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Robotic-assisted ventral hernia repair: a multicenter evaluation of clinical outcomes

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Abstract
Background The open approach continues to be widely performed for ventral hernia repair, while the minimally invasive laparoscopic approach has grown adoption over the last decade. Recently, robotic operation was described as a new modality due to the ease for performing intracorporeal closure of the hernia defect. This study is one of the first multi-institutional case series evaluating robotic-assisted laparoscopic ventral hernia repairs, with the goal of describing robotic-assisted surgical techniques for ventral and incisional hernia repair and the outcomes in teaching and community hospital settings.
Methods Medical records of consecutive patients (including surgeon's learning curve cases) who underwent ventral or incisional hernia repair utilizing the da Vinci Surgical System (Intuitive Surgical Inc, Sunnyvale CA) were retrospectively reviewed. Data collected included preoperative history and perioperative outcomes.
Results Data for a total of 368 patients from four institutions involving five surgeons were analyzed. They were predominantly females (60.3 %), and the mean age was 51 years. The majority of the patients were obese or morbidly obese (47.8 and 20.9 %), and 83.2 % of the patients had a history of prior abdominal operation. Conversion rate was 0.8 %, and mean length of stay was 1 day. Total postoperative complications rate up to 30 days was 8.4 %, of which incidence of paralytic ileus was 2.4 %.
Conclusion This large case series of 368 patients demonstrates reproducibility of safety and performance associated with robotic-assisted ventral hernia repairs performed by five surgeons at four institutions. In addition, the results of short term perioperative outcomes for surgeons during their early experience for robotic-assisted cases are in the range of what is reported in the existing published data on laparoscopic and open ventral hernia repairs. Further comparative evidence initiatives are being pursued to determine the benefits of robotic-assisted technique and technology for long-term and patient-reported outcomes.

Keywords Ventral hernia · Incisional hernia · Robotic incisional hernia · Robotic ventral hernia · Laparoscopic hernia repair · Open hernia

Repair of ventral and incisional hernias are areas of intense debate in the surgical community. Interest and publications in this area have grown in the past 5 years (2010 to 2015) with more than 11,000 publications on this topic [1], but despite this, a broadly applied solution has not been accepted. Hernia operation was revolutionized in 1958 when usher utilized a prosthetic mesh for hernia repair [2]. However, regardless of the advances in surgical techniques and use of materials, recurrence rates remain high.

Laparoscopic hernia repair, as described by LeBlanc's technique [3], implies intraperitoneal placement of a

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prosthetic mesh without closure of the fascial defect. In some cases, with the laparoscopic approach, the mesh bulges through the defect and produces the sensation of "hernia recurrence". If symptomatic, the patient may require reoperation to ensure no recurrence exists and approximation of the fascia. Due to these issues, various fascial closure techniques have been described to approximate the defect laparoscopically [4, 5]. Closure of the defect performed in a minimally invasive fashion seemed best for recreation of the abdominal wall and to prevent recurrence or bulging. Performance of this maneuver is limited to skilled laparoscopic surgeons. Therefore, robotic-assisted operation has been described as a new modality in this field that can facilitate intracorporeal closure of the defect [6]. Since the results of this initial study seemed promising and the adoption by others continuously grows, a larger cohort among various surgeons is reviewed here.

There is a paucity of evidence in the literature on the robotic-assisted laparoscopic approach. This study is one of the first multi-institutional case series evaluating robotic-assisted laparoscopic ventral hernia repairs. The purpose of this study is to describe the robotic-assisted surgical approach for ventral and incisional hernia repair and to evaluate the outcomes of a multi-institutional experience in teaching and community hospital settings.

Methods

Under approval of the Institutional Review Boards (IRBs) for all participating institutions, we reviewed 368 medical records of consecutive patients who underwent ventral or incisional hernia repair utilizing the da Vinci robotic platform (Intuitive Surgical Inc, Sunnyvale CA) between July 2011 and February 2015. Procedures were performed by 5 surgeons at the following 4 centers: Baptist Health South Florida (AMG, JRR), Hillcrest Medical Center (ED), Steward Good Samaritan Medical Center (YK), and Mid-Florida Surgical Associates (CJ). All hernia types were included both primary and incisional. There were no exclusion criteria, and all patients who underwent a robotic-assisted repair were entered.

Data collected include preoperative history, operating time, perioperative outcomes including conversions, length of stay, and postoperative complications (for the first 30 days postoperation). Surgical variables include closure of the defect, use of tacks/sutures, and use of mesh, but not size of the defect or perioperative imaging.

Hernia types according to location were categorized using the European Hernia Society (EHS) classification for primary or incisional ventral hernias. Since study data consist of all cases starting with each surgeon's initial use of the robot, operating times include those that represent an initial period of learning.

Data are summarized with descriptive statistics using counts and percents for categorical variables such as gender, ASA class, comorbidities, hernia type, and complications. For continuous variables including age, BMI, operating time, and hospital length of stay (LOS), we report mean and standard deviation as well as median and range where exploratory plots indicated a skewed distribution. We also provide categorical representation of BMI using standard cut points for excess weight and obesity. Additionally, operating time is categorized by hour and LOS by day, to better illustrate the peaks and tails of these distributions.

Robotic- assisted surgical technique

As with all multi-port robotic-assisted operation, the patient is placed under general anesthesia. Entry into the abdomen is performed per the surgeon's preference, but starts with the laparoscopic approach. Robotic ports are placed depending on the platform used but should occur as lateral as possible to allow the surgeon to close the defect and fixate the mesh with appropriate overlap. If lysis of adhesions is needed to place ports, it is completed by laparoscopy. A basic principle for docking the robot was utilized: "The robot, the hernia, and the camera should be in a straight line." This approach requires the use of 3 ports, one for the camera (8.5 mm) and two for the robotic arms (5 or 8 mm each according to the surgical platform), and if deemed necessary by the surgeon, one assistant port (12 mm) is used. When utilizing the Si system, the robot has to be docked either at the left or the right side of the patient, or in case of a suprapubic hernia, the Si robot is docked between the legs with the patient in lithotomy position. Once docked, continued lysis of adhesions and reduction in hernia contents into the abdominal cavity is performed. Hernia sac is removed per the surgeon's discretion. A measuring tape is used inside the abdominal cavity to measure the length and width of the defect to allow mesh overlap of 3 to 5 cm in all directions (ED, YK, CJ). Next, if deemed appropriate by the surgeon, closure of the defect is performed. Lowering the intraabdominal pressure facilitates fascial closure and decreases wound tension. During this stage of the procedure, the assistant may facilitate final approximation of the fascial edges. Closure of the defect is performed with interrupted non-absorbable sutures placed in a figure of eight fashion (AMG) or using running absorbable barbed suture (ED, YK, JRR). Surgeon (AMG, JRR) measured the defect after closure, by using a measuring tape inside the abdominal

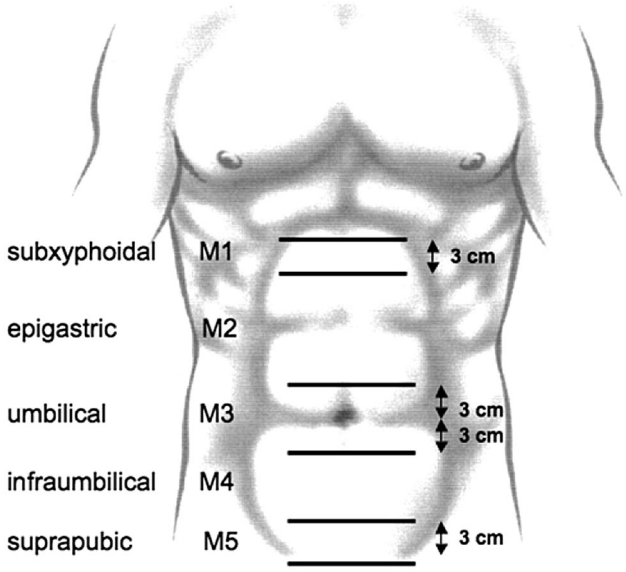

Fig. 1 EHS classification for hernias. EHS classification for midline primary or incisional ventral hernias, using as landmarks the two lateral margins of the rectus muscle sheaths, five zones are defined. (taken from Classification of primary and incisional abdominal wall hernias, Muysoms et al. [29] with permission)

cavity to allow mesh overlap of 3 to 5 cm in all directions (Fig. 1).

In a small number of cases, myofascial release was performed to allow closure of the defect. The various techniques used for component separation were unilateral or bilateral transverse abdominis release, unilateral external oblique release, and bilateral postrectus sheath incision.

The following different mesh fixation techniques are used during these robotic-assisted cases:

- Mesh fixation with tacks and interrupted nonabsorbable sutures;
- Mesh fixation with tacks only;
- Mesh fixation with running sutures only (either traditional or barbed).

Results

Data from 368 consecutive cases of robotic ventral hernia repairs were collected and reviewed from 4 institutions. The average age was 55.1 years (SD = 31.2), and females were predominant (60.3 %). Obese patients accounted for 47.8 % and 20.9 % were morbidly obese. Most patients were ASA class II (198, 54 %) or III (149, 40.6 %). A history of prior abdominal operation was found in 306 (83.2 %) of the patients in the study. Hypertension (58.8 %), smoking history (29.9 %), and diabetes (16.6 %) were the most frequent comorbidities (Table 1).

Table 1 Patient characteristics

Age (years)	Mean		55.1
	SD		13.2
	Median		55.0
BMI	Mean		33.9
	SD		7.6
	Median		32.6
		Patients	%
Gender			
Female		222	60.3
Male		146	39.7
BMI (4 unknown)			
Underweight, <19		4	1.1
Normal, 19–<25		25	6.9
Overweight, 25–<30		85	23.4
Obese, 30–<40		174	47.8
Morbidly obese,>40		76	20.9
ASA class (1 unknown)			
ASA 1		14	3.8
ASA 2		198	54.0
ASA 3		149	40.6
ASA 4		6	1.6
Previous abdominal surgery		306	83.2
Comorbidity			
Hypertension		214	58.2
Hx smoking (3 unknown)		109	29.9
Diabetes		61	16.6
COPD		28	7.6
Dyspnea		16	4.3
Hx AAA		1	0.3
Hx abd wall SSI		8	2.2
Ulcerative colitis		1	0.3
CAD		36	9.8
Total patients with 1 or more comorbidity		273	74.2

SD standard deviation

Hernias were classified according to cause (primary or incisional) and anatomical site (Table 2). In total, 271 cases were incisional hernias (73.6 %), and 97 (26.4 %) were primary ventral hernias. Midline only was the most common site for incisional hernias (85.2 %), while umbilical was most common among primary ventral hernias (67.0 %).

Patients with just one hernia defect and repair were reported in 207 patients (92.8 %) of 223 patients with available data. Information regarding the location was available in 243 hernias. The most common type of ventral hernias was umbilical M3 ($n = 133$, 59.6 % of hernia) followed by epigastric hernias M2 ($n = 69$, 30.9 %).

Table 2 Patients by type of hernia

Hernia type	Components	Patients	%
Ventral incisional	Midline only	152[a]	41.3
	Lateral only	23	6.3
	Both	9	2.4
	Total ventral incisional	184	50.0
Recurrent ventral incisional	Midline only	79[b]	21.5
	Lateral only	4	1.1
	Both	4	1.1
	Recurrent incisional	87	23.6
	Total recurrent incisional	271	73.6
Primary ventral	Midline umbilical	65	17.7
	Midline epigastric	15	4.1
	Both	11	3.0
	Lateral spigelian	4	1.1
	Lateral lumbar	2	0.5
	Total primary ventral	97	26.4
	Total hernias	368	100.0

[a] Includes 3 cases with component separation

[b] Includes 5 cases with component separation

Table 3 Procedure details

	Patients	%
Concomitant procedures		
Lysis of adhesions	30	8.2
Inguinal hernia repair	14	3.8
Gynecologic	10	2.7
Mesh removal	3	0.8
Cholecystectomy	3	0.8
Urologic	2	0.5
Bowel resection	1	0.3
Other[a]	10	2.7
Total patients with 1 or more procedure[b]	71	19.3
Closure of primary defect	255	69.3
Mesh used	364	98.9
Mesh type (7 unknown)		
Absorbable synthetic	1	0.3
Biologic	2	0.5
Permanent synthetic	358	99.2
Mesh fixation		
Tacks only	146	40.1
Transabdominal suture only	2	0.5
Tacks and transabdominal suture	4	1.1
Suture only	212	58.2
Myofascial release	8	2.2

[a] Other procedures included biopsy, breast reconstruction, resections, and excisions

[b] Sixty-nine patients had a single concomitant procedure and 2 others each had two procedures (gynecologic and lysis of adhesions; mesh repair and lysis of adhesions)

The most common concomitant procedure (Table 3) was lysis of adhesions reported in 30 patients (8.2 %). Other concomitant procedures were performed with less frequency (gynecologic (2.7 %), inguinal hernia repair (3.8 %), cholecystectomy (0.8 %), and others.). Closure of the fascial defect(s) was performed in 255 cases (69.3 %), and intraperitoneal meshes were used in 364 cases (98.9 %). The most commonly used mesh was permanent synthetic (99.2 %). Mesh fixation techniques included tack use in 150 patients (41.2 %) and transabdominal sutures use in 6 patients (1.6 %). Intracorporeal suture fixation of mesh was used in 58.2 % of cases.

As reported in Table 4, conversions were required for three patients (0.8 %), two of which were due to large defects sizes not suitable for closure of the defect; the third case resulted in conversion due to the presence of dense adhesions and intraop bowel injury. Operating time (skin to skin) ranged from 35 to 393 min with a median of 89 min. Majority of the patients 236 out of 368 (64.3 %) had an operating time in the range of 60–119 min. The mean operating time was 102.1 min (SD 48.3) due to the influence of a relatively small number of cases exceeding 3 h duration; that is, outliers in a skewed distribution. Same day discharge was achieved in 219 (59.7 %) patients, while an additional 94 (25.6 %) patients were discharged the day after operation.

Intraoperative bowel injury occurred in two cases (0.5 %). One patient required an extended ICU stay, and the other injury resulted in conversion to open to complete the procedure. Postoperative 30 day complication rate was 8.4 %, which included paralytic ileus 2.4 %, wound and mesh infection 1.4 %, and seroma requiring intervention with aspiration and drainage in 3.8 %. The procedure-related 30 day readmission and reoperation rates were 3 and 1.9 %, respectively (Table 5). Reoperations were related to removal of infected mesh ($n = 2$) and one case each of small bowel obstruction, missed enterotomy, I&D for abscess, perforated bowel, and recurrent hernia.

Discussion

Primary ventral and incisional hernias are clinical entities that will follow surgeons through their practice. As previously mentioned, incisional hernia rates remain high, despite the advances in technology and surgical techniques. When comparing open versus laparoscopic ventral hernia repair, several studies from large clinical databases have shown better outcomes for the laparoscopic option, such as shorter length of stay, cost effectiveness, improved safety,

Table 4 Surgical outcomes and hospital length of stay

	Patients	%
Conversion	3	0.8
Operating time (minutes) (1 unknown)		
0–59	39	10.6
60–119	236	64.3
120–179	68	18.5
180–239	16	4.4
240+	8	2.2
	Mean (SD)	Median (range)
Operating time (skin to skin) (minutes)	102.1 (48.3)	89 (35–393)
LOS (days) (1 unknown)	1.0 (2.4)	0 (0–29)
	Patients	%
Same day discharge	219	59.7
Next day discharge	94	25.6
2–3 days	30	8.2
4 + days	24	6.5

SD standard deviation

and decreased wound-related complications [7–12]. The minimally invasive laparoscopic approach for primary ventral or incisional hernia repair has a shorter length of stay when compared to the open repair, and in our case series, the mean length of stay was of 1 day (SD = 2.4). Of note, larger case series and meta-analyses have reported a longer length of stay for open and laparoscopic approaches (ranging from 2 to 8 days), as shown in Table 6 [10, 11, 13–15].

A major disadvantage reported for the laparoscopic approach when compared to the open counterpart is the increased operative time. A meta-analysis performed by Sains et al. [16], in a pooled series of 351 patients undergoing either laparoscopic ($n = 148$) or open approach ($n = 203$), reported a mean longer operative time of 12 min ($P = 0.003$) in the laparoscopic group. Overall, mean operative times in each of the five laparoscopic case series that they analyzed were of 95, 108, 120, 124, and 140 min, respectively. Some have found no difference in operative times when comparing laparoscopic and open repairs. Pierce et al. [14] in a meta-analysis that involved open ($n = 758$) versus laparoscopic ($n = 619$) repairs did not find any statistical difference in operative times. In our case series, the mean operative time was of 102.1 min (SD 48.3) showing comparable results to what has been reported in the literature [13, 14, 16] even with closure of the fascial defect in the majority of cases (69.3 %).

Intracorporeal laparoscopic closure of fascial defects is a surgical practice that is not broadly accepted nor performed due to the surgical complexity and demands for advanced laparoscopic skills. Since most of the reported experience on laparoscopic ventral/incisional hernia repair does not include closure of fascial defects, mesh bulging has been reported, and in some cases, it can be perceived as hernia recurrence [17, 18]. Carter et al. [17] and Nguyen et al. [18] both report that failure to close the central defect was associated with clinical eventration or mesh bulging. From a patient's perspective, eventration can be symptomatic or present as a bulge that is perceived as a hernia recurrence. This has a negative impact on patient's lifestyle and mobility [17]. Tse et al. [19], in a case series of 121 repairs with a minimum follow-up of 11 months also reported 20 patients ($n = 16.5$ %) who perceived hernia recurrence, of which only 4 (3.3 %) were true recurrences and 2 other cases were due to development of new incisional hernias. Once a recurrence is suspected, the initial workup requires diagnostic

Table 5 Complications

	N	%
Intraoperative complication		
Bowel injury	2	0.5
Postoperative complication related to hernia repair within 30 days	31	8.4
Paralytic ileus	9	2.4
Wound and mesh infection	5	1.4
Seromas requiring intervention	14	3.8
Urinary retention	3	0.8
Readmission[a]	11	3.0
Reoperation[b]	7	1.9

[a] Readmission for paralytic ileus ($n = 2$), small bowel obstruction ($n = 3$), dehydration, wound infection, abdominal pai, Seroma, perforated bowel, and clotted AVF, one case each

[b] Reoperation for removal of infected mesh ($n = 2$) and one case each of small bowel obstruction, missed enterotomy, I&D for abscess, perforated bowel, and recurrent hernia

Table 6 Surgical outcomes reported in the literature

Outcomes	Current study	Eker et al. [13] Multicenter trial		Ecker et al. [15] (statewide claims data, NY and CA)		Kaoutzanis et al. [11] (NSQIP review 2009–2010)		Mason et al. [10] (NSQIP 2005–2009)		Pierce et al. [14] (Meta-analysis)	
	Robotic assisted $N = 368$	Open ($n = 100$)	Laparoscopic ($n = 94$)	Open ($n = 9228$)	Laparoscopic (4339)	Open ($n = 21,463$) Reducible = 15,520 Incarcerated = 5943	Laparoscopic ($n = 5303$) Reducible = 3883 Incarcerted = 1.420	Open ($n = 59,139$)	Laparoscopic ($n = 11,915$)	Open ($n = 758$)	Laparoscopic ($n = 619$)
Operative Time—minutes, mean (SD)	102 .1 (48.3)	76 (33)	100 (49)	NA	NA	Reducible: 84.9* Incarcerated: 81.2*	Reducible: 94 Incarcerated: 96.4	NA	NA	104.5	115.0
Conversions	3 (0.8 %)	–	8 (8 %)	NA	NA	NA	NA	NA	NA	–	3.9 %
Seroma	14 (3.8 %)	4 (4 %)	7 (7.5 %)	NA	NA	NA	NA	NA	NA	12 %	12.1 %
Bowel injury	2 (0.5 %)	1(1 %)*	5 (5 %)	1 %*	1.4 %	NA	NA	NA	NA	1.2 %*	2.9 %
Hematoma	0 (0 %)	11 (11 %)	10 (10.6 %)	NA	NA	NA	NA	NA	NA	NA	NA
Length of stay	1.0										
Mean (SD)	1.0 (2.4)	NA	NA	NA	NA			4.4 (8.1)	3.2 (5.1)	4.3	2.4
Median (IQR)	0 (0–1)	3 (2–5)	3(2–4)	3 (3)	2 (3)	NA	NA	NA	NA	NA	NA
Surgical site infection	5 (1.4 %)	5 (5 %)	4 (4.3 %)*	1.9 %	0.9 %*	Reducible = 763 (4.9 %) Incarcerated = 346 (5.8 %)	Reducible = 43 (1.2 %)* Incarcerated = 33 (2.3 %)*	2449 (4.14 %)	168 (1.4 %)*	10.4 %	2.3 %*

Data are reported as *n* (%) except where noted

* Data achieved statistical significance favoring either laparoscopic or open repair

imaging, and in some cases, the patients must undergo operation to confirm a true recurrence [19, 20].

Several techniques have been reported for the laparoscopic closure of fascial defects. The most common practice involves the passage of transfascial sutures [4, 5, 21] through multiple incisions commonly referred to as "the shoelace technique". Postoperative pain is known to be associated with the use of transfascial sutures [22, 23]. The robotic approach offers the ergonomic movements and dexterity of wristed instrumentation that provides advantages for minimally invasive hernia repair, such as fixation of mesh without the use of tacks, and a strong technical ability to close the defect, which is typically a challenge for the laparoscopic surgeons [24–26]. The primary reason for the adoption of robotic primary ventral/incisional hernia repair in the study surgeon's practices was the ability and ease of closure of the fascia as shown in Gonzalez et al. [6], where mean overall surgical time was similar to that reported in the literature even with the closure of the fascial defect, suggesting that addition of the robot may facilitate other aspects of the procedure. The present study shows closure of the fascial defect in 69.3 % of cases, while surgeons are at their initial experience.

Minimizing postoperative complications such as surgical site infections have been a known benefit of the minimally invasive approach to ventral hernia repair [27, 28]. Surgical site infection rates for primary ventral/incisional hernia repair have been reported from 1.9 to 10 % in open hernia repairs and 0.9–4.3 % in the laparoscopic approach (Table 6). Our study data show infection rates of 1.4 %, which falls in the range to what is reported in the literature for laparoscopic cases. A retrospective review made by Kaoutzanis et al. in 2013 [11] from the American College of Surgeon's National Surgical Quality Improvement Program database (NSQIP) over the years 2009 and 2010 reported 26,766 primary/incisional hernia repairs, of them 21,463 cases (72 %) were open repairs and 5303 (28 %) cases were performed laparoscopic. The overall surgical site infection rates were 4.9 and 5.8 % for the open approach (reducible and incarcerated hernias, respectively) and 1.2 and 2.3 % for the laparoscopic group (reducible and incarcerated hernias, respectively). An earlier review of the NSQIP database by Mason et al. [10] from the years 2005 through 2009 included 71,054 patients, 17 % of cases were performed laparoscopic and 83 % were performed open, their results revealed similar outcomes favoring the laparoscopic approach with statistical significance for Surgical Site Infections (1.4 % for lap vs. 4.14 % for open). Our robotic case series reported 5 (1.4 %) surgical site infections that compares to this reported rate in NSQIP laparoscopic group reported by Mason et al. [10].

The strength of this study is the multi-institutional analysis of 368 patients. This study is the first of its kind, evaluating robotic-assisted ventral hernia repair across teaching and community hospital settings, providing evidence of safety and performance as a multi-institutional case series.

The limitation of this study lies on its retrospective nature, as long-term outcomes, pain, and quality of life were not available. The manner of fascial or defect closure varied between surgeons. Patients were followed postoperatively as deemed necessary by the surgeon for adequate postoperative care. Beyond history and physical examination on the postoperative patient, imaging was used as needed for the care of the patient. Furthermore, information about hernia recurrence was limited. In recognition of these limitations, prospective data collection initiatives such as the American Hernia Society Quality Collaborative are being pursued. In conclusion, this large cases series of 368 patients demonstrates reproducibility of safety and performance of robotic-assisted ventral hernia repairs performed by five surgeons at four institutions. In addition, the current study provides comparable short term results for surgeons during their early experience in robotic-assisted cases to the existing published data on laparoscopic and open repairs.

Further comparative evidence initiatives are being pursued to determine the benefits of robotic-assisted technique and technology for long-term and patient-reported outcomes.

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Compliance with ethical standards

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