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Perioperative outcomes and cost of robotic-assisted versus laparoscopic inguinal hernia repair

Jad Khoraki[1] · Pedro P. Gomez[1] · Guilherme S. Mazzini[1] · Bernardo M. Pessoa[1] · Matthew G. Browning[1] · Gretchen R. Aquilina[1] · Jennifer L. Salluzzo[1] · Luke G. Wolfe[1] · Guilherme M. Campos[1]

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Abstract

Background Utilization of robotic-assisted inguinal hernia repair (IHR) has increased in recent years, but randomized or prospective studies comparing outcomes and cost of laparoscopic and Robotic-IHR are still lacking. With conflicting results from only five retrospective series available in the literature comparing the two approaches, the question remains whether current robotic technology provides any added benefits to treat inguinal hernias. We aimed to compare perioperative outcomes and costs of Robotic-IHR versus laparoscopic totally extraperitoneal IHR (Laparoscopic–IHR).

Methods Retrospective analysis of consecutive patients who underwent Robotic-IHR or Laparoscopic-IHR at a dedicated MIS unit in the USA from February 2015 to June 2017. Demographics, anthropometrics, the proportion of bilateral and recurrent hernias, operative details, cost, length of stay, 30-day readmissions and reoperations, and rates and severity of complications were compared.

Results 183 patients had surgery: 45 (24.6%) Robotic-IHR and 138 (75.4%) Laparoscopic-IHR. There were no differences between groups in age, gender, BMI, ASA class, the proportion of bilateral hernias and recurrent hernias, and length of stay. Operative time (Robotic-IHR: 116 ± 36 min, vs. Laparoscopic-IHR: 95±44 min, $p<0.01$), reoperations (Robotic-IHR: 6.7%, vs. Laparoscopic-IHR: 0%, $p=0.01$), and readmissions rates were greater for Robotic-IHR. While the overall perioperative complication rate was similar in between groups (Robotic-IHR: 28.9% vs. Laparoscopic-IHR: 18.1%, $p=0.14$), Robotic-IHR was associated with a significantly greater proportion of grades III and IV complications (Robotic-IHR: 6.7% vs. Laparoscopic-IHR: 0%, $p=0.01$). Total hospital cost was significantly higher for the Robotic-IHRs ($9993 vs. $5994, $p<0.01$). The added cost associated with the robotic device itself was $3106 per case and the total cost of disposable supplies was comparable between the 2 groups.

Conclusions In the setting in which it was studied, the outcomes of Laparoscopic-IHR were significantly superior to the Robotic-IHR, at lower hospital costs. Laparoscopic-IHR remains the preferred minimally invasive surgical approach to treat inguinal hernias.

Keywords Robotic surgery · Surgery · Laparoscopic surgery · Inguinal hernia · Cost · Complication

Inguinal hernia repair (IHR) is one of the most common surgical procedures in the USA, with an estimated 770,000 cases performed annually [1]. While complication and recurrence rates after the standard open tension-free mesh repair are low [2, 3], continued efforts aimed at improving cost-effectiveness and recovery from this operation [4–8] have led to the introduction of minimally invasive surgery (MIS) techniques and a transition from the inpatient to the outpatient setting for the majority of IHRs done in the USA [6, 9–11], where in 2010, an estimated 449,000 IHRs were outpatient cases [11].

The current mainstream MIS techniques to repair inguinal hernia (IH) are the laparoscopic transabdominal preperitoneal (TAPP) and the totally extraperitoneal (TEP, Laparoscopic-IHR) techniques; and there is no clear advantage of one

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✉ Guilherme M. Campos
guilherme.campos@vcuhealth.org

[1] Division of Bariatric and Gastrointestinal Surgery, Department of Surgery, Virginia Commonwealth University School of Medicine, Richmond, VA, USA

technique over the other, with surgeons choosing a technique based on personal preferences [12]. Nevertheless, in the USA, only about 28% of primary unilateral IHRs were done using MIS techniques between 2005 and 2012 [13]. The reasons behind the relatively low utilization of MIS techniques to treat IHs are multiple and include a steep learning curve [14–17], increased hospital costs [18–20], and longer operative time in selected series [3, 18, 20, 21]. Further, Level 1 evidence that MIS techniques, compared to open repair, provide superior patient-related outcomes (decreased postoperative pain, faster return to normal activities and lower wound infection rates) is available only for bilateral and recurrent IHs [3, 16, 17, 22].

Robotic technology was fast embraced by urologic surgeons in the USA, as it allowed for the transition from open prostatectomy to MIS robotic prostatectomy, most without any experience with laparoscopic techniques [23, 24]. Indeed, MIS robotic prostatectomy is a procedure that is suited to robotic-assisted technology as it involves delicate suturing of the urethra deep in the confines of the male pelvis.

Interestingly, the utilization of robotic technology to treat ventral and inguinal hernias has been the main driver for the growth of robotic surgery in General Surgery in the USA [25], with an estimated increase from 140,000 general surgery robotic procedures in 2015 to 246,000 in 2017.

Of note, and important to the issue at hand, the increasing utilization of Robotic-IHR has been at the expense of decreasing utilization of Laparoscopic-IHR rather than a decrease in the utilization of Open-IHR [26].

With the absence of evidence from randomized or retrospective studies supporting any superior patient outcomes or hospital benefits of the current robotic technology compared to standard laparoscopic techniques, concerns of higher costs with the robotic approach, and conflicting results from five retrospective series available in the literature comparing the two approaches [27–31], the question remains as to whether the utilization of robotic technology to treat IHs should be encouraged.

This study aimed to compare perioperative outcomes and costs of Robotic-IHR versus Laparoscopic-IHR at a tertiary academic medical center in the USA.

Materials and methods

Patient population

With the approval of the institutional review board, a retrospective analysis was performed of all consecutive patients that underwent laparoscopic- or robotic-IHR from February 2015 to June 2017 at a dedicated MIS unit of a tertiary academic medical center in the USA. The Institution's Enterprise Analytics System was queried to identify all cases of minimally invasive IHRs done during the study period using the Current Procedural Terminology (CPT) codes 49650, 49651, and 49659 [32]. Only cases which were performed by one of the four fellowship-trained MIS division faculty surgeons, all of which were skilled in laparoscopic TEP and TAPP repairs, were included in this study. The Robotic-IHRs were performed between March 2015 and April 2017 by the only one of the four surgeons who had expertise in robotic-assisted surgery and served as a robotic abdominal wall hernia proctor for the da Vinci® Surgical System (Intuitive Surgical Inc., Sunnyvale, CA). The Laparoscopic-IHRs were performed between February 2015 and June 2017 by all four surgeons. Selection for Robotic or Laparoscopic approach was based on the surgeon and patient's preferences. Additionally, patients were excluded from the study if they were prisoners, pregnant women, individuals younger than 18 or older than 85 years, and those undergoing inguinal hernia repair concomitantly with a second major procedure (e.g., large ventral hernia repair).

Data collection and outcomes studied

Patients' electronic medical records were reviewed, and the following data were collected: patient's demographic and anthropomorphic information (age, gender, BMI), American Society of Anesthesiologists Physical Status Classification (ASA class) [33], comorbid diseases (including type-2 diabetes, hypertension, hyperlipidemia, chronic obstructive pulmonary disease (COPD)/asthma, obstructive sleep apnea, chronic kidney disease, atrial fibrillation, gastroesophageal reflux disease, congestive heart failure and history of cerebrovascular accident), hernia laterality (unilateral vs. bilateral), presentation (primary vs. recurrent), operative details, surgery cost measures, rate of in-patient admissions, length of stay, 30-day readmissions and reoperations, and the rate and severity of complications. Operative details included surgical technique (robotic vs. laparoscopic), operative time, type of mesh, use of tacks or fibrin sealant to secure the mesh, and the need for conversion to open procedure. Operative time was defined as the time from skin incision to wound closure.

Complications and Clavien–Dindo classification

The severity of complications was categorized using the Clavien–Dindo classification of surgical complications as follows. Grade I was defined as any deviation from the normal postoperative course without the need for pharmacologic treatment or surgical, endoscopic, or radiologic intervention (except for antiemetics, antipyretics, analgesics, diuretics and electrolytes, and physiotherapy). This grade also includes wound infections opened at the bedside. Grade II were events requiring other medications, blood transfusion, or total parenteral nutrition. Grade III were those requiring surgical, endoscopic, or radiologic intervention without general anesthesia (IIIa) or under general anesthesia (IIIb). Grade IV were any life-threatening complication leading to a single (IVa) or multiple (IVb) organ failure, and Grade V comprised of complications resulting in patient's death [34]. We further categorized the various Clavien–Dindo Grades into Minor or Severe Complications. Complications classified as Grade I or II were considered Minor and those classified as Grade III or higher were considered Severe Complications.

Cost analyses

Cost information was provided by the institution's financial department and compared between the 2 groups. Hospital charges and reimbursement data varied between insurances and were not reported in this study. Three separate cost analyses were obtained and are presented:

1. Total hospital costs: this included the estimated cost of anesthesia, operating room, and recovery in addition to the disposable supplies and medications used during surgery. Only costs associated with the index admission for the IHR procedure were included. Costs of any readmission and reoperation were not included in this analysis. For this analysis, a combination of case-level and time-based system (per 1/2 h increment) is adopted by our institution to calculate the cost of surgery. Case-level is determined by the patient's ASA class, the complexity of the procedure, and the equipment and staff requirements.
2. Total disposable supplies and specific categories costs: data combining detailed operating room usage with actual supply pricing was used for this analysis. Each surgery had its disposable supplies usage queried using the SurgiNet® Perioperative Documentation Application and cross-referenced with the Lawson Software® Item Master. The amount and costs for trocars, fixation devices, meshes, medications, drapes, and all accessories and other disposable equipment and parts were collected. Cost was adjusted to the 2017 dollar value. Total cost of the disposable supplies and categorized items including Access Instruments (trocars, trocar caps and balloon dissectors), Meshes, Fixation devices (tacker and Tisseel™ fibrin sealant), and Others (sutures, pads, drapes, medications, etc.) were tabulated and compared between the 2 groups.
3. Capital and service cost of the Robotic da Vinci® Surgical Systems: the actual cost of the robotic systems was obtained and its depreciation over time was calculated based on an estimated 6-year lifespan of the robotic system. The capital cost associated with utilizing the robot per case was calculated as the total depreciation of the capital cost during the study period divided by the number of all and any robotic cases performed by all surgeons at our institution during the same time period. The cost of the maintenance services per case was also calculated and the total added cost was noted.

Operative technique

Laparoscopic-IHRs were performed in the standard TEP approach. Patients were placed in the supine position. A curvilinear incision to the side of the umbilicus was made and dissected down to the anterior fascia that was incised, and the rectus muscle was lateralized. A balloon dissector was then passed anterior to the posterior sheath down towards the pubic bone under laparoscopic direct vision and inflated. The balloon dissector was removed, and the structural trocar balloon was then inserted into the retrorectus space and the preperitoneal space was insufflated with CO2. Two additional 5 mm trocars were then inserted in the midline in between the umbilicus and pubic bone. Blunt dissection was performed to identify the symphysis pubis, pubic tubercle, Cooper's ligament, and the inferior epigastric vessels. The myopectineal orifice was evaluated and any direct, indirect, femoral, obturator hernia was reduced. If an indirect hernia was identified, the spermatic cord was skeletonized and the hernia sac dissected to the level of the psoas muscle. Mesh was then inserted with complete coverage of the myopectineal orifice. Fixation was case based. During reduction of the pneumoperitoneum, graspers were used to keep the mesh from rolling up posteriorly and ensure that the peritoneum stayed above the mesh(es). Trocars were removed, and the anterior fascia in the periumbilical incision was closed using zero monofilament suture. Finally, the skin was closed, and incisions were injected with 0.25% Marcaine.

Robotic-IHRs were performed with the TAPP approach. A 12-mm robotic trocar was inserted through a supraumbilical incision under direct camera visualization. Two 8-mm trocars were then placed at the same level to left and right of the midline. The robotic arm was docked, and the procedure was started by creating a preperitoneal flap. The preperitoneal flap was raised from the median umbilical ligament and dissected to identify the Cooper's ligament, to the anterior superior iliac spine. Once the flap was developed, the same anatomic principles of laparoscopic hernia repair listed above were followed. The mesh was placed in the preperitoneal space with coverage of the myopectineal orifice and secured using 4 mL of Tisseel™ fibrin sealant (Baxter Corp., Deerfield, IL). The peritoneum was closed over the mesh using a 2-0 V-Loc™ (Medtronic, Minneapolis, MN, US) under running fashion. The robot was undocked. The 12-mm trocar site fascia was closed. The skin was closed, and incisions were injected with 0.25% Marcaine.

Statistical analysis

Numeric variables were presented as mean ± standard deviation (SD) and compared using Student's *t* test, whereas categorical variables were compared using Fisher's exact test. Statistical significance was determined if $p \leq 0.05$. To determine if there was a learning curve effect influencing operative time, we used linear regression to study operative time as a dependent variable and the date of surgery as the independent variable adjusted for recurrent hernias, bilateral hernias, and umbilical or ventral hernias repaired concurrently repaired. This model was applied to the Robotic-IHR and the Laparoscopic-IHR groups, as well as individually to each surgeon. We also divided the surgeries in quartiles according to the date of surgery and compared the rate of complications in each quartile, also to determine if a learning effect could change the incidence of complications along the study period. IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA) and SAS V9.4 (SAS Institute, Cary, NC, US) were used for statistical analyses.

Results

During the study period, a total of 183 patients underwent minimally invasive IHR (232 hernias): 45 patients (24.6%), including 8 (17.8%) with bilateral IHs had Robotic-IHR (all done by surgeon 1); and 138 patients (75.4%), including 41 (29.7%) with bilateral IHs had Laparoscopic-IHR [surgeon 1 ($n = 30$), surgeon 2 ($n = 36$), surgeon 3 ($n = 8$), and surgeon 4 ($n = 64$)]. There were no statistically significant differences between patients in Robotic-IHR and Laparoscopic-IHR groups in age, gender, BMI, or ASA class (Table 1). Patients in the Robotic-IHR group were more likely to have the diagnosis of obstructive sleep apnea and chronic kidney disease than the Laparoscopic-IHR group (6.7% vs. 0.7%; $p = 0.04$ and 8.9% vs. 1.4%; $p = 0.03$, respectively). The proportion of bilateral and recurrent hernias, type of mesh, and the rate of conversion to open surgery were also similar between the two groups (Table 2). Laparoscopic tacks to secure the mesh were only used with the Laparoscopic-IHR technique ($n = 91$, 65.9%). Only two tacks were placed, one in midline in pubic bone and another in the midline posterior abdominal wall (Table 2), whereas Tisseel™ fibrin sealant (Baxter Corp., Deerfield, IL) was used to secure the mesh in Robotic-IHRs.

Mean operative time was 21 min longer for the Robotic-IHRs (1 h 56 min ± 36 min vs. 1 h 35 min ± 44 min, $p < 0.01$). Similarly, operative time for unilateral IHRs was significantly longer in the Robotic-IHR (1 h 50 min ± 35 min vs. 1 h 28 min ± 37, $p < 0.01$). On the other hand, while there was a trend toward longer operative time for bilateral repairs (29 min longer for the Robotic-IHRs), the difference was not statistically significant ($p = 0.06$) (Table 2).

Linear regression analysis showed that mean operative time in the Robotic-IHR group did not vary significantly throughout the study period ($R^2 = 0.008$, $p = 0.62$).

Table 1 Patients' demographics and clinical characteristics

	Laparoscopic-IHR $n = 138$	Robotic-IHR $n = 45$	*p* value
Age (years), mean ± SD	50 ± 13.7	49.6 ± 13.3	0.86
Male gender, *n* (%)	133 (96.4)	42 (93.3)	0.41
BMI (kg/m^2), mean ± SD	26.2 ± 3.6	27.5 ± 5.8	0.16
ASA class, *n* (%)			
I	50 (36.2)	13 (28.9)	0.11
II	76 (55.1)	23 (51.2)	
III	12 (8.7)	9 (20)	
Type-2 diabetes, *n* (%)	14 (10.1)	2 (4.4)	0.36
Hypertension, *n* (%)	43 (31.2)	15 (33.3)	0.85
Hyperlipidemia, *n* (%)	29 (21)	8 (17.8)	0.83
COPD/Asthma, *n* (%)	8 (5.8)	4 (8.9)	0.49
Obstructive sleep apnea, *n* (%)	1 (0.7)	3 (6.7)	0.04
Chronic kidney disease, *n* (%)	2 (1.4)	4 (8.9)	0.03
Atrial fibrillation, *n* (%)	4 (2.9)	1 (2.2)	0.81
Gastroesophageal reflux disease, *n* (%)	15 (10.9)	5 (11.1)	0.96
Congestive heart failure, *n* (%)	2 (1.4)	0 (0)	0.57
Cerebrovascular accident, *n* (%)	1 (0.7)	1 (2.2)	0.43

IHR inguinal hernia repair, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *ASA Class* Anesthesiologists Physical Status Classification, *SD* standard deviation

Table 2 Types of inguinal hernia, operative technical detail, and outcomes

	Laparoscopic-IHR $n=138$	Robotic-IHR $n=45$	p value
Bilateral hernias, n (%)	41 (29.7)	8 (17.8)	0.13
Recurrent hernias, n (%)	6 (4.3)	5 (11.1)	0.14
Type of mesh, n (%)			
3Dmax™ (BARD)	67 (48.6)	23 (51.1)	
Parietex™ (Medtronic)	71 (51.4)	21 (46.7)	0.97
PROLENE® (Ethicon)	0 (0)	1 (2.2)	
Use of tacks, n (%)	91 (65.9)	0 (0)	< 0.01
Operative time, mean ± SD			
All cases	1 h 35 min ± 44 min	1 h 56 min ± 36 min	< 0.01
Unilateral	1 h 28 min ± 37 min	1 h 50 min ± 35 min	< 0.01
Bilateral	1 h 54 min ± 54 min	2 h 23 min ± 33 min	0.06
Conversion to open surgery, n (%)	1 (0.7)	0 (0)	0.57

IHR: inguinal hernia repair; SD: standard deviation

This finding suggests that the longer operative time in this group may have not been influenced by a learning curve. In the Laparoscopic-IHR group, the mean operative time significantly decreased during the study period ($R^2=1.33$, $p<0.001$), and that finding was driven by a decrease in the operative time over time of one of the surgeons exclusively in the Laparoscopic-IHR group. The percentage of patients with complications was also similar across the time quartiles in both groups (Robotic-IHR: Q1 = 15.4%, Q2 = 15.4%, Q3 = 38.5%, Q4 = 30.8%, $p=0.47$ vs. Laparoscopic-IHR: Q1 = 32%, Q2 = 32%, Q3 = 24%, Q4 = 12%, $p=0.34$).

The rate of hospital admission and the length of stay were similar in the two groups. One (2.2%) and 4 (2.9%) patients were admitted overnight following Robotic-IHR and Laparoscopic-IHR, respectively, all due to urinary retention ($p=0.81$).

Total hospital cost of the index surgery was significantly higher for the Robotic-IHRs versus Laparoscopic-IHRs ($9993 vs. $5994, $p<0.001$). Total cost of disposable supplies was similar for the Laparoscopic-IHRs versus Robotic-IHRs. Detailed analyses of the costs of disposable supplies showed that Access Instruments had higher costs in the Laparoscopic-IHR group, while Meshes and Others Supplies had higher costs in the Robotic-IHR group.

The added capital cost of the robot per each case was $2130 in our institution. During the study period, two da Vinci® Surgical Systems were utilized to perform a total of 697 robotic-assisted surgeries. The total cost of both systems was $4,133,861 and the estimated depreciation was $1,484,472. Total cost of maintenance services during the study duration was $680,094 ($976 per case), making the total added cost per case $3106 (Table 3).

Types and severity of perioperative complications, rates of reoperation due to complications, and rates of 30-day readmission are summarized in Table 4. Although the overall proportion of patients with any perioperative complication was similar between groups (Robotic-IHR: 28.9% vs. Laparoscopic-IHR: 18.1%, $p=0.14$), all complications in the Laparoscopic-IHR group were minor complications classified as Clavien–Dindo Grade I (seroma, urinary retention and hematoma), while only patients who underwent Robotic-IHRs had severe complications classified as grades III and IV ($p=0.01$). In addition, reoperations due to perioperative complications were only necessary in the Robotic-IHR group (Robotic-IHR: 6.7% vs. Laparoscopic-IHR: 0%, $p=0.01$).

Readmission within 30 days postoperatively was required more frequently following Robotic-IHR (Robotic-IHR: 6.7% vs. Laparoscopic-IHR: 0.7%, $p=0.04$). Three patients in the Robotic-IHR group required reoperation due to: 1-L hemoperitoneum, strangulated robotic port-site hernia requiring laparotomy and small bowel resection and an incarcerated loop of bowel in an opening of the peritoneal flap closure. One patient in the Laparoscopic-IHR group required readmission due to prolonged postoperative ileus, which ultimately resolved with non-operative management. Of note, the two comorbidities (obstructive sleep apnea and chronic kidney disease) which were more prevalent in patients undergoing Robotic-IHR seem to not have impacted complication rates. None of the patients with obstructive sleep apnea in either group had any complication; the patient with hemoperitoneum had no comorbidites and one patient with chronic kidney disease in each group had a seroma which did not impact their length of stay and did not require any additional management.

Table 3 Cost calculations of laparoscopic versus robotic inguinal hernia repairs

	Laparoscopic-IHR $n=138$	Robotic-IHR $n=45$	p value
Total hospital cost[a]	5995 ± 3049	9994 ± 2498	< 0.01
Total cost of disposable supplies	1380 ± 565	1588 ± 1298	0.31
Mesh cost	330 ± 221	468 ± 372	0.027
Mesh fixation cost[b]	407 ± 66	492 ± 649	0.55
Access instruments cost[c]	269 ± 63	190 ± 117	< 0.01
Other supplies cost	454 ± 287	679 ± 551	0.014
Total added cost of the robot per case		3106	
Capital cost of the robot per case		2130	
Robot maintenance services cost per case		976	

IHR inguinal hernia repair, *SD* standard deviation

[a]Cost data is presented in US dollars as mean ± SD

[b]Laparoscopic Tackers, Tisseel™ fibrin sealant and applicator

[c]Trocars, Trocar Caps, Balloon Dissectors

Table 4 Types of perioperative complications, rates of reoperation due to complications and 30-day readmission, and severity of complications according to the Clavien–Dindo classification of surgical complications

	Laparoscopic-IHR $n=138$	Robotic-IHR $n=45$	p value
In-patient admission, *n* (%)	1 (2.2)	4 (2.9)	0.81
Length of hospital stay, mean (range)	0.04 (0–1)	0.13 (0–2)	0.16
Patients with any complication, *n* (%)	25 (18.1)	13 (28.9)	0.14
Reoperation due to complication, *n* (%)	0 (0)	3 (6.7)	0.01
30-day readmission, *n* (%)	1 (0.7)	3 (6.7)	0.04
Postoperative ileus, *n* (%)	0 (0)	1 (2.2)	0.25
Superficial surgical site infection, *n* (%)	0 (0)	1 (2.2)	0.25
Seroma, *n* (%)	16 (11.6)	5 (11.1)	0.93
Hemoperitoneum, *n* (%)	0 (0)	1 (2.2)	0.25
Small bowel obstruction, *n* (%)	0 (0)	2 (4.4)	0.06
Urinary retention, *n* (%)	7 (5.1)	2 (4.4)	0.87
Hematoma, *n* (%)	1 (0.7)	1 (2.2)	0.43
Clavien–Dindo grade, *n* (% of all patients) [% of patients with complications]			
I	25 (18.1) [100]	10 (22.2) [76.9]	0.01[a]
IIIb	0 (0) [0]	2 (4.4) [15.4]	
IVa	0 (0) [0]	1 (2.2) [7.7]	
Mild complications: Clavien-Dindo Grade I or II	25 (18.1) [100]	10 (22.2) [76.9]	0.01[a]
Severe complications: Clavien-Dindo Grade III or IV	0 (0) [0]	3 (6.7) [23.1]	

IHR inguinal hernia repair

[a]$p=0.01$ comparison of all patients ($n=183$) and $p=0.03$ comparison of only patients with complications ($n=38$)

Discussion

In this single-center series, Robotic-IHR compared to Laparoscopic-IHR was associated with inferior perioperative outcomes, including longer operative time and a greater rate of higher-grade perioperative complications, readmissions, and reoperations and higher costs of the index admission. Our findings mirror results of other case series in which the robotic cases were associated with about $2200 to $2600 added cost and longer operative time compared to laparoscopic cases (Table 5) [27, 30].

The significance of studying the outcomes of IHR stems not only from its impact on the health and well-being of hundreds of thousands of patients with this condition [1, 11] but also from its substantial possible burden on the economy and direct healthcare costs of inguinal hernia repair surgeries that are estimated to be around $2.5 billion per year [1], and the estimated nearly $30 billion of indirect costs associated with the effect of surgery on employment, sick leave, and disability insurance [35, 36]. Thus, researching surgical outcomes for a common surgical condition such as inguinal hernia and scrutinizing the cost-effectiveness of established and new techniques and technologies are of paramount importance.

Since the beginning of the modern evolution in inguinal hernia surgery, the open tension-free repair has been the gold standard and most popular technique starting in the 1990s [26]. Ironically, this was the same period when minimally invasive IHR started to be proposed as an alternative to the open repair with early experiences of the Laparoscopic-IHR occurring in the early 1990s and Robotic-IHR in the late 1990s [37, 38].

So far, the laparoscopic (TEP or TAPP) techniques have failed to prove superior perioperative outcomes or lower recurrence rates for the most common cases of primary unilateral hernias [3, 16, 17, 22], while both have been shown to reduce postoperative pain and improve recovery when used to treat bilateral and recurrent IHs [4–8].

In recent years, an increased number of authors have been reporting experiences with Robotic-IHR, as another minimally invasive surgical option for an inguinal hernia [27–29, 31, 39–43]. National estimates of utilization of the robot in IHR in the USA are still lacking but data from the only manufacturer of the currently used robotic system (Intuitive Surgical Inc., Sunnyvale, CA) shows an increase of utilization of their technology in general surgery in the USA from 140,000 procedures in 2015 to 246,000 procedures in 2017, with most of the growth attributed to ventral and inguinal hernia repairs, but procedure-specific numbers were not reported [25]. Data from the Emergency Care Research Institute (ECRI), an independent non-profit organization that researches approaches to improving patient care, shows that 79% of all robotic-assisted surgeries worldwide were done in the USA. Of those, 24% were in general surgery comprising a bigger share of the robotic surgery market than urology in 2014, with cholecystectomy and IHR being the most commonly performed procedures [44].

Importantly, and in association with marketing efforts [25, 45] and the attractiveness of the robotic-assisted approach to some patients [45], there has been an increasing number of centers offering the Robotic-IHR. However, this growth in utilization of Robotic-IHR has been at the expense of the Laparoscopic-IHR rather than decrease in the utilization of Open-IHR [26]. This is supported by the findings of a recent study of utilization trends of common surgical procedures using a large administrative database of more than 300 academic medical centers and their affiliated hospitals (Vizient database®). Armijo et al. found a negative trend in utilization of Laparoscopic-IHR, decreasing from 12.6% in 2008 to 10.8% in 2015. At the same time, there was an increase in Robotic-IHRs from 3.1% in 2008 to 4.5% in 2015. On the other hand, Open-IHR remained the overwhelmingly most common approach, and its utilization did not change over time [26].

Proponents of the robotic technology have advocated the feasibility of executing more complex cases [46] and potential patient outcomes are a benefit compared to the Open-IHR [40, 43], but not Laparoscopic-IHR [27–29]. However, to our knowledge, no equipoise or superiority to the laparoscopic technique has been reported.

The five main modifiable determinants of economic cost-effectiveness of any surgical procedure are the cost of the instrument or technology used and related consumables, operative time, length of hospital stay, return to work/convalescence, and complications/readmissions. The capital cost of the da Vinci® Surgical System has ranged from $0.9 to $2.4 million for each unit [44, 47]. In an analysis of the added cost associated with robotic-assisted surgery, Barbash and Glied reviewed studies that reported the costs of 20 types of robotic-assisted procedures published in the first decade of utilization of this technology and estimated that the additional variable cost of using the robot was, on average, $1600 or 6% of the cost of the procedure. This increased to $3200 or 13% of the cost of the procedure when the amortized cost of the device itself was included [47]. Similarly, van Dam et al. estimated that the capital cost of the robot adds approximately €1000 to €4000 (around $1140 to $4500) per case when a range of 100–400 robotic procedures a year are performed [48]. Our cost analyses showed that Robotic-IHRs were associated with an average additional $4000 per case, which sums up to $7106 when adding the estimated capital cost of the robot and maintenance services ($3106 at our institution). This estimated added cost is based on the utilization of the robotic systems at our institution by our division and all other divisions and surgeons during the study period. And while maximizing utilization may reduce this cost, others have shown that even with optimal utilization, the per case incremental cost of the robot remains significant [49] and cannot be ignored in any comparative cost analysis. Using data from the 2013 Intuitive Surgical Investors report which contains the manufacturer's actual revenue of the robotic systems and service revenue, Schwaitzberg [49] modeled the added net costs during robotic-assisted cholecystectomy and hernia repairs, with varying assumptions of types of robotic system and case-volumes. The added cost ranged from $2908 to $8675. In the best-case scenario of high utilization of the least expensive system, the added cost was $2600 for cholecystectomy and $2200 for hernia repairs [49]. Our analysis did not include the capital cost of the laparoscopic tower systems used in the Laparoscopic-IHR cases; however, it has been estimated that the capital cost of the laparoscopic towers and their maintenance fees add only about $50 and $100 per case, respectively [49].

The two main factors driving the higher cost of the Robotic-IHRs were operative time and equipment and staff requirements with higher case-levels. While we found differences in the detailed cost analyses of those supplies between the 2 groups, the total cost of disposable supplies was similar. Detailed cost analysis of disposable supplies of Robotic- vs. Laparoscopic-IHR is reported in only 1 previous study [50]. Similar to our series, Higgins et al. reported significantly higher cost of mesh supplies in the Robotic-IHR cases, and the total supply cost was also significantly higher in the Robotic-IHR group in that series ($1954 vs. $1471, $p<0.01$) but not in ours [50]. Although we did not obtain detailed costs of reusable instruments, others have estimated the cost of robotic instruments (which are replaced every 10 uses versus the laparoscopic instruments, most of which remain reusable for years) to be about $2000 per case [50]. In our analysis, the cost associated with the robotic instruments, in addition to the added operative time, is reflected in the higher case-levels and time-based system of cost calculation of all cases, thus contributing to the $4000 cost increase associated with utilizing the robot.

Of note, the cost of readmissions and reoperations, which occurred more frequently in the Robotic-IHR group, were not included in our cost analysis. Thus, even if Robotic-IHR had comparable readmission and reoperation rates, the costs of the index admission for Robotic-IHR would still be significantly higher than Laparoscopic-IHR. This is in agreement with two recent studies comparing Robotic-IHR and Laparoscopic-IHR [27, 30] (Table 5). Charles and colleagues studied the cost and outcomes of 69 Robotic-IHRs compared to 241 Laparoscopic-IHRs and 191 Open-IHRs. They found a $2600 and $2900 increase in hospital cost for Robotic-IHR compared to laparoscopic- and open-IHR, respectively [27]. Similarly, Abdelmoaty et al. reported that $2248 added hospital cost was associated with utilizing Robotic-IHR ($n=734$) compared to Laparoscopic-IHR ($n=1671$) [30]. Interestingly, another study found that the Robotic-IHR was not associated with increased cost compared to Laparoscopic-IHR; however, the authors chose not to include the capital cost of the robot in their analysis [31]. Although a similar cost discrepancy has been discussed in the past between open- and laparoscopic-IHR [18, 51], further research showed cost-efficacy advantages related to the laparoscopic techniques in selected cases [4–8].

In our series, operative time was approximately 21 min longer in the Robotic-IHRs compared to Laparoscopic-IHRs. However, when analyzing separately cases of unilateral and bilateral repairs, only unilateral repairs took longer with the robot. Of note, in our series, while there was a trend toward longer operative time for bilateral repairs (29 min longer for the Robotic-IHRs), the difference was not statistically significant ($p=0.06$). This is likely due to the relatively small sample size of bilateral hernias studied. The finding of greater OR time in robotic cases is similar to previous studies that showed an increase between 9 to 31 min for unilateral repairs [27, 29–31] (22 min in this study) and 10 to 28 min for bilateral repairs [29, 31].

Operative time has been studied as a surrogate measure for the learning curve effect of surgical techniques [14, 17, 29]. However, little is known about the effect of the learning curve for the Robotic-IHR; however, it has been suggested that it may be as short as 25 cases [29] which, if that is true, is significantly shorter than the 65–250 cases required to overcome the learning curve in the Laparoscopic-IHR with the TEP approach [14, 17]. It's interesting to note that Kudsi et al. is the only other series in the literature specifically comparing Laparoscopic-IHR using the TEP approach ($n=157$) and Robotic-IHR ($n=118$), and they reported equivalent operative time between the two techniques even though the Robotic-IHR group included more complex cases [28]. Another report by Muysoms et al. comparing Laparoscopic-IHR, done through the TAPP approach, ($n=64$) to Robotic-IHR ($n=49$) showed that operative time decreased in the Robotic-IHR group over time to become similar to that of the Laparoscopic-IHR group after the first 25 cases [29]. Each of these two studies reports a single surgeon's experience adopting the robotic-assisted approach after extensive prior experience with laparoscopic groin surgery. Therefore, as the authors rightly noted, the learning curve effect was likely different than what is expected for surgeons adopting the Robotic-IHR without prior proficiency in Laparoscopic-IHR [28, 29].

In the largest series to date comparing cost and operative time between the two techniques, Abdelmoaty et al. found that the operative time was significantly longer in the Robotic-IHR compared to Laparoscopic-IHR (87 vs. 56 min, $p<0.001$). In a sub-analysis that included only five surgeons in each group with the highest volume and most experience, they found similar results of longer operative time in the robotic-assisted repairs (73 vs. 41 min, $p<0.001$) [30].

IHR can generally be done on an outpatient setting with any of the currently available techniques: open, laparoscopic and robotic-assisted. Neither the present study nor other reports found a significant difference between the Robotic-IHR and the other surgical techniques regarding length of hospital stay [27, 29–31] including comparison with the Open-IHR [27]. In a multicenter retrospective review, Gamagami et al. compared 444 Open-IHRs matched to 444 Robotic-IHRs and found that Robotic-IHR was associated with a shorter hospital stay than Open-IHR for inpatient cases but not the overall cohort. The authors did not find any differences between the two groups in regards

Table 5 Review of studies comparing robotic-assisted versus laparoscopic inguinal hernia repair

	Charles (2018)[a] [27]	Kudsi (2017) [28]	Muysoms (2018) [29]		Abdelmoaty (2018) [30]		Waite (2016) [31]
Study design	Retrospective single-center	Retrospective single-center	Retrospective single-center		Retrospective multicenter		Retrospective single-center
Country	US	US	Belgium		US		US
Inclusion	Primary unilateral IHRs	All IHRs	All IHRs[c]		All IHRs		Unilateral IHRs
Laparoscopic technique	NR	TEP	TAPP		NR		TAPP
N, R-IHR:L-IHR	69:241	118:157	49:64[c]		734:1671		39:24
Surgeons, N R-IHR:L-IHR	2:8	1:1	1:1		49:115		1:1
L-IHR experience before R-IHR	NR	Yes	Yes		Yes		NR
Operative time for unilateral IHRs (min)							
Measure	Median [interquartile range]	Mean ± SD	All cases	Tertile 3	All surgeons	Most experienced	Mean
			Mean ± SD	Mean ± SD	Average	Average	
R-IHR	105 [76–146]	69 ± 35	54 ± 16	44 ± 10	87	73	68
L-IHR	81 [61–103]	69 ± 26	45 ± 11	49 ± 12	56	41	55
p value	< 0.001	NS	NR (significant)	NR (NS)	< 0.001	< 0.001	NR (NS)
Cost calculation method	NR	NR	NR		Personnel, devices, reusables and disposables		Robotic system cost and non-disposables not included
Total hospital costs (USD)							
Measure	Median [interquartile range]				Average		Average
R-IHR	7162 [5942–8375]				5517		3479
L-IHR	4527 [2310–6003]				3269		3216
p value	< 0.001				< 0.001		0.99
Any complication, *n* (%)							
R-IHR	2 (2.9)	8 (6.8)[b]	Unilateral	Bilateral	NR		NR
			3 [9]	2 [13]			
L-IHR	8 (3.3)	8 (5.1)[b]	0 (0)	3 [7]			
p value	NS	NS	NS	NS			
Severe complications, *n* (%)							
R-IHR	0 (0)	NR			NR		NR
L-IHR	1 (0.4)		0 (0)				
p value	NS						
Readmission due to complication, *n* (%)							
R-IHR	0 (0)	4 (3.4)	0 (0)		NR		NR
L-IHR	5 (2.1)	3 (1.9)					
p value	NS	NS					

Table 5 (continued)

	Charles (2018)[a] [27]	Kudsi (2017) [28]	Muysoms (2018) [29]	Abdelmoaty (2018) [30]	Waite (2016) [31]
Reoperation, *n* (%)					
R-IHR	0 (0)	0 (0)	0 (0)	NR	NR
L-IHR					
p value					

IH inguinal hernia, *TEP* totally extraperitoneal, *TAPP* transabdominal preperitoneal, *L-IHR* laparoscopic inguinal hernia repair, *R-IHR*, robotic inguinal hernia repair, *NR* not reported, *SD* standard deviation

[a]Charles et al. studied R-IHR versus L-IHR versus Open-IHR. This table only includes comparisons between R-IHR versus L-IHR

[b]Postoperative complications are reported for the first 3 months after surgery

[c]Muysoms et al. studied groin hernia. The majority were IHs and a small subset ($n=2$) were femoral hernias. They reported an overall longer operative time in the R-TAPP compared to L-TAPP but equivalent operative time for cases done after the first 25 R-TAPP repairs

to perioperative complications except for lower pain on postoperative day 1 for the Robotic-IHR patients [43]. In the present study, only 2.2% and 2.9% of patients required admission to the hospital in the Robotic-IHR and Laparoscopic-IHR groups, respectively.

Perioperative complications after IHR are mostly mild and usually due to urinary retention, seroma/hematoma or wound infection. Still, a subset of patients requires readmissions and sometimes reoperations due to complications [2, 27–29, 43]. Our series and previous reports comparing the Robotic-IHR to Laparoscopic-IHR did not find significant differences in the rate of overall perioperative complications [27–29]. We did find, however, a higher likelihood of severe complications (Clavien–Dindo Grade III or IV) after Robotic-IHR. Although differences between IHR techniques in terms of perioperative complications seem to be small due to the overall low serious complication rates, Robotic-IHR seems to be associated with specific types of complications such as superficial surgical site wound infection [27, 52] and robotic port-site hernia [53, 54] which may be related to the use of 8- to 12-mm ports in the robotic-assisted surgeries and strength of lateral movement of robotic arms possibly further enlarging the trocar site [53, 55]. To prevent port-site hernia, fascial closure of all robotic ports has been advocated, but port-site hernias have still been reported despite routine fascial closure [56]. In the Robotic-IHR group of our study, two patients required reoperation due to port-site hernias. We also found a higher risk of readmission following Robotic-IHRs, a finding consistent with another report of Robotic-IHR vs. Laparoscopic-IHR [27].

Postoperative pain after IHR has been studied and it may play a role in the return to normal activities with potential impact on cost-effectiveness. Studies comparing Robotic-IHR and Laparoscopic-IHR also report conflicting results in postoperative pain between the two minimally invasive techniques [28, 29, 31].

In summary, the findings of this study, in agreement with data from most other comparative studies of IHR techniques [27, 31], shows inferior results of the Robotic-IHR compared to Laparoscopic-IHR in 3 of the 5 determinants of cost-effectiveness of surgical procedures (technology and hospital cost, operative time and severity of complication and readmissions rates). We did not evaluate the impact on postoperative pain or return to normal activities, but others have shown equivalent results between the two techniques. In our division, and while one of the surgeons continued to selectively offer robotic inguinal hernia repairs, we disclose to patients the currently available data as part of the informed consent and continue to monitor outcomes and costs.

As in all previous five reports comparing the Robotic-IHR and Laparoscopic-IHR [27–31] (Table 5), our study is also limited by its retrospective nature. However, our manuscript is only one of two series reporting cost, operative time, and details, providing a detailed and comprehensive cost analyses, in addition to perioperative outcomes comparing the two approaches [27]. Additionally, this is a single-center experience in which only one of the four MIS faculty utilized the robotic platform. However, this surgeon had experience in both techniques and served as a robotic training proctor for the robotic company. Also, while operative times did not change during the study period for Robotic-IHR, the learning curve may have had a role in patient outcomes. Another limitation is comparing two different minimally invasive techniques [Robotic-IHR (TAPP) vs. Laparoscopic-IHR (TEP)]. Nonetheless, others have shown that laparoscopic TEP and TAPP have equivalent outcomes [12] and even though the TEP technique is known to have a longer learning curve than the TAPP [14, 17, 57], the TEP repair still showed superior results to the robotic-assisted TAPP approach.

Conclusions

In the setting in which it was studied, perioperative outcomes of laparoscopic inguinal hernia repair were superior to the current robotic-assisted technique, at lower hospital costs; thus, remains the preferred minimally invasive surgical approach to treat inguinal hernias.

Larger and randomized studies may be necessary to elucidate if the robotic technique offers any benefit over the laparoscopic approach in the management of inguinal hernias.

Compliance with ethical standards

Disclosure Drs. Khoraki, Gomez, Mazzini, Pessoa, Browning, Aquilina, Salluzzo, and Campos, and Mr. Wolfe have no conflicts of interest or financial ties to disclose.

References

1. Rutkow IM (2003) Demographic and socioeconomic aspects of hernia repair in the United States in 2003. Surg Clin N Am 83(5):1045–1051, v–vi
2. Kockerling F, Bittner R, Kofler M, Mayer F, Adolf D, Kuthe A et al (2017) Lichtenstein versus total extraperitoneal patch plasty versus transabdominal patch plasty technique for primary unilateral inguinal hernia repair. A registry-based, propensity score-matched comparison of 57,906 patients. Ann Surg 269(2):351–357
3. McCormack K, Scott NW, Go PM, Ross S, Grant AM, Collaboration EUHT (2003) Laparoscopic techniques versus open techniques for inguinal hernia repair. Cochrane Database Syst Rev (1):CD001785
4. Khajanchee YS, Kenyon TA, Hansen PD, Swanstrom LL (2004) Economic evaluation of laparoscopic and open inguinal herniorrhaphies: the effect of cost-containment measures and internal hospital policy decisions on costs and charges. Hernia 8(3):196–202
5. Ielpo B, Nunez-Alfonsel J, Duran H, Diaz E, Fabra I, Caruso R et al (2018) Cost-effectiveness of Randomized Study of Laparoscopic Versus Open Bilateral Inguinal Hernia Repair. Ann Surg 268(5):725–730
6. McCormack K, Wake B, Perez J, Fraser C, Cook J, McIntosh E et al (2005) Laparoscopic surgery for inguinal hernia repair: systematic review of effectiveness and economic evaluation. Health Technol Assess 9(14):1–203, iii–iv
7. Coronini-Cronberg S, Appleby J, Thompson J (2013) Application of patient-reported outcome measures (PROMs) data to estimate cost-effectiveness of hernia surgery in England. J R Soc Med 106(7):278–287
8. Gholghesaei M, Langeveld HR, Veldkamp R, Bonjer HJ (2005) Costs and quality of life after endoscopic repair of inguinal hernia vs open tension-free repair: a review. Surg Endosc 19(6):816–821
9. Corbitt JD Jr (1991) Laparoscopic herniorrhaphy. Surg Laparosc Endosc 1(1):23–25
10. Swanstrom LL (1996) Laparoscopic herniorrhaphy. Surg Clin North Am 76(3):483–491
11. National Health Statistics Reports (2017) Ambulatory surgery data from hospitals and ambulatory surgery centers: United States, 2010. https://www.cdc.gov/nchs/data/nhsr/nhsr102.pdf. Updated 28 Feb 2017, cited 2019
12. Bittner R, Montgomery MA, Arregui E, Bansal V, Bingener J, Bisgaard T et al (2015) Update of guidelines on laparoscopic (TAPP) and endoscopic (TEP) treatment of inguinal hernia (International Endohernia Society). Surg Endosc 29(2):289–321
13. Willoughby AD, Lim RB, Lustik MB (2017) Open versus laparoscopic unilateral inguinal hernia repairs: defining the ideal BMI to reduce complications. Surg Endosc 31(1):206–214
14. Suguita FY, Essu FF, Oliveira LT, Iuamoto LR, Kato JM, Torsani MB et al (2017) Learning curve takes 65 repetitions of totally extraperitoneal laparoscopy on inguinal hernias for reduction of operating time and complications. Surg Endosc 31(10):3939–3945
15. El-Dhuwaib Y, Corless D, Emmett C, Deakin M, Slavin J (2013) Laparoscopic versus open repair of inguinal hernia: a longitudinal cohort study. Surg Endosc 27(3):936–945
16. Cavazzola LT, Rosen MJ (2013) Laparoscopic versus open inguinal hernia repair. Surg Clin North Am 93(5):1269–1279
17. Neumayer L, Giobbie-Hurder A, Jonasson O, Fitzgibbons R Jr, Dunlop D, Gibbs J et al (2004) Open mesh versus laparoscopic mesh repair of inguinal hernia. N Engl J Med 350(18):1819–1827
18. Spencer Netto F, Quereshy F, Camilotti BG, Pitzul K, Kwong J, Jackson T et al (2014) Hospital costs associated with laparoscopic and open inguinal herniorrhaphy. JSLS. https://doi.org/10.4293/JSLS.2014.00217
19. Hynes DM, Stroupe KT, Luo P, Giobbie-Hurder A, Reda D, Kraft M et al (2006) Cost effectiveness of laparoscopic versus open mesh hernia operation: results of a Department of Veterans Affairs randomized clinical trial. J Am Coll Surg 203(4):447–457
20. Tadaki C, Lomelin D, Simorov A, Jones R, Humphreys M, daSilva M et al (2016) Perioperative outcomes and costs of laparoscopic versus open inguinal hernia repair. Hernia 20(3):399–404
21. Karthikesalingam A, Markar SR, Holt PJ, Praseedom RK (2010) Meta-analysis of randomized controlled trials comparing laparoscopic with open mesh repair of recurrent inguinal hernia. Br J Surg 97(1):4–11
22. O'Reilly EA, Burke JP, O'Connell PR (2012) A meta-analysis of surgical morbidity and recurrence after laparoscopic and open repair of primary unilateral inguinal hernia. Ann Surg 255(5):846–853

23. Ahlering TE, Skarecky D, Lee D, Clayman RV (2003) Successful transfer of open surgical skills to a laparoscopic environment using a robotic interface: initial experience with laparoscopic radical prostatectomy. J Urol 170(5):1738–1741
24. Sumitomo M, Kanao K, Kato Y, Yoshizawa T, Watanabe M, Zennami K et al (2015) Comparative investigation on clinical outcomes of robot-assisted radical prostatectomy between experienced open prostatic surgeons and novice open surgeons in a laparoscopically naive center with a limited caseload. Int J Urol 22(5):469–474
25. Intuitive Surgical Inc (2017) Intuitive Annual Report 2017. http://www.annualreports.com/HostedData/AnnualReports/PDF/NASDAQ_ISRG_2017.pdf. Updated 2 Feb 2018; cited 2019
26. Armijo PR, Pagkratis S, Boilesen E, Tanner T, Oleynikov D (2018) Growth in robotic-assisted procedures is from conversion of laparoscopic procedures and not from open surgeons' conversion: a study of trends and costs. Surg Endosc 32(4):2106–2113
27. Charles EJ, Mehaffey JH, Tache-Leon CA, Hallowell PT, Sawyer RG, Yang Z (2018) Inguinal hernia repair: is there a benefit to using the robot? Surg Endosc 32(4):2131–2136
28. Kudsi OY, McCarty JC, Paluvoi N, Mabardy AS (2017) Transition from laparoscopic totally extraperitoneal inguinal hernia repair to robotic transabdominal preperitoneal inguinal hernia repair: a retrospective review of a single surgeon's experience. World J Surg 41(9):2251–2257
29. Muysoms F, Van Cleven S, Kyle-Leinhase I, Ballecer C, Ramaswamy A (2018) Robotic-assisted laparoscopic groin hernia repair: observational case-control study on the operative time during the learning curve. Surg Endosc 32(12):4850–4859
30. Abdelmoaty WF, Dunst CM, Neighorn C, Swanstrom LL, Hammill CW (2018) Robotic-assisted versus laparoscopic unilateral inguinal hernia repair: a comprehensive cost analysis. Surg Endosc 33(10):3436–3443
31. Waite KE, Herman MA, Doyle PJ (2016) Comparison of robotic versus laparoscopic transabdominal preperitoneal (TAPP) inguinal hernia repair. J Robot Surg. 10(3):239–244
32. Senkowski C, Savarise M, Roth JS, Nagle J (2017) Coding and practice management corner: hernia repair and complex abdominal wall reconstruction. Bull Am Coll Surg 102(4):52–59
33. American Society of Anesthesiologists (2014) ASA Physical Status Classification System 2014. https://www.asahq.org/standards-and-guidelines/asa-physical-status-classification-system. Updated 15 Oct 2014; cited 2019
34. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD et al (2009) The Clavien–Dindo classification of surgical complications: five-year experience. Ann Surg 250(2):187–196
35. Nathan JD, Pappas TN (2003) Inguinal hernia: an old condition with new solutions. Ann Surg 238(6 Suppl):S148–S157
36. Salcedo-Wasicek MC, Thirlby RC (1995) Postoperative course after inguinal herniorrhaphy: a case-controlled comparison of patients receiving workers' compensation vs patients with commercial insurance. Arch Surg 130(1):29–32
37. Dion YM, Morin J (1992) Laparoscopic inguinal herniorrhaphy. Can J Surg 35(2):209–212
38. Cadiere GB, Himpens J, Germay O, Izizaw R, Degueldre M, Vandromme J et al (2001) Feasibility of robotic laparoscopic surgery: 146 cases. World J Surg 25(11):1467–1477
39. Escobar Dominguez JE, Ramos MG, Seetharamaiah R, Donkor C, Rabaza J, Gonzalez A (2016) Feasibility of robotic inguinal hernia repair, a single-institution experience. Surg Endosc 30(9):4042–4048
40. Kosturakis AK, LaRusso KE, Carroll ND, Nicholl MB (2018) First 100 consecutive robotic inguinal hernia repairs at a Veterans Affairs Hospital. J Robot Surg. 12(4):699–704
41. Iraniha A, Peloquin J (2018) Long-term quality of life and outcomes following robotic assisted TAPP inguinal hernia repair. J Robot Surg. 12(2):261–269
42. Arcerito M, Changchien E, Bernal O, Konkoly-Thege A, Moon J (2016) Robotic inguinal hernia repair: technique and early experience. Am Surg 82(10):1014–1017
43. Gamagami R, Dickens E, Gonzalez A, D'Amico L, Richardson C, Rabaza J et al (2018) Open versus robotic-assisted transabdominal preperitoneal (R-TAPP) inguinal hernia repair: a multicenter matched analysis of clinical outcomes. Hernia 22(5):827–836
44. ECRI Institute (2015) Robotic Surgery Infographic 2015. https://www.ecri.org/Resources/ASG/Robotic_Surgery_Infographic_MS15369_web.pdf. Updated Aug 2015; cited 2019
45. Dixon PR, Grant RC, Urbach DR (2015) The impact of marketing language on patient preference for robot-assisted surgery. Surg Innov. 22(1):15–19
46. Cetrulo LN, Harmon J, Ortiz J, Canter D, Joshi AR (2015) Case report of a robotic-assisted laparoscopic repair of a giant incarcerated recurrent inguinal hernia containing bladder and ureters. Int J Med Robot. 11(1):15–17
47. Barbash GI, Glied SA (2010) New technology and health care costs–the case of robot-assisted surgery. N Engl J Med 363(8):701–704
48. van Dam P, Hauspy J, Verkinderen L, Trinh XB, van Dam PJ, Van Looy L et al (2011) Are costs of robot-assisted surgery warranted for gynecological procedures? Obstet Gynecol Int. 2011:973830
49. Schwaitzberg SD (2016) Financial modeling of current surgical robotic system in outpatient laparoscopic cholecystectomy: how should we think about the expense? Surg Endosc 30(5):2082–2085
50. Higgins RM, Frelich MJ, Bosler ME, Gould JC (2017) Cost analysis of robotic versus laparoscopic general surgery procedures. Surg Endosc 31(1):185–192
51. Schneider BE, Castillo JM, Villegas L, Scott DJ, Jones DB (2003) Laparoscopic totally extraperitoneal versus Lichtenstein herniorrhaphy: cost comparison at teaching hospitals. Surg Laparosc Endosc Percutan Tech. 13(4):261–267
52. McCracken EKE, Mureebe L, Blazer DG III (2019) Minimally invasive surgical site infection in procedure-targeted aCS NSQIP pancreaticoduodenectomies. J Surg Res 233:183–191
53. Diez-Barroso R Jr, Palacio CH, Martinez JA, Makris K, Massarweh NN, Chai CY et al (2018) Robotic port-site hernias after general surgical procedures. J Surg Res 230:7–12
54. Narayanan S, Davidov T (2018) Peritoneal pocket hernia: a distinct cause of early postoperative small bowel obstruction and strangulation: a report of two cases following robotic herniorrhaphy. J Minim Access Surg. 14(2):154–157
55. Tsu JH, Ng AT, Wong JK, Wong EM, Ho KL, Yiu MK (2014) Trocar-site hernia at the 8-mm robotic port after robot-assisted laparoscopic prostatectomy: a case report and review of the literature. J Robot Surg. 8(1):89–91
56. Tapscott A, Kim SS, White S, Graves R, Kraft K, Casale P (2009) Port-site complications after pediatric urologic robotic surgery. J Robot Surg. 3(3):187
57. Voitk AJ (1998) The learning curve in laparoscopic inguinal hernia repair for the community general surgeon. Can J Surg 41(6):446–450