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REVIEW ARTICLE

Robotic endocrine surgery: technical details and review of the literature

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Abstract Over the last decade, robotic technology has been used in multiple general surgical procedures. Endocrine surgeons have embraced this technology and subsequently transformed neck operations into more cosmetically acceptable procedures and improved ergonomics. Technical details of various robotic endocrine surgical procedures have recently been described. The aim of this review is to illustrate these technical details and analyze the current data to propose an evidence-based approach to robotic endocrine surgery.

Keywords Robotics · Endocrine surgical procedures · Adrenalectomy · Thyroidectomy · Parathyroidectomy

Introduction

The history of robotic surgery goes back to AESOP (Automated Endoscopic System for Optimal Positioning; Computer Motion, Goleta, CA), which was the first robotic surgical system approved by the Food and Drug Administration (FDA) [1]. At that time, laparoscopic surgical techniques had already become the gold standard for various abdominal procedures. Initially, the idea motivating the use of robotic technology within the field of laparoscopic surgery was to create a situation in which the surgeon could function solo, without the need of assistants. To this end, AESOP was designed as a camera holder in laparoscopic surgery. However, the da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA) was subsequently developed with the purpose to remotely control laparoscopic instruments; this system was approved by the FDA for use in general surgical procedures in 2000. This was followed by the ZEUS robotic surgical system (Computer Motion, Goleta, CA), which was also approved by the FDA. In 2003, the latter two companies decided to merge to develop the da Vinci robotic surgical system [2, 3].

The initial clinical studies with robotic assisted laparoscopic surgery were reported from Europe. In 2001, Cadiere et al. [4] reported 146 cases that were performed laparoscopically using the robot, beginning in 1997 with fundoplication. This was the first published clinical study on robotic-assisted surgery and included gynecologic, urologic, and general surgical procedures. The first report from the USA was published by Horgan et al. [5] at the end of 2001. They had performed 34 advanced laparoscopic cases, but only one endocrine surgical procedure (bilateral adrenalectomy), using the da Vinci system.

The use of robot assisted techniques in head and neck surgery was delayed because of the narrow operative field, lack of working space, and risk of injury to critical nerves and vessels. Nevertheless, in 2005, 8 years after the first application of robotic technology in general surgery, Lobe et al. reported the first clinical application of robotic neck surgery [6]. Since then, multiple studies have been published on the safety and feasibility of robotic endocrine surgery.

In 2008, our group established a robotic endocrine surgery program and developed techniques for various robotic endocrine surgical procedures. The aim of this report is to

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describe the technical details of robotic endocrine surgical procedures using an evidence-based approach.

Robotic thyroidectomy

Minimally invasive approaches to neck pathologies have gained popularity during the last 15 years. In this period, several techniques for minimal invasive thyroidectomy have been described. The first endoscopic approach to neck surgery was described by Gagner in 1996 for a 3 ½ gland parathyroidectomy; this was followed by a report by Hüscher et al. on the first endoscopic right thyroid lobectomy [7, 8]. After these initial reports, various methods, including axillary, breast, axillo-breast, and anterior chest approaches, were described by several groups [9–12]. However, endoscopic surgery has several limitations, such as technical difficulties associated with nonflexible endoscopic instruments, video camera platform instability, two-dimensional and inadequate visualization, unsatisfactory operator ergonomics, and a long learning curve [4, 13]. Robotic surgical technology was developed to overcome these limitations.

In 2005, the first clinical use of da Vinci surgical system in head and neck surgery was reported by Lobe et al. [6]. They performed right thyroid lobectomy through a combination of endoscopic and robotic techniques and concluded that the transaxillary approach was feasible and safe in terms of avoiding cervical scarring. They also described the robotic instruments as having greater degrees of freedom and emphasized that three-dimensional visualization facilitated manipulation in the narrow space. In 2006, gasless endoscopic thyroidectomy via an axillary approach was reported in a series of 30 cases by Yoon et al. [14]. These authors commented that this technique provided a wider and clearer working space. More recently, Kang et al. in South Korea developed a robotic-assisted gasless transaxillary approach for removal of the thyroid gland [15, 16]. This technique was initially performed via double incisions in the axilla and chest or the neck [13, 16]. Different approaches, such as the concomitant bilateral axillary breast, combined axillary and sternal, and bilateral transaxillary procedures, have also been described for total thyroidectomy [17–19]. Chung and colleagues subsequently modified this technique, abandoned the cervical incision, and described a single axillary incision technique for total thyroidectomy. One study comparing single- versus two-incision techniques for robotic thyroidectomy (RT) reported similar surgical outcomes, better cosmesis, and improved patient comfort using the single-incision approach [20]. The reported series of RT and perioperative outcomes are given in Table 1 [13, 15–17, 19–32].

Chung and colleagues defined the indications for robotic transaxillary thyroidectomy as well-differentiated thyroid carcinoma less than 2 cm without extrathyroidal extension, lateral lymph node metastasis, and distant metastasis [25]. They described the exclusion criteria for RT as including a history of previous neck operations and severe Grave's disease. For nodules with follicular proliferation, their cut-off size was ≤5 cm without posterior location [15]. When the reported series are analyzed for conversion to open thyroidectomy, it can be seen that only one of the conversions due to bleeding is reported in the literature [21].

A number of studies have compared RT with the conventional open technique [16, 27, 28]. Kang et al. [16] reported a shorter operation time, fewer postoperative complications, and a similar number of retrieved lymph nodes for RT. In a prospective study comparing the open procedure with RT, Lee et al. [28] showed an excellent cosmetic outcome, reduced postoperative neck and swallowing discomfort, similar pain level and number of retrieved central lymph nodes, but higher operative times for RT. In another comparison study by Tae et al. [27], higher operative time and chest pain, lower number of removed lymph nodes, and better cosmetic results were reported for RT.

Miyano et al. [32] used the techniques of robotic and nonrobotic-assisted bilateral transaxillary endoscopic approach (BAEA) in a small series involving nine pediatric patients with Grave's disease. They subjectively commented on several advantages of BAEA, such as improved cosmetic results, lower morbidity, less postoperative pain, and an early return to normal activity, but they did not report any comparison between these two techniques. The first study comparing the endoscopic and robotic approach was reported by Lang et al. [24], who reported a longer operation time and higher postoperative pain level for RT versus endoscopic thyroidectomy. On the contrary, Lee et al. [13] found RT to be superior to the endoscopic approach in terms of total operation time, number of retrieved cervical lymph nodes, and learning curve. Moreover, they also emphasized the three-dimensional (3D) view using a stable camera and the elimination of hand tremor as other superior features of RT compared with the traditional endoscopic thyroidectomy. In another study, the same group reported increased surgeon comfort and decreased neck and/or back pain duration after robotic versus open and endoscopic approaches [21]. The first human experience in the USA reported in the literature was by our group in 2010 involving two patients [29].

The first reported completion thyroidectomy using the robotic single incision transaxillary approach in the USA was by Landry et al. [33]. Subsequently, Kandil et al. [34] reported that completion thyroidectomies following diagnostic lobectomies could be adequately performed through

Table 1 Summary of robotic thyroidectomy studies

First author	N	Procedure[a]	Diagnosis[b] (N)	Operation type	CLND[c] (n)	TNM staging (N)	Mean tumor size (cm)	Length of procedure (min)	Mean hospital stay (days)	Complication (n)
Lee [21]	2,014	RATT	PTC (1,947)	Total (740); subtotal (1,274)	CCND (1,865)	I (1,662)	0.8	119.7	3.4	Transient hypocalcemia (257); transient hoarseness (60); permanent RLN injury (9); permanent hypocalcemia (1); hematoma (21); tracheal injury (4); chyle leakage (14); brachial plexus neuropraxia (5); Horner's syndrome (1); seroma (38)
			FC (6)	Subtotal (1,274)	CCND + MRND (61)	II (8)				
			HCC (1)		CCND + SLND (11)	III (272)				
			MTC (5)			IVA (17)				
			Benign (55)							
Seybt [22]	8	RATT	Benign (8)	Total (1)	0	0	NR	NR	NR	Pulmonary emboli (1)
				Subtotal (7)						
Lee [13]	163	RATT	PTC (151)	Total (48)	CCND (149)	I (134)	0.87	110.1	2.8	Transient hypocalcemia (6); transient hoarseness (3); permanent hoarseness (1); hematoma (1); seroma (5); chyle leakage (1); brachial plexus neuropraxia (1)
			FC (1)	Subtotal (115)	SLND (3)					
			Benign (11)							
Kang [23]	33	RATT	PTC (33)	Total (33)	MRND (33)	I (25)	1.09	280.8	5.4	Transient hypocalcemia (17); seroma (4); transient hoarseness (2); chyle leakage (3)
						IVA (8)				
Lee [17]	139	RBABA	PTC (132)	Total (121)	CCND (117)	I (92)	0.69	206	3.4	Transient hypocalcemia (21); hematoma (1); transient RLN palsy (17); chyle leakage (1)
			Benign (7)	Subtotal (18)	SLND (4)	III (17)				
Lang [24]	7	RATT	Malign (1)	Total (4)	0	NR	2.5	149	2[f]	Permanent RLN injury (1)
			Benign (7)	Subtotal (3)						
Landry [19]	11 (12)[d]	RATT	PTC (1)	Completion (1)	0	NR	2.1	142	1[f]	Wound infection (1); severe shoulder pain (1); transient unlar nerve palsy (1); hematoma (1)
			FTC (1)	Subtotal (11)						
			Benign (9)							
Ryu [20]	281	Single-incision RATT	PTC (279)	Total (109)	CCND (NR)	I (244)	0.73	114.9	3.1	Transient hypocalcemia (42); seroma (4); transient RLN palsy (2); hematoma (1)
			FTC (1)	Subtotal (172)		III (37)				
			MTC (1)							
	766	Two-incision RATT	PTC (763)	Total (262)	CCND (NR)	I (639)	0.78	134.8	3.4	Transient hypocalcemia (91); seroma (19); transient RLN palsy (38); hematoma (15); permanent RLN injury (9); brachial plexus neuropraxia (2)
			FTC (1)	Subtotal (504)		III (126)				
			MTC (2)			IVA (1)				

Table 1 continued

First author	N	Procedure[a]	Diagnosis[b] (N)	Operation type	CLND[c] (n)	TNM staging (N)	Mean tumor size (cm)	Length of procedure (min)	Mean hospital stay (days)	Complication (n)
Lee [25]	1,043	RATT	PTC (1,041)	Total (366)	CCND (940)	1 (878)	0.8	132.4	2.9	Permanent RLN injury (5); brachial plexus neuropraxia (3); hematoma (5); seroma (21); transient hypocalcemia (192); tracheal injury (3); transient hoarseness (45); Horner's syndrome (1); chyle leakage (12)
			FTC (2)	Subtotal (677)	SLND (11)	II (7)				
					MRND (35)	III (152)				
						IV (6)				
Lee [26]	644	RATT	PTC (616)	Total (353)	CCND (644)	I (530)	0.87 (in ES)	NR	NR	Permanent RLN injury (5), Brachial plexus neuropraxia (1),
			FTC (13)	Subtotal (291)		III (99)	0.79 (in NS)	NR		Permanent hypocalcemia (2); hematoma (3); seroma (11); transient hypocalcemia (62); tracheal injury (1); transient hoarseness (16)
			Benign (15)							
Tae [27]	41	RATT	PTC (27)	Total (10)	CCND (24)	NR	1.63	179	6.4	Transient RLN palsy (1); transient hypocalcemia (2); seroma (2)
			Benign (14)	Subtotal (31)						
Lee [28]	41	RATT	Malign (41)	Total (26)	CCND (41)	I (37)	0.83	128.6	2.5	Transient hypocalcemia (5); transient hoarseness (1); seroma (2)
				Subtotal (15)		III (4)				
Berber [29]	2	RATT	PTC (1)	Total (1)	0	I (2)	1.4	130[e]	1	Transient hypocalcemia (1)
			HCC (1)	Subtotal (1)						
Kang [15]	338	RATT	PTC (332)	Total (104)	CCND (332)	I (281)	0.8	144	3.3	Transient hypocalcemia (43); brachial plexus neuropraxia (1); permanent RLN injury (3); transient hoarseness (13); seroma (6); hematoma (2); Horner's syndrome (1)
			Benign (6)	Subtotal (234)		III (50)				
						IVA (1)				
Lee [30]	15	RBABA	PTC (15)	Total (13)	CCND (12)	NR	NR	218	3.5	0
				Subtotal (1)	SLND (1)					
Kang [31]	200	RATT	PTC (200)	Total (45)	CCND (200)	I (165)	0.8	141.1	3.2	Transient hypocalcemia (12); permanent RLN injury (1); transient hoarseness (8), seroma (2)
				Subtotal (155)		III (34)				
						IVA(1)				

Table 1 continued

First author	*N*	Procedure[a]	Diagnosis[b] (*N*)	Operation type	CLND[c] (*n*)	TNM staging (*N*)	Mean tumor size (cm)	Length of procedure (min)	Mean hospital stay (days)	Complication (*n*)
Kang [16]	100	RATT	PTC (100)	Total (16) Subtotal (84)	CCND (100)	I (83) III (16) IVA (1)	0.79	136.5	3[g]	Transient hypocalcemia (1), transient hoarseness (2)
Miyano [32]	2	RABEA	Benign	Total (2)	0		0	NR	385	NR

RLN recurrent laryngeal nerve; NS, non-robotic thyroid surgery experienced surgeon group, *ES* robotic thyroid surgery experienced surgeon group

[a] *RATT* Robotic-assisted transaxillary thyroidectomy, *RBABA* robotic-assisted bilateral axillo-breast approach, *RABEA* robotic-assisted bilateral transaxillary endoscopic approach

[b] *PTC* Papillary thyroid carcinoma, *HCC* Hürthle cell carcinoma, *FC* follicular carcinoma, *MTC* medullary thyroid carcinoma

[c] *CLND* Cervical lymph node dissection, *CCND* central compartment node dissection, *MRND* modified radical neck dissection, *SLND* selective lateral node dissection; *NR* not reported

[d] Total number of procedures is shown in parenthesis

[e] These data are defined as console time

[f] Median value

[g] Authors determined that most of patients were discharged within 3 days after surgery

the first axillary incision, if performed within 1 week before a significant fibrotic reaction had occurred. Undoubtedly, the learning curve for robotic surgery is very important, and this curve affects the outcomes of surgery. The learning curve for RT has been suggested to range between 30 and 50 cases [13, 26, 34, 35]. In addition, body habitus and surgeon experience are important factors determining the feasibility of RT [35]. Landry et al. [33] speculated higher complication rates for RT via single axillary incision and underscored the difficulty of this procedure due to larger body mass index and body habitus in the USA population versus the Korean population.

The transaxillary RT allows easy manipulation of the tissues in a small space due to a magnified 3D view and multiarticulated instruments. Kang et al. [23] also described a modified radical neck dissection (MRND) technique using the robotic transaxillary approach and reported that this operation was technically both feasible and safe, and resulted in excellent cosmetic outcomes. The oncologic safety of the robotic technique based on complication rates, number of retrieval lymph nodes, and/or thyroglobulin levels at the 1-year follow-up has also been shown in several studies [16, 17, 30, 31]. Moreover, in a multicenter study, Lee et al. [25] also reported that robotic thyroidectomy using a gasless transaxillary approach for thyroid malignancy provided similar outcomes compared with open or endoscopic procedures. Finally, Chung and colleagues, as the most experienced group in the world, recently proposed that the indications for robotic thyroidectomy should be expanded to also include patients with advanced thyroid cancer [23].

To summarize, according to data in the literature, robotic transaxillary thyroid surgery seems to be a valid option for those patients with an appropriate body habitus and small thyroid pathology. There is a trend for using a single axillary incision rather than the two-incision approach. Whether total thyroidectomy should be done through a unilateral or bilateral axillary approach is still being debated. According to the data in the literature, in this patient population, robotic thyroidectomy yields similar perioperative outcomes, but there is still a need for more data on oncologic outcomes.

Surgical techniques

Robotic gasless transaxillary thyroidectomy

We prefer this method for nodules of <3 cm in those patients without any evidence of thyroiditis or Grave's disease. Our cut-off for preoperatively known cancer cases is 2 cm. The patient is positioned supine with the ipsilateral arm partially extended cephalad to expose the axilla and flexed at the elbow using blankets to support the arm. A beanbag support is used to hyperextend the neck. The patient's contralateral arm is tucked adjacent to his/her patient's body. A 5- to 6-cm incision is made along the anterior border of the axilla. We perform total thyroidectomy through a single axillary incision. Using blunt dissection and electrocautery, a subcutaneous plane is developed above the pectoralis fascia and clavicle. A plane is identified between the clavicular and sternal heads of the sternocleidomastoid muscle (SCM). The sternal head of the SCM and the strap muscles are retracted superiorly. An automatic retractor with table mount lift is placed under the strap muscles. The robot is then docked approaching from the contralateral shoulder of the patient. A 30° down-looking scope, Harmonic scalpel, and Cadiere dissector are inserted through the axillary incision (Fig. 1). The first assistant uses a laparoscopic suction irrigator through the axillary incision when needed. The conduct of the operation is similar to the conventional open technique. The dissection is carried out using the Harmonic scalpel and the inferior pole vessels are divided (Fig. 2). The middle thyroid vein is then divided during this part of the dissection. At this stage we identify the recurrent laryngeal nerve and the parathyroid glands. The upper pole vessels are divided. The ligament of Berry is divided, using caution to avoid thermal injury to the nerve. The thyroid is then divided along the isthmus, and the ipsilateral lobe is removed. The dissection for the contralateral lobe is carried out in a medial to lateral direction. The inferior and superior pole vessels are divided, and the thyroid is separated from the trachea using a subcapsular dissection plane. The contralateral lobe is removed similarly through the axilla. The dissection bed is then irrigated and checked for hemostasis.

Fig. 1 Intraoperative photo showing the position of the robotic instruments for transaxillary thyroidectomy

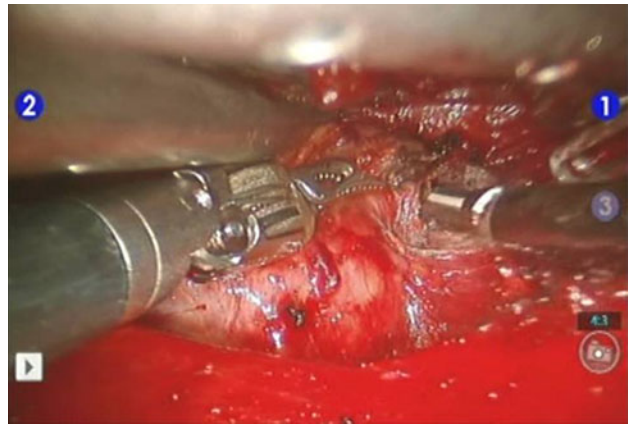

Fig. 2 Intraoperative photo showing dissection of the lower pole of the right thyroid lobe

The robot is removed, and the skin is closed in a subcuticular fashion. We do not use drain for the flap.

Robotic parathyroidectomy

Minimal invasive approach for parathyroidectomy has gained popularity over the past decade. Gagner [7] performed the first endoscopic parathyroidectomy in 1996 at the Cleveland Clinic. Due to several complications, such as massive subcutaneous emphysema and hypercarbia caused by CO_2 insufflation, reported using this technique, in 1998 Miccoli et al. developed a new technique using a special external retractor for visualization [7, 36, 37]. The results of a large prospective randomized study carried out by Miccoli's group demonstrated a shorter operative time, better cosmetic outcome, and lower pain level for video-assisted parathyroidectomy compared with conventional bilateral neck exploration [38].

The latest development in the field of parathyroidectomy is the transaxillary robotic approach. Non-robotic endoscopic procedures have certain disadvantages, including the limited mobility of straight instruments, an unstable camera, a 2D view, and poor ergonomic position. Although in comparison the robotic approach is not any less invasive due to the wider space of dissection, it does have several advantages, such as 3D magnified visualization, wristed instrumentation, hand-tremor filtration, and the avoidance of a neck incision [33, 39, 40]. The indications for this procedure are thin patients with a single gland seen on preoperative imaging with sestamibi and/or neck ultrasound. The robotic removal of mediastinal parathyroids has also received a lot of attention as multiple case reports have been published in literature (Table 2) [33, 39–47].

According to the current evidence, robotic approach seems to be a reasonable technique for mediastinal parathyroids. There is still a need for more data on the transaxillary robotic approach for cervical disease.

Table 2 Summary of the robotic parathyroidectomy studies

First author	*N*	Site (*N*)	Diagnosis (*N*)	Supporting methods[a]	Length of procedure (min)	Hospital stay (days)	Complication
Harvey [41]	1	Anterior mediastinum	Primary HP	Intraoperative PTH guidance	123	2	0
				Radio-guided			
Landry [33]	2	Right-sided servical localization (2)	Primary HP (2)	Intraoperative PTH guidance	102–115	NR	0
Chan [42]	1	Right superior mediastinum	Tertiary HP	Methoxyisobutylisonitrile scan	210	3	0
Ismail [43]	5	Left thymus (2)	Secondary recurrent HP (2)	Intraoperative PTH guidance	58 (42–125)	3 (2–4)	0
		Anterior mediastinum (2)	Primary recurrent HP (1)				
		Aortic arch (1)	Primary HP (2)				
Brumann [44]	5	Mediastinum (5)	NR	NR	58 (42–140)	5 (2–7)	0
Timmerman [45]	1	Anterior mediastinum	Primary HP	Intraoperative PTH guidance	22	<3	0
Augistin [46]	1	Aortopulmonary window	Primary HP	NR	134	NR	0
Tanna [47]	1	Left thymus	Primary HP	Intraoperative PTH guidance	NR	5	0
Bodner [40]	1	Aortopulmonary window	Primary HP	NR	134	4	Transient left RLN palsy
Profanter [39]	1	Aortopulmonary window	Primary HP	Intraoperative PTH guidance	130	4	Transient left RLN palsy

Data are given as the median with the range in parenthesis

PTH Parathyroid hormone, *HP* hyperparathyroidism, *NR* not reported, *RLN* recurrent laryngeal nerve

[a] With the exception of sestamibi scan, single-photon emission computed tomography, computed tomography, ultrasonography, and magnetic resonance

Robotic gasless transaxillary parathyroidectomy

A similar approach to the cervical region is used as above described for robotic thyroidectomy. A focal or unilateral approach is possible, guided by intraoperative parathyroid hormone and frozen section (Fig. 3).

Robotic thoracoscopic mediastinal parathyroidectomy

In this technique, standard single lung ventilation is used, and three robotic ports are placed in the second, fourth, and sixth interspaces, medial to the anterior axillary line. Carbon dioxide insufflation is started to keep the pressure at 8–10 mmHg with careful hemodynamic monitoring. The mediastinum is visualized and inspected. If the parathyroid adenoma is not identified with the thoracoscopic/robotic view, resection of pericardial fat and thymic tissue may be necessary based on preoperative localization. A radio-guided approach with inspection of the specimen on the back table with the Neoprobe hand-held gamma probe can be used to ensure resection of the parathyroid gland seen on preoperative imaging. A chest tube is then placed into the pleural space.

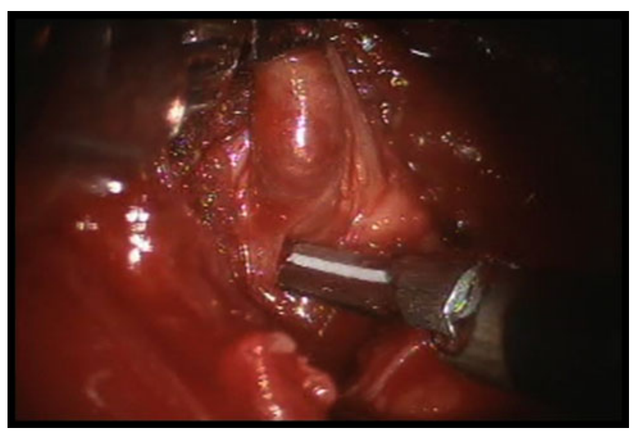

Fig. 3 Removal of a right lower parathyroid adenoma through a transaxillary approach

Robotic adrenalectomy

The first published robotic adrenalectomy (RA) was by Piazza et al. [48] in 1999, as a right adrenalectomy in a patient with Conn's syndrome using the ZEUS AESOP

Table 3 Summary of the robotic adrenalectomy studies

First author	N	Diagnosis	Procedure[a]	Mean size	Procedure length (min)	Mean hospital stay (day)	Conversion[b]	Complication
Choi [51]	2	Pheochromocytoma (1); nonfunctioning adenoma (1),	R-LESS	2.5	167	3.5	0	0
Giulianotti [52]	42	Cortical adenoma (19); pheochromocytoma (9); hemorrhagic cyst (6); aldosteronoma (2); bilateral hyperplasia (2); adrenal carcinoma (1); ganglioneuroma (1); myelolipoma (1); metastasis (1)	RAA	5.5	118	4[d]	0	Adrenal capsular tear (1)
Berber [53]	8	Nonfunctioning adenoma (3); aldosteronoma (2); pheochromocytoma (1); Cushing syndrome (1); lymphangioma (1)	RPRA	2.9	214.8	1[g]	0	0
Boris [54]	10 (13)[c]	Pheochromocytoma (11); cortical hyperplasia (2)	RALPA	2.7[d]	200[d]	NR	1 (COA)	Bile leak; ureteral stricture[I]
Brunaud [55]	100	Nonfunctioning adenoma (19); cyst (2); pheochromocytoma (24); aldosteronoma (39); Cushing adenoma (11); hyperplasia (Cushing) (5)	RAA	2.9	171	6.4	1 (CLA) 4 (COA)	Cyst rupture (1); bleeding (3); wound infection (1); urinary tract infection (1); facial edema (1); pneumonia (1)
Wu [56]	5	Cortical adenoma (4), Pheochromocytoma (1)	RAA	5.1	188	4	0	0
Krane [57]	4	Nonfunctioning adenoma (2); Hhperplasia (1); pheochromocytoma (1)	RAA	5.25	75.5[e]	1.25	0	0
Winter [58]	30	Pheochromocytoma (11); aldosteronoma (9); Cushing syndrome (5); adrenal adenoma (1); combined (aldosterone/cortisol) adenoma (1) 'macronodular hyperplasia (1); metastasis (1); angiomyolipoma (1)	RAA	2.4[d]	185[d]	2[d]	0	Postoperative ileus (1); atelectasis (1)
Miyake [59]	3	Aldosteronoma (2); Cushing syndrome (1)	RAA	1.9	188	8.7	0	0
Corcione [60]	2	NR	RAA	NR	NR	2.2[d,h]	0	NR
Morino [61]	10	Nonfunctioning adenoma (3); aldosteronoma (3); pheochromocytoma (4)	RAA	3.3	169	5.7	4 (CLA)	0
Hanly [62]	30	Adrenal masses (18); pheochromocytoma (9); aldosteronoma (3)	RAA	NR	NR	NR	0	NR
Undre [63]	2	Aldosteronoma (2)	RAA	NR	118.5	4	0	Pulmonary embolus (1)
Talamini [64]	6	NR	RAA	NR	188[f]	1[d,f]	NR	NR
Desai [65]	2	Leiomyosarcoma (1); pheochromocytoma (1)	RAA	3.75	137.5	2.5	0	Adrenal capsular tear (1)

Table 3 continued

First author	N	Diagnosis	Procedure[a]	Mean size	Procedure length (min)	Mean hospital stay (day)	Conversion[b]	Complication
Bentas [66]	4	Pheochromocytoma (2); aldosteronoma (1); metastasis (1)	RAA	3.7	220	5	0	0

[a] *R-LESS* Robotic laparoendoscopic single-site, *RAA* robotic assisted adrenalectomy, *RPRA* robotic posterior retroperitoneal adrenalectomy, *RALPA* robot-assisted laparoscopic partial adrenalectomy

[b] *CLA* Converted to laparoscopic adrenalectomy, *COA* converted to open adrenalectomy

[c] Total number of procedures is shown in parenthesis

[d] Median value

[e] These data are defined as console time

[f] These six adrenalectomy cases were part of large series of 211 robotic procedures, and this value was seen the mean operation time of overall cases

[g] Authors determined that all patients were discharged home within 24 h after surgery

[h] These two adrenalectomy cases were part of series of 29 robotic procedures, and these data are the mean values of overall cases

[I] This patient underwent repeat partial nephrectomy at the time of partial adrenalectomy

system. In the same year, Hubens et al. [49] also reported a case that was performed as a left adrenalectomy using AESOP. These studies were reported from Europe. The first application of the robotic system for adrenalectomy was reported in pigs at the Cleveland Clinic in the USA [50]. After the da Vinci system had received FDA approval for use in general surgical procedures in July 2000, Horgan et al. reported 34 advanced cases (including single bilateral adrenalectomy) that were performed using this system [4]. Since then, numerous studies and case reports describing RA have been published in the literature (Table 3) [51–66].

The first use of robotic surgery in adrenal malignancy was described by Zafar et al. [67]. Giulianotti et al. [52] reported another case 3 years later, and several groups have also described this procedure for adrenal metastasis [52, 58, 66]. Although limited experience with this approach has been reported in the literature, available studies indicate that this procedure could be performed safely for malignant cases as well, and with increased surgical ergonomics. Robotic adrenalectomy has also been reported to be safe in pregnant women and children [68–70]. Podolsyki et al. [68] commented that the robotic surgical systems provided advantages such as enhanced visualization and easiness of dissection in the confined space due to pregnancy. Fechner et al. [71] also reported the advantages of using the robot in a pregnant patient. Rogers et al. [69] subsequently reported robotic partial adrenalectomy in a pediatric patient with Von Hippel–Lindau (VHL) disease and indicated that robotic precise dissection was useful for performing a cortical sparing adrenalectomy in this patient. Based on a series of 134 robotic pediatric surgical procedures, including adrenalectomy in one patient, Alqahtani et al. [70] reported that robot-assisted surgery appeared also to be safe and feasible for pediatric patients.

While laparoscopic partial adrenalectomy has been well defined in large series [72–77], there are only three case reports and one case series on robotic partial adrenalectomy [54, 69, 78, 79]. The first laparoscopic robot-assisted partial adrenalectomy (RAPA) was reported by Julien et al. [79] in a patient with VHL disease. Kumar et al. [78] also described RAPA in a patient with isolated adrenal metastasis from renal clear cell carcinoma.

Causes of conversion to laparoscopic or open adrenalectomy from robotic surgery have been reported to be due to malposition of robotic trocars, difficulty in hemostasis and/or visualization of the adrenal vein, prolonged operation time, and visceral injury [54, 55, 61]. Nevertheless, in their comparison of standard laparoscopic and robotic assisted techniques, Brunaud et al. [80] found no objective data demonstrating that robotic adrenalectomy was superior to the standard laparoscopic approach for unilateral adrenalectomy. The first prospective randomized clinical trial comparing these procedures was reported by Morino et al. [61]. In their series, conversion to standard laparoscopic surgery was required in four of ten patients with attempted robotic adrenalectomy. These authors commented that laparoscopic adrenalectomy was superior to the robotic technique in terms of feasibility, morbidity, duration, and cost. In the same year, Brunaud et al. [81] evaluated and compared the perioperative quality of life in patients after laparoscopic versus RA—and demonstrated no difference. After a learning curve of 20 cases, RA was reported to have similar perioperative outcomes in terms of morbidity, conversion rates, length of stay, and operative time compared to lateral transperitoneal laparoscopic adrenalectomy [82]. In addition, tumor side, previous clinical experience, and first assistant's skill were main predictors of operative time in RA.

More recently, Giulianotti et al. [52] reported on 42 patients who underwent robotic transabdominal lateral adrenalectomy. In this series, the mean lesion size was 5.5 cm, with a median blood loss of 27 cm. The postoperative morbidity was 2.4% and mortality was 2.4%. Median hospital stay was 4 days.

According to current evidence, robotic adrenalectomy is safe and feasible. However, there is a need for comparison studies with laparoscopic adrenalectomy to critically assess the advantage of robotic over the laparoscopic approach. Use of the robot for the posterior approach appears to be advantageous, as this approach may eliminate the issues related to ergonomics of the procedure.

Robotic posterior retroperitoneal adrenalectomy

We prefer this method for adrenal tumors of <6 cm. After intubation, the patient is placed in a prone jackknife position using a Wilson frame. A transcutaneous ultrasound scan (US) is then performed to map out the ipsilateral kidney, 12th rib, and adrenal gland. This guides subsequent trocar placement. A 1-cm incision is made about 2 cm inferior and parallel to the 12th rib. Gerota's space is then entered using an optical trocar. This trocar is replaced by a dissecting balloon, and a potential space is created under direct view. A 12-mm long trocar is inserted into the space, and carbon dioxide insufflation is started to keep the pressure at 15–20 mmHg. Under optical vision, two 5-mm trocars are inserted medial and lateral to the initial port. It is important to insert these as far as possible from the first port to prevent collision of the instruments. Laparoscopic US is performed to identify the adrenal gland. These 5-mm trocars are then replaced by the robotic 5-mm trocars. In cases in which insertion of the trocars into the working space is easier, we start right away with the robotic 5-mm trocars. Then the robot is docked (Fig. 4). The operating table is rotated about 30 degrees clockwise, and the robot is brought in from the head of the table, between the

Fig. 4 Intraoperative photo showing left posterior retroperitoneal robotic adrenalectomy

shoulders, with the final alignment depending on the location of the adrenal gland. We use a robotic grasper from the lateral port and the robotic Harmonic scalpel from the medial port. Depending on the progress of the case, these instruments may need to be swapped. The dissection is started superiorly and laterally first; the inferior border is dissected next and the medial border last (Fig. 5). The adrenal vein is identified and divided between 5-mm clips placed by the first assistant through the medial port. This requires the temporary removal of the Harmonic scalpel. Suctioning is also performed by the first assistant through the same port when necessary. The robot is undocked after the completion of adrenalectomy. The specimen is extracted with specimen retrieval bag. The fascial incision for the 12-mm port and the skin incisions are closed.

Robotic transperitoneal lateral adrenalectomy

The patient is placed in a lateral decubitus position. Adrenalectomy is generally performed using four ports. Trocar placement is the same as laparoscopic adrenalectomy. Laparoscopic US is used to identify the localization of adrenal gland assess relationship with surrounding structures. The robot is docked into position coming from the ipsilateral shoulder of the patient and connected to the robotic arms (Fig. 6). We use Cadiere forceps from the left port and the robotic Harmonic scalpel from the right port in both sides. On the left side, the splenocolic and splenorenal ligaments are divided. On the right side, the right triangular ligament of the liver is divided with the Harmonic scalpel for mobilization of the right hepatic lobe. The lateral and superior borders of the adrenal are dissected first, followed by the inferior and medial aspects (Fig. 7). The adrenal vein is divided using the Harmonic scalpel if <4 mm and using clips if larger. We prefer metallic clips placed by the

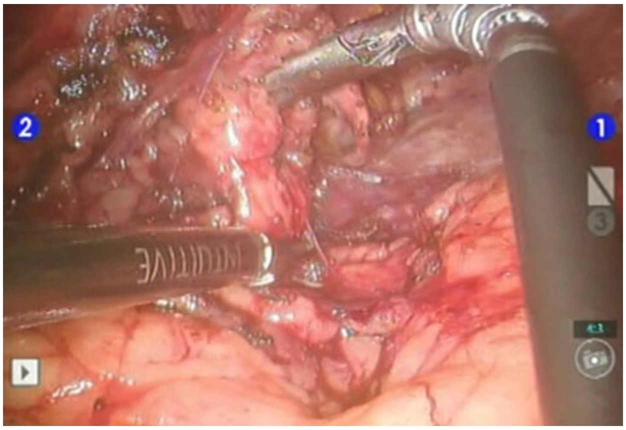

Fig. 5 Intraoperative photo showing dissection of the adrenal gland in the posterior robotic approach

Fig. 6 Positioning of the robot for a left lateral transabdominal adrenalectomy. In this procedure there is an additional port for the first assistant

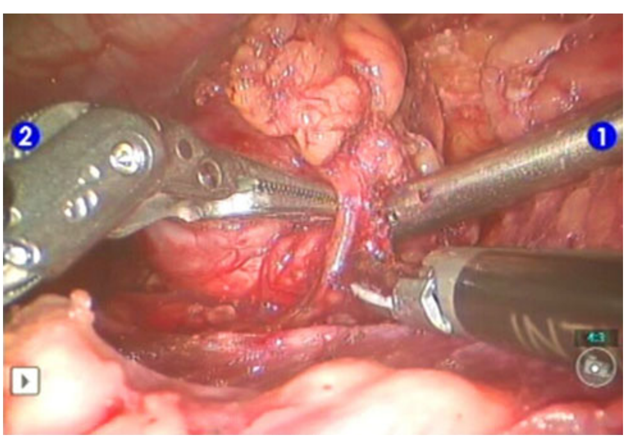

Fig. 7 Intraoperative photo showing dissection of the left adrenal gland with the lateral transabdominal approach

first assistant, but robotic locking clips may also be used. After the adrenalectomy is completed, the robot is undocked and hemostasis is checked laparoscopically.

Conclusion

The use of the robotic systems has enabled alternative approaches or more efficient and ergonomic techniques to be developed for various endocrine surgical procedures. Initial experience is encouraging. Comparative outcome studies will establish the role of the robot in endocrine surgery.

Conflict of interest None.

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