Surg Endosc (2006) 20: 119–124
DOI: 10.1007/s00464-005-0082-0

SURGICAL ENDOSCOPY
and Other Interventional Techniques

Thirty robotic adrenalectomies

A single institution's experience

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Received: 16 February 2005/Accepted: 5 July 2005/Online publication: 7 December 2005

Abstract
Background: Robotic adrenalectomy is a minimally invasive alternative to traditional laparoscopic adrenalectomy. To date, only case reports and small series of robotic adrenalectomies have been reported. This study presents a single institution's series of 30 robotic adrenalectomies, and evaluates the procedure's safety, efficacy, and cost.
Methods: Thirty patients underwent robotic adrenalectomy at the Johns Hopkins Hospital between April 2001 and January 2004. Patient morbidity, hospital length of stay, operative time, and conversion rate to traditional laparoscopic or open surgery are presented. Improvement in operative time with surgeon experience is evaluated. Hospital charges are compared to charges for traditional laparoscopic and open adrenalectomies performed during the same time period.
Results: Median operative time was 185 min. Patient morbidity was 7%. There were no conversions to traditional laparoscopic or open surgery. The median hospital stay was 2 days. Operative time improved significantly by 3 min with each operation. Hospital charges for robotic adrenalectomy ($12,977) were not significantly different than charges for traditional laparoscopic ($11,599) or open adrenalectomy ($14,600).
Conclusions: Robotic adrenalectomy is a safe and effective alternative to traditional laparoscopic adrenalectomy.

Key words: Adrenalectomy — Robot — da Vinci — Laparoscopy — Cost — Learning curve

Laparoscopic adrenalectomy is now considered to be the preferred surgical approach for the management of benign adrenal disease. The first laparoscopic adrenalectomy was performed in 1992 by Gagner et al. [8]. A recent meta-analysis of studies that compared laparoscopic to open adrenalectomy found that the former technique results in less blood loss, reduced patient morbidity, and shorter hospital stays [10].

In addition, hospital costs for laparoscopic adrenalectomy may be less than hospital costs for open adrenalectomy. In a review of a single surgeon's experience at the Johns Hopkins Hospital between 1993 and 2000, hospital costs for patients who underwent laparoscopic and open adrenalectomy were $10,929 and $13,336, respectively [20]. The authors attributed this difference in hospital charges to shorter hospital stays for those patients who underwent laparoscopic adrenalectomy.

Despite the benefits of laparoscopic adrenalectomy, the procedure has shortcomings that are shared by other laparoscopic techniques. Commonly noted problems include the absence of three-dimensional perception, minimal tactile feedback, decreased dexterity compared to open surgery, and poor ergonomics for the surgeon [13, 16]. Robotic technology has the potential to provide solutions to many of these problems.

The role of robotics in the management of adrenal disease has not been defined. This study describes the Johns Hopkins experience with robotic adrenalectomy and evaluates the safety and efficacy of that procedure. Furthermore, this study attempts to characterize the learning curve for robotic adrenalectomy, and compares the cost of the procedure with that of traditional laparoscopic and open adrenalectomy.

Materials and methods

Patients

Three surgeons from the Johns Hopkins Hospital performed 30 robotic adrenalectomies between April 2001 and January 2004. The patients included 11 men and 19 women; the median age was 52 years (range, 18–75 years). Patients underwent robotic adrenalectomy if they

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had an adrenal mass that appeared to be appropriate for a minimally invasive resection (for example, benign tumors smaller than 10 cm [15]), with two exceptions. One of the surgeons performed two traditional laparoscopic adrenalectomies during the time interval between his first and third robotic adrenalectomies. However, the surgeon's next 24 minimally invasive adrenalectomies were performed with the robotic system.

Patient and specimen data were obtained, with Institutional Review Board (IRB) approval, from electronic patient records and the Johns Hopkins adrenalectomy database. Data include age, gender, body mass index (BMI), history of previous abdominal operations, histological diagnosis, operative time, complications, perioperative mortalitiy (in-hospital death or death within 30 days of the operation), hospital length of stay, operative charge, and total hospital charge. Data were also examined for 45 patients who underwent traditional laparoscopic adrenalectomy and 20 patients who underwent open adrenalectomy at the Johns Hopkins Hospital during the time period in which the robotic adrenalectomies were performed. The traditional laparoscopic cases were performed by surgeons who do not use the robotic system to perform minimally invasive adrenal surgery. Patient morbidity and conversion rates to open adrenalectomy in the laparoscopic and robotic groups were determined and compared.

Operation

Robotic adrenalectomies at the Johns Hopkins Hospital were performed using the da Vinci Robotic Surgical System (Intuitive Surgical, Sunny Valley, CA, USA). The da Vinci system and other robotic surgical devices are reviewed in detail by Jacobsen et al. in a recent update of robotic surgery [14].

Right robotic adrenalectomy is performed with the patient in the left lateral decubitus position on a bean bag with the left arm extended on an armboard at 90°. The right arm is taped to the left arm and armboard after interposing several pillows. The table is flexed at the level of the kidneys. The patient is secured into place with wide cloth tape at the level of the shoulders and hips. Warmers are applied to the upper torso and on the legs. The patient's abdomen and right flank are prepped and draped. The first port, a 12-mm camera port, is placed midway between the umbilicus and the right costal margin. Two robotic instrument ports, both 8 mm, are then placed along a line two fingerbreadths from the costal margin, so that an equilateral triangle is created with the camera port. A 5-mm liver retraction port is placed in the midline in the epigastrium through which a triangular liver retractor can be placed. In many cases a 10-mm accessory port is placed in the right abdomen through which a Ligasure (Valleylab, Boulder, CO, USA) device or ultrasonic shears can be placed. The positioning of this port is variable and depends on body habitus and internal anatomy. It should be kept sufficiently distant from the camera port and robotic arm port to avoid collision and obstruction. An assistant at the operating table usually changes the robotic instruments as necessary and manipulates suction or accessory devices through this port.

For a right robotic adrenalectomy, an atraumatic grasper is placed for manipulation by the right robotic arm and the hook cautery is placed for manipulation by the left robotic arm for most of the procedure. Depending on the exact task required during the case, these positions can be exchanged. If an energy source such as the Ligasure device or ultrasonic shears is being used extensively through the accessory port, then having the robotic arms manipulate two graspers may be more efficient. The sequential steps taken for a right robotic adrenalectomy are similar to those for a traditional laparoscopic right adrenalectomy. The liver is mobilized away from the retroperitoneum and the right triangular ligament is divided to expose the right bare area. This allows the liver to be mobilized into the midline, providing better exposure of the adrenal bed. Next, attention is directed to the infrahepatic IVC and the right adrenal and right renal veins are exposed. Controlling the right adrenal vein as early as possible minimizes the potential for injury during mobilization of the adrenal gland. Once mobilized, the right adrenal vein can be controlled with clips or the Ligasure device (if long enough) and divided. The right adrenal gland with any associated pathology is then progressively dissected off of the superior pole of the kidney and the retroperitoneum in a circumferential manner. Much of this can be accomplished with the hook cautery device, with strategic use of the Ligasure device, or with ultrasonic shears where necessary. The specimen is then placed into a specimen pouch and removed through the accessory port.

Table 1. Patient characteristics

Median age, years (range)	52 (18–75)
Gender:	
Male, *n*	11
Female, *n*	19
Median body mass index (range)	25.8 (19.1–46.6)
Number of patients with prior abdominal operations, *n*	10

Left robotic adrenalectomy is performed with the patient in the right lateral decubitus position. Positioning is the mirror image of that for the right robotic adrenalectomy described above. The first port, a 12-mm camera port, is placed midway between the umbilicus and the left costal margin. Two robotic instrument ports, both 8 mm, are then placed along a line two fingerbreadths from the costal margin, so that an equilateral triangle is created with the camera port. In many cases a 10-mm accessory port is placed in the left abdomen through which a Ligasure device or ultrasonic shears can be placed. The same issues regarding placement of this accessory port apply as discussed previously.

For a left robotic adrenalectomy, the atraumatic grasper is placed for manipulation by the left robotic arm and the hook cautery is placed for manipulation by the right robotic arm for most of the procedure. Depending on the exact task required during the procedure, these positions can be exchanged. If the Ligasure device or ultrasonic shears is being used extensively through the accessory port, then using two graspers on the robotic arms may be more efficient. The steps taken for a left robotic adrenalectomy are very similar to traditional laparoscopic left adrenalectomy. The splenic flexure of the colon is first mobilized away from the retroperitoneum, whereupon gravity allows it to fall in a medial direction. Care should be taken to keep the dissection anterior to the left kidney in order to avoid inappropriately mobilizing the kidney. Next, the spleen and the tail of the pancreas are mobilized away from the retroperitoneum. As this mobilization occurs, gravity will pull the spleen and tail of the pancreas toward the midline, exposing the left adrenal bed. Locating the left adrenal vein is more challenging than locating the right adrenal vein. However, once it is located, it is easier to ligate and divide because it is usually longer and narrower than the right adrenal vein. As on the right side, it is preferable to control the left adrenal vein early in the procedure to prevent injury during mobilization of the adrenal gland. Once mobilized, this vessel can be controlled with clips or the Ligasure device and divided. The left adrenal gland with any associated pathology is then circumferentially dissected away from the superior pole of the kidney and the retroperitoneum. The specimen is then placed into a specimen pouch and removed through the accessory port.

Statistics

Data analysis was performed in Intercooled Stata v. 7.0 from Stata Corporation. Median values are provided whenever possible. Median hospital charges for patients who underwent robotic, traditional laparoscopic, and open adrenalectomy were compared using the Kruskal-Wallis test. A simple linear regression of operative time vs operative experience by a single surgeon was performed to determine a single surgeon's learning curve for robotic adrenalectomy. Statistical significance was defined as a $p < 0.05$.

Results

Patient characteristics are given in Table 1. The median age was 52 years. Sixty-three percent of the patients were women and 37% percent of the patients were men. The median BMI was 25.8. One-third of the patients had prior abdominal surgery. There were 15 left robotic adrenalectomies and 15 right robotic adrenalectomies. No bilateral adrenalectomies were performed. Adrenal tu-

Table 2. Pathologic data

Diagnosis	Number
Pheochromocytoma	11
Aldosteronoma	9
Glucocorticoid adenoma	5
Adrenal adenoma	1
Angiomyolipoma	1
Combined aldosterone/cortisol secreting adenoma	1
Metastatic carcinoma	1
Macronodular hyperplasia	1

Table 3. Intraoperative and postoperative data

Time to complete various components of the operation, min (range)	
Median robot setup time	4 (0.7–7)
Median robot use	102 (52–225)
Median operative time	185 (130–295)
Median room time	261 (178–365)
Conversions to laparoscopy, *n* (%)	0 (0)
Hospital complications, *n* (%)	2 (7)
Median hospital stay, days (range)	2 (1–5)

mors ranged in size between 1.1 and 8 cm; the median tumor size was 2.4 cm. Pathologic data are listed in Table 2. Histologic types included pheochromocytoma ($n = 11$), aldosteronoma ($n = 9$), glucocorticoid secreting adenoma ($n = 5$), nonfunctioning adrenal adenoma ($n = 1$), angiomyolipoma ($n = 1$), aldosterone and cortisol secreting adenoma ($n = 1$), metastatic carcinoma ($n = 1$), and macronodular hyperplasia ($n = 1$).

Intraoperative and postoperative data for the 30 patients who underwent robotic adrenalectomy are summarized in Table 3. Time data are reported for four phases of the robotic operation. The median robot setup time (the time interval needed to move the robot from the corner of the operating room to the patient's side and attach the robotic arms to the appropriate trocars) was 4 min. The median robot time (the duration of robot utilization) was 102 min. The median operative time (the time from incision to dressing placement) was 185 min. The median room time (the time that the patient spent in the operating room) was 261 min. Patients with pheochromocytomas required significant additional time to monitor the patient properly and to induce general anesthesia.

There were no intraoperative complications, equipment failures, conversions to traditional laparoscopy, or conversions to open adrenalectomy. The overall hospital complication rate was 7%. One patient had a prolonged postoperative ileus; another patient suffered a brief episode of hypoxemia that was likely due to a combination of bronchitis and atelectasis. Both patients were discharged on the fifth postoperative day. The median length of hospital stay (number of postoperative days spent in the hospital) for the entire group was 2 days. There were no perioperative deaths.

During the same time period that these 30 patients underwent robotic adrenalectomy, 45 patients underwent traditional laparoscopic adrenalectomy by a different set of surgeons at the Johns Hopkins Hospital. They had a hospital complication rate of 11% and a median hospital stay of 2 days, which were similar to the values observed for patients who underwent robotic adrenalectomy. Nine percent of the traditional laparoscopic adrenalectomies were converted to the open procedure. The difference in conversion rates between the two techniques does not achieve statistical significance.

Figure 1 demonstrates that operative times improved with surgeon experience. This figure reports data from 25 robotic adrenalectomies performed by a single surgeon. Simple linear regression was used to calculate the equation of a line that represents the surgeon's operative time vs his *n*th operation. A horizontal line that represents the median operative time for all of the robotic adrenalectomies performed at our institution is superimposed on the graph. On average, each operation was 3 min shorter than the previous operation. The slope of the line achieved statistical significance ($p = 0.01$). Of note, the surgeon's 14th operation took considerably longer than the corresponding point on the linear regression, because of an umbilical hernia repair performed at the end of the operation.

Operative and total hospital charges for all adrenalectomies performed at the institution between April 2001 and January 2004 were examined. Median operative charges (operating-room minute charge and supply charges) were $8,645 for robotic adrenalectomy, $6,414 for traditional laparoscopic adrenalectomy, and $3,666 for open adrenalectomy. However, overall hospital charges for patients who had a robotic adrenalectomy did not differ significantly from the hospital charges assessed for patients in the other two groups. Total hospital fees are represented in Fig. 2. The median hospital charge was $14,600 for patients in the open group, $12,977 for patients in the robotic group, and $11,599 for patients in the traditional laparoscopic group. Total hospital charges for patients in the robotic and traditional laparoscopic groups tended to be less than the total charges for patients in the open group, primarily because of shorter hospitalizations for the patients who underwent minimally invasive surgery.

Discussion

The first reported robotic adrenalectomy was performed by Horgan et al. in 2001 [12]. To our knowledge, there are currently 10 publications that describe 43 robotic adrenalectomies. These reports are summarized in Table 4. Early experiences with robotic adrenal surgery demonstrated that the procedure could be performed safely and effectively. Two publications compared robotic adrenalectomy and traditional laparoscopic adrenalectomy. Both studies reported similar patient morbidity and hospital length of stays in the two patient populations [1, 3]. Our series of 30 robotic adrenalectomies provides further evidence that the procedure is a reasonable alternative to traditional laparoscopic adrenalectomy.

Guazzoni et al. recently surveyed the English literature for studies comparing traditional laparoscopic and open adrenalectomy [10]. The authors found eight

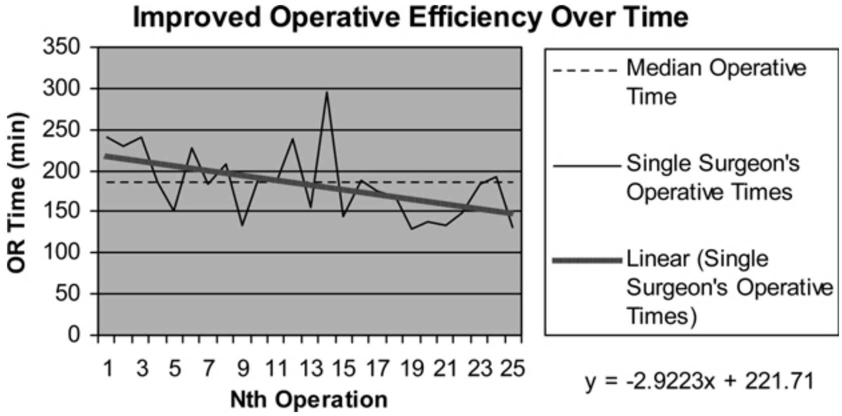

Fig. 1. Operative time vs. the nth operation by a single surgeon. The equation in the figure represents a simple linear regression of the surgeon's operative times. The horizontal line demonstrates the institution's median operative time.

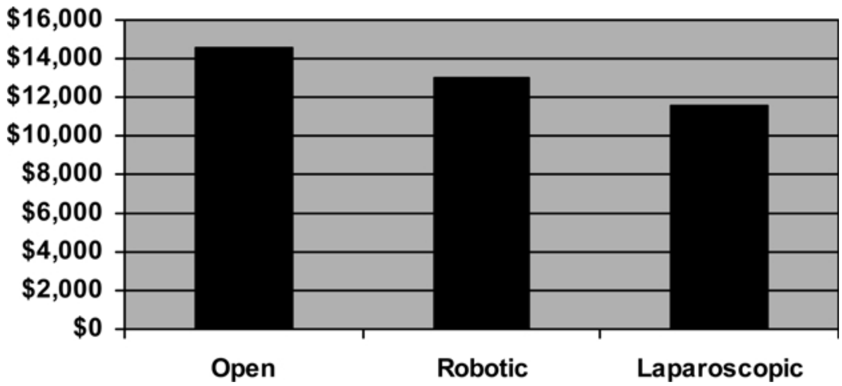

Fig. 2. Median total hospital charges for open ($n = 20$), robotic ($n = 30$), and laparoscopic ($n = 45$) adrenalectomy at the Johns Hopkins Hospital, between April 2001 and May 2004. The Kruskal-Wallis test was used to compare the robotic group to the open group ($p = 0.5$) and the laparoscopic group ($p = 0.09$).

Table 4. Published reports of robotic adrenalectomy Data are supplied as median values, unless otherwise indicated

Lead author, in chronological order	Number of cases	Operative time (min)	Hospital complications	Conversions to laparoscopy	Hospital stay (days)
Horgan & Vanuno [12]	1	—	0	0	—
Desai et al. [7]	2	147.5	1 (capsule tear)	0	2.5
Young et al. [19]	1	100	0	0	1
Bentas et al. [2]	4	195	0	0	4
Giulianotti et al. [9]	3	120	0	0	—
Beninca et al. [1]	9	132.8*	0	4	5.7*
Brunaud et al. [3]	14	111*	3	1	6.9*
Talamini et al. [17]	6	—	—	—	—
D'Annibale et al. [5]	1	130	0	0	2
Undre et al. [18]	2	118.5	1 (PE)	0	4
Present authors	30	185	2 (ileus, bronchitis)	0	2

* reported as a mean average - not reported

studies published between 1997 and 2002 that included at least 17 patients in laparoscopic and open adrenalectomy groups. The following data were reported for laparoscopic and open adrenalectomy, respectively: mean blood loss volumes were 123 and 182 ml, mean hospital stays were 4.4 and 8.5 days, and mean complication rates were 7.4% and 29%. Robotic adrenalectomy appears to share many of the advantages previously described for traditional laparoscopic surgery, including early resumption of normal daily activities.

Data from the present series demonstrates that robotic adrenalectomy and laparoscopic adrenalectomy have similar morbidity (7% and 11%, respectively) and conversion rates to open adrenalectomy (0% and 9%, respectively). Although these procedures were performed during the same time interval, direct comparison between the two techniques is complicated by the fact that the procedures were performed by different surgeons. At our institution, the surgeon's choice between minimally invasive techniques is based on comfort level with the robot, and does not involve patient characteristics. The three surgeons who performed robotic adrenalectomies in the present series performed just two laparoscopic adrenalectomies during the specified time interval. The two traditional laparoscopic procedures were performed because the robot was unavailable to the surgeon. Prospective, randomized trials will be necessary to determine if robotic adrenalectomy has superior outcomes compared to laparoscopic adrenalectomy.

Some surgeons report anecdotally that robotic adrenalectomy has a steeper learning curve than traditional laparoscopic adrenalectomy [2]. David et al. analyzed retrospectively 100 laparoscopic adrenalectomies performed by one surgical team [6]. The authors separated their patients chronologically into three groups of 33 or 34 patients. Major morbidity and the conversion rate to open surgery appeared to plateau after 33 laparoscopic adrenalectomies. In contrast, there were no major complications or conversions to open surgery in our institution's early robotic adrenalectomy experience. The authors of the traditional laparoscopic adrenalectomy study also reported that operative times leveled off at 120 min after 33 laparoscopic operations. Interestingly, our linear regression model predicts that it would take a similar number of operations (approximately 34 robotic adrenalectomies) to achieve an operative time of 120 min. Prospective, randomized studies comparing robotic and traditional laparoscopic adrenalectomy would help to determine if the slopes of the learning curves differ for the two techniques. Furthermore, greater experience with the robot is necessary in order to learn the lower limit of operative time needed to perform a robotic adrenalectomy.

Surgeons have tried to characterize the learning curve observed with the da Vinci system in laboratory experiments. For example, in a study by Hubens et al., medical students without surgical experience performed a series of exercises with the da Vinci system and traditional laparoscopic equipment. The students performed every task faster and with greater precision using the robot [13]. The greatest differences were observed with complicated tasks. In a second study, by Hernandez et al., two groups of surgeons performed bowel anastamoses using the da Vinci system; one group had extensive laparoscopic experience, whereas the other group had minimal laparoscopic experience [11]. The authors measured operative times and scored the performance of each anastamosis. Operative speed and skill improved significantly between the first and the fifth bowel anastamoses in both surgeon groups. The authors noted that laparoscopic experience did not affect surgeon performance. This suggests that the da Vinci system may offer surgeons with minimal laparoscopic experience an alternative means to learn minimally invasive surgery with greater safety and ease.

The benefits of the da Vinci system observed in these experiments are due to certain features of the device that are absent in traditional laparoscopy. The system provides the surgeon with a three-dimensional display that enhances depth perception. The system also enables the surgeon to operate in a comfortable sitting position in which the eye, hand, and target are in line. Furthermore, the instruments contain a "wrist" joint to improve dexterity. Current drawbacks of the da Vinci system include the lack of tactile feedback, a difficult mechanism for instrument exchange, increased trocar size, and the requirement for an additional port site to allow the use of an energy source (e.g., Ligasure) [4, 13, 16].

Although hospital charges between the robotic group and the traditional laparoscopic group did not achieve statistical significance in our study, median charges were approximately $1,500 more for patients who underwent robotic adrenalectomy. Robotic instruments and increased operative times early in the robotic series were likely the main causes for this price discrepancy. The difference in hospital charges did not reflect the capital costs of the robot or yearly maintenance expenses. At our hospital, these costs are spread across both robot and nonrobot hospital charges. Nevertheless, it is possible to estimate the contribution of the capital and maintenance costs of the da Vinci system to each robotic procedure. The da Vinci system used in this series costs approximately $1,000,000. The presumed lifespan of a robot is 10 years [4]. The robotic system at our institution is over 4 years old, and several systems in Europe are over 7 years old. The annual maintenance contract for the da Vinci system costs approximately $90,000. If an institution performs two robotic operations per day, 10 robotic operations per week, or just over 500 robotic operations per year, then capital and maintenance costs for the robot would be $380 per procedure. This calculation demonstrates that capital and maintenance costs can be affordable at centers that perform high-volume robotic surgery.

In the future, robotic surgery will likely assume an increased role in the management of surgical disease. Research teams are dedicated to the development of robotic systems with greater intelligence and instruments with expanded capabilities. For instance, efforts are underway to integrate microsensors into robotic instruments in order to provide surgeons with accurate tactile feedback [16]. It is important that surgeons continue to evaluate new technologies critically and with an open mind.

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