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Myotomy length informed by high-resolution esophageal manometry (HREM) results in improved per-oral endoscopic myotomy (POEM) outcomes for type III achalasia

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Abstract

Introduction High-resolution esophageal manometry (HREM) is essential in characterizing achalasia subtype and the extent of affected segment to plan the myotomy starting point during per-oral endoscopic myotomy (POEM). However, evidence is lacking that efficacy is improved by tailoring myotomy to the length of the spastic segment on HREM. We sought to investigate whether utilizing HREM to dictate myotomy length in POEM impacts postoperative outcomes.

Methods Comparative analysis of HREM-tailored to non-tailored patients from a prospectively collected database of all POEMs at our institution January 2011 through July 2017. A tailored myotomy is defined as extending at least the length of the diseased segment, as initially measured on HREM.

Results Forty patients were included (11 tailored versus 29 non-tailored). There were no differences in patient age ($p=0.6491$) or BMI ($p=0.0677$). Myotomy lengths were significantly longer for tailored compared to non-tailored overall (16.6 ± 2.2 versus 13.5 ± 1.8; $p<0.0001$), and for only type III achalasia (15.9 ± 2.4 versus 12.7 ± 1.2; $p=0.0453$), likely due to more proximal starting position in tailored cases (26.0 ± 2.2 versus 30.0 ± 2.7; $p<0.0001$). Procedure success (Eckardt < 3) was equivalent across groups overall ($p=0.5558$), as was postoperative Eckardt score (0.2 ± 0.4 versus 0.8 ± 2.3; $p=0.4004$). Postoperative Eckardt score was significantly improved in the tailored group versus non-tailored for type III only (0.2 ± 0.4 versus 1.3 ± 1.5; $p=0.0435$). A linear correlation was seen between increased length and greater improvement in Eckardt score in the non-tailored group ($p=0.0170$).

Conclusions Using HREM to inform surgeons of the proximal location of the diseased segment resulted in longer myotomies, spanning the entire affected segment in type III achalasia, and in lower postoperative Eckardt scores. Longer myotomy length is often more easily achieved with POEM than with Heller myotomy, which raises the question of whether POEM results in better outcomes for type III achalasia, as types I and II do not generally have measurable spastic segments.

Keywords Per-oral endoscopic myotomy · High-resolution esophageal manometry · Eckardt score · Type III achalasia

Abbreviations

LES	Lower esophageal sphincter
HREM	High-resolution esophageal manometry
POEM	Per-oral endoscopic myotomy
EGJOO	Esophagogastric junction outflow obstruction
LHM	Laparoscopic Heller myotomy
BMI	Body mass index
IRP	Integrated relaxation pressure
Botox	Botulinum toxin

Achalasia is a rare esophageal motility disorder with failure of peristaltic propagation during deglutition and impaired relaxation of the lower esophageal sphincter (LES) which results in attenuated food bolus transit into the stomach.

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The worldwide incidence of achalasia is approximately 1/100,000 each year, with rates of hospitalization as high as of 37/100,000 [1]. Furthermore, the prevalence of achalasia is rising, with a five-fold increase in the last decade [2]. The symptoms are likely due to a functional loss of nitric-oxide-producing neurons within the myenteric plexus ganglia in the distal esophagus and LES, causing unopposed cholinergic stimulation [1]. In time, this leads to a breakdown and eventual absence of peristalsis. The combination of a hypertensive LES and aperistalsis leads to a progressive constellation of symptoms that can initially present with dysphagia, and may progress to solid, and later, liquid intolerance. Other presenting symptoms include food regurgitation, chest pain, and weight loss in advanced disease due to oral intolerance. The Eckardt score, a validated system now commonly used to quantify disease severity and measure treatment response, assigns each of these symptoms a value based on whether the patient experiences them occasionally, daily, or with every meal (or in the case of weight loss, if the patient has lost no weight, < 5, 5–10, or > 10 kg) [3].

Medical treatment of achalasia consists of balloon dilatation and injection of botulinum toxin (botox), but neither treatment is thought to be superior to surgical myotomy of the LES [4]. Laparoscopic Heller myotomy (LHM) has long been considered the gold standard for the treatment of achalasia, but is known to be limited by the length of intra-abdominal esophagus, thus limiting the length of the myotomy. Furthermore, Heller myotomy requires full dissection of the esophageal hiatus, leaving the patient at high risk for developing postoperative gastroesophageal reflux disease. Given this, most surgeons advocate for concomitant fundoplication.

Per-oral endoscopic myotomy (POEM) was first reported in an animal model by Pasricha et al. [5] and in humans by Inoue et al. [6]. The procedure has quickly caught on worldwide, and large case series [7, 8] have now appeared in the literature. Advantages of POEM are that it is typically incisionless and is performed endoscopically. Thus, there is typically no limit to the length of the myotomy from an anatomic standpoint, offering the potential for much longer myotomies than would be possible to attain during a Heller myotomy. However, a limitation in understanding published evidence in early POEM series is that there is not yet a recognized standard for myotomy length. Therefore, interpreting the results of other series is limited by a lack of understanding of how surgeons choose myotomy length. Further, understanding how myotomy lengths correlate to achalasia subtype is poorly understood.

The use of high-resolution esophageal manometry (HREM) has become the standard to diagnose and classify achalasia into clinically relevant subtypes based on their physiological differences. The development of this technology confirmed the three functional types as well as esophagogastric outlet obstruction as an additional related category, laid out under the framework of the Chicago classification [9], with distinct potential for therapeutic intervention. Type I achalasia is the classic presentation, with aperistalsis and a hypertensive LES. Type II achalasia features pan-esophageal pressurization, a pattern easy to identify on HREM. Type III achalasia was formerly known as spastic achalasia, or "vigorous achalasia," and the spastic segment can often be observed with specific anatomic measurement of its length. Esophagogastric junction outflow obstruction (EGJOO) is also thought to be a variant of achalasia, with some peristalsis preserved with an elevated LES pressure and disordered LES relaxation. Multiple publications now support the prognostic value of achalasia subtypes, and have begun to suggest which mode of treatment could provide the best symptomatic response based on subtype [10–12].

Not only has the advent of HREM differentiated the pathological subtypes seen in achalasia, it offers the potential for specific anatomic information related to the abnormal segment of the esophagus in spastic disorders such as in type III achalasia. The object of this study was to identify whether utilizing HREM data to tailor the starting point of the myotomy would result in a better outcome, as opposed to choosing an arbitrary myotomy length derived from anatomic landmarks or previous experience. We hypothesized that myotomies that encompass the entire length of the affected spastic segment in type III achalasia patients would lead to an improvement in outcomes, as measured by postoperative Eckardt score [3].

Methods

All patients over 18 years of age who underwent a POEM for achalasia and had undergone preoperative HREM were included in the study. Most data were extracted from a prospectively collected database of all patients who underwent POEM at our institution between January 2011 and July 2017. Institutional review board approval was obtained to collect HREM-specific data retrospectively on each of these patients. Patients who were diagnosed with an esophageal dysmotility disorder other than achalasia (e.g., distal esophageal spasm or Jackhammer esophagus) were excluded from the analysis. Patients were stratified into HREM-tailored to non-tailored study groups. We defined a tailored myotomy as one that extends beyond the length of the diseased segment, as initially measured on HREM.

Demographic data and baseline preoperative characteristics were extracted, including age, gender, body mass index (BMI), and prior intervention for the patient's achalasia symptoms (botox, pneumatic balloon dilation, Heller myotomy or POEM). HREM data included resting LES pressure, integrated relaxation pressure (IRP), and any

pressure anomalies in the tubular esophagus, to include panesophageal pressurization (in type II patients) or the length and pressure of any spastic segment encountered signifying type III patients. The primary outcome was procedure success as measured by an Eckardt score of < 3, with a significant change in pre- to postoperative Eckardt score (delta Eckardt). Secondary outcomes included myotomy length, myotomy starting position and ending position, operative time, length of hospital stay, as well as the change in pre- to postoperative dysphagia component of the Eckardt score.

Descriptive analyses were reported as percentages for categorical variables and as mean ± standard deviation or median with range for quantitative variables. Comparison across achalasia subtypes was evaluated with 3 × 2 Chi -square contingency tables for categorical data and with one-way analysis of variance for continuous data. Analysis of continuous variables between tailored and non-tailored groups was performed using unpaired *t* tests and categorical comparisons were performed using Fisher's exact tests. Univariate comparisons of outcomes (e.g., pre- versus post-op Eckardt scores) were performed using paired, non-parametric *t* tests. Linear regression models were fit to determine potential associations between myotomy length and starting position, with postoperative Eckardt score and delta Eckardt score. Analyses were executed on Graphpad Prism 7.0 (Graphpad Software Inc., La Jolla, CA).

Results

Forty patients underwent POEM with preoperative HREM at our institution between October 2014 and July 2017. Four patients were diagnosed with type I achalasia, 22 with type II, and 14 with type III. Of the patients with type III achalasia, the length of the myotomy was tailored to preoperative HREM data for 11 patients. Patient age, gender ratio, and BMI were similar across achalasia types, as well as tailored versus non-tailored study groups (Table 1). The average age of patients undergoing the procedure was 54.1 ± 13.6. The majority of patients were female (62.5%). Average BMI was 32.2, though there was a trend for higher BMI in the tailored group compared to the non-tailored (36.8 ± 7.3 versus 30.4 ± 10.0; $p = 0.0677$). There was no difference between the proportion of patients who underwent endoscopic or surgical interventions prior to their POEM across achalasia types or study groups (Table 2). One patient in the tailored group and one patient in the non-tailored group had had a prior LHM. Nine patients in the non-tailored group had had previous pneumatic balloon dilation, versus two in the tailored group ($p = 0.3485$).

Preoperative Eckardt scores did not differ across achalasia types (8.8 ± 1.9 type I versus 7.7 ± 2.6 type II versus 6.9 ± 2.5 type III; $p = 0.3246$) or across study groups (7.6 ± 2.5 non-tailored versus 7.2 ± 2.6 tailored; $p = 0.5908$). This was consistent on subgroup comparison of tailored and non-tailored groups for type II achalasia as well (7.2 ± 2.6 versus 7.6 ± 2.5, respectively; $p = 0.5908$). The dysphagia component of these scores was similar across achalasia types and study groups as well (Table 2). Comparison of resting LES pressure and of IRP did not demonstrate any significant difference preoperatively between non-tailored and tailored groups (45.1 ± 15.7 versus 43.4 ± 22.2, $p = 0.4229$; and 27.7 ± 12.3 versus 24.8 ± 7.5, $p = 0.7443$, respectively).

Myotomy lengths were significantly longer for type III achalasia at 15.7 ± 2.6 cm compared to type I at 14.3 ± 1.0 cm and II at 13.5 ± 2.0 cm ($p = 0.0165$), and for tailored at 16.6 ± 2.2 cm compared to non-tailored at 13.5 ± 1.8 ($p < 0.0001$; Table 2; Fig. 1A). When looking only at type III achalasia, the average length of the tailored myotomy was still significantly longer, measuring 15.9 ± 2.4 cm, versus non-tailored, measuring 12.7 ± 1.2 cm ($p = 0.0453$; Fig. 1B). There was no difference in the distal position of the myotomy on the gastric cardia, measuring at an average of 42.5 ± 1.1 cm in the tailored group and 43.5 ± 2.6 cm in the non-tailored group ($p = 0.2413$; Fig. 1C). Therefore, the longer length in tailored cases appeared to be due to more proximal starting position compared to non-tailored (26.0 ± 2.2 versus 30.0 ± 2.7 cm; $p < 0.0001$; Fig. 1C).

Procedure success was statistically equivalent across study groups overall, with an 89.7% success rate in non-tailored and 90% in tailored ($p = 0.5558$, Table 3), as well as for the type III subgroup comparison (66.7% in non-tailored versus 90% in tailored; $p = 0.1387$; Table 4). The average postoperative Eckardt score was equivalent as well (0.8 ± 2.3 non-tailored versus 0.2 ± 0.4 tailored; $p = 0.4004$). The average score for dysphagia component was the same for both groups at 0.2 ± 0.4

Table 1 Demographics and baseline characteristics

	All ($N = 40$)	Type I ($N = 4$)	Type II ($N = 22$)	Type III ($N = 14$)	*p* Value	All non-tailored ($N = 29$)	All tailored ($N = 11$)	*p* Value
Age (SD)	54.1 (13.6)	47.8 (15.1)	15.2 (14.9)	54.1 (11.4)	0.5788	54.7 (14.8)	52.5 (10.3)	0.6491
Sex: male (%)	15 (37.5%)	1 (25.0)	10 (45.5)	4 (28.6)	0.5125	13 (44.8)	2 (18.1)	0.1159
BMI (SD)	32.2 (9.7)	32.0 (18.4)	29.8 (9.2)	35.9 (6.8)	0.1969	30.4 (10)	36.8 (7.3)	0.0677

Table 2 Peri-operative characteristics

	All ($N=40$)	Type I ($N=4$)	Type II ($N=22$)	Type III ($N=14$)	p Value	All non-tailored ($N=29$)	All tailored ($N=11$)	p Value
Preoperative interventions: total (%)	13 (32.5)	1 (25.0)	7 (31.8)	5 (35.7)	0.9171	10 (34.5)	3 (27.3)	0.4859
Botox (%)	1 (2.5)	0 (0.0)	0 (0.0)	1 (7.1)	0.3860	0 (0.0)	1 (9.1)	0.2750
Dilations (%)	11 (27.5)	1 (25.0)	6 (27.3)	4 (28.6)	0.989	9 (31.0)	2 (18.2)	0.3485
Myotomy (%)	1 (2.5)	0 (0.0)	1 (4.5)	0 (0.0)	0.657	1 (3.4)	0 (0.0)	0.7250
Pre-op Eckardt score (SD)								
Total score (SD)	7.5 (2.5)	8.8 (1.9)	7.7 (2.6)	6.9 (2.5)	0.3246	7.6 (2.5)	7.2 (2.6)	0.5908
Dysphagia (SD)	2.6 (0.7)	3 (0.0)	2.6 (0.8)	2.5 (0.7)	0.3237	2.7 (0.8)	2.6 (0.5)	0.4016
HREM								
Resting pressure (SD)	43.9 (20.1)	46.2 (40.0)	44.2 (20.9)	43.1 (15.3)	0.9265	43.4 (22.2)	45.1 (15.7)	0.4229
Integrated relaxation pressure (SD)	26.8 (11.0)	30.7 (17.2)	28.0 (12.9)	24.5 (6.8)	0.8475	27.7 (12.3)	24.8 (7.5)	0.7443
Operative characteristics								
Myotomy length, cm (SD)	14.3 (2.4)	14.3 (1.0)	13.5 (2.0)	15.7 (2.6)	0.0165	13.5 (1.8)	16.6 (2.2)	< 0.0001
Myotomy start, cm (SD)	28.9 (3.1)	30.3 (3.7)	30.2 (2.5)	26.6 (2.7)	0.0011	30.0 (2.7)	26.0 (2.2)	< 0.0001
Myotomy end, cm (SD)	43.3 (2.3)	44.5 (4.2)	43.6 (2.2)	42.3 (1.5)	0.2055	43.5 (2.6)	42.5 (1.1)	0.2413
Operative time: median, min (range)	129 (64–196)	103.5 (94–125)	132 (64–196)	131.5 (85–155)	0.1885	1 (1–3)	1 (1–4)	0.3334
Length of stay: median, days (range)	1 (1–4)	1 (0–1)	1 (1–3)	1 (1–4)	0.1030	17.9 (9.1–28.0)	19.4 (13.6–22.1)	0.0908

($p=0.5908$). However, postoperative Eckardt score was significantly decreased in the tailored group versus non-tailored when looking only at type III (1.3 ± 1.5 for non-tailored versus 0.2 ± 0.4 for tailored; $p=0.0435$).

While no correlation was noted between myotomy length and improvement in Eckardt score for the tailored group overall ($p=0.8114$) on linear regression, a correlation was seen between increased length and greater improvement in Eckardt score in the non-tailored group overall ($p=0.0170$, Fig. 2).

Median follow-up was 8.1 weeks (ranging from no follow-up through 82.7 weeks), though mean follow-up was 16.3 weeks (Table 3).

Discussion

As the familiarity with high-resolution manometry developed, a working group formed to categorize different esophageal motility disorders based on color topography plots in HREM studies. The first version of what became known as the Chicago classification was published in 2009 [13]. The most recent version, v3.0, was published in 2015 [14], and is the basis by which HREM studies are currently interpreted.

An important feature of v3.0 of the classification scheme is the division of achalasia into distinct subtypes. While all subtypes feature an IRP greater than the upper limit of normal, subtypes II and III are distinguished by over 20% panesophageal pressurizations and > 20% spastic contractions, respectively [14]. These subtypes were previously referred to as "vigorous achalasia," terminology of which was abandoned due to a lack of clear definition. Further, in previous descriptions of the Chicago classification, there was confusion about what to call spastic contractions in patients with some preserved peristalsis. Patients with premature contractions are classified as type III achalasia, while patients with preserved peristalsis are considered to have EGJOO [14].

It is becoming increasingly clear that treatment efficacy for achalasia varies by subtype, with type II achalasia

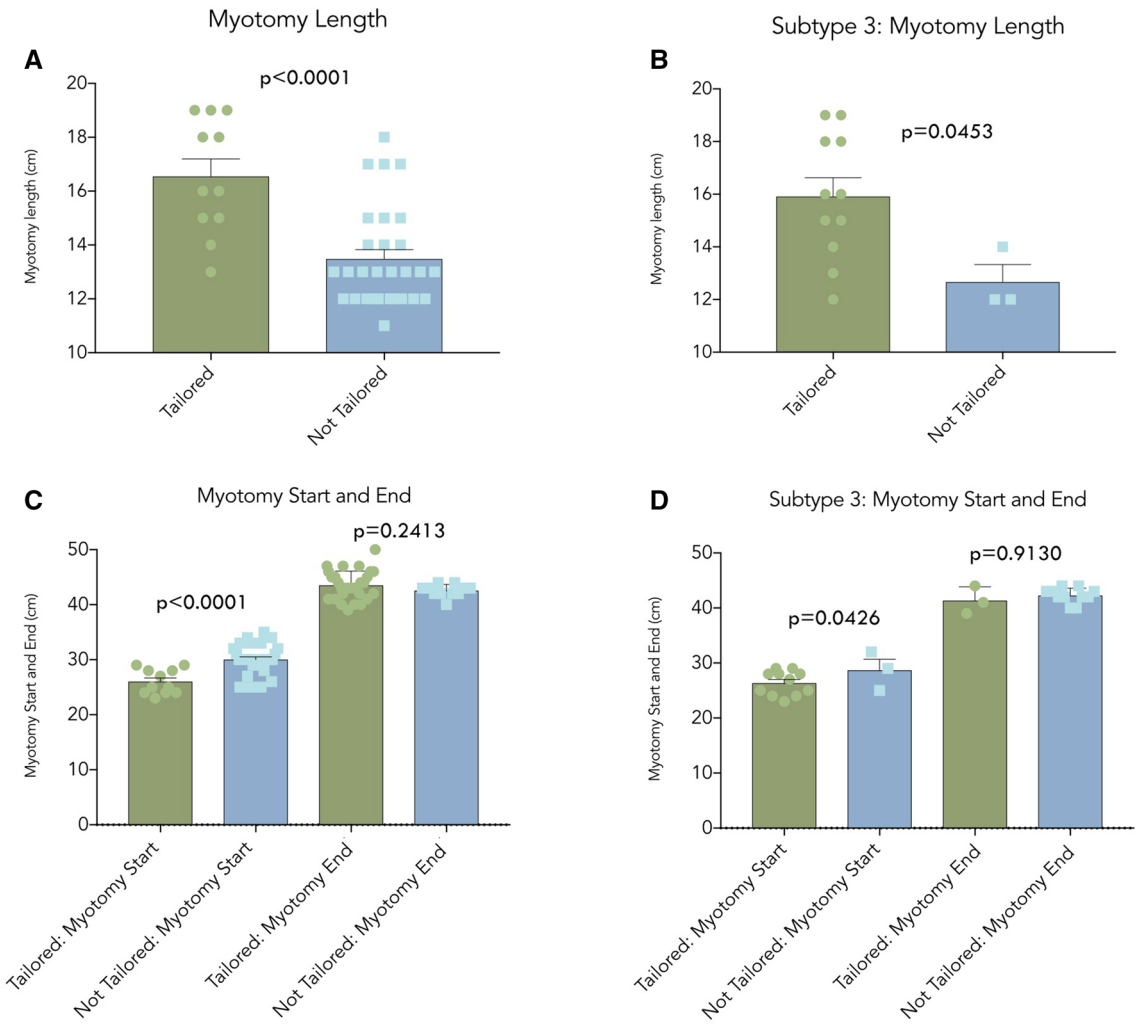

Fig. 1 **A** Mean myotomy length was significantly longer for the tailored group than for the non-tailored group (16.6 ± 2.2 versus 13.5 ± 1.8 cm; $p < 0.0001$). **B** Mean myotomy length was significantly longer for the tailored group than for the non-tailored group on subgroup analysis of type III achalasia only (15.9 ± 2.4 versus 12.7 ± 1.2 cm; $p = 0.0453$). **C** Mean starting position was more proximal for the tailored group than for the non-tailored group (26.0 ± 2.2 versus 30.0 ± 2.7 cm; $p < 0.0001$) and mean end position was equivalent between tailored and non-tailored groups (42.5 ± 1.1 versus 43.5 ± 2.6 cm; $p = 0.2413$). **D** Mean starting position was more proximal for the tailored than the non-tailored group on subgroup analysis of type III achalasia only (26.0 ± 2.2 versus 28.7 ± 3.5 cm; $p = 0.0426$) and mean end position was equivalent between tailored and non-tailored groups (42.5 ± 1.1 versus 41.3 ± 2.5 cm; $p = 0.9130$)

Table 3 Outcomes

	All ($N=40$)	Type I ($N=4$)	Type II ($N=22$)	Type III ($N=14$)	p Value	All non-tailored ($N=29$)	All tailored ($N=11$)	p Value
Post-op Eckardt score								
Total score (SD)	1.0 (2.4)	0.8 (1.5)	1.0 (2.7)	0.8 (2.1)	0.2548	0.8 (2.3)	0.2 (0.4)	0.4004
Dysphagia (SD)	0.2 (0.4)	0.3 (0.5)	0.1 (0.2)	0.3 (0.5)	0.2982	0.2 (0.4)	0.2 (0.4)	0.5908
Delta Eckardt	6.5 (3.3)	8.0 (1.8)	6.7 (0.2)	6.7 (3.1)	0.6645	6.6 (3.3)	6.9 (2.8)	0.8267
Operative success (%)	35 (87.5)	3 (75.0)	20 (90.1)	11 (84.6)	0.8910	26 (89.7)	9 (90%)	0.5558
Follow-up median length, weeks (range)	8.1 (0–82.7)	28.9 (2.7–82.7)	7.6 (1.7–56.0)	11.8 (0-53.3)	0.0536	8.1 (1.7–82.7)	8.3 (0–27.7)	0.3140

Table 4 Subgroup comparison of type III achalasia

	Type III not tailored ($N=3$)	Type III tailored ($N=11$)	p Value
Age (SD)	60.3 (15.5)	52.5 (10.3)	0.3065
Sex: male (%)	2 (66.7)	2 (18.1)	0.3654
BMI (SD)	32.4 (3.2)	36.8 (7.3)	0.3476
Preoperative interventions: total (%)	2 (66.7)	3 (27.3)	0.2747
Botox (%)	0 (0.0)	1 (9.1)	0.7857
Dilations (%)	2 (66.7)	2 (18.2)	0.1758
Myotomy (%)	0 (0.0)	0 (0.0)	1.0000
Pre-op Eckardt score (SD)			
Total score (SD)	6.0 (2.0)	7.2 (2.6)	0.5664
Dysphagia (SD)	2.3 (1.5)	2.6 (0.5)	1.0000
Operative characteristics			
Myotomy length, cm (SD)	12.7 (1.2)	16.6 (2.2)	**0.0453**
Myotomy start, cm (SD)	28.7 (3.5)	26.0 (2.2)	0.0426
Myotomy end, cm (SD)	41.3 (2.5)	42.5 (1.1)	0.9130
Post-op Eckardt score: total score (SD)	1.3 (1.5)	0.2 (0.4)	**0.0435**
Dysphagia (SD)	0.3 (0.6)	0.2 (0.4)	1.000
Delta Eckardt	4.7 (0.5)	6.9 (2.8)	0.2589
Operative success (%)	2 (66.7)	9 (90%)	0.1387
Follow-up median length, weeks (range)	46.1 (21.9–53.3)	8.3 (0–27.7)	0.0027

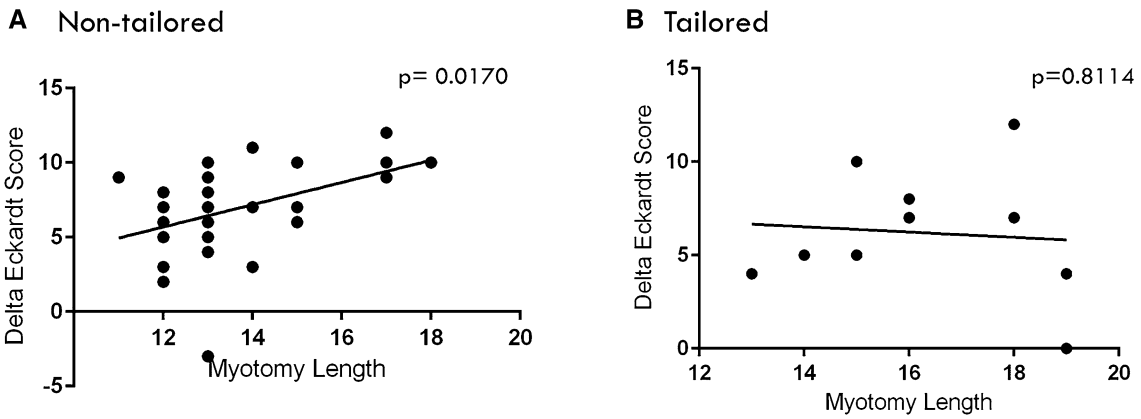

Fig. 2 **A** Correlation noted on linear regression between increasing myotomy length and delta Eckardt (difference between pre- and post-operative Eckardt scores, indicating symptom improvement) for the non-tailored group ($p=0.0170$, $R^2=0.1935$). **B** Correlation was not noted on linear regression between increasing myotomy length and delta Eckardt for the tailored group ($p=0.8114$, $R^2=0.0075$)

repeatedly demonstrating the best response to non-medical treatment and type III the poorest [5, 9, 15–20]. This was demonstrated in the European achalasia trial [9], where type II patients had improved efficacy with PD over LHM (100 versus 93%, respectively; $p=0.03$), whereas type III patients had better results with LHM (86 versus 40%; not significant due to small sample size). A meta-analysis by Ou et al. [18] also examined LHM versus PD by subtype, and came to the same conclusion that the best results were in type II patients, and worst outcomes were in type III patients. Guidelines by the American Gastroenterology Association (AGA) reported that overall treatment outcomes were more efficacious for type II achalasia than for type I or III, regardless of whether PD or LHM was performed [15]. In contrast to the results of these other studies, a study published by Crespin et al. [21] of 72 consecutive achalasia patients who underwent laparoscopic extended Heller myotomy showed equivocal results across all manometric subtypes. The authors state that their uniformly positive outcomes are due to extending the myotomy 3 cm over the stomach. However, this study was limited by its retrospective nature and by a small population size, particularly for type III achalasia ($N=5$).

One can argue that study results could be skewed by both operator bias in choosing the procedure (e.g., surgeons might favor LHM and gastroenterologists favor PD), as well as inconsistency with how PD is performed (some operators may not go beyond 30 mm for fear of perforation). Both of these procedures are limited in different ways. PD features uncontrolled tearing of muscle fibers, typically including the LES, whereas LHM is limited in myotomy length by how much esophagus can be safely mobilized into the abdomen and how much can be safely visualized in the mediastinum.

When reviewing the literature that included POEM as a potential treatment across achalasia subtypes, POEM was found to have favorable outcomes for patients with type III achalasia in particular, compared to the use of PD or LHM. A multicenter comparative study by Kumbhari et al. [22] examined type III achalasia in both LHM and POEM, finding a better outcome for POEM compared to LHM (98.0 versus 80.8%), which correlated with a longer myotomy length (16 versus 8 cm). The study was significantly limited by its retrospective nature and that of a comparison of multicenter results (LHM) with a single center (POEM). Nonetheless, the authors concluded that POEM allows for a longer myotomy than LHM, which may improve clinical outcomes. After performing their own review of the available studies, the AGA put out guidelines that endorse POEM as the primary therapy for type III achalasia, stating that other therapies limited to the LES have less robust outcomes [15]. They again note that POEM is efficacious because the myotomy may be made as long as necessary. They furthermore state that POEM should be considered comparable to LHM for any of the other achalasia types, as long as expertise in the technique is available. In another recent review [23], Kahrilas et al. sought to categorize recommended treatment algorithms by phenotype of achalasia. This review suggests that POEM should be the procedure of choice for type III achalasia, whereas PD is recommended for type II due to lower cost. Ihara et al. published a second review [24] suggesting PD or LHM/POEM as first-line therapy for type I patients and PD or POEM for type II or III patients, with medical therapy as first-line treatment for EGJOO patients.

Conceptually, POEM has an inherent advantage over LHM in that there is not a technical limitation of myotomy length. As there is no guideline or expert consensus with regard to minimal myotomy length recommended in POEM or LHM, therapeutic outcomes have been variable based on the lengths used at different centers, particularly for type III achalasia. Kim et al. [12] reported a 90.9% success rate in type III achalasia, which was lower than the other subtypes (97.9% for type I and 100% for type II), with no difference in myotomy lengths. The mean length for type III was 9.4 cm, which may be too short based on our experience, as noted above. Greene et al. [25] looked retrospectively at both LHM and POEM patients across all subtypes, finding that type II patients faired better, with a 93% efficacy rate, than types I (80% efficacy) or III (89% efficacy). Nevertheless, they used resolution of dysphagia as their metric of treatment success. Chen et al. [26], found similar results in a small series with 2-year follow-up, demonstrating no outcome differences between subtypes despite similar myotomy lengths (9.6 cm). Zhang et al. [27] specifically looked at outcomes in type III achalasia patients and reported a 90.6% treatment success rate at a median follow-up of 27 months with a mean myotomy length of 8.2 cm. An international multicenter study [28] retrospectively looked at spastic esophageal disorders (type III achalasia, distal esophageal spasm, and jackhammer esophagus) and had a 93% short-term success rate with a mean myotomy length of 16 cm. One new study [29] published mid-term results showing poorer results with type I than type II or type III (16.6% failure rate versus 1.1% versus 0%, respectively) with a mean myotomy length of 12.1 cm. Khan et al. [30] reported a 92% success rate for type III patients with a mean myotomy length of 17.2 cm.

Guo et al. [31] recently published a series of POEM with minimum of 3-year follow-up. Their success rate was 94% for type II achalasia patients, compared to only 77% (10/13) type I patients, and 50% (2/4) of type III patients. One of the type III patients had no therapeutic effect with a postoperative Eckardt score of 8, while the other patient recurred after 6 months. This study reported similar myotomy lengths: 10.6 cm for type I and II and 10.9 cm for type III, which may not have spanned the entire spastic segment. The type III sample size is small, making it difficult to generate conclusions based on subtype in this analysis. While Ju et al. [32] did not specifically report the length of their myotomies (nor did they differentiate length based on subtype), they found the worst efficacy for type III, as determined by the overall change in Eckardt score. Again, the sample of type III patients was small ($N=20$), making conclusions difficult to reach.

In our study, we aimed to utilize HREM data to inform an exact myotomy length in type III patients specifically, as it is rare to elicit discrete anatomic data informing suggested myotomy length in type I or II patients. We concluded that there was an improvement in type III patients in whom the myotomy was tailored as opposed to non-tailored (0.2 ± 0.4 versus 1.3 ± 1.5; $p=0.0435$). We noted a linear relationship between increased myotomy length and improvement in symptoms for the non-tailored, as measured by decreased Eckardt score, indicating that patients had better outcomes with more of the affected segment cut. This linear relationship was not seen for the HREM-tailored patients because, by definition, the length of the myotomy already spanned the entire affected segment, so beyond this, the length of the myotomy did not result in a noticeable difference. Generally, longer myotomies needed to span the affected segment in type II achalasia are difficult to perform in LHM and

are easier to perform in POEM. However, more long-term POEM outcome data is needed to determine whether there is a true advantage compared to LHM in type II achalasia.

This study is limited by its retrospective and non-randomized nature and relatively small sample size of 40 patients, particularly when looking only at patients diagnosed with type III achalasia, impairing our ability to power our comparative analysis. Another limitation is only having short-term follow-up for the majority of patients, especially those in the tailored group. We did note that the longer follow-up seen in the type III non-tailored group likely occurred because these patients were treated before we began tailoring our myotomes to HREM data. As this is a single center study, more data from other centers are needed to observe if a similar correlation between tailored myotomy and successful outcomes in type III patients is reproducible. A randomized trial of tailored versus non-tailored (i.e., standardized length) myotomies across multiple centers would likely answer this question. It does appear that older studies observing poorer outcomes in type III achalasia patients might be due to limited myotomy length, especially in LHM series, and that longer myotomy length studies as are more easily achieved in POEM, do seem to favor better outcomes overall. Studies such as these have the potential to lead to a standardized recommendation on myotomy length depending on subtype, which would then in turn lead to more broadly applicable results.

Compliance with ethical standards

Disclosures Dr. John R. Romanelli is a consultant for Covidien but no funding or support was received for this work. Drs. David J. Desilets, Vikram Budhraja, and Erica D. Kane have no conflicts of interest or financial ties to disclose.

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