ORIGINAL ARTICLE

A comparison of robotic mesh repair techniques for primary uncomplicated midline ventral hernias and analysis of risk factors associated with postoperative complications

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Abstract

Purpose We aim to compare short-term outcomes of robotic intraperitoneal onlay (rIPOM), transabdominal preperitoneal (rTAPP) and retromuscular (rRM) repair for uncomplicated midline primary ventral hernias (PVH) and determine risk factors associated with postoperative complications.

Methods The three groups were compared in terms of pre-, intra-, and post-operative variables. Postoperative complications were assessed using previously validated classifications. Univariate analyses were conducted to determine which variables influence postoperative complications (up to 90 days), followed by a multivariate regression analysis revealing statistically important risk factors.

Results A total of 269 patients who underwent robotic PVH repair patients were grouped as rIPOM ($n=90$), rTAPP ($n=108$), and rRM ($n=71$). rRM repair allowed for the use of larger-sized meshes for larger defects; however, it was associated with higher-grade complications. rTAPP repair resulted in the lowest morbidity and offered the highest mesh-to-defect ratio for smaller-sized hernias. Operative time for the rRM group was longer. The rIPOM group had a higher morbidity, likely due to higher frequency of minor complications, as compared to rTAPP and rRM groups. Multivariate regression analysis revealed that coronary artery disease, absence of defect closure, intraperitoneally placed mesh, and skin-to-skin time (minutes) were significantly associated with postoperative complications.

Conclusion Robotic PVHR contributes multiple techniques to a surgeon's armamentarium, such as IPOM, TAPP, and RM mesh placements. Patient characteristics as well as the potential consequences of each technique need to be taken into consideration when deciding the appropriate approach for the repair of primary uncomplicated midline ventral hernias.

Keywords Robotic ventral hernia repair · Ventral hernia · IPOM · TAPP · Retromuscular

Introduction

Ventral hernia repair (VHR) is one of the most common procedures that surgeons perform [1]. However, surgical correction of primary ventral hernias (PVHs) continues to be a poorly clarified abdominal hernia treatment [2]. Despite the simplicity of PVHs, no consensus has been reached regarding the best practice methods [2]. A variety of options, ranging from primary suture repair to reinforcement with mesh, are available for VHR. Furthermore, surgical approaches afforded to the surgeon include open, laparoscopic, robotic, endoscopic or a combination of the above techniques. There are also multiple options regarding the location of the mesh, including intraperitoneal onlay (IPOM), transabdominal preperitoneal (TAPP) and retromuscular (RM). Today, various robotic platforms are utilized in a number of surgical subspecialties. The use of robotic platforms for minimal invasive VHR has been slowly growing, with the aim of achieving similar quality of repair as the open technique, while minimizing its associated morbidity [3, 4]. Previous studies have compared outcomes of robotic VHR (RVHR) utilizing different mesh positions using combined data of patients with incisional (IH) and PVHs. However, no studies have detailed the outcomes of several RVHR techniques performed for patients with only PVHs. Our aim is to compare perioperative and short-term results of RVHR utilizing different

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techniques for IPOM, TAPP, and RM mesh locations. We hypothesize that there would be no difference in perioperative outcomes between the three techniques for RVHR and PVHs.

Materials and methods

The data for this study were obtained from a prospectively collected and retrospectively reviewed database of cases between February 2013 and November 2019. We included patients who underwent RVHR for primary uncomplicated midline hernias. Uncomplicated hernias were defined as elective hernias with a clean surgical site. Patients with incisional, emergent/urgent, or lateral hernias were excluded from the study. Patients who underwent concomitant procedures, such as cholecystectomies and inguinal hernia repairs, were also excluded for better clarification of postoperative complications. Patients were then grouped according to the mesh location of the index robotic procedure (rIPOM, rTAPP, rRM).

The database includes patient demographics [age, sex, body mass index (BMI), and comorbidities], hernia characteristics (etiology, hernia content, localization, hernia defect size), operative variables [procedure type, conversion to other approaches, duration of procedures (skin-to-skin and console times), mesh type and size, mesh fixation method, estimated blood loss (EBL), fascial defect closure, diastasis recti repair, and intraoperative complications], and early postoperative results [pain scores—assessed by an anesthesiologist in the postoperative care unit (PACU) using a 0–10 scoring system: 0—no pain, 10—worst pain, type and number of given pain medications in the PACU, hospital length of stay (LOS), emergency department (ED) visit or hospital readmission within a 30-day postoperative period, and post-op complications up to 90 days]. The LOS (days) was defined as the difference in time between the date of the operation and the date of hospital discharge. Any ED visit within 30 days postoperatively was classified as a re-visit. Patients presenting to the ED requiring inpatient admission were classified as a re-admission. Additional calculations were performed according to intraoperative measurements, including defect area in cm^2 (oval formula), mesh area in cm^2 (oval or rectangular formula), mesh overlap in cm (craniocaudal and transverse), and mesh-to-defect ratio [(M/D ratio), calculated by dividing mesh area by defect area] as described previously [5].

The surgeon's follow-up visits and patients' medical records were reviewed for postoperative complications. Postoperative complications were categorized according to the Clavien–Dindo classification system [6]. Surgical site events (SSEs) were classified as surgical site infections (SSIs including cellulitis, superficial, deep and organ-space

infections), surgical site occurrences (SSOs including fluid collections, such as seroma and hematoma), and surgical site occurrence or infection requiring procedural interventions (SSO/SSI-PIs; SSOs or SSIs requiring any procedural intervention, such as reopening a wound, placing a drain, percutaneous aspiration, or reoperation) [7, 8]. Postoperative morbidity score was measured using the Comprehensive Complication Index (CCI®, University of Zurich, Zurich, Switzerland) [9].

Surgical technique

The patients were placed in the supine position while flexing the table to obtain adequate distance between the pubis and costal margin. The skin was then prepped with chlorhexidine and covered with an iodophor-impregnated drape. The trocars were inserted depending on the type of repair, and the patient side cart of the da Vinci surgical robotic system (Model Si & Xi, Intuitive Surgical, Sunnyvale, CA) was docked. For intraperitoneal onlay mesh (IPOM) repair, after adhesiolysis at the expected landing zone of the mesh on the posterior fascia, the defect was measured and primary fascial closure was performed by running a long-lasting absorbable barbed suture (Stratafix 0™ on CT-1 needle, Ethicon, Somerville, NJ, USA) under reduced intra-abdominal pressure (4–8 mmHg). The mesh was secured to the posterior fascia using barbed absorbable sutures (2–0 V-Loc™; Medtronic, Minneapolis, MN, USA) in a running fashion. For transabdominal preperitoneal (TAPP) repair, the initial peritoneal incision was made 5 cm away from the defect. The preperitoneal dissection was extended at least 5 cm in all directions around the defect to provide adequate mesh deployment. After approximating anterior fascia by running a long-lasting absorbable barbed suture, the mesh was secured to the posterior fascia using absorbable sutures. The peritoneal flap was closed with a barbed absorbable suture. For retromuscular (RM) repair, the procedures were performed with either transabdominal (TA) or totally extraperitoneal (TEP) access. For TA-access RM repair, lateral, caudo-cranial, and double-docking approaches were used to enter the retrorectus space. For TEP access, the initial retrorectus dissection was performed via standard laparoscopy after inserting the first trocar via optical trocar entry. After entering the retrorectus plane, dissection was carried out medially. The medial edge of ipsilateral rectus sheath was incised, the preperitoneal plane was dissected at the posterior aspect of linea alba, and the medial edge of contralateral rectus sheath was incised. Transversus abdominis release (TAR) was performed as needed. Once the dissection was completed, primary closure of the anterior fascial defect was accomplished by running a long-lasting absorbable barbed suture. For TA access, the mesh is inserted and then the opening of the posterior rectus sheath was approximated

using barbed absorbable suture in a running fashion. For TEP access, the mesh was inserted and pneumoperitoneum was released under direct vision. Any fascial incisions larger than 10 mm, if present, as well as skin incisions were closed using absorbable sutures after administration of local anesthetic (1% bupivacaine hydrochloride) at the trocar sites. The routine postoperative follow-up schedule includes visits at 3 weeks, 3 months, 6 months, 1 year, and yearly afterwards, as well as unscheduled telephone calls.

Statistical analysis

All statistical analyses were performed using SPSS software (Statistical Package for Social Sciences for Windows Version 22). Categorical variables were presented in terms of frequency (*n* and/or %), while continuous variables were reported as the mean ± the standard deviation (SD) for normal distributions or the median with interquartile range (IQR) for non-normal distributions. Chi-square test or Fisher's exact test was used for categorical variables. One-way ANOVA test or Kruskal–Wallis test was used for continuous variables as appropriate. Additional univariate analyses were performed between patients who experienced any postoperative complication and those who did not. Accordingly, a multivariate regression analysis was run to determine risk factors associated with the development of any complication at follow-up visits. Odds ratio (OR) with 95% confidence interval (CI) was provided for statistically significant predictors. A *p* value of < 0.05 was considered as statistically significant.

Results

From a total of 589 patients who underwent robotic VHR, 269 patients who underwent elective robotic midline primary VHR were enrolled in this study. Of these, rIPOM repair was performed in 90 (33.5%) patients, rTAPP in 108 (40.1%) patients, and rRM repair in 71 (26.4%) patients. A patient selection flowchart is presented in Fig. 1. Patient demographics are summarized in Table 1.

Among rRM repairs, transabdominal trocar access was utilized in 24 (33.8%) patients and a totally extraperitoneal trocar placement was used in 47 (66.2%) patients. Five rRM repairs required a unilateral TAR and one repair required a bilateral TAR. The comparison of hernia characteristics and operative variables between groups is summarized in Table 2. In terms of defect area, the defects were larger in the rRM group vs. the rTAPP and rIPOM groups. Primary fascial closure rate was higher in rTAPP and rRM groups as compared to the rIPOM group. In 18 (6.7%) patients, diastasis recti repair was performed in addition to fascial defect closure. Although the rate of diastasis recti repair
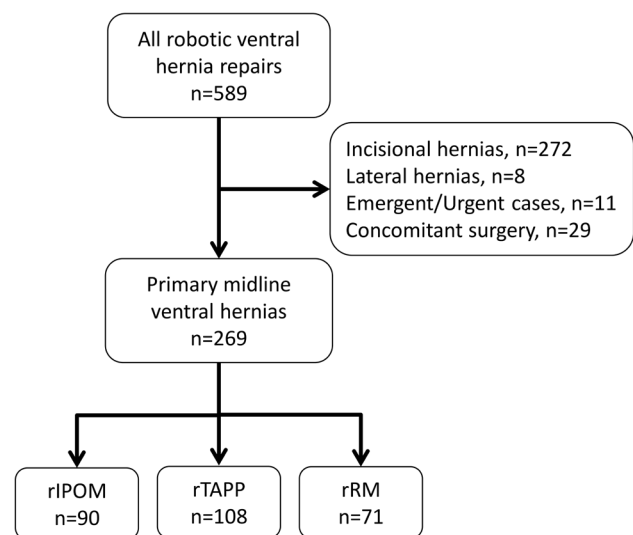

Fig. 1 Patient selection flowchart, *rIPOM* robotic intraperitoneal onlay mesh, *rTAPP* robotic transabdominal preperitoneal, *rRM* robotic retromuscular

was the highest in the rRM group, it did not differ significantly between the groups. There was a statistical difference between groups in regard to mesh area as well as craniocaudal and transverse mesh overlap in favor of the rRM group. Regarding M/D ratios, a ratio of 16:1 or above was achieved in all groups and we found the median M/D ratio was higher in the rTAPP group compared to the rIPOM and rRM groups. In a binary subgroup comparison, this ratio did not differ statistically between rIPOM and rRM groups. In terms of mesh materials, polypropylene, polyester, and expanded polytetrafluoroethylene (ePTFE) meshes were used in all three approaches, thereby showing statistical differences. In the binary subgroup comparison, however, the use of polyester and ePTFE meshes did not differ between the rIPOM and rTAPP groups. All rIPOM repairs (100%) required circumferential mesh fixation with absorbable suture; 82 (75.9%) of rTAPP repairs and 15 (21.9%) of rRM repairs required a minimal number of interrupted absorbable sutures to hold the mesh in place. The use of self-gripping mesh was most commonly observed in the rTAPP group, while no fixation was most commonly observed in the rRM group. A closed suction drain was needed in one patient in the rRM group (1.4%). There was one (0.9%) intraoperative complication in a patient who underwent rTAPP repair in the form of a serosal gastric injury which was sutured. None of the patients required conversion to an open or laparoscopic approach.

There were no differences between groups in terms of pain scores assessed immediately after surgery in the PACU (*p* = 0.183). While 85.5% of patients were given either fentanyl, ketorolac tromethamine, or hydromorphone

Table 1 Patient demographics

	Total (n = 269)	rIPOM (n = 90)	rTAPP (n = 108)	rRM (n = 71)	p
Age, mean ± SD	49.9 ± 14.2	47.9 ± 14.5	50.2 ± 14.2	52 ± 13.7	0.188
Sex, female, n (%)	104 (38.7)	48 (53.3)	30 (27.8)	26 (36.6)	0.001*
BMI, kg/m², mean ± SD	31.1 ± 6.1	31.3 ± 6.3	30.5 ± 5.7	30 ± 6.4	0.228
ASA score					
ASA-1, n (%)	40 (14.9)	18 (20)	14 (13)	8 (11.3)	0.071
ASA-2, n (%)	138 (51.3)	50 (55.6)	57 (52.8)	31 (43.7)	
ASA-3, n (%)	91 (33.8)	22 (24.4)	37 (34.3)	32 (45.1)	
Comorbidities and risk factors					
Hypertension, yes, n (%)	112 (41.6)	35 (38.9)	47 (43.5)	30 (42.3)	0.799
Coronary artery disease, yes, n (%)	14 (5.2)	6 (6.7)	3 (2.8)	5 (7)	0.339
Myocardial infarct, yes, n (%)	1 (0.4)	0 (0)	0 (0)	1 (1.4)	0.247
COPD, yes, n (%)	24 (8.9)	9 (10)	9 (8.3)	6 (8.5)	0.907
Smoking[a], yes, n (%)	60 (22.3)	17 (18.9)	26 (24.1)	17 (23.9)	0.624
Diabetes mellitus, yes, n (%)	37 (13.8)	11 (12.2)	15 (13.9)	11 (15.5)	0.835
Immunosuppression, yes, n (%)	4 (1.5)	1 (1.1)	2 (1.9)	1 (1.4)	0.910
History of wound infection, yes, n (%)	5 (1.9)	2 (2.2)	1 (0.9)	2 (2.8)	0.626
MVHWG-grade					
Grade-1, n (%)	77 (28.6)	27 (30)	29 (26.9)	21 (29.6)	0.869
Grade-2, n (%)	192 (71.4)	63 (70)	79 (73.1)	50 (70.4)	

rIPOM robotic intraperitoneal onlay mesh, *rTAPP* robotic transabdominal preperitoneal, *rRM* robotic retromuscular, *SD* standard deviation, *BMI* body mass index, *ASA* the American society of anesthesiologists, *COPD* chronic obstructive pulmonary disease, *MVHWG* modified ventral hernia working group

[a]Defined as smoking within 3 months of the operation; *Statistically significant *p*-value

hydrochloride, 14.5% of patients did not require any pain medications. Of the patients who required narcotics in the PACU (n = 209), 12% of patients in the rIPOM group required more than one type of narcotic, as opposed to 1% of patients in the rTAPP group and 0% in the rRM group (p = 0.001). When comparing groups in terms of morphine equivalents, the rRM group had the lowest median (IQR) compared to rTAPP and rIPOM groups [p < 0.001; 7.5 (0–15) vs. 10 (10–20) vs. 15 (7.5–20), respectively].

The vast majority of the patients were discharged on the same day of the procedure (95.2%). The mean hospital length of stay (LOS) was 0.74 days (SD = 0.39, range = 0–4 days) for the entire cohort. There was a statistical significance between the three groups in terms of mean LOS (p = 0.001). The proportion of patients who required overnight hospital stay was higher in the rRM group than the rIPOM and rTAPP groups (p = 0.002; 12.7%, 2.2%, and 1.9%, respectively).

All patients were assessed by either a postoperative telehealth or clinic visit within a 90-day follow-up period. The rate of ED re-visit within the 30-day postoperative period was significantly higher in the rIPOM group (15.6%) than the rTAPP (2.8) and rRM (7%) groups (p = 0.004). However, the rate of hospital readmission did not differ between groups (p = 0.483). Postoperative complications are shown

in Table 3. The Clavien–Dindo grades and the rate of SSEs differed between groups with the Clavien–Dindo Grade 2 score higher in the rIPOM group and Clavien–Dindo Grade 4a score higher in the rRM group. The Grade 4a complications in the rRM group were hepatic encephalopathy requiring ICU care for a patient with end-stage liver disease, and ICU care for postoperative respiratory distress and carbon dioxide retention in two patients. Both these complications occurred in patients undergoing a unilateral and bilateral TAR, respectively. However, a subgroup analysis of the rRM group showed that TAR had no statistically significant effect on postoperative complications (p = 0.104). The proportion of patients who experienced more than one type of complication was significantly higher in the rIPOM group (9/13) than the rTAPP (1/4) and rRM (0/7) groups (p = 0.009). Accordingly, the calculated CCI® scores were also the highest in the rIPOM group. The rate of SSOs, consisting of seromas and hematomas, was higher in the rIPOM group than the rTAPP and rRM groups. Although the rate of SSIs did not differ between groups, SSEs were more frequently observed in the rIPOM group. No patients experienced any recurrence within the 90-day follow-up period.

A further univariate analysis was conducted to determine factors associated with overall postoperative complications. Coronary artery disease (yes), primary defect closure (no),

Table 2 Hernia characteristics and operative variables

	Total ($n = 269$)	rIPOM ($n = 90$)	rTAPP ($n = 108$)	rRM[a] ($n = 71$)	p
Hernia EHS classification					
Epigastric, yes, n (%)	35 (13)	9 (10)	12 (11.1)	14 (19.7)	0.143
Umbilical, yes, n (%)	257 (95.5)	83 (92.2)	104 (96.3)	70 (98.6)	0.134
Concomitant diastasis recti, n (%)	24 (8.9)	8 (8.9)	7 (6.5)	9 (12.7)	0.364
Primary fascial defect closure, n (%)	254 (94.4)	79 (87.8)	104 (96.3)	71 (100)	<0.001*
Diastasis recti repair, n (%)	18 (6.7)	6 (6.7)	4 (3.7)	8 (11.3)	0.140
Hernia defect area, cm^2, median (IQR)	4.7 (3.1–9.2)	3.1 (3.1–6.2)	3.1 (3.1–7)	14.1 (7.6–18.8)	<0.001*
Mesh area, cm^2, median (IQR)	113 (63.6–225)	113 (63.6–113)	113 (63.6–177)	225 (225–300)	<0.001*
Mesh overlap, craniocaudal, median (IQR)	5 (3.5–5.5)	3.5 (3.5–5)	4.8 (3.5–5.5)	6 (5–6.5)	<0.001*
Mesh overlap, transverse, cm, median (IQR)	5 (3.5–5.5)	3.5 (3.5–5)	4.5 (3.5–5)	5.5 (5.5–6)	<0.001*
Mesh/defect ratio, median (IQR)	19.2 (11.9–32.6)	20.2 (16–36)	23.4 (19–36)	18 (13.3–28.1)	<0.001*
Mesh materials					
Polypropylene, n (%)	59 (21.9)	2 (2.2)	11 (10.2)	46 (64.8)	<0.001*
Polyester, n (%)	195 (72.5)	86 (95.6)	95 (88)	14 (19.7)	
ePTFE, n (%)	15 (5.6)	2 (2.2)	2 (1.9)	11 (15.5)	
Mesh fixation					
Absorbable suture, n (%)	187 (69.5)	90 (100)	82 (75.9)	15 (21.1)	<0.001*
Self-gripping, n (%)	36 (13.4)	0 (0)	24 (22.2)	12 (16.9)	
None, n (%)	46 (17.1)	0 (0)	2 (1.9)	44 (62)	
Skin-to-skin time, min., mean ± SD	63.6 ± 34.3	51.6 ± 22	57 ± 26.9	88.1 ± 44	<0.001*
Console time, min., mean ± SD	49 ± 30.2	37.5 ± 17.8	43.6 ± 22.5	71.6 ± 39.8	<0.001*
Estimated blood loss, mL, median (IQR)	5 (5–5)	5 (5–5)	5 (5–5)	5 (5–5)	0.066

rIPOM robotic intraperitoneal onlay mesh, *rTAPP* robotic transabdominal preperitoneal, *rRM* robotic retromuscular, *EHS* the European Hernia Society, *ePTFE* expanded polytetrafluoroethylene, *IQR* interquartile range, *SD* standard deviation

[a]Six patients (8.5%) in the rRM group required adjunctive transversus abdominis release (TAR); *Statistically significant p-value

intraperitoneal mesh (yes), skin-to-skin time (min), and console time (min) were found to be associated with postoperative complications. Consequently, a multivariate regression analysis evaluating which factors were most predictive of postoperative complications, including pain, SSEs, and all medical complications, was run with statistically significant variables. Multivariate regression results are shown in Table 4. Skin-to-skin time, which includes the console time, was shown to be more predictive of the overall postoperative complication rate; therefore, console time was excluded from the analysis.

Discussion

There is an ongoing debate among surgeons performing hernia repair regarding which operative technique is the most precise and effective. These techniques differ according to defect closure, mesh selection and positioning [4]. Complication rates after hernia repair reported in the literature have been found to be largely influenced by mesh position [10–13].

In laparoscopic VHR (LVHR), the mesh is routinely placed intraperitoneally. However, with the advent of robotics, there has been a renewed interest in extraperitoneal mesh placement [14]. In our previous study, we compared perioperative and short-term outcomes between rIPOM and rTAPP techniques [5]. After conducting a propensity-score match (PSM), two well-balanced groups were obtained in terms of hernia etiology, and almost 75% of the groups involved PVHs. Of the risk factors found in the study [5], intraperitoneal mesh position (OR = 2.027, $p = 0.046$, 95% CI = 1.013–4.059) and longer procedure duration (console time) (OR = 1.014, $p = 0.049$, 95% CI = 1.000–1.028) were correlated to postoperative complications. Similarly, in another study [10], we compared outcomes after rIPOM and rRM–TEP repairs using a PSM analysis of patients with IHs and PVHs. Prolonged (> 30 min) adhesiolysis ($p = 0.015$; OR = 5.152, 95% CI = 1.368–19.404), rIPOM repair ($p = 0.043$; OR = 3.632, 95% CI = 1.041–12.670), and craniocaudal defect size ($p = 0.012$; OR = 1.417, 95% CI = 1.081–1.856) were found to be risk factors for postoperative complications, while operative time (skin-to-skin time) and hernia type were not. In this study, which included patients who underwent RVHR for PVHs, intraperitoneal

Table 3 Postoperative complications

	Total ($n=269$)	rIPOM ($n=90$)	rTAPP ($n=108$)	rRM ($n=71$)	p
Minor complications, yes, n (%)	18 (6.7)	11 (12.2)	3 (2.8)	4 (5.6)	0.028*
Clavien–Dindo[a] Grade-1	12 (4.5)	6 (6.7)	2 (1.9)	4 (5.6)	0.225
Clavien–Dindo Grade-2	6 (2.2)	5 (5.6)	1 (0.9)	0 (0)	0.030*
Major complications, yes, n (%)	6 (2.2)	2 (2.2)	1 (0.9)	3 (4.2)	0.343
Clavien–Dindo Grade-3a	2 (0.7)	1 (1.1)	1 (0.9)	0 (0)	0.399
Grade-3b	1 (0.4)	1 (1.1)	0 (0)	0 (0)	
Clavien–Dindo Grade-4a	3 (1.1)	0 (0)	0 (0)	3 (4.2)	0.015*
CCI® score[b], median (range) mean rank	0 (0–42.4)	0 (0–40.6) 143	0 (0–26.6) 128	0 (0–42.4) 136	0.030*
SSEs, n (%)	13 (4.8)	10 (11.1)	1 (0.9)	2 (2.8)	0.003*
SSI, n (%)	4 (1.5)	3 (3.3)	1 (0.9)	0 (0)	0.183
Cellulitis, n (%)	3 (1.1)	2 (2.2)	1 (0.9)	0 (0)	
Superficial, n (%)	1 (0.4)	1 (1.1)	0 (0)	0 (0)	
SSOs, n (%)	10 (3.7)	7 (7.8)	1 (0.9)	2 (2.8)	0.036*
Seroma, n (%)	7 (2.6)	5 (5.6)	1 (0.9)	1 (1.4)	
Hematoma, n (%)	4 (1.5)	3 (3.3)	0 (0)	1 (1.4)	
SSO/SSI-PI, n (%)	2 (0.7)	2 (2.2)	0 (0)	0 (0)	0.135

CCI comprehensive complication index® (University of Zurich, Zurich, Switzerland), *SSEs* surgical site events, *SSI* surgical site infection, *SSO* surgical site occurrences, *SSO/SSI-PI* surgical site occurrence or surgical site infection procedural intervention, *N/A* not available

[a]If the patient has more than one complication, the higher complication grade degree was presented

[b]Although median CCI® scores are 0 for all groups, a statistically significant difference is still present. This is evident by the mean rank which captures the extent to which one group's values differs from other groups; *Statistically significant p-value

Table 4 Multivariate logistic regression for postoperative complications

Variables	p value	OR	%95 CI for OR	
			Lower	Upper
Coronary artery disease (yes)	<0.001	13.586	3.931	46.956
Primary defect closure (no)	0.041	4.267	1.059	17.201
Intraperitoneal mesh (yes)	0.018	3.614	1.245	10.489
Skin-to-skin time (min)	<0.001	1.021	1.009	1.032

CI confidence interval, *OR* odds ratio

mesh placement was found to be a risk factor with an odds ratio of 3:6.

The minimally invasive robotic platform facilitates several operative steps in PVH, among which is the fascial closure [4]. A previous retrospective study showed that robotic repair was correlated with increased operative time, decreased surgical site occurrences, and increased rates of fascial closure compared to laparoscopic surgery (77.1 vs. 66.7%, $p < 0.01$) [15]. In a multicenter retrospective study, comparing the outcomes of robotic ventral hernia repair, defect closure was achieved in 69.3% and was found to decrease postoperative seroma formation. Primary defect closure, mainly studied in IPOM repair, has been shown to be beneficial in decreasing postoperative seroma formation [16]. In this study, although we found an association between defect closure and overall complication rate, this association was not specific to seroma rates. The rate of defect closure was lower in the rIPOM group as compared to the rTAPP and rRM groups. Accordingly, in the regression analysis, we found that the lack of defect closure was associated with a 4.2-fold risk for all postoperative complications. Due to the small number of SSOs, we are unable to make a comment on whether SSOs in the rIPOM group is from the mesh position or from an unclosed defect. Further studies with a larger sample size could better elucidate this issue.

Another controversial topic for PVHs is the presence of concurrent diastasis recti. A number of surgical techniques have been described and proven efficacious for diastasis recti repair, but there is a lack of comparative studies to help establish the superiority of a single technique [17]. The purpose of diastasis recti repair is to restore the functionality of the abdominal wall and as a secondary objective, to improve cosmesis [18]. We prefer a patient-tailored approach, taking into consideration individual clinical situations. In this study, diastasis recti repair was performed in ventral hernia patients with a BMI < 30 kg/m^2 with symptomatic rectus diastasis, whose findings of diastasis were determined by clinical examination and/or imaging. Diastasis recti repair was performed by plicating the linea alba along the length of the diastasis and reinforcing with a tailored mesh so as to cover the entire sutured line, in addition to the area required for mesh overlap of the PVH.

Mesh reinforcement and its separate components, including mesh type, defect area, and mesh overlap, remain highly debatable in VHR [19]. The M/D ratio was described theoretically to be more important in bridging repair for hernias by Tulloh and Beaux [20]. A prospective series of 213 patients, 158 of which have primary ventral hernias, underwent laparoscopic ventral hernia repair using a bridging technique for mesh. The M/D ratio of 16:1 was found to be the optimal ratio where there were virtually no hernia recurrences during a median follow-up of 5 years [21]. All robotic hernia approaches in this study involved the use of mesh, regardless of hernia size. We measured the overlap as well as the size of the mesh in relation to defect size, which had a mean of 4.7 cm. All three approaches for RVHR were able to achieve an M/D ratio of at least 16:1. The current study period of 90 days, however, is not enough to portray the importance of this ratio. Larger M/D ratios were obtained in the rTAPP and rIPOM groups due to a smaller hernia size. The importance of the M/D ratio with extraperitoneal mesh placement has yet to be validated.

Mesh fixation is another component of VHR which may have implications on patient outcomes. In robotic extraperitoneal hernia repair, the mesh is held in place between abdominal layers, limiting the need for mechanical mesh fixation. Displacement of the mesh is prevented by tailoring the mesh to occupy the entirety of the dissected plane, thereby minimizing the necessity for fixation. This entails a larger mesh overlap and M/D ratio, which have proven benefits for patients as discussed previously. In all rIPOM repairs, mesh fixation was achieved using continuous circumferential suturing, which is an alternative to the tackers and transfascial sutures mostly used in LVHR. Transfascial sutures used in laparoscopic IPOM may contribute to increased postoperative pain [22]. In terms of postoperative pain, although no baseline preoperative pain scores were available for comparison, we did not find a difference in early postoperative pain scores between the three groups. However, the use of multiple narcotics was significantly higher in the rIPOM group. Less mechanical fixation is used in extraperitoneal mesh placement, theoretically resulting in reduced pain as compared to traditional IPOM placement. These benefits would be better elucidated by a randomized trial.

Hernia complexity influences total operative time. For instance, relative to PVHs, adhesiolysis during IH repair significantly contributes to total operative time. Operative time is also affected by the surgical approach and repair method. Operative time increases when more dissection is needed. In the literature, mean operative time for IPOM ranged from 75 to 180 min [17]. Our study showed a mean total operative time of 63.6 min for all types of robotic hernia repair, 51.6 min for IPOM, 57 min for TAPP, and 88.1 min for RM. Total operative time for rRM repair was found to be longer than that of rTAPP and rIPOM,

likely due to time-consuming operative steps, such as trocar placement, crossover, and adjunctive TAR, which are required to dissect the retromuscular plane. Although the length of the procedure emerged as an independent risk factor for the development of postoperative complications, the regression analysis revealed an odds ratio of approximately 1, which is clinically negligible.

Another outcome reflecting repair quality is SSE rate, including SSOs and SSIs. One study evaluating differences between laparoscopic and rIPOM–VHR among 215 patients found that robotic IPOM repair resulted in significantly less SSOs than laparoscopic IPOM repair (4.2 vs. 18.8%, $p < 0.001$) [15]. On the other hand, another study by Warren et al. [23] also compared two groups undergoing LVHR and RVHR. Most of the patients in the laparoscopic group underwent IPOM repair (90.3%), while most of the patients in the robotic group underwent extraperitoneal repair (96.2%). They found a higher rate of seroma formation in the robotic group (47.2%) as compared to the laparoscopic group (16.5%, $p < 0.001$), with no differences in terms of SSI rate. In our study, the rate of SSOs in the rIPOM group (7.8%) was significantly higher than in the rTAPP (0.9%) and rRM (2.8%) groups ($p = 0.036$). No differences were observed in terms of SSI rate between the three groups, with an overall rate of 1.5%, which coincides with published rates in recent hernia guidelines (0.9–3.8%) [17].

After comparing the results of all three groups, it is clear that each technique has specific advantages and disadvantages. We should not ask which approach is absolutely superior, but rather which patients can benefit from a particular surgical technique. As discussed previously, extraperitoneal techniques resulted in a lower minor complication rate (rTAPP—2.8%; rRM—5.6%) as compared to the rIPOM group (12.2%, $p = 0.028$). On the other hand, all the three reported Grade 4a major complications were observed in the rRM group. Simultaneously, we observed a large proportion of patients with significant comorbidities across the three groups, among which was CAD, and was found to be a significant predictor of postoperative complications in our multivariate regression analysis. Therefore, low-risk patients may fully benefit from the advantages of rRM repair in terms of its wide dissection plane allowing for a large overlap and minimal use of fixation. However, in patients with relevant comorbidities, such as CAD, these advantages may be offset by increased operative time necessary to achieve that dissection. As for rTAPP repair, this could be a suitable choice of technique for patients with smaller defects, combining the advantage of a larger M/D ratio and minimal mesh fixation, without the risks associated with intraperitoneal repair. Patients with larger defects may lose these advantages and, therefore, may benefit from a rIPOM or rRM repair. An important take-home message for surgeons is to tailor their

approach based on individual patient characteristics to ultimately improve outcomes and quality of life.

There are several limitations of our study. First, although our data were recorded prospectively, the study's retrospective structure can be considered as a limiting factor due to the introduction of selective bias. For instance, there was a gender disproportion between the three groups, with the majority of female patients undergoing rIPOM repair. Similarly, larger defect sizes were present in the rRM group as compared to rIPOM and rTAPP groups. However, despite these imbalances, neither univariate nor multivariate analyses showed a statistically significant relationship between these variables and the presence of postoperative complications. Another limitation is that this was a single-center study, which admittedly may hinder its generalizability. Multicenter studies that represent more diverse surgeon experience could provide additional value. Other study limitations include the absence of patient-reported outcomes, such as quality of life assessments and objective pain assessments through visual analog scales. Despite this limitation, pain reported by any patient was factored into the Clavien–Dindo grades and CCI® scores. Furthermore, long-term follow-up outcomes are needed to assess the durability of repair. In conclusion, robotic PVHR provides several approaches at a surgeon's disposal which can be implemented based on patient demographics and hernia characteristics.

Compliance with ethical standards

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