Journal of Robotic Surgery (2020) 14:123–129
https://doi.org/10.1007/s11701-019-00945-y

ORIGINAL ARTICLE

Short- and intermediate-term clinical outcome comparison between laparoscopic and robotic-assisted median arcuate ligament release

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Received: 8 February 2019 / Accepted: 25 February 2019 / Published online: 21 March 2019

Abstract
While laparoscopic median arcuate ligament (MAL) release remains the most common approach, robotic-assisted MAL release has been increasingly performed by several institutions. This study aims to compare surgical outcomes between laparoscopic and robotic-assisted MAL release. This is a retrospective study of patients undergoing laparoscopic and robotic-assisted MAL release in a teaching hospital from January 1999 to December 2018. Intraoperative and postoperative outcomes as well as short- and intermediate-term clinical outcomes were compared between the two groups. A total of 16 laparoscopic and 18 robotic cases were included. Demographics and baseline characteristics were similar between the two comparison groups. Median operative time was shorter in the robotic group [179.5 (IQR 127.3–225) vs. 106 (IQR 80.8–122.8) minutes; $p < 0.001$]. The rates of conversion to open operation were similar in both groups (6.3% vs. 5.6%, $p = 0.99$). Conversions to laparotomy were performed due to bleeding and extensive adhesions in one laparoscopic case and due to technical difficulties in a patient with narrow body habitus in the robotic group. Postoperative complication rates were similar (12.5% vs. 16.7%, $p = 0.99$), all in grade I and II. Complete pain resolution rates (37.5% vs. 44.4%, $p = 0.93$), symptom recurrence rates (37.5% vs. 27.8%, $p = 0.93$), and overall clinical improvement at last follow-up (87.5% vs. 77.8%, $p = 0.66$) were not statistically different. Both laparoscopic and robotic-assisted MAL release offer similar short- and intermediate-term clinical outcomes. A shortened operative time may be achieved by incorporating the robot platform.

Keywords Median arcuate ligament release · Laparoscopic procedure · Robotic-assisted procedure · Outcome comparison

Introduction

The surgical management of median arcuate ligament syndrome (MALS), a.k.a. celiac artery compression syndrome (CACS) has gradually evolved over the past few decades in correspondence with changing hypotheses of its pathophysiology and advances in surgical technology [1–5]. Surgical release of the extrinsic compression on the celiac artery and plexus caused by the median arcuate ligament (MAL) and surrounding fibrous tissues remains the mainstay of therapy. Overall success rates ranged from 53 to 79% with the majority of patients reporting immediate postoperative symptom relief [6].

While many approaches have been reported for access to the celiac plexus, including an open technique, retroperitoneal endoscopic, laparoscopic, hybrid (laparoscopic and endovascular stenting) and robotic [6–10], the laparoscopic approach has been widely performed since its initial report in 2000 [11]. In 2007, Jaik et al. first successfully demonstrated the application of robotic assistance to laparoscopic MAL release [2]. More institutional case series have later demonstrated that these minimally invasive techniques are associated with very low morbidity and mortality [4, 12].

One of the major hypothesized advantages of the robotic surgical platform is the technical advantage that may be achieved with the use of its multi-articulated end effectors when operating in deep anatomical regions. While no

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objective measures exist for quantifying technical ease, operative time has been used as a substitute outcome parameter for a degree of procedural complexity and sometimes been found to correlate with postoperative outcome [13, 14].

In this study, we seek to compare intraoperative and postoperative outcomes as well as short- and intermediate-term clinical outcomes of laparoscopic and robotic-assisted MAL release.

Materials and methods

This is a retrospective study of patients who underwent laparoscopic and robotic-assisted MAL release at UCLA Ronald Reagan Medical Center from January 1999 to December 2018. All patients who were referred to our institution for suspected MALS underwent an extensive gastrointestinal workup to rule out other differential diagnoses prior to surgery. Specific MALS diagnosis criteria at our institution included the demonstration of a fish hook deformity and post-stenotic dilatation of the proximal celiac artery on computed tomography angiography (CTA) or magnetic resonance angiography (MRA), and/or elevated peak systolic velocity (PSV) of the celiac artery above 200 cm/s during expiratory phase on duplex scan [15]. Starting in the year 2010, all eligible surgical candidates were offered both laparoscopic and robotic-assisted approaches. The decision to proceed with either of these two approaches was made by mutual agreement between surgeon and patient following an informed consent process. All procedures were performed by board-certified surgeons in vascular and minimally invasive surgeries.

Patients were included in the current study if their discharge record demonstrated both (1) international classification disease-10 (ICD-10) code for celiac artery compression syndrome (I77.4), and (2) current procedural terminology (CPT) code for unlisted vascular procedure (37,799), unlisted laparoscopy (49,329) and robotic-assisted laparoscopic procedure (17.42). Patients were excluded if they received endovascular treatments prior to receiving surgery, including balloon angioplasty or celiac artery stenting; if concomitant intraabdominal or mesenteric vascular diseases were diagnosed; or if complete postoperative follow-up up to 1 month could not be achieved. Patients were categorized as undergoing robotic-assisted or laparoscopic MAL release. Medical charts of included patients were then reviewed for extraction of pre-determined variables of interest.

The primary outcomes of interest were intraoperative and postoperative complications. Secondary outcomes were short- and intermediate-term clinical outcomes following the procedure including the success of symptom resolution, the rates of readmission, and the rates of requiring adjunctive endovascular treatment due to a recurrence of symptoms.

The preoperative variables of interest included age, gender, smoking status, American Society of Anesthesiologists (ASA) classification, Charlson comorbidity index (CCI) [16], body mass index (BMI), history of prior abdominal surgery, serum albumin level, symptom duration, PSV of the celiac artery, and degree of stenosis from CTA or MRA. The presenting and residual symptoms were obtained from the physician's notes, which consisted of self-reported information from the patient. The overall clinical improvement was determined at last follow-up as the following: those who experienced a complete symptom resolution, or markedly improved symptoms, or mild recurrence of pain were considered having overall clinical improvement; and those who experienced a recurrence of severe pain, or symptoms remained the same as prior to the operation were considered not having overall clinical improvement. The severity of postoperative complications was graded according to the Clavien–Dindo classification [17]. Radiographic improvement following surgical release was measured by a decrease in degrees of celiac artery stenosis following surgery.

The release of the median arcuate ligament and the surrounding adhesions for both laparoscopic and robotic-assisted approaches were performed in a similar technique. The patient was positioned in steep reverse Trendelenburg. The position of the trocars in laparoscopic and robotic procedures is shown in Fig. 1. The liver retractor was inserted to provide an exposure of the relevant structures. In robotic procedure, the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) was then docked following the insertion of the liver retractor. The gastrohepatic ligament was identified and incised. Sharp and blunt dissections were carried on posteriorly until the right and left crura were identified. Dissection was continued using

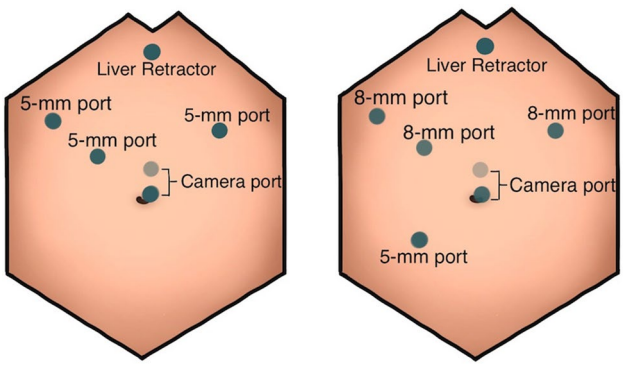

Fig. 1 Port positions in laparoscopic and robotic-assisted median arcuate ligament release. The left diagram demonstrates the port positions in laparoscopic procedure including three 5-mm laparoscopic ports. The right diagram demonstrates the port positions in robotic procedure including three 8-mm robotic ports placed on the subcostal regions and a 5-mm assistant port placed on the right lower quadrant. (Program used to create the artwork: Procreate)

hook cautery as an energy device. The fibers of both crura were divided as well as the MAL and the nerve fibers of the celiac ganglion plexus until the proximal trunk of the celiac artery was completely freed from the surrounding compression. Care was taken when dissecting around the anterior surface of the aorta and the proximal celiac trunk. A complete ganglionectomy of the celiac ganglions was not performed at our institution. The operation was considered complete when the proximal celiac trunk was fully released from the surrounding adhesions.

Descriptive analyses involving univariate comparisons were performed for all baseline and outcome variables between the two comparison groups. All categorical and ordinal variables were compared using Chi-Square and Fisher's exact tests, while the Mann–Whitney *U* test was used to analyze continuous variables in consideration of their skewed distribution. Data are demonstrated in median and interquartile range (IQR) as well as the number of patients (*n*) and percentages. All statistical analyses were performed using Statistical Package for the Social Sciences statistical (SPSS) software version 25 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (Microsoft Corp., WA, USA). This study was approved by the UCLA Institutional Review Board.

Results

Patient demographics and baseline characteristics

A total of 37 patients were identified as undergoing laparoscopic and robotic-assisted MAL release at our institution during the study period, among whom three were excluded due to having had prior endovascular stent placement of the celiac artery, concomitant diagnosis of superior mesenteric artery syndrome, and being lost to follow-up within one month. The median age of the all included patients was 41.0 years (IQR 21.8–41.8), and 26 (76.5%) were female. The median symptom duration was 1.0 year (range 0.7–3.0 years). The median expiratory PSV of the celiac artery was 386 cm/s (IQR 274–444), while 20 (64.5%) patients demonstrated high-grade celiac artery stenosis on mesentery vascular imaging. Most common presenting symptoms were postprandial abdominal pain (85.3%), weight loss (85.3%) and nausea and vomiting (70.6%).

Of the included patients, 16 underwent laparoscopic MAL release, and 18 underwent robotic-assisted MAL release. No significant difference in preoperative demographics, comorbidities, symptom duration or radiographic finding was observed, except in the laparoscopic group which had a higher percentage of female patients (see Table 1). In

Table 1 Baseline characteristics

	Laparoscopic group ($n=16$)	Robotic group ($n=18$)	*p* values
Age, years			
Median (IQR)	41.5 (19.3–53.5)	38.5 (23.5–45.5)	0.99
Female gender, *n* (%)	15 (93.8)	11 (61.1)	0.04[a]
Current smoker, *n* (%)	1 (6.3)	1 (5.6)	0.99[a]
BMI, kg/m^2	23.3 (18.8–29.2)	21.5 (18.1–24.9)	0.25
Prior abdominal surgery, *n* (%)	10 (62.5)	12 (66.7)	0.80
ASA classification, *n* (%)			
Class I	1 (6.3)	2 (11.1)	
Class II	11 (68.8)	11 (61.1)	0.85
Class III	4 (25.0)	5 (27.8)	
Preoperative albumin level, g/dL	4.1 (4.1–4.6)	4.2 (4.0–4.7)	0.62
Charlson comorbidity index	0 (0–1)	0 (0–2)	0.46
Preoperative symptom duration, years	1.3 (0.5–3.0)	1.0 (1.0–3.3)	0.70
Celiac artery duplex scan			
Inspiration PSV, cm/s	168 (142–292)	245 (191–248)	0.57
Expiration PSV, cm/s	371 (261–415)	412 (290–525)	0.32
Degree of celiac artery stenosis on CT/MRA, *n* (%)			
Mild stenosis	1 (6.7)	4 (25.0)	
Moderate stenosis	3 (20.0)	3 (18.8)	0.37
High-grade stenosis	11 (73.3)	9 (56.3)	

IQR interquartile range, *ASA* American Society of Anesthesiologists, *PSV* peak systolic velocities, *BMI* body mass index

[a]Fisher's exact test

Table 2 MALS symptoms before and after surgery, *n* (%)

	Laparoscopic group (*n* = 16)	Robotic group (*n* = 18)	*p* values
Presenting symptoms			
Postprandial pain	14 (87.5)	15 (83.3)	0.99
Weight loss	14 (87.5)	15 (83.3)	0.99
Nausea and vomiting	10 (62.5)	14 (77.8)	0.33*
Diarrhea	4 (25.0)	4 (22.2)	0.99
Nonspecific abdominal pain	2 (12.5)	3 (16.7)	0.99
Exertional pain	0 (0)	1 (5.6)	0.99
Residual symptoms at last follow-up			
Nonspecific abdominal pain	6 (37.5)	6 (33.3)	0.80*
Nausea and vomiting	4 (25.0)	5 (27.8)	0.99
Postprandial pain	3 (18.8)	4 (22.2)	0.99
Weight loss	4 (25.0)	1 (5.6)	0.16
Diarrhea	2 (12.5)	2 (11.1)	0.99

All *p* values were calculated using Fisher's exact test, except those with * were calculated using Chi-Square test

addition, subjective symptoms of MALS were also similar between the two groups, as shown in Table 2.

Intraoperative and postoperative outcomes

Intraoperative and postoperative outcomes are shown in Table 3. Blood loss was recorded as minimal in all cases. Operative time was found to be significantly shorter among robotic procedures than laparoscopic procedures. The rates of conversion to open procedure in both groups were similar (6.3% in the laparoscopic group and 5.6% in the robotic group). One patient in the laparoscopic group, the operation in its nearly complete stage was converted to an open operation for hemostasis following extensive adhesiolysis. The patient underwent direct repair with patch angioplasty of the celiac trunk. One patient in the robotic group, conversion to open operation was performed due to significant instrument crowding and impeded visualization as a result of the patient's extraordinarily narrow body habitus. No other major intraoperative complications were encountered in both groups.

Table 3 Intraoperative, postoperative and follow-up parameters

	Laparoscopic group (*n* = 16)	Robotic group (*n* = 18)	*p* values
Intraoperative parameters			
Operative time, min			
Median (IQR)	179.5 (127.3–225)	106 (80.8–122.8)	< 0.001
Conversion to open, *n* (%)	1 (6.3)	1 (5.6)	0.99[a]
Postoperative parameters			
Postoperative complications, *n* (%)	2 (12.5)	3 (16.7)	0.99[a]
Clavien–Dindo class I	2	1	0.40[a]
Clavien–Dindo class II	0	2	
Length of hospital stay, days	2 (2–3.8)	2 (2–3)	0.73
30-day readmission, *n* (%)	0 (0)	3 (16.7)	0.23[a]
Postoperative abdominal pain resolution, *n* (%)			
Complete resolution	6 (37.5)	8 (44.4)	0.93
Improvement/mild residual pain	2 (12.5)	2 (11.1)	
Recurrence of pain	6 (37.5)	5 (27.8)	
No improvement	2 (12.5)	3 (16.7)	
Follow-up parameters			
Radiographic improvement*, *n* (%)	5 (55.6)	6 (60.0)	0.99[a]
Overall clinical improvement at last follow-up, *n* (%)	14 (87.5)	14 (77.8)	0.66[a]
Follow-up duration, months	13.5 (1.6–34)	15 (1–33.5)	0.73
Time to symptom recurrence, months[#]	3 (1–36)	4 (1–9)	0.75
Underwent adjunctive endovascular procedure, *n* (%)	4 (25.0)	3 (16.7)	0.68[a]
Balloon angioplasty only	1 (6.3)	2 (11.1)	0.99[a]
Balloon angioplasty with stenting	3 (18.8)	1 (5.6)	0.32[a]

IQR interquartile range

*Nine patients in laparoscopic group and ten patients in robotic group received repeat mesentery imaging following surgery

[#]Five patients in laparoscopic group and six patients in robotic group experienced symptom recurrence

[a]Fisher's exact test

Postoperatively, there were no major complications greater than grade II in either group. Minor postoperative complications included a patient with self-limited fever and a patient with prolonged nausea in the laparoscopic group and a patient with poor pain control and one with left hemothorax requiring chest tube drainage in the robotic group.

Short- and intermediate-term clinical outcomes

No patients experienced 30-day readmission in the laparoscopic group, while three patients in the robotic group were readmitted due to dehydration, inadequate pain control, and unspecified fever. No significant differences between the two groups were observed with respect to residual symptoms following the operation (Table 2), abdominal pain resolution rate or clinical improvement during the last follow-up (Table 3). The rates of undergoing adjunctive endovascular procedure in patients with symptom recurrence were not significantly different between the two groups. All patients underwent balloon angioplasty with stenting later experienced recurrence of pain and symptoms.

Discussion

In this study examining a single-institution experience over the past 19 years, we have found both laparoscopic and robotic-assisted MAL release to be associated with similar complication rates. In addition, both approaches achieved comparable rates of symptom resolution in an intermediate-term follow-up. However, operative time was shorter in the robotic group, with median operative time being over 1 h shorter than laparoscopic procedures.

Laparoscopic MAL release has increasingly performed among the institutions since its initial introduction [11]. Besides allowing surgeons to obtain enhanced visualization of the celiac axis, it is associated with reduced intraoperative blood loss, postoperative pain, length of stay, and recovery time in comparison with open surgery [18, 19]. In addition, a growing body of literature has demonstrated the safety and efficacy of laparoscopic MAL release [1, 20–24]. In our study, we have found comparable outcomes among our patients to those previously reported. In addition, rates of success in achieving clinical and radiographic improvement following surgery are also similar to the previously published case series [25].

The robotic-assisted laparoscopic approach has been introduced to MAL release procedures due to the several limitations associated with conventional laparoscopic procedures, including its fulcrum effect due to the use of long straight instruments, loss of depth perception, camera instability, and poor ergonomics [26]. Dissection in deep space such as that around the celiac axis could be particularly challenging with long stiff laparoscopic instruments, prompting several surgeons to experiment with incorporating the robotic surgical platform to MAL release procedures [3–5, 8, 12]. Do et al. described their institutional experience in which 12 patients underwent laparoscopic procedure, and 4 patients underwent robotic-assisted operation. The operative time was longer in the robotic group (145.8 vs. 101.7 min). In their experience, complete resolution of symptoms at mean follow-up duration of 22.2 months was found to be greater in the laparoscopic group (67% vs. 50%). They had demonstrated that robotic MAL release was likely safe and comparable in the outcome to a laparoscopic approach for MAL release [12]. In our current study, we have also found comparable safety profile and efficacy for MALS between robotic and laparoscopic approaches.

While the incorporation of the robotic platform has been associated with longer operative time for many procedures [27–29], several reports have described relative technical ease when operating in deep anatomical regions such as the pelvis [30]. We hypothesize that the observed reduction in operative time is likely associated with the robot's increased dexterity and the multi-articulated joints in its end effectors, which allow surgeon to operate more nimbly in deep anatomical regions near the celiac axis. In contrast to the prolonged operative times commonly cited in early robotic-assisted MAL release case reports [3–5, 8, 12], our institutional experience showed that significant reduction in operative time could be achieved with the use of the robotic platform in the hands of an experienced minimally invasive surgeon. Reduced operative time, while not necessarily associated with improved patient outcome [31], may lead to an overall reduction in operating room costs for the hospital [32, 33]. Moreover, we believe that another factor associated with the reduced operative time in the robotic cases at our institution was surgeons' experience and learning curve, since the robotic cases were performed after 2010 when the attending surgeons already had extensive experience with minimally invasive procedures.

In view of our experience, we have developed a preference for the robotic-assisted MAL release over a conventional laparoscopic approach among patients who are candidates for minimally invasive surgery. Despite the similar outcomes with regard to safety and efficacy, we found that the robotic EndoWrist (Intuitive Surgical Inc., Sunnyvale, CA, USA) provided more technical ease when operating in deep anatomical regions near the celiac axis, especially when a low-lying pancreas may obstruct the reach of straight laparoscopic instruments and necessitate additional effort and attention for retraction. However, not all MALS patients will be candidates for a minimally invasive approach. Patient factors such as severe adhesion from prior surgery, thicker scar tissue surrounding the celiac plexus and anomalies in vascular structure, as well as surgeon factors such as

individual experience and learning curve must all be taken into consideration when choosing the optimal approach for MAL release.

Several limitations were evaluated in our study. As these data were not prospectively collected, surgical outcome data including intraoperative and postoperative parameters were influenced by the differences in surgical techniques and surgeons' learning curve, since the majority of the laparoscopic cases were performed prior to the time when the robotic cases were initiated at our institution. Each robotic case was performed by two attending surgeons. Thus, these results may not be applicable to other institutions with less minimally invasive experience and in different settings. Furthermore, the follow-up interval in each patient varies. Follow-up information for symptoms extracted from electronic medical records was subjective, and no validated questionnaires were used. Further prospective studies or multi-center studies would be valuable to prevail over these limitations.

In conclusion, our study demonstrates that laparoscopic and robotic-assisted MAL release offer comparable surgical outcomes and similar short- and intermediate-term clinical outcomes. Robotic MAL release can be associated with a substantially shorter operative time than laparoscopic MAL release with the hypothesis of improved dexterity offered by the robotic instrument's multi-articulated joints when working in deep anatomical regions, as well as surgeon's experience in minimally invasive technique.

Funding None.

Compliance with ethical standards

Conflict of interest Usah Khrucharoen, Yen-Yi Juo, Yijun Chen, Juan C. Jimenez, and Erik P. Dutson declare that they have no conflict of interest.

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