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Robotic median arcuate ligament release: management algorithm and clinical outcomes from a large minimally invasive series

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Abstract

Background Median arcuate ligament syndrome (MALS) is a rare and debilitating condition that remains difficult to diagnose. Proper patient selection remains key to achieving favorable outcomes for those undergoing MALR. The robotic technique facilitates a minimally invasive MALR approach given the fine precision of the instrumentation and stability of visualization. Here we describe our management algorithm and clinical outcomes for a large series of robotic MALR patients.

Methods This retrospective cohort study analyzed adult patients who underwent robotic MALR performed by a single surgeon at a tertiary academic hospital from 2014 to 2021. The diagnosis of MALS was made using objective criteria from celiac artery duplex ultrasound with a peak systolic velocity of > 350 cm/s combined with a right upper quadrant abdominal ultrasound, esophagogastroduodenoscopy, and computer tomography or magnetic resonance angiography to exclude other diagnoses. Information on patient demographics, perioperative factors, and patient reported symptoms up to 1-year postoperatively were collected.

Results A total of 74 patients underwent robotic MALR during the study period. The mean age was 27.3 ± 7.9 years and the majority of patients were female (n = 60/74, 81.1%). The most common presenting symptom was post-prandial abdominal pain (n = 65/74, 87.7%). The mean operative time was 52.6 ± 18.1 min. There were no conversions to open surgery and minimal blood loss (mean = 13.9 ± 8.4 mL). At 3-months, 12% (n = 9/74) of patients had persistent abdominal pain and underwent additional imaging. 5 of these 9 patients had persistently elevated DUS expiratory PSV and were referred for angioplasty. 3 of these 5 referred patients had resolution of abdominal pain after angioplasty. At 1-year follow up, 90.3% (n = 56/62) continued to have no abdominal pain.

Conclusions Through this series, the largest set of minimally invasive (laparoscopic or robotic) MALR procedures published to date, we show that with strict adherence to a management algorithm, the robotic approach to MALR is safe and feasible, with good patient outcomes.

Keywords Median arcuate ligament · Median arcuate ligament syndrome · Median arcuate ligament release · Celiac artery stenosis · Celiac artery syndrome · Robotic surgery

Median arcuate ligament syndrome (MALS) is a rare and debilitating condition that remains difficult to diagnose. Classic symptoms of MALS include post-prandial epigastric pain, weight loss, nausea and vomiting—all nonspecific symptoms seen in a number of gastrointestinal disorders. In addition, the pathophysiology of MALS remains poorly understood. It is thought to involve external mechanical compression of the celiac artery (CA) by the median arcuate ligament (MAL) [1]. Some hypothesize that there may also be a neurogenic component to the disease resulting from concomitant compression of the celiac ganglion. Compression of the CA is not uncommon, as up to 33% of patients may have a degree of CA compression on routine imaging. However, a much smaller percentage experience symptoms from this and develop MALS [2]. Robust guidelines are lacking for the diagnosis of MALS as it is nuanced and involves the exclusion of other diagnoses, limited diagnostic criteria and vague patient symptoms.

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Over time, the treatment for MALS has evolved and included multiple specialties and operative approaches. Endoluminal stenting and angioplasty generally have not been found to be effective as primary treatment in themselves as external compression from the median arcuate ligament remains [3]. Median arcuate ligament release (MALR) is thought to be the best initial approach to patients suffering from MALS. MALR was first described through a laparotomy in 1965. Currently, the most common initial approach to MALR is through a minimally invasive approach, either laparoscopically or robotically, given its advantages over the traditional open approach including a shorter recovery time, decreased post-operative pain, and decreased post-operative complications [4]. However, MALR is a technically challenging procedure to perform laparoscopically given the difficult exposure, need for precise dissection and the potential for significant hemorrhage. The robotic platform may facilitate a enhanced minimally invasive MALR approach given the fine precision and dexterity of the instrumentation and stability of the camera platform [5]. The first robotic MALR case was published in 2007, with a subsequent handful of small studies reporting comparable outcomes between the robotic and laparoscopic approaches [6–8]. However, due to the rarity of this disease and sub-specialized robotic approach to MALR, there remains a significant lack of robotic MALR management guidelines, perioperative data and long-term clinical outcomes in a large patient cohort.

Proper patient selection remains key to achieving favorable outcomes for those undergoing MALR. While definitive guidelines are lacking, there are generally agreed upon patient characteristics and screening methods to assist in identifying patients who may benefit from MALR. Here, we describe our clinical algorithm for workup and management of patients with MALS, our operative approach, and clinical outcomes of our longitudinal database.

Materials and methods

Study design

A retrospective cohort review was performed of all patients that underwent robotic MALR at a tertiary academic medical center from January 2014 to December 2021. Data was analyzed from a prospectively maintained, IRB-approved, database. All surgeries were performed by a single expert robotic surgeon.

Information on patient demographics, peri-operative outcomes, and patient reported symptoms up to 1-year post-operatively were collected. Baseline patient demographics included: the presence of abdominal pain and associated characteristics, weight loss, grade of CA stenosis on CT and pre-operative duplex ultrasound (DUS) expiratory peak systolic velocity (PSV). Peri-operative outcomes included: operative time, conversion to open laparotomy, complications, estimated blood loss (EBL), length of stay (LOS), need for re-operation within 30 days and 30-day in-hospital mortality. Symptom and quality-of-life information was collected using a modified SF-36 form and a gastroparesis symptom severity form.

Data was collected and entered into an Excel spreadsheet. Categorical data was compared using Chi-Square tests. Continuous data was compared using unpaired *t*-test. Statistical significance was set at a P-value < 0.05.

Pre-operative workup

The diagnosis of MALS in this patient population was made using objective criteria. All patients first underwent upper endoscopy and cross-section imaging (CT/CTA or MRI/MRA) to exclude other sources of pathology. Patients who still had a gallbladder also underwent right upper quadrant abdominal ultrasound to evaluate for biliary pathology. If the right upper quadrant abdominal ultrasound did not reveal gallstone disease, a HIDA scan was performed to rule out biliary dyskinesia. At the pre-operative clinic appointment, patients are given a quality-of-life scoring sheet and Gastroparesis Cardinal Symptom Index (GCSI). If sufficient symptoms were endorsed by the patient that indicated gastroparesis as a possible etiology, they underwent a 4-h, solid-phase gastric emptying study to evaluate for gastroparesis. If they were discovered to have other pathology, they were referred for appropriate further evaluation and management.

If other pathology was excluded, patients then underwent CA DUS. We utilized a cutoff celiac artery expiratory PSV of > 350 cm/s which is associated with an 83% sensitivity, 100% specificity, and 100% positive predictive value for the diagnosis of MALS [9]. In addition, respiratory variation of at least 50% difference between inspiratory and expiratory PSV was considered as supporting evidence in the diagnosis of MALS. If they had a expiratory PSV of > 350 cm/s on DUS with inspiratory/expiratory variation, they were considered to be eligible for MALR (Fig. 1).

Operative technique

Patients are placed in the supine position with both arms tucked and legs on spreader bars with split foot boards in 30 degree reverse Trendelenburg position. A first-generation cephalosporin is given for pre-operative antibiotic prophylaxis. Four 8 mm robotic trocars are placed across the upper abdomen, with a non-robotic assistant port placed near the umbilicus.

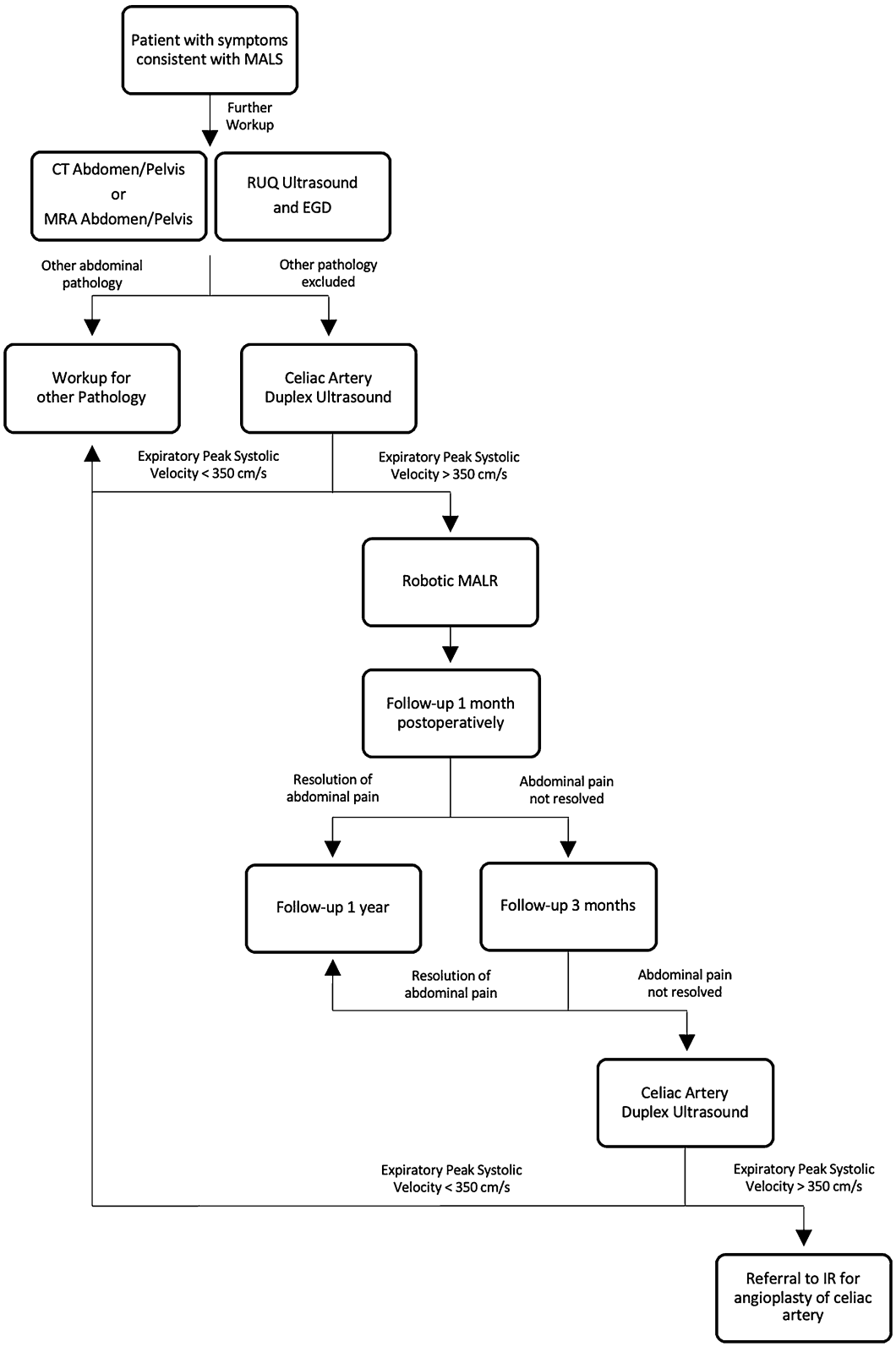

Fig. 1 Algorithm for median arcuate ligament syndrome diagnosis, treatment, and post-operative care

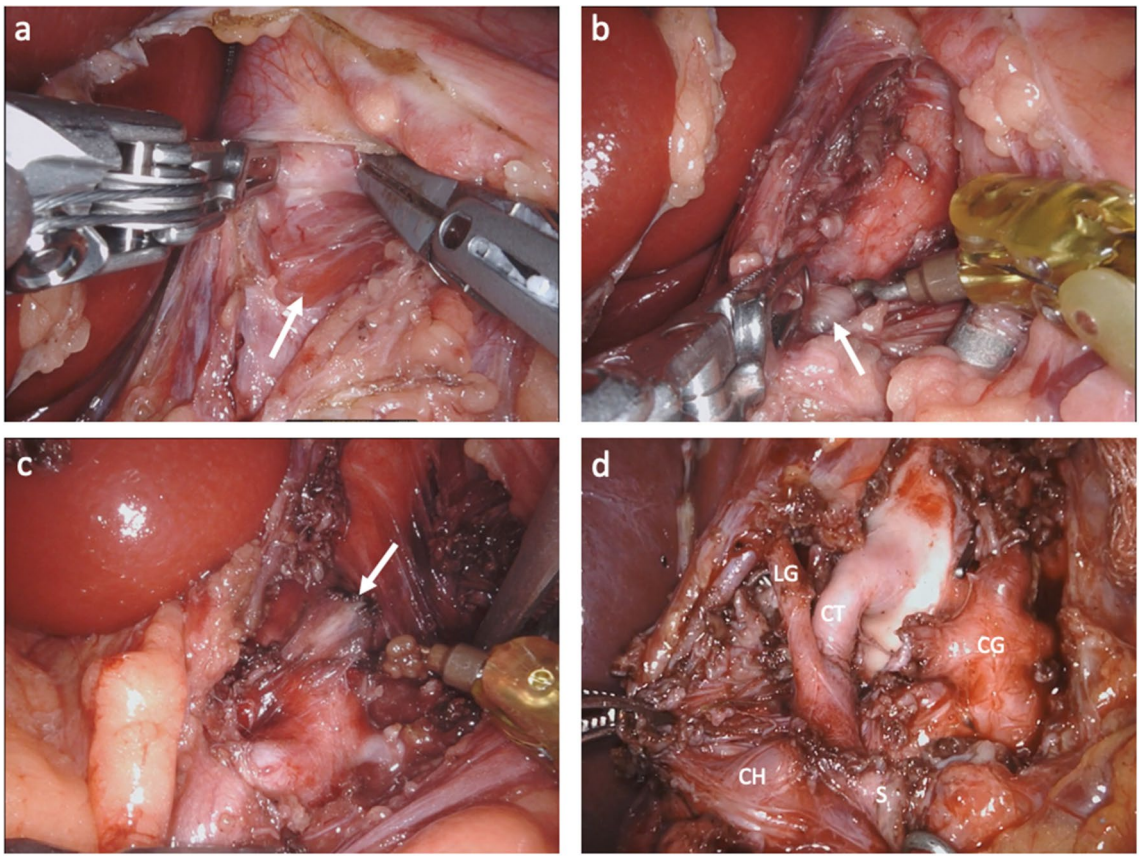

Fig. 2 Intraoperative images. **a** The crura are bluntly separated with dissection carried down to supraceliac abdominal aorta. Arrow: Diaphragmatic crura. **b** Median arcuate ligament is divided in its entirety. Arrow: Median arcuate ligament. **c** Celiac ganglion nerve fibers are divided. Arrow: Celiac ganglion. **d** Dissection is continued until the main branches of celiac trunk are identified. *CT* Celiac artery trunk, *LG* Left gastric artery, *CH* Common hepatic artery, *S* Splenic artery, *CG* Celiac ganglion

The gastrohepatic ligament is first divided with care being taken to preserve an accessory or replaced hepatic artery if present. The lesser curve of the stomach is retracted towards the patient's left side, to expose the posterior confluence of the right and left crura. The crura are then bluntly separated and dissection is carried down onto to the supraceliac abdominal aorta. Superficial aortic tissue is cleared and dissection continues on the anterior surface of the aorta towards the origin of the celiac truck. The median arcuate ligament is then divided in its entirety using monopolar electrosurgical energy. Dissection is continued antegrade until the three main branches of the celiac trunk are identified. Concurrently, we routinely perform a celiac splanchnicectomy. This is done to address the possible neurogenic component of pain that MALS patients experience, by dividing the celiac ganglion branches that course over the celiac trunk. Nerve fibers crossing over the celiac trunk are divided completely using a bipolar electrosurgical energy device. Hemostasis is confirmed and the procedure is completed (Fig. 2).

Post-operative management

Patients are discharged either same day or next day and seen for their first follow-up visit at 1 month. If a patient endorses continued abdominal pain or other symptoms at 1-month post-operatively, they are counseled that this may be due to persistent edema and are encouraged to follow up again at 3-months in the anticipation that the edema should have resolved by that time. If a patient still endorses symptoms at the 3-month follow up visit, a repeat CA DUS is performed to assess for improved patency of the CA post-MALR. If the DUS expiratory PSV is still > 350 cm/s at 3 months, the patient is referred for possible CA angioplasty or stenting by interventional radiology or vascular surgery. This is done in the event that the patient has persistent CA stenosis even after MALR, commonly due to arterial hardening and inelasticity from atherosclerosis or calcification. If the 3-month DUS expiratory PSV has dropped to < 350 cm/s, the patient is considered a technical success from a MALR standpoint, but a clinical non-respondent. These patients likely have had symptoms from causes other than MALS and are referred to

their primary care and gastrointestinal physicians to evaluate other etiologies of their abdominal pain.

Results

A total of 74 patients underwent robotic MALR during the study period. The mean age was 27.3 ± 7.9 years and the majority of patients were female (*n* = 60/74, 81.1%). The most common presenting symptoms were post-prandial abdominal pain (*n* = 65/74, 87.7%) and an epigastric location of pain (*n* = 57/74, 77.0%). The mean preoperative DUS expiratory PSV was 373.4 ± 28.9 cm/s (Table 1).

The mean operative time was 52.6 ± 18.1 min. There were no conversions to open surgery and minimal blood loss (mean = 13.9 ± 8.4 mL). The mean length of stay was 0.8 ± 0.3 days and both re-operation and in hospital mortality in 30 days was 0%. There were 3 (4.1%) post-operative complications, including an intraoperative injury with bleeding requiring post-operative ICU monitoring but no transfusion, and two instances of postoperative ileus (Table 2).

Table 1 Baseline characteristics of patients who underwent robotic median arcuate ligament release

Baseline characteristics	All patients (*N* = 74)
Age (years)	27.3 (± 7.9)
Sex	
Female	60 (81.1%)
Male	14 (18.9%)
BMI (kg/m^3)	21.9 (± 3.1)
Presenting clinical features	
Abdominal pain	74 (100%)
Constant	22 (29.7%)
Postprandial	65 (87.8%)
Epigastric location	57 (77.0%)
Nausea/vomiting	15 (20.3%)
Weight loss	38 (51.4%)
Amount of weight loss (lbs)	15.1 (± 8.5)
Period of weight loss (months)	5.7 (± 3.4)
Length of symptoms (months)	9.1 (± 6.9)
Labs/Imaging	
Stenosis on CT/MRI	72 (97.3%)
Stenosis grade	
< 50%	2 (2.8%)
50–70%	15 (20.8%)
> 70%	57 (79.2%)
Preoperative DUS peak systolic velocity	
PSV-inspiration (cm/s)	183.4 (± 39.1)
PSV-expiration (cm/s)	373.4 (± 28.9)

At 1-month follow up, 78.4% (*n* = 58/74) of patients had complete resolution of abdominal pain. At 3-month follow-up, 3 additional patients had resolution of their symptoms while 9 had persistent abdominal pain. These 9 patients underwent repeat CA DUS; 5 of these 9 patients had persistently elevated DUS expiratory PSV > 350 cm/s and were referred for angioplasty. All 5 of these patients underwent angioplasty with IR resulting in decreased DUS expiratory PSV; 3 of these 5 patients had resolution of abdominal pain after angioplasty. Of patients with 1-year follow-up, 90.3% (*n* = 56/62) continued to have no abdominal pain (Table 3).

Table 2 Peri-operative outcomes of patients who underwent robotic medial arcuate ligament release

Peri-operative outcomes	All patients (*N* = 74)
Intra-operative data	
Operative time (minutes)	52.6 (± 18.1)
Estimated blood loss (mL)	13.9 (± 8.4)
Complications	
Intra-operative injury	1 (1.4%)
Conversion to open (laparotomy)	0 (0%)
Post-operative ileus	2 (2.7%)
Blood transfusion	0 (0%)
Thromboembolic complications	0 (0%)
Respiratory failure	0 (0%)
Pancreatitis	0 (0%)
Myocardial infarction	0 (0%)
Length of stay (days)	0.8 (± 0.3)
Re-operation within 30 days	0 (0%)
30 day in-hospital mortality	0 (0%)

Table 3 Long-term post-operative outcomes of patients who underwent robotic median arcuate ligament release

Long-term outcomes	Post-operative		
	1 Month (*N* = 74)	3 Months* (*N* = 16)	1 Year (*N* = 62)
Persistent symptoms overall	16 (21.6%)	9 (12.1%)	6 (9.7%)
Symptom**			
Abdominal pain	15 (20.3%)	8 (10.8%)	6 (9.7%)
Nausea/vomiting	8 (10.8%)	4 (5.4%)	3 (4.1%)
Weight loss	3 (4.1%)	1 (1.4%)	3 (4.1%)

*Only patients with persistent symptoms at 1 month were seen at 3 months

**Symptom breakdown values/percentages do not sum to persistent symptoms overall values as patients were able to note multiple persistent symptoms at post-operative follow-up

Discussion

This study represents the largest minimally invasive (laparoscopic or robotic) MALR series published to date. We highlight favorable peri-operative and long-term outcomes that can be achieved in a high-volume center using a strict patient management algorithm. Compared to published reviews of large laparoscopic MALR series, the robotic approach achieved favorable and perhaps shorter mean hospital length of stay (0.8 days vs 2.8 days) and shorter operative time (53 min vs 136 min) [4, 10]. In addition, there were minimal complications and no conversions to open. At 1-year follow-up, 90% of patients who underwent a robotic MALR continued to have relief of abdominal pain. This compares favorably to published series of laparoscopic MALR symptom resolution rates of 85.3% and open MALR symptom resolution rates of 78% [4, 10]. Our results show that the robotic approach is safe, feasible, and can produce long-term patient benefit similar to other common approaches to MALR.

We believe that appropriate identification and careful selection of patients that may benefit from MALR along with a safe technical approach are keys to achieving favorable perioperative and post-operative outcomes. In addition, close longitudinal follow-up of non-respondents with persistent abdominal pain is important, as many of these patients may achieve relief with subsequent percutaneous interventions. The majority of these patients were able to obtain resolution of their abdominal pain after angioplasty. A multidisciplinary approach involving minimally invasive surgeons, gastroenterologists, vascular surgeons, diagnostic and interventional radiologists can help the majority of appropriately selected patients obtain long-term relief of their symptoms.

MALR is a highly technical procedure involving precise dissection in a narrow space. Given the proximity to the aorta, the potential for catastrophic bleeding is not insignificant. Expertise in minimally invasive techniques, high resolution pre-operative imaging, and a thorough knowledge of the relevant anatomy is essential to the safe conduct of MALR. Robotic assistance may further facilitate MALR surgery, given the added dexterity, precision, and visualization afforded by the robotic instrumentation.

While this was a large, prospectively collected series, a limitation of this study is that all patients were treated at a single center by a single high-volume surgeon. This may limit the generalizability of the results. Also, while long-term follow-up was generally good, 16% of patients were not seen in clinic at 1 year due to loss of follow-up, death, or reluctance due to resolution of symptoms.

In summary, with proper patient selection, the involvement of a multi-disciplinary team, adherence to a strict treatment algorithm, and careful technical approach, relief can be achieved for this challenging patient population. In our series, the large majority of patients treated with robotic MALR had relief of abdominal pain, with durable outcomes at 1-year at a rate comparable to or better than published open or laparoscopic MALR series. The robotic approach to MALR may facilitate some of the more difficult, technical aspects of this procedure and bolster surgeon confidence.

Declarations

Disclosures Dr. Awad has educational simulation Grants from Applied Medical, Baxter, Bard/BD, Ethicon, Intuitive, Medtronic and Stryker. He has consultant fees from Ethicon and Intuitive. Drs. William Gerull and William Sherrill have no conflicts of interest or financial ties to disclose.

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