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Robotic Surgery for Median Arcuate Ligament Syndrome

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ABSTRACT

Background: Compression of the celiac artery by the median arcuate ligament results in median arcuate ligament syndrome (MALS). Using a consecutive cohort of patients with MALS, this study evaluated the efficacy and safety of robotic median arcuate ligament release (MALR).

Methods: A retrospective chart review was performed on patients who underwent robotic MALR from August 2012 to April 2018. Patient workup included history and physical examination, mesenteric Doppler ultrasound, and CT (Computed Tomography) scan. Outcomes included pain improvement, length of stay, operation duration, narcotic use, and postoperative complications.

Results: Twenty-seven patients met inclusion criteria. Two thirds of the cohort were female and the mean age was 49 ± 15.5 years. Postprandial abdominal pain was the most common preoperative symptom (25/27, 93%). CT (Computed Tomography) was performed in 24 (89%), and celiac stenosis > 70% was observed in all. Operative duration was 95 minutes on average (range, 53–358 minutes), and in 24/27 (89%) patients, estimated blood loss was < 100 mL. Eighty-one percent of patients were discharged the day of surgery (22/27). Two cases were converted to open, with only one major complication occurring. At 30 or more days postoperation, 17 patients (68%) had full, 1 (4%) partial, and 1 (4%) no symptom resolution, 6 (24%) had symptom recurrence after initially having resolution. Fifty-six percent achieved narcotic liberation 9/16 (56%).

Conclusions: Robotic MALR is a safe option for treatment of MALS with high response rates, early hospital discharge, and opportunity for narcotic liberation.

Key Words: MALS; Celiac Stenosis; Median Arcuate Ligament; complication; narcotic use.

INTRODUCTION

Median arcuate ligament syndrome results from compression of the proximal celiac artery (CA) and celiac ganglion by the median arcuate ligament of the diaphragmatic crura. Patients suffering from median arcuate ligament syndrome (MALS) experience symptoms including nausea, vomiting, weight loss, and postprandial epigastric pain. Due to its rarity, MALS is usually diagnosed by exclusion of more common diagnoses. The diagnosis may be confirmed by mesenteric duplex ultrasonography, computed tomography angiography, magnetic resonance angiography, gastric tonometry, and mesenteric arteriography. There are several interventions proposed for median arcuate ligament release (MALR; e.g., open surgery, laparoscopic surgery, vascular reconstruction, endovascular angioplasty). Although most of these techniques have shown to improve symptoms in many patients, the long-term outcome has shown variable degrees of symptom return.[1]

Of the several interventions for the release of this ligament, the use of open surgery to decompress the CA is seen as the traditional form of treatment. First published findings were in 1965 by Dunbar et al,[2] who reported open decompression in 13 subjects with no follow up intervention needed. Since then multiple studies have shown varying degrees of symptom recurrence and need for additional intervention.[3–7] During open decompression, there are three reported options for vascular reconstruction, depending on the status of the celiac artery, that may lead to better long-term outcomes for select patients.[8,9] Revascularization can be achieved with patch

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angioplasty of the celiac artery, bypass of the narrowed section, or reimplantation of the CA on the aorta. Various results have been seen with each of these procedures in combination with MALR, but each comes with increased operative risk.[3,10] Recently, the acceptance of the use of laparoscopy to decompress the CA has increased. Benefits compared to open decompression include smaller incisions leading to shorter recovery times and decreased postoperative complications. Compared to open release, the use of laparoscopic surgery comes with possible drawbacks such as increased difficulty controlling hemorrhage and inability to perform vascular reconstruction without conversion to laparotomy.[10]

The first reported use of robotic surgery for the treatment of MALS, by Jaik et al,[11] showed symptom remission in a 23 y-old woman at 6-week follow up. Since that time there have been 6 other small studies of robotic MALR published.[12–17] The very limited literature published about this controversial robotic surgery has shown mixed outcomes. With such limited data on outcomes for these patients, this study looks to nearly double the current published data, leading to a better understanding of likely outcomes from this surgery. Using a consecutive cohort of patients with MALS, this study evaluated the efficacy and safety of robotic MALR, as well as compared these outcomes to those of current published literature.

MATERIALS AND METHODS

Study Population and Design

After appropriate Institutional Review Board approval, a retrospective chart review was performed to include consecutive patients with MALS who underwent robotic MALR from August 2012 to April 2018 at a single institution by a single surgeon. Patient workup included history and physical examination, mesenteric Doppler ultrasound, and CT (Computed Tomography) scan. Several patients underwent endoscopy and hepatobiliary iminodiacetic acid scan during their workup to rule out gallbladder pathology. Select patients underwent diagnostic angiography.

Preoperative data collected included demographics, comorbidities, American Society of Anesthesiologists physical status classification scores (ASA scores), narcotic regimen, symptoms on presentation, diagnostics used, significant CT scan findings, and duplex ultrasound velocities. Operative data collected included operative duration, intra-operative findings and complications (blood transfusion, vasopressor need, arterial injury), and estimated blood loss. Postoperative data included complications (deep vein thrombosis/pulmonary embolism, surgical site infection, re-exploration), 90-day readmission, resolution of symptoms at initial and subsequent followup, and current narcotic regimen. Narcotic data was included only if prescribed for abdominal pain management.

The primary outcome measures were long-term improvement or resolution of symptoms and symptom recurrence. Each patient had at least one follow-up visit with the operating surgeon within the first 22 days postoperation. Data was collected on improvement or resolution of symptoms at this initial follow-up visit. In order to examine long-term outcomes or changes in resolution status, each subsequent visit with any local provider that was recorded in the electronic medical record from the time of surgery to the time of data collection was reviewed. Any instance where a physician commented on the patient's current status in regards to MALS symptoms was documented, and the patient's symptom resolution status was changed accordingly. If the patient had complete elimination of all symptoms, they were classified as "full resolution." If the patient's condition was improved, but some symptoms remained, they were classified as "partial resolution." If the patient had no symptom improvement they were classified as "no resolution." Finally, if they had symptoms return at a subsequent follow-up they were classified as "symptom recurrence." Other secondary outcomes included operative duration, length of stay, postoperative complications, and liberation from narcotics.

Operative Technique

In all patients, robotic ports were placed as demonstrated in **Figure 1** with modifications as appropriate for use with two different robotic surgical platforms (Intuitive Surgical daVinci sI and xI). Both monopolar and bipolar current of 35 W were utilized to lyse the tissue and maintain hemostasis. The upper retroperitoneum was exposed by incision of the gastrohepatic ligament. The location of the common hepatic artery and left gastric artery were identified and each structure fully dissected to expose the adventitia. The arteries were then followed proximally to identify the trifurcation of the CA. Next the splenic artery was exposed and all tissue surrounding the CA trifurcation removed. Careful dissection along the adventitial plane of the CA allowed elevation of the MAL (Median Arcuate Ligament), which was divided until 3 cm of aortic surface was exposed proximal to the CA origin. The field was inspected to ensure no remaining muscular or nervous

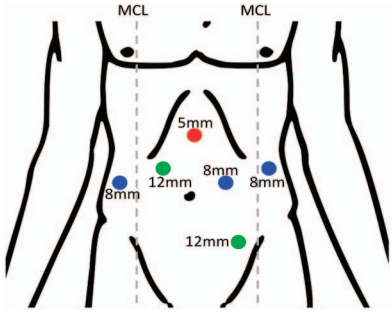

Figure 1. Surgical Port Placement: 5-mm epigastric]em]liver retractor (laparoscopic), 12-mm right periumbilical—camera (laparoscopic), 8-mm right mid abdomen—Maryland bipolar (robotic), 8-mm left periumbilical—monopolar hook (robotic), 8-mm left upper quadrant—prograsp (robotic), 12-mm left lower quadrant—assistant (laparoscopic).

fibers remained crossing over the artery (**Figure 2**). Intraoperative ultrasound was then used to assess for adequate release. A decrease in peak flow and loss of respiratory variability are used to confirm adequate release. All operations were scheduled as outpatient surgery, and patients received transversus abdominis plane injection of bupivicaine preoperatively. If endoscopy was not performed preoperatively it was performed at the time of operation.

Literature Review

To aggregate all of the current data on robotic release of the median arcuate ligament, a PubMed literature review was performed on April 1, 2020, and added to this study. Search parameters included key words "median arcuate ligament" or "celiac compression." All published studies with data on robotic MALR were included along with a large series of laparoscopic and open release studies. The primary data collected was patient symptom outcomes. All robotic studies used the same terminology (full resolution, partial resolution, no resolution, or symptom recurrence) and same standards as this study. The keywords searched were the same as that for robotic release data.

RESULTS

Patient Characteristics

Twenty-seven patients were found to meet the inclusion criteria and were included for study. Two patients were lost to followup; therefore, data on symptom resolution was not collected for them. Two thirds of the cohort were female and the mean age was 49 ± 15.5 years. Average patient BMI (Body Mass Index) was 27.0 kg/m^2 (20.4–36.5 kg/m^2). All patients were Caucasian.

Comorbidities present in more than one quarter of the cohort included depression/anxiety (16/27, 59.3%), hypertension (8/27, 29.6%), and gastroesophageal reflux disease (7/27, 25.9%). The most common preoperative symptoms were postprandial abdominal pain, persistent abdominal pain, weight loss, and nausea. Other preoperative symptoms are listed in **Table 1**. Duration of symptoms was < 6 months in 14 (51.9%), 6–12 months in 2 (7.4%), and > 12 months in 11 (40.7%). Preoperatively, patients underwent workups including CT scan with intravenous contrast (24/27, 88.9%), mesenteric Doppler ultrasound including arterial flow velocities (19/27, 70.3%), endoscopy (15/27, 55.6%), hepatobiliary iminodiacetic acid scan (7/27, 25.9%), and diagnostic angiogram (6/27, 22.2%) prior to seeing the operating surgeon. Celiac stenosis > 70% was observed in 24 (88.9%) as determined by radiologist interpretation of either CT or ultrasound findings of flow > 200 cm/s, and median peak velocity by

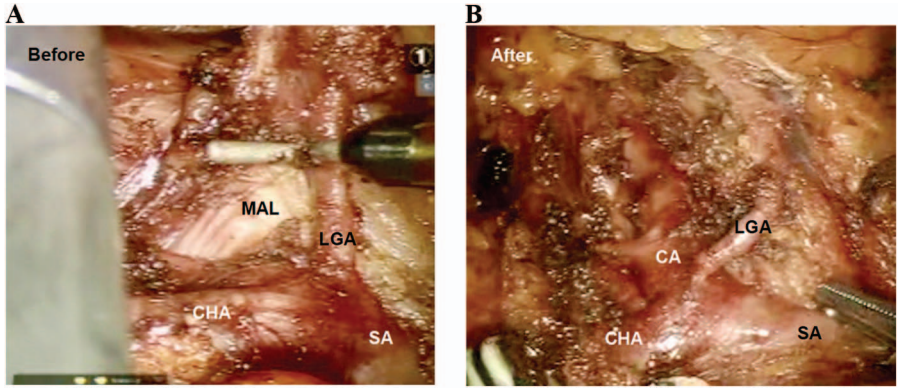

Figure 2. Intraoperative photos before (**A**) and after (**B**) division of MAL (Median Arcuate Ligament). CHA, common hepatic artery; LGA, left gastric artery; SA, splenic artery, CA, celiac artery.

Table 1.
Preoperative Symptoms

Symptom	N (%)
Post-prandial pain	25 (92.6)
Persistent abdominal pain	16 (59.3)
Weight loss	15 (55.6)
Nausea	14 (51.9)
Pain with positional changes	9 (33.3)
Constipation	7 (25.9)
Emesis	6 (22.2)
Diarrhea	6 (22.2)
Abdominal bloating	6 (22.2)

duplex was 311 cm/s (range, 184–562 cm/s). ASA scores ranged from one to 3, with 2 being the most common (15/27, 55.6%). Sixteen patients (59.3%) were using narcotic medications for their pain at the time of surgical evaluation.

Perioperative Outcomes

Operative duration was 95 minutes on average (range, 53–358 minutes), and in 24/27 (89%) patients, estimated blood loss was < 100 mL. Average estimated blood loss was 145 mL, median estimated blood loss was 10 mL, and the range was 5–3000 mL. Eighty-one percent of patients were discharged the day of surgery (22/27), range being 0–6 days. Two cases required conversion to open. The first conversion was secondary to extensive adhesions from multiple prior abdominal surgeries and the second due to inadvertent arteriotomy of the celiac trunk that occurred while dividing diaphragmatic fibers on the artery's caudad aspect. As this was a repeat surgery for MALS, attempts were made to dissect the artery circumferentially. Two vascular surgeons on backup were available to assist in repair but found the location of injury and integrity of the artery suboptimal to allow repair. Ligation of the CA with oversewing of the orifice was required to control hemorrhage, and estimated blood loss was 3000 mL. On follow-up contrast imaging, retrograde perfusion of the hepatic, splenic, and gastric arteries was observed. This was the only major complication, and the patient was discharged home on postoperative day 6 with no long-term sequelae. The other 4 patients who were not discharged the day of surgery were attributed to postoperative symptom management. There were no long-term sequelae in these patients.

Impact on Symptom Relief

At initial follow up with 25 patients (2 patients lost to followup), 20 patients (80%) had full and 3 (12%) partial symptom resolution. Thus, the initial treatment response rate was 92%. Initial follow up ranged from 3 to 22 days postoperation, with the average being 12 days. At subsequent followups, 17 patients (68%) had full and 1 (4%) partial symptom resolution. One patient (4%) continued to have no symptom improvement, and symptoms were later attributed to irritable bowel syndrome and somatic dysfunction. Six patients (24%) had symptom recurrence on subsequent followup. Of the 6 with symptom recurrence, 3 were attributed to continued celiac stenosis, 2 had the procedure repeated, and 1 received a celiac stent. Of the 2 who had repeat procedures, 1 patient had improved symptoms and the other did not, suggesting another etiology. The other 3 patients were diagnosed with another disorder responsible for recurrence of symptoms. Therefore, the long-term treatment response rate was 72%. Long-term followup ranged from 77 to 2,163 days postoperation, with the average being 905 days. Long-term narcotic liberation was achieved in 9/16 (56.3%). There were no nonopioid users who were converted to opioid users postoperatively. Of the 7 patients who continued their narcotic regimen postoperatively, 3 were attributable to other comorbid conditions. Therefore, the treatment response rate in patients prescribed narcotics was 12/16 (75.0%).

Literature Review and Summary

Within the published literature, there are 7 articles reporting a total of 37 cases of robotic MALR. Three of the reports are case studies.[11,13,14] Excluding the case studies, 47.1% of the patients achieved complete resolution of symptoms, 26.5% had partial resolution, 14.7% had symptom recurrence, and 11.7% had no resolution. Combining the 7 previously published studies with those reported herein, there are a total of 62 patients. Overall response was complete in 36 (58.1%), partial in 10 (16.1%), and absent in 5 (8.1%). Eleven patients (17.7%) had symptom recurrence. Summary of these data are provided in **Table 2**. The larger quantity of studies looking at laparoscopic and open release showed higher percentage of immediate symptom relief than the current robotic literature. To achieve this, both pre- and postoperative adjunctive therapies, along with the use of arterial reconstruction and stenting were used more often in these studies.[23–29] Therefore, the current literature makes accurate comparison of outcomes between pure treatment modalities difficult. The data also showed an increased conversion rate to

Table 2.
Patient Outcomes for all Current Published Literature on Robotic Median Arcuate Ligament Release

Author	N	Complete Symptom Resolution	Partial Symptom Resolution	No Symptom Resolution	Symptom Recurrence	Average Follow-up Time Per Patient (Days)
Jaik et al, 2007[11]	1	1 (100%)	0	0	0	42
Meyer et al, 2012[13]	1	1 (100%)	0	0	0	480
Relles et al, 2012[12]	3	2 (66.7%)	1 (33.3%)	0	0	350
You, et al, 2013[14]	1	1 (100%)	0	0	0	14
Do et al, 2013[16]	4	2 (50%)	1 (25%)	1 (25%)	0	600
Thoolen et al, 2015[17]	9	4 (44.4%)	5 (55.6%)	0	0	175
Khrucharoen et al, 2019[15]	18	8 (44.4%)	2 (11.1%)	3 (16.7%)	5 (27.8%)	450
Current series	25	17 (68.0%)	1 (4.0%)	1 (4.0%)	6 (24.0%)	905
All	**62**	**36 (58.1%)**	**10 (16.1%)**	**5 (8.1%)**	**11 (17.7%)**	585

open in laparoscopic studies compared to the data presented here.[23–25,27–29]

DISCUSSION

We sought to examine outcomes in a consecutive cohort of patients with MALS treated by robotic MALR. Our findings demonstrate this approach is safe and effective in an often challenging patient population. Compared to the current evidence available, our results demonstrate a higher percentage of complete resolution of symptoms. This supports the growing evidence that the robotic approach is at least comparably effective to laparoscopic or open release. Khrucharoen et al[15] showed symptom resolution rates of 37.5% and 44.4% with the laparoscopic and robotic approaches, respectively.

There was a large variation in operative duration on both a case to case basis in this study, and between different studies for both laparoscopic and robotic approaches. In the study reported in this paper, the surgeon often performed additional procedures during the operation such as a cholecystectomy or repair of a hiatal hernia for example, creating vast differences in operative duration. The robotic approach has been historically associated with longer operative duration, though this measure can be influenced by a multitude of factors. While there is certainly a learning curve for the robotic platform, as experience grows across procedure types, there is likely to be minor differences between robotic and laparoscopic approaches. Robotic release does, however, offer enhanced 3-D visualization, a more stable platform offering improved motion control, and an increased ability to perform intricate maneuvers in confined spaces due to jointed instrumentation. These factors can lead to improved ergonomics for the surgeon and the capacity for more precise ligament release as well as allowing patients access to an outpatient procedure. Despite these advantages, robotic procedures are more costly and smaller institutions may not have access. The robotic platform is also limited by the lack of haptic feedback when compared to the use of straight stick laparoscopy. Additionally, in the event of arterial injury there may be increased time to hemorrhage control as equipment is moved out of the field. This can be mitigated by technical prowess to robotically repair small injuries and strategic use of instrumentation to control bleeding while proceeding with laparotomy. With a low incidence of hemorrhage (1/27 in this cohort), the authors believe it is not necessary to have cross-matched blood or cell saver present at the time of surgery. However, all patients should be blood typed and screened with cell salvage being readily available when needed.

With only two conversions to open out of 27 patients, robotic release seems to allow for a lower conversion rate when compared to laparoscopic release. The conversion due to intra-abdominal adhesions was anticipated knowing the patient's prior abdominal surgical history.

Unfortunately, the conversion for hemorrhage in a repeat MALR was emergent, yet blood loss was minimized during the process of conversion by controlling bleeding with a robotic instrument as the remaining instruments and ports were removed and laparotomy incision was made. The reported blood loss was primarily encountered during arterial repair by a vascular surgeon. In order to prevent emergent conversion, these cases show that it is important to anticipate which patients will likely need conversion to

open. The first case demonstrated that multiple abdominal surgeries is an indication to anticipate conversion, and the second case, although converted emergently, showed that repeat MALR may also be an indication to anticipate conversion.

With only one major complication out of 27 patients (3.7%), robotic release appears to be a safe approach. Without incision of any visceral or vascular structures, there is limited potential for significant complications after the operation has concluded. Therefore, patients may be discharged once tolerating pain and oral intake, which is typically the day of surgery.

Symptom recurrence was found in our experience to be attributed to two factors: persistent celiac stenosis and symptoms attributed to comorbid conditions. Such diagnoses may include exocrine pancreatic insufficiency, sphincter of Oddi dysfunction, irritable bowel syndrome, and somatic dysfunction. Due to the overlapping symptom profile of both irritable bowel syndrome and celiac stenosis, evaluation of irritable bowel syndrome should be considered upon symptom continuation or recurrence after MALR. It is also recommended that consideration of biliary dyskinesia, including sphincter of Oddi dysfunction, be included in the differential diagnosis when evaluating patients with MALS. Although the patients in this study were not followed by the operating surgeon long term, one could justify the use of repeat mesenteric duplex (30 days out) to assess for adequacy of release.

Contrast CT and Doppler ultrasound results were found to be sufficient for diagnosis in patients who did not undergo standard invasive angiography. Given the sensitivity of CTA (Computed Tomography Angiography), MRA (Magnetic Resonance Angiography), and duplex mesenteric ultrasonography for medial arcuate ligament compression of the celiac trunk, invasive angiography should be avoided if possible. However, a study of 75 autopsies of people who did not carry the diagnosis of MALS, performed by Lindner and Kemprud,[31] demonstrated that the median arcuate ligament crossed the CA origin entirely 33% of the time, and partially 48% of the time, causing celiac stenosis in majority of specimens. This evidence supports that MALS should be a diagnosis of exclusion. Therefore, more investigation preoperatively could have led to less unnecessary surgery in those whose symptoms were later attributed to other causes.

The surgeon for this data set is trained in minimally invasive foregut as well as hepatopancreaticobiliary surgery, with extensive experience in vascular dissection of the CA for malignant disease. Therefore, skeletonization of the CA and its branches for release of the median arcuate ligament is within their realm of expertise. Absent any arterial injury, the presence of a vascular surgeon is felt to be unnecessary, yet we do feel their immediate availability is mandatory. For this reason, the procedure is not performed at hospitals in the system that do not have vascular surgery coverage.

Following the data collection performed for this study, the operating surgeon began to refer patients to interventional radiology for celiac plexus block if they were determined to be of high surgical risk due to comorbidities. This strategy is also used to assist in predicting prognosis in patients with diagnostic uncertainty. The addition of this diagnostic and therapeutic approach could possibly lead to a decrease in unnecessary surgery, decreasing the incidence of patients with no symptom relief postoperation. Celiac plexus blocks have also since been added to the surgeon's MALR procedure, and are performed with each release. Future studies could examine the use of celiac plexus block as an adjunct to robotic MALR.

With symptom duration of over 6 months prior to diagnosis in nearly one half of patients in this study, it is a population where narcotic use is prevalent. Nine of 16 patients prescribed narcotics prior to their operation were liberated. This is an important endpoint in this population and has ramifications for quality of life and overall health beyond just symptom improvement.

Due to the lack of published data on robotic MALR outcomes, this study substantially adds to the limited current evidence. The inherent limitations of selection bias from a single-institution retrospective series are present herein, though this does represent a consecutive series of patients treated at our facility. Being a purely observational study, it is limited to subjective comparisons between patients; therefore, the use of a standardized questionnaire could be used in future studies to further validate results. A feasible next step toward improving reporting and data quality for MALR would be to create a prospective national registry to investigate both short- and long-term outcomes of the various interventions available.

In conclusion, robotic MALR offers an attractive option for treatment of MALS with high response rates to treatment, short hospital stay, and opportunity for narcotic liberation.

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