number involving median vessels and/or both renal pedicles
	Neuroblastoma of the Zuckerkandl ganglia		Paravertebral neuroblastoma with foraminal and intraspinal extension
	ETV/EPBV >1% AND	ETV/EPBV 1–2%	ETV/EPBV >2%
	No IDRF		
Paragangliomas/ pheochromocytomas			Encasement of major vessels
Adrenocortical carcinomas			All adrenocortical carcinomas
Solid pseudopapillary neoplasms			All solid pseudopapillary tumors

ETV/EPBV, ellipsoid tumor volume (0.52 × width × length × height, mm^3) over estimated patient blood volume (75 mL/kg for children >3 months); IDRF, image-defined risk factors.

surgeon's hand (37). Such an approach has proven beneficial for patients with a decreased complications rate, better resection margins and preserved renal function in a multicentric study on partial nephrectomy in adult renal cancer (38). Several papers have reported the use of Indocyanine green in tumor resection using Firefly® (Intuitive Surgical, Sunnyvale, CA, USA), the dedicated robotic interface for near-infrared-fluorescence-guided surgery, both in pediatric and adult surgery (39-41). Robotic gamma detection probes are also being explored for radio-guided surgery as described by Martelli *et al.* who used radiopharmaceuticals for the resection of neuroblastic tumors (42).

Andras *et al.* (43) have reviewed possible applications of integrated artificial intelligence in robotic surgery: as an assessment tool for surgical skills in surgical training, to predict operative time and postoperative outcome based on clinical and intraoperative data, to replace haptic feedback with a suture breakage warning system, or using enhanced reality as surgical guidance. Autonomous robotic surgery with human supervision could be a future prospect as the use of such a technology has already been described on human cadavers (44). With continued miniaturization and instrumentation improvements, robotic surgery should be able to overcome its current challenges in the pediatric population, namely in neonatal surgery with the use of 3-mm robotic instruments (45).

Conclusions

The robotic technology may reduce the morbidity of surgical oncology in children and improve the postoperative outcome in terms of pain, recovery, hospital stay and scarring. The oncologic outcome remains the primary goal and robotic-assisted laparoscopy cannot be used at the expense of the oncologic principles. The robotic technology allows the surgeon to push the boundaries of conventional laparoscopy. Specific surgical guidelines are, therefore, necessary to define the indications and contraindications of robotic resection for pediatric tumors. Their heterogeneity and scarcity make it all the more difficult and underline the need to identify expert centers.

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Footnote

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