ORIGINAL ARTICLE

Robotic ventral hernia repair: a safe and durable approach

M. E. Sharbaugh[1,3] · P. B. Patel[1] · J. A. Zaman[1] · A. Ata[1] · P. Feustel[1] · K. Singh[2] · T. P. Singh[1]

Abstract

Background Short-term success following robotic-assisted ventral hernia repair (RVHR) is well established; however, data describing outcomes after the first year are limited. In this study, we followed a cohort of patients with an average of 1.8 years of follow-up to demonstrate the durability of this technique and examine risk factors for recurrence.

Methods A retrospective analysis of RVHR performed by a single surgeon from 2012 to 2016 was done. The technical approach for hernia repair consisted of tension-free primary fascial closure with placement of preperitoneal mesh when possible. The primary end point of hernia recurrence was determined based on physical examination or imaging documented in the medical record. A logistic regression model was used to identify patient risk factors for recurrence.

Results One hundred and eight RVHRs were performed over 4 years. Mean age was 52.72 ± 13.61 years, BMI was 33.07 ± 7.82 kg/m^2, and hernia defect size was 70.1 ± 86.3 cm^2. In terms of patient characteristics, 17.6% of patients were diabetic, 13.9% were smokers preoperatively, 72.2% were ASA class 3 or higher, and 29.6% had prior VHR. Primary fascial closure was achieved in all RVHRs, with 23.1% requiring component separation. Mesh was used in 97.2% of patients: 79.5% had preperitoneal mesh and 17.6% had intraperitoneal onlay mesh. Ninety-eight percent of patients had long-term follow-up at a mean of 625.6 days. Recurrence rate was 12%, with one recurrence attributed to an inguinal hernia fixed concurrently with a midline defect. There were no statistically significant differences in gender, age, BMI, ASA class, incidence of diabetes, smoking status, or number of previous hernia repairs. Hernia defect size and perioperative complications including SSO, ileus, obstruction, or any other medical complication were not predictive of recurrence. Technical approach did not affect outcomes.

Conclusion RVHR is safe and durable with a low recurrence rate at a mean of 21 months postoperatively. Patient characteristics or type of repair were not predictive of recurrence.

Keywords Incisional hernia · Robotic hernia repair · Robotic ventral hernia · Outcomes · Recurrence rate · Wound morbidity

Introduction

Ventral hernia repair is one of the most common operations performed in America today, with over 350,000 repairs done annually [1, 2]. However, the optimal technical approach to this complex condition remains unknown. The majority of these elective repairs are done through an open midline approach [3] with robotic surgery making up less than 4% of operations performed in 2013 [4]. The open technique has long been the standard of care since Rives-Stoppa popularized the retrorectus repair. This approach has a durable 5-year recurrence rate of 14.5%, but the creation of large skin flaps carries a 12% wound infection rate [5], making it less optimal. With the advent of the transversus abdominis release (TAR) modification, larger midline defects are able to be closed under less tension with a recurrence rate at two-year follow-up of only 4.7%. The trade-off, however, is an increase in wound complications to upwards of 24% [6].

Given the high incidence of wound morbidity associated with open hernia repairs, the laparoscopic approach was initially seen as a technique to decrease these complications; however, the long-term recurrence rates stemmed initial enthusiasm [7]. More recent literature suggests the

✉ M. E. Sharbaugh

1 Department of General Surgery, Albany Medical Center, Albany, NY, USA

2 Boston College, Boston, MA, USA

3 Department of General Surgery, Northern Light Health, 489 State Street, Bangor, ME, USA

actual recurrence rate after laparoscopic ventral hernia repair (LVHR) ranges anywhere from 7 to 18% [8–10]. The increased recurrence rate seen in laparoscopic surgery is likely due to the technical inability to close the midline fascia and instead relies on large mesh overlap. This technique leads not only to high recurrence rates, but also to mesh eventration and bulging at the hernia site, which becomes a common and chronic patient complaint. Transfacial suture techniques are described to close the midline fascia but ultimately lead to an increase in postoperative pain scores [11]. Therefore, in theory, the robotic ventral hernia repair (RVHR) combines the benefits of decreased wound morbidity of the laparoscopic repair with a durable tension-free midline fascial closure seen during open surgery.

To date, there are many studies reporting the feasibility and safety of the RVHR in the short term [4, 12–15]. However, there are minimal data after the first year postoperatively, which may lead to reluctance in adoption of RVHR. This study aims to review RVHR outcomes at almost two years. Furthermore, it aims to identify risk factors and patient characteristics that may predict recurrence after RVHR.

Methods

After institutional IRB approval was obtained, we retrospectively reviewed 108 consecutive robotic ventral hernia repairs performed by a single surgeon from January 2012 to March 2016. The medical record was examined for patient characteristics, hernia characteristics, perioperative and postoperative details, and long-term results. The patient data included age, body mass index (BMI), gender, diabetes, smoking status, and American Society of Anesthesiologist (ASA) class. The included hernia characteristics were: prior hernia surgery, hernia defect size, mesh size, type of hernia repair, and hernia location based on the European Hernia Society (EHS) classification. Perioperative details included wound class, concurrent procedures, estimated blood loss (EBL), operating room time (as defined from skin incision to dressing application), length of stay (LOS), and complications. The last date of follow-up was determined from the outpatient clinical record. Recurrence after RVHR was determined by either radiographic imaging, reoperative dictation, or physical examination.

The statistical analysis included a univariate analysis performed on categorical variables to elucidate risk factors for hernia recurrence. Fischer's exact test and Chi-squared test were used to determine the significance of each risk factor and to delineate complications by type of repair. Two-sample T tests with a 95% confidence interval were used to determine significance for continuous variables. Significance was defined as $p < 0.05$. Standard deviation was calculated for hernia defect and mesh size. A logistic regression model was created to identify significance of surgical approach and patient risk factors. Statistics were tabulated with Minitab v17 (State College, PA, USA) and R statistical software (Auckland, New Zealand).

Our approach for RVHR begins with preoperative prophylactic antibiotic administration in accordance with Surgical Care Improvement Project (SCIP) Guidelines. The patients were then placed supine on the operating room table with the arms extended on both sides. Foley catheter and orogastric tube were used early in the development of this technique but are now used with decreasing frequency. The abdomen was entered through an open Hassan incision opposite the largest portion of the hernia. Primarily, this included lateral port placement for a midline hernia, superior port placement for suprapubic hernia, or inferior port placement for epigastric hernias. A 10-mm balloon tipped trocar was used to establish pneumoperitoneum. Two additional 8-mm robotic working ports were then added, each 8 cm away from the next to avoid exterior robotic arm collisions. An Si or Xi da Vinci Surgical System (Intuitive Surgical Inc, Sunnyvale, CA, USA) was used to accomplish the repair. When bilateral component separation was required to accomplish a tension-free closure, three additional ports were placed contralateral to the defect and a double docking technique is used. Primary tension-free fascia closure was attempted in all cases (1-0 polydioxanone-style, barbed suture (Stratafix, Ethicon, Sommerville, NJ, USA)), with the decision to create flaps and preform component separation at the discretion of the attending surgeon.

Intraperitoneal onlay mesh (IPOM) techniques required full lysis of adhesions and hernia sac reduction. The midline was closed as above and a coated polyester mesh placed with at least 3-cm overlap on all sides. The perimeter of the mesh was then sutured to the abdominal wall using a 2-0 Monocryl-style barbed suture (Stratafix, Ethicon, Sommerville, NJ, USA). Transabdominal preperitoneal (TAPP) mesh repairs required the peritoneum be incised > 2 cm from the hernia sac, and a large peritoneal flap is created. The midline fascia was closed in standard fashion and self-gripping polyester mesh (Progrip, Medtronic, Minneapolis, MN) placed to overlap the defect by 3 cm on all sides. The peritoneal flap was then reapproximated with a 2-0 Monocryl-style barbed suture (Stratafix, Ethicon, Sommerville, NJ, USA). Component separation technique was performed by creating a retromuscular plane and performing a complete myofascial release. TAR was added, if necessary, to facilitate closure of the posterior component with a zero polydioxanone-style, barbed suture (Stratafix, Ethicon, Sommerville, NJ, USA). The midline defect was closed and a mesh placed in this created space. Upon completion of the procedure, the fascia was closed overlying the Hasson cannula site with a zero polyglactin 910 suture (Vicryl, Ethicon, Sommerville, NJ,

USA) and the skin reapproximated with suture and Derma-bond skin adhesive (Ethicon, Cincinnati, OH, USA).

Results

A total of 108 RVHRs were performed from January 2012 to March 2016. The patient cohort had a mean age of 52.72 ± 13.61 years and was primarily female (n = 68, 63.0%). The patients were obese with an average BMI of 33.07 ± 7.82 kg/m^2. Fourteen patients had a BMI > 40 (range 18–57). Diabetic patients made up 17.6% of the population, 13.9% were tobacco users preoperatively, and 72.2% were ASA class 3 or higher. The mean hernia defect size was 70.1 ± 86.3 cm^2. The mean mesh size was 139.8 ± 148.0 cm^2. Reoperative hernia repair consisted of 29.6% of the population. Primary fascial approximation was achieved in all patients. Mesh was placed primarily extra-peritoneal (79.5%). Twenty-three percent of patients underwent component separation. Follow-up was documented for 98% of patients with a mean of 625.6 days (Table 1).

Eighty patients (74.1%) had their precise hernia location, as defined by the European Hernia Society, documented in the medical record. Of these, 51 (64%) had hernias that spanned multiple defined locations (Table 2). A hernia located at the umbilicus was the most common location with 85% patients having part of their hernia repaired in this location. Epigastric and infraumbilical hernias were present in 37.5% and 26.2% of patients, respectively. Subxiphoid and suprapubic locations had hernias defects only 15% and 8.8%

Table 1 Patient characteristics

Comorbidities	
Number of patients	108
Age (years)	52.72 ± 13.61
BMI (kg/m^2)	33.07 ± 7.82
Hernia defect size	70.1 ± 86.3
Mesh size (cm^2)	139.8 ± 148.0
Male	40
Diabetes (%)	17.6
Smoker (%)	13.9
ASA class ≥ 3 (%)	72.2
Prior hernia repair (%)	29.6
Primary fascia closure (%)	100
Component separation	23
Mesh placement (%)	97.2
Preperitoneal mesh (%)	79.5
Intraperitoneal onlay (%)	17.6
Recurrence rate (%)	12
Mean follow-up (days)	625.6

Table 2 Hernia location

Location of hernia	n
Subxiphoid (M1)	12
Epigastric (M2)	30
Umbilical (M3)	68
lnfraumbilical (M4)	21
Suprapubic (M5)	7
Lateral (L1–4)	8

of the time, respectively. Lateral hernias were present in 10% of patients.

Of the 106 patients with long-term follow-up, thirteen patients (12.3%) had a hernia recurrence. Ten patients (9.4%) underwent a second RVHR. Three patients (2.8%) were offered subsequent repair but opted to forgo a second operation. One of these patients had a concomitant inguinal hernia repair which was the source of recurrence.

Primary fascial closure was accomplished in all patients. When possible, mesh was placed in a position where it would not contact the viscera. Preperitoneal and retrorectus mesh placement was preferred (Table 3). Primary hernia repair alone with no mesh placement was done in 3 patients (2.8%) due to a patient refusal, prior mesh infection, and enterotomy with small bowel resection due to enteric contamination. Nineteen patients had an IPOM repair, of which 18 patients (17.0%) had long-term follow-up and four (3.8%) had recurrent herniation. Sixty-one patients underwent TAPP repair; all but one patient had long-term follow-up with six patients (5.7%) demonstrating recurrence of their hernia. Twenty-five component separations were performed with two recurrences (1.9%) identified within the study period.

The overall complication rate was low over the study follow-up (Table 4). There were no deaths in the study. Two patients (1.9%) were converted to open operation: One was due to skin devitalization during a large hernia sac reduction and the second was due to an enterotomy made during entry into an abdomen with dense adhesions. The second patient developed a recurrent hernia, but the first did not. Three patients (2.8%) developed seromas, and four (3.8%) developed hematomas. All patients remained stable and

Table 3 Repair type in patients with long-term follow-up (n = 106) and recurrence given type of repair

Type of hernia repair	Number of patients	Recurrence given type of repair (%)
Primary	3	1 (33.33)
TAPP	60	6 (9.84)
CS	25	2 (8.00)
IPOM	18	4 (21.50)
p value		p = 0.50

Table 4 Complications

Complications	NR	*R*	*p* value
Conversion to open	1	1	0.231
Seroma	2	1	0.327
Hematoma	3	1	0.412
Infection	3	0	1.000
Ileus	2	0	1.000
SBO	2	0	1.000
Intraop complication	2	1	0.327

were managed non-operatively in the immediate postoperative period, as is our preferred practice. However, all seroma patients went onto need a soft tissue operation for definite management. Half of the hematoma patients (1.9%) needed a similar soft tissue operation. Ileus and small bowel obstruction each affected two patients (1.9%). Both ileus patients were managed with nasogastric decompression and had

resolution. Both obstruction patients had an opening in the peritoneum in which bowel became incarcerated requiring exploration. Three patients (2.8%) developed an infection: The first was an intraabdominal abscess requiring surgical drainage, the second was an infected hematoma requiring surgical drainage, and the third was a wound infection requiring an operative debridement.

For the most part, the incidence of complications was not statistically significant when broken down by type of repair (Table 5). Twelve percent of patients undergoing component separation developed a postoperative hematoma, which neared statistical significance. There was also a statistically significant increase in wound infection after primary repair alone; however, this patient also had a history of prior infected mesh that was removed.

Seventy-four patients (69.8%) underwent initial hernia repair (Fig. 1). Sixty-six patients (62.3%) had no recurrence after undergoing 45 preperitoneal repairs, 13 component separations, and 8 IPOMs. There were 8 recurrences (7.5%)

Table 5 Complications based on type of repair

Repair Type (*n*)	Converted to open % (*n*)	Enterotomy% (*n*)	Seroma % (*n*) (*n*)	Hematoma% (*n*)	Wound infection % (*n*)	Ileus % (*n*)	SBO % (*n*)
Primary (3)	33.33 (1)	0 (0)	0 (0)	0 (0)	33.33 (1)	0 (0)	0 (0)
TAPP (61)	0 (0)	1.64 (1)	4.92 (3)	0 (0)	0 (0)	1.64 (1)	0 (0)
CS (25)	4.00 (1)	0 (0)	0 (0)	12.00 (3)	4.00 (1)	0 (0)	8.00 (2)
IPOM (19)	0 (0)	0 (0)	0 (0)	5.26 (1)	5.26 (1)	5.26 (1)	0 (0)
	p=0.000	*p*=0.855	*p*=0.498	*p*=0.06	*p*=0.005	*p*=0.624	*p*=0.115

Fig. 1 Flow diagram of hernia recurrences based on previous repair and operative technique. *PP* preperitoneal, *CS* component separation, *IPOM* intraperitoneal onlay mesh
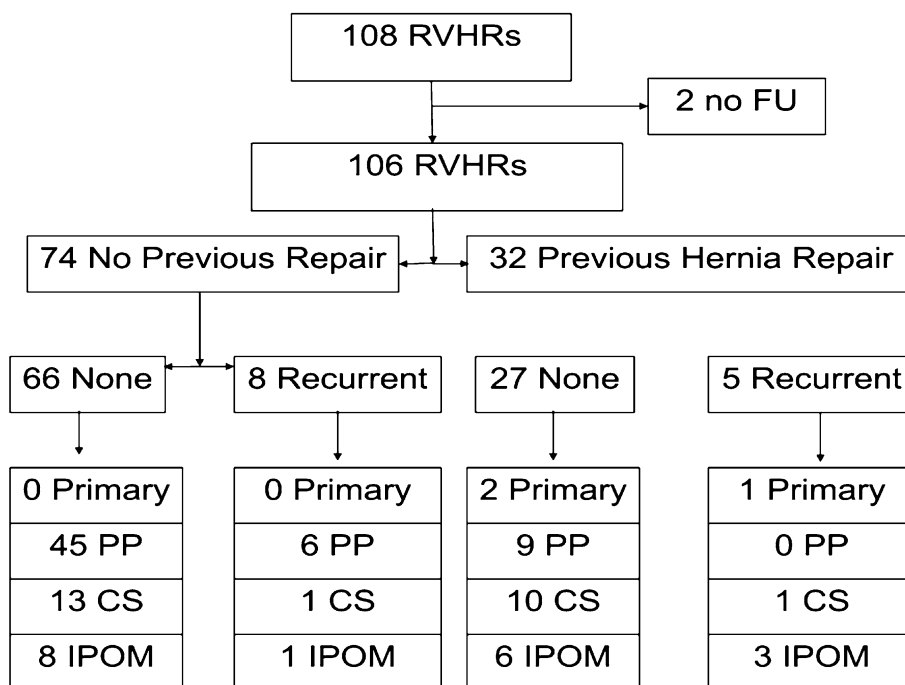
after initial hernia repair. Six were preperitoneal, 1 was a component separation, and 1 was an IPOM. Thirty-two patients (30.2%) underwent recurrent hernia repair. Twenty-seven (25.5%) had a durable repair during the study period. This group consisted of 2 primary repairs, 9 preperitoneal, 10 component separations, and 6 IPOMS. Five patients (4.7%) had recurred after their second hernia operation: One patient underwent primary repair, one underwent component separation, and 3 underwent IPOM.

Prior hernia repair was not a significant predictor of recurrence ($p = 0.526$) (Table 6). The average hernia defect size was not significantly different between the two groups (64.1 cm$^2 \pm$ 76.5 cm^2 vs. 97.9 cm$^2 \pm$ 125.4 cm^2, $p = 0.247$). In addition, mesh size did not lead to a significant increase in hernia recurrence (129.2 cm$^2 \pm$ 137.2 cm^2 vs. 220.1 cm$^2 \pm$ 204.4 cm^2, $p = 0.202$). The average EBL was similar between the nonrecurrent and recurrent groups (30 cc vs. 27 cc, $p = 0.690$). The OR time was not a significant contributing factor for recurrence (152.6 min vs. 180.7 min, $p = 0.147$). Length of stay was not significantly different between those who recurred and those who didn't (3.2 days vs. 2.1 days, $p = 0.218$).

Univariate analysis only found male gender to be a significant risk factor for hernia recurrence ($p = 0.029$) (Table 7). Nonrecurrent patients were similar in age (53.0 years vs. 49.5 years, $p = 0.381$), BMI (32.9 kg/m^2 vs. 35.2 kg/m^2, $p = 2.333$), diabetes status (19% vs. 8%, $p = 0.455$), ASA class of ≥ 3 (72% vs. 77%, $p = 0.727$), and active tobacco users (15% vs. 8%, $p = 1.000$). The follow-up was significantly longer in patients who developed a hernia recurrence than those without recurrence (866 days vs. 592 days, $p = 0.031$).

A logistic regression model was created to determine the significance of risk factors that correlate with recurrence. The variables examined are listed in Table 1. None of the patient or operative characteristics proved significant (Table 8). Gender, as identified in the univariate analysis as significant, was the only risk factor that approached significance but had a p value > 0.05. Age, BMI, DM, ASA class, and smoking status were all nonsignificant. Prior hernia repair and wound class were not predictors of hernia

Table 6 Hernia variables

Variable	Nonrecurrent	Recurrent	p value
Prior hernia repair	27	5	0.526
Mean defect size (cm^2)	64.1 ± 76.5	97.9 ± 125.4	0.247
Mesh size (cm^2)	129.2 ± 137.2	220.1 ± 204.4	0.202
Mean estimated blood loss (cc)	30	27	0.690
OR time (min)	152.6	180.7	0.147
LOS (days)	2.1	3.2	0.218

Table 7 Comorbidities contributing to hernia recurrence

Comorbidities	Nonrecurrent	Recurrent	p value
Number of patients (%)	93 (88)	13 (12)	
Age (years)	53.0	49.5	0.381
BMI (kg/m^2)	32.9	35.2	0.233
Male (%)	31 (33)	9 (69)	0.029
Diabetes (%)	18 (19)	1 (8)	0.455
Smoker (%)	14 (15)	1 (8)	1.000
ASA class $\geq$ (%)	67 (72)	10 (77)	0.727
Mean follow-up (days)	592	866	0.031

recurrence. Operative technique did not affect recurrence rate.

Discussion

To date, the data surrounding the RVHR have been primarily short-term studies documenting the safety and feasibility of RVHR [12, 16, 17]. Even fewer have gone beyond the perioperative period and demonstrated low recurrence rates with a favorable side effect profile [18, 19]. Some studies have compared RVHR directly with LVHR or OVHR. In one large-scale retrospective study, patients with LVHRs were more likely to recur, have longer LOS, and have surgical site infections [13]. One of the advantages of RVHRs is the ability for component separation to be performed with lower morbidity and hospital length of stay [14]. When comparing RVHR and OVHR, both with TAR, patients undergoing

Table 8 Logistic regression model showing no difference in recurrence rate based on patient and hernia characteristics or surgical approach

Patient or operative variable	p value
Age	0.151
Sex	0.059
BMI	0.470
Diabetes	0.478
ASA	0.457
Smoker	0.745
Prior hernia	0.336
Wound class	0.995
Concurrent procedures	0.978
OR time	0.180
EBL	0.712
IPOM	0.994
Component	0.995
Preperitoneal	0.994

RVHR had lower morbidity at 90 days [20], LOS reduced by 4.7 days, and readmissions were eliminated [14].

Even with the above literature and data, the optimal approach toward the repair of the ventral hernia remains a highly debated topic. With a large number of hernia repairs being done on an annual basis and a relative paucity of general surgeons in the USA, almost all will encounter a significant volume of ventral hernias over the course of their careers. That leaves the general surgeon with limited evidence based data to determine an optimal repair.

The current open technique can lead to a high rate of wound morbidity in up to 10% of patients [21]. The addition of large soft tissue flaps and musculofascial releases can see that number climbs as high as 24% [6]. Several studies have been published showing decreased wound infection rates of 3–12% when a laparoscopic approach is used [7, 10, 17, 21]. Smaller incisions and avoidance of the devitalizing skin flaps created during open surgery lead to decreased wound morbidity. With these principles, RVHR itself has been shown in the short term to have low wound infection rates ranging from 0 to 1.4% [12, 16, 17]. This present study remains consistent with the published literature determining a wound infection rate of 2.8% and thus reinforcing the safety profile for RVHR.

Although LVHR decreases wound morbidity, it often leaves the fascial defect without reapproximation, leaving the myofascial envelope disrupted and the biomechanics of the abdominal wall altered. In addition, laparoscopic IPOM can lead to painful and unsightly mesh eventration. Laparoscopic techniques have been developed to remedy this issue which include the transfascial [22] and intracorporeal suturing. The former technique is limited to smaller hernias and leads to an increase in postoperative pain scores [23]. The latter technique is a skill set reserved for only the most facile laparoscopic surgeons. The major advantage of the RVHR is in its ease of midline closure. The robotic system allows the entire midline to be visualized in a clear magnified fashion. Greater degrees of freedom and ease of motion seen on the da Vinci platform allow a tension-free closure to be done more easily. Some early series have reported a 69.3% midline fascia closure rate [12]; however, as the technique develops, the number will likely be much greater. In this series, all 106 patients had their midline fascia closed.

The gold standard metric of any hernia repair is recurrence rate. Nationally, OVHR carries a recurrence rate of 30% [24]. The addition of retrorectus repairs and transverses release can reduce the open hernia recurrence rate to 14.5% and 4.7%, respectively [5, 6]. LVHR carries a recurrence up to 18% in the literature [7–10]. Many studies have shown RVHR to be durable in the short term with recurrence rates < 1% [12, 16, 17]. The recurrence rate in this study was 12% at an average of 625.6 days. The additional study period allowed more recurrences to be captured as the average time

to recurrence was 544 days. Three patients had a recurrence identified over 1000 days later. One of the recurrences in this study was a patient that had concomitant ventral and inguinal hernia repair. The recurrence was inguinal in location, and we chose to include this patient as we see the use of the robotic platform as a way to reconstruct the entire abdominal wall. The four-quadrant operative ability of the da Vinci Xi system allows the inguinal region to be reconstructed with relative ease during midline hernia repair. We anticipate the standard of care in the near future to be repair of asymptomatic inguinal hernias at the time of ventral hernia repair.

A major advantage of the RVHR is the ability to place the mesh extraperitoneally. Laparoscopic extra-peritoneal mesh placement is described but is technically demanding and only performed by a few skilled laparoscopists [25]. Meshes placed outside of the abdominal cavity are theorized to incorporate better into the abdominal wall musculature, decrease infection rates, and reduce intraabdominal adhesion formation. In this study, mesh was able to be placed in this location 79.5% of the time. This is reflected in our low SSI rate and absent mesh infections.

With RVHR being in its infancy, there are multiple techniques described to repair midline hernias. A strength of this study was the diversity of robotic approaches to hernia repair. The technical approach in this study was not a significant predictor of recurrence in a logistic regression model. Therefore, the key to reducing recurrence rates in RVHR lies in the ease of robotic midline fascial closure.

Prior hernia repair and patient characteristics such as BMI, gender, DM, and smoking status have long been thought to be predictors of hernia recurrence [26–29]. Reluctance to repair these hernias can leave a subset of the population untreated. Newer evidence is emerging that suggests BMI may not be as crucial when the robotic system is used. In one study regarding RVHRs and component separation, recurrence rates were less likely to be related to BMI at the 6-month follow-up [15], showing a potential benefit in the obese population. In this study, logistic regression modeling failed to identify BMI as a significant risk factor leading to recurrence after RVHR. We believe this paradigm shift is due to the nature of the robotic repair itself. The increased precision, visualization, and ability to identify small fascial defects easily missed with other techniques allow easy identification and incorporation of these defects into the midline repair. Further large randomly controlled trials are required to further investigate this concept.

The major limitation of this paper is the retrospective nature of the data set which has inherent limitations. Hernia location data were available on only 75% of patients. Often the operative notation contained a single dimension of hernia defect that was measured after the midline was closed resulting in a portion of the patients without two-dimensional size data. Because of this omission size, data were not

able to be included in the logistic regression analysis which may still play an important part in hernia recurrence. This study is one of the few to examine the outcomes beyond the one year. The majority of hernia recurrences do occur within the first two years, but as stated above this study identified 3 recurrences beyond 1000 days. Long-term studies beyond 3 years are still needed to validate these results.

Another significant weakness of this study is the limited sample size of patients which increases the likelihood for a type II error. Given that the rate of overall complications including recurrence being low, a larger sample size is necessary to distinguish if factors such as patient comorbidities, body mass index, or hernia approach make a statistically significant difference. We are continuing to track our data and will accumulate more robust information about our outcomes with time.

Conclusion

The data supporting RVHR are still in its infancy, but this study is one of the first to demonstrate intermediate outcomes from a large cohort of patients undergoing RVHR. We found the RVHR to be both safe and durable. In addition, we found no patient or operative characteristics that significantly increased the risk of hernia recurrence. In recent years, the RVHR has gained some traction nationally as a way to combat wound morbidity and as a way to reestablish midline fascia. The technique now represents 3% of total ventral hernia repairs done in 2013 [4], and we expect its utilization to continue increasing in the near future.

Compliance with ethical standards

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