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Learners favour high resolution oesophageal manometry with better diagnostic accuracy over conventional line tracings

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Abstract

Background—High resolution manometry (HRM) provides a colourful representation of oesophageal motility. Novice and intermediate learners were tested to compare HRM Clouse plots and conventional manometry for accuracy, ease of interpretation and knowledge retention.

Methods—36 learners evaluated 60 randomised motility sequences (30 HRM Clouse plots with corresponding line tracings) 4 months apart, following a tutorial. Learners rated prior knowledge of oesophageal pathophysiology and manometry and scored ease and speed of interpretation on 10 cm visual analogue scales (VAS).

Results—Understanding of oesophageal pathophysiology was low in all cohorts (2.9 ± 0.4 on VAS) and knowledge of HRM and conventional motility studies was even lower (1.9 ± 0.4 and 1.8 ± 0.3 , respectively, $p = \text{NS}$). After the tutorial, diagnostic accuracy was significantly higher with HRM Clouse plots than with line tracings ($p < 0.001$). HRM gains in diagnostic accuracy were evident over line tracings (43.1%), particularly with aperistalsis (36.1%), oesophageal body hypomotility (25.8%) and relaxation of the lower oesophageal sphincter (21.0%) ($p < 0.001$ for each comparison); these were maintained at the second evaluation. Gains were independent of academic level ($F = 0.56$, $p = 0.5$) and did not correlate with prior experience of learners ($r = -0.18$, $p = 0.29$). Learners favoured HRM Clouse plots (80.6%) over line tracings and reported faster interpretation (94.4%).

Conclusions—HRM Clouse plots provide ease of interpretation that translates into higher diagnostic accuracy and better knowledge retention in novice and intermediate learners of oesophageal manometry. These results implicate the value of pattern recognition in HRM interpretation, irrespective of academic level and prior understanding of oesophageal motor function.

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INTRODUCTION

Oesophageal manometry has long been the gold standard for the diagnosis of oesophageal motor disorders. Conventional manometry represents oesophageal pressure phenomena as line tracings in stacked x,y format (time on x axis, amplitude on y axis).¹ In contrast, high resolution manometry (HRM) provides topographic contour plots (Clouse plots) of oesophageal peristaltic phenomena in x,y,z format (time on x axis, location along oesophagus on y axis and pressure on z axis, represented as colour contours).² While conventional line tracings are considered cumbersome to interpret, HRM Clouse plots provide vivid and colourful images of normal and abnormal motor phenomena, and visual recognition of abnormal motor patterns could potentially assist interpretation.²⁻⁴

Several gains have been recognised in oesophageal motility testing with the use of HRM. The process of data acquisition has shortened, particularly from elimination of the stationary pull-through manoeuvre that is necessary for localisation of the lower oesophageal sphincter (LES) with conventional manometry.³ The sensitivity of diagnosis of abnormal LES relaxation, both in the context of achalasia and in non-achalasia dysphagic syndromes, has substantially improved over the use of point pressure sensors.^{5,6} Abnormal bolus transit is inferred from identification of compartmentalisation of intrabolar pressure proximal to an obstructive gastro-oesophageal junction process.^{7,8} However, there has only been limited research to determine if these gains translate into better teaching of oesophageal physiology and pathophysiology with the use of HRM.^{4,9} In particular, a single published study determined that spatiotemporal data provided by HRM provided for more accurate diagnosis and was better received by medical students than conventional line tracings.⁴ The simplicity afforded by HRM pattern recognition in the diagnosis of oesophageal motor pathophysiology could potentially make the learning process easier and provide better retention of oesophageal motility knowledge over time.

In this study we aimed to assess the value of HRM in the education of oesophageal motor physiology and pathophysiology in novice and intermediate learners compared with line tracings obtained from the same HRM studies to represent conventional manometry. We tested the role of pattern recognition by only allowing static Clouse plots from individual swallows without software tools in identifying normal and abnormal motor patterns in the oesophageal body and LES. We assessed retention of knowledge by repeating the study elements after a period of time. Our hypotheses were that HRM Clouse plots would allow for higher diagnostic accuracy over line tracings independent of learner level and that, by virtue of pattern recognition, knowledge of HRM patterns would be retained with higher diagnostic accuracy over time compared with line tracings.

METHODS

Subjects

Thirty-six learners at various levels of medical education were recruited (12 gastroenterology fellows, 12 internal medicine residents and 12 fourth year medical students), all enrolled in training at Washington University School of Medicine and Barnes-Jewish Hospital in St Louis, Missouri. All individuals had only a basic level of knowledge

of oesophageal pathophysiology and motor disorders obtained during the course of medical school education and training experiences. Learners with an advanced level of knowledge of conventional manometry or HRM—that is, participation in studies involving interpretation of oesophageal motility studies—were excluded from the medical resident and medical student cohorts but were allowed in the gastroenterology fellow cohort because motility education is part of fellowship training and because the fellow group could then serve as an intermediate level learner cohort. Participants did not have their identities recorded, but self-reported learner level and their prior knowledge of oesophageal motor physiology and pathophysiology were recorded. Implied consent was obtained following study recruitment and subsequent participation in the study, and participants were paid an honorarium at study completion. The study protocol, questionnaires used and subsequent analysis of data were approved by the Human Research Protection Office at our institution.

Manometric data

The manometric swallow sequences used in this study were obtained from a database of oesophageal motility studies conducted at our institution's motility laboratory using a solid-state HRM system (Sierra Scientific, Los Angeles, California, USA). Data were acquired using a solid state motility catheter with 36 circumferential sensors at 1 cm intervals, and dedicated display software was used to visualise Clouse plots (ManoView; Sierra Scientific). Representative Clouse plots of individual swallows were extracted from the motility studies and the corresponding line tracings were generated from the same swallows in each instance, consisting of seven stacked tracings (one upper oesophageal sphincter, four oesophageal body, one LES from the electronic sleeve recording and one gastric). Patient information was de-identified on each sequence. The swallow sequences were printed in colour and compiled in the questionnaire packet in random order.

Sample size

To adequately assess the goals we used values from the solitary study that compared diagnostic accuracy of HRM with conventional methods, where diagnostic accuracy of 89% was reported with HRM in manometry-naïve medical students exposed to a computer tutorial session.⁴ Thus, assuming accuracy of 90% with HRM and 60% with line tracings⁴ and using 36 trainees, a total of 58 manometric studies (29 HRM and 29 line tracings) would be needed to demonstrate a group proportion difference of 0.3 between the HRM plots and line tracings, assuming an α of 0.05 and β of 0.2.

Comparison of HRM Clouse plots and conventional line tracings

Learners were given a 30 min tutorial by one of the study investigators (CPG) with experience in both HRM and conventional line tracings. The purpose of the tutorial was to introduce the cohort to the general principles of oesophageal pathophysiology, motor disorders and their representations on each of these modalities. Both HRM Clouse plots and conventional line tracings were explained in detail, focusing on normal patterns and the spectrum of motor disorders ranging from achalasia and hypermotility disorders to hypomotility disorders and aperistalsis. Several examples of each type of abnormality for both oesophageal body and LES were shown, but none from the patients whose sequences were used in the questionnaire. Immediately following the tutorial, learners evaluated HRM

Clouse plots and conventional line tracings from 30 representative swallow sequences from unique patients (30 HRM Clouse plots, 30 conventional line tracings), preassembled in random order in a vivid colour questionnaire packets. Two separate questionnaire versions with different random orders of swallows were used to maintain integrity of the evaluation process, with conventional and HRM swallows separated and independently randomised so that corresponding swallows could not be directly compared.

The spectrum of conditions represented in the study questionnaires were categorised into LES and oesophageal body patterns. LES patterns included 16 sequences with normal LES function (clearly visible robust swallow-induced LES relaxation) and 14 sequences with clearly visible abnormal LES function (integrated relaxation pressure >15 mm Hg), most with visibly elevated ramp or intrabolus pressures proximally. Oesophageal body patterns were assessed independently of LES patterns and included: (a) normal pattern, with both smooth muscle contraction segments of normal amplitude, <3 cm break if any between skeletal and smooth muscle segments and no breaks between smooth muscle segments (11 swallows); (b) oesophageal body hypomotility (5 swallows), with either fragmented contractions (showing >3 cm breaks between skeletal and smooth muscle contraction segments or between the two smooth muscle contraction segments) and low amplitude contractions <30 mm Hg; (c) oesophageal body hypermotility (5 swallows), with any of high amplitude contractions >180 mm Hg, multiple peaked waves, repetitive contractions or simultaneous contractions; and (d) aperistalsis (9 swallows) showing no peristaltic activity in the oesophageal body. To standardise the HRM Clouse plots, each swallow sequence was displayed as a 1 min tracing (x axis) and 0–150 mm Hg pressure range; the colour scale used in the Clouse plot was provided. However, other software tools were not used and all automated markings including the eSleeve box (Sierra Scientific) were removed. Line tracings were displayed as 1 min stacked tracings with a 0–100 mm Hg pressure range.

Learners evaluated each sequence for LES pattern and oesophageal body pattern. Answers were not provided and the learners had to write in both parameters for each HRM Clouse plot and line tracing in the questionnaire booklet. Designations of ‘aperistalsis’ or ‘hypermotility’ or ‘simultaneous’ in the oesophageal body in conjunction with ‘abnormal LES relaxation’ at the LES constituted a diagnosis of achalasia. No specific time limit was set for completion of the evaluation; however, no learner took longer than 30 min. Immediately before the swallow sequences, learners rated their prior exposure to and understanding of oesophageal motor pathophysiology, HRM and conventional line tracings on 10 cm visual analogue scales (VAS, 0=least, 10=most). Following the swallow sequences they rated relative ease and speed of analysis, comparing HRM and line tracings on a 10 cm VAS scale anchored by line tracings at one end and HRM at the other end. VAS is well validated in the measurement of subjective events and entities, especially when extreme extents of the entity being measured can be identified.¹⁰

To assess knowledge retention, the same cohort of learners was administered a second questionnaire 4 months later, containing the identical 30 HRM Clouse plots and 30 line tracings as used in the first session, but was not preceded by a tutorial. Prior exposure and understanding of oesophageal pathology was not reassessed, nor was ease and speed of analysis. Participation was 100% among the study cohorts for both questionnaires.

Data analysis

Grouped questionnaire and survey results are reported as mean $\pm$ SEM. Questionnaire responses were compared with expert interpretation of each tracing as determined from the official reading provided by the senior author (CPG). Questionnaires were scored by an investigator (ASS) not involved in selection of the motility sequences used in the study. Grouped data were compared using the two-tailed Student t test, with discrete variables being compared using the χ^2 test and Fisher exact test as appropriate. Intergroup comparisons were performed using ANOVA. Gains or losses on diagnostic accuracy were calculated as percentage change from the comparator value. For each value comparison, $p<0.05$ was required for statistical significance. All statistical analyses were performed using PASW statistics version 17.0 (SPSS Inc).

RESULTS

Thirty-six learners were recruited for the study through email advertisement. The learners consisted of 12 medical students (all in their fourth year of training), 12 internal medicine residents (five interns, six second year residents, one third year resident) and 12 gastroenterology fellows. Other demographic data were not deemed relevant to the study and therefore were not collected. VAS evaluation showed that pre-existing understanding of oesophageal motor pathophysiology was minimal (2.9 ± 0.4); exposure to HRM Clouse plots (1.9 ± 0.4) and line tracings (1.8 ± 0.3) was even lower. Gastroenterology fellows had the highest prior exposure on each of these assessments, but only their self-report of prior understanding of HRM (4.3 ± 0.6) was significantly higher among the learner groups ($p<0.05$, figure 1).

At the first evaluation, HRM had a significantly higher diagnostic accuracy than line tracings among the cohort as a whole (table 1). HRM gains in diagnostic accuracy were highest when evaluating oesophageal body motor pattern (87.9% compared with 71.1% with line tracings, $p<0.001$). Slightly lower diagnostic accuracy was evident with both modalities when LES relaxation patterns were evaluated, but HRM still provided significant gains over line tracings (73.1% vs 60.5%, $p<0.001$). Broad groups of motor patterns (aperistalsis, hypermotility, hypomotility, normal) all demonstrated significantly higher diagnostic accuracy than line tracings (table 1). HRM diagnostic gains were noted for overall body, LES patterns and composite diagnosis over line tracings (figure 2), and were most pronounced when evaluating aperistalsis (36.1%), hypomotility (25.8%) and composite diagnosis (43.1%, $p<0.001$ for each comparison with line tracings; figure 2).

At the second evaluation conducted 4 months later, there was a modest decline in diagnostic accuracy with both manometric methods: 5.8% with HRM ($p=0.08$) and 14.9% with line tracings ($p=0.004$). However, the higher diagnostic accuracy of HRM over line tracings was maintained for both oesophageal body motor patterns (82.0% vs 67.7%, $p<0.001$) and LES relaxation (69.3% vs 54.8%, $p<0.001$; table 1). HRM diagnosis of aperistalsis was correctly identified 95.8% of the time at second evaluation (2.6% increment over the first HRM evaluation, $p=0.4$), compared with 61.0% with line tracings (10.8% decline over the first line tracing evaluation, $p=0.15$).

The composite of oesophageal body and LES impressions was evaluated to determine the accuracy of achalasia diagnoses compared with aperistalsis in the absence of achalasia. In this way, achalasia was accurately identified 61.7% of the time with HRM compared with 51.7% of the time with line tracings ($p<0.001$, table 1). The decline in diagnostic accuracy at second evaluation was 7.7% for HRM ($p=0.5$) and 29.6% with line tracings ($p=0.01$). Aperistalsis from primary hypomotility (with normal LES relaxation) was identified accurately in 88.9% with HRM but only in 31.7% with line tracings ($p<0.001$); these values remained relatively stable at second evaluation (gain of 4.2% with HRM, no change with line tracings, $p=NS$).

Gastroenterology fellows were better than the other two cohorts in identifying normal patterns on HRM (76.0% vs 86.2%, $p=0.03$) and hypermotility on line tracings (76.2% vs 84.3%, $p=0.05$); fellowship training provided no advantage to identification of other patterns on either modality. When evaluating level of medical education and training and prior exposure of learners to motility disorders, gains in diagnostic accuracy with HRM were found to be independent of academic level ($F=0.56$, $p=0.5$) and did not correlate with prior exposure ($r=-0.018$, $p=0.29$). Finally, the learners as a group overwhelmingly indicated that they favoured HRM in terms of ease of interpretation (80.6%) and speed of interpretation (94.4%); median scores by group on 10 cm VAS are depicted on figure 3.

DISCUSSION

In this study we demonstrate that, in a cohort of learners of different levels, HRM Clouse plot interpretation provided a faster, easier and more accurate avenue for identification of motor patterns on individual swallow sequences than conventional line tracings. These findings were independent of the level of medical training or prior knowledge of oesophageal pathophysiology and manometry interpretation. Retention of interpretation knowledge over a 4-month period was higher with HRM than with line tracings, potentially from pattern recognition afforded by the Clouse plots. We also note that teaching of oesophageal pathophysiology in medical school curricula is probably suboptimal given the learners' low self-rated confidence in their knowledge within this field, but their overwhelming preference for HRM affords hope that incorporating HRM into medical education might benefit teaching and learning of oesophageal motor function.

Measures were taken to ensure a study design that could address the aims of the study definitively. To minimise unintentional diagnostic bias towards HRM, study hypotheses were not revealed to the cohort; the learners were only told that diagnostic yields would be compared between the two techniques. In addition, to assure standardisation of introductory learning, the tutorial session provided to all learners stressed oesophageal pathophysiology and motility patterns with both HRM and line tracings. Only typical examples of each motor pattern were used in the questionnaires, and the ability to designate individual swallows into broad motor patterns (hypermotility, hypomotility, achalasia, normal) was tested. By standardising all pressure and time scales for each modality, variation in appearance of Clouse plots and line tracings was minimised to the extent possible. Manometric software tools were not used for HRM Clouse plots. The study methodology therefore forced the learners to focus on recognising patterns on HRM Clouse plots. This study uniquely

examined a varied cohort of learners at different levels of medical training, allowing for an assessment of the impact of medical training level on learning HRM interpretation compared with line tracing interpretation. Our results concur with the two available studies in the literature reporting the improved ability to teach HRM (over conventional line tracings) using its pressure measurement analysis through use of software tools to groups of learners (students,⁴ fellows⁹). Our findings go one step further in suggesting that pattern recognition by itself may achieve the objective of ease of teaching and learning.

With both the first and second evaluation, gains in diagnostic accuracy with HRM were seen across motor patterns but were most marked for achalasia and aperistalsis. Visual recognition of achalasia on HRM Clouse plots is partly dependent on identification of compartmentalisation of pressure, either panoesophageal or between the contractile front and the LES when some peristaltic effort is retained.¹¹ Such compartmentalisation of pressure, especially in the presence of aperistalsis, has a consistent appearance on HRM and has been shown to allow prediction of bolus transit.⁷⁸ Despite this, the overall accuracy of assessment of LES function was lower than that for oesophageal body patterns, especially in the absence of achalasia. This observation implies that visual recognition of LES relaxation remains difficult with HRM and that software tools developed for interrogation of LES function are on target. The electronic sleeve (eSleeve) allows for detection of nadir pressures within a prespecified area within the period of LES relaxation.⁵¹² With the use of these software tools, accuracy of diagnosis of abnormal LES relaxation reaches >97%.⁵ We therefore speculate that electronic software tools for measurements of LES relaxation may serve as an important complement to visual pattern recognition, especially in the absence of typical achalasia patterns.¹³

Among oesophageal body motor patterns, hypermotility patterns with exaggerated contraction amplitudes and multiple peaked waves were easy to identify on line tracings, hence gains with HRM over line tracings were not as prominent as for other patterns. Low amplitude contractions were not identified as well with line tracings and were misdiagnosed as aperistalsis, while HRM plot analysis on these same cases resulted in prominent gains over line tracings. It is fair to note that software tools available with HRM complement visual impressions of oesophageal body motor patterns, and that these may have resulted in still higher gains of HRM over conventional line tracings. For example, the use of the isobaric contour tool available with HRM analysis would probably have added to the diagnostic accuracy using either the 30 mm Hg—or, as recently reported, the 20 mm Hg setting—to identify peristaltic patterns deemed adequate for bolus transit.¹⁴ Tools for the evaluation of hypermotility patterns include the distal contractile integral, a metric that assesses the vigour of smooth muscle contraction¹⁵; this may have further benefited the identification of hypermotile patterns.

The second evaluation, conducted 4 months after the first, complemented information obtained from the first evaluation. As expected, there was a decline in diagnostic accuracy in all groups of learners. This decline was more pronounced with line tracings than with HRM Clouse plots, particularly for achalasia. While the students and medical residents were not exposed to motility studies and interpretation in the 4 months between the evaluations, senior gastroenterology fellows have ongoing training in neurogastroenterology and

motility. However, fellowship only provided an advantage in identifying normal HRM patterns and hypermotility on line tracings. Therefore, understanding of oesophageal motor patterns continues to be an area that needs attention, both for the teacher and the learner. In this light, our study findings indicate that future success of motility training may lie in greater exposure to HRM patterns. We feel that the dichotomy in interpretation skills between HRM and line tracings, and the retained superiority of HRM over line tracings in diagnostic accuracy over time, are both explained by the simple conceptual basis of HRM and the better retention of pattern recognition. Our results show that HRM interpretation is generally preferred by all learners, and confirm the ease with which HRM pattern recognition can be taught, appropriately applied and retained by all levels of learners.

Our study has a few limitations. First, an artificial interpretation environment was created by including single swallow sequences without access to the entire motility study, software tools or patient history. While this methodology was essential to our study aims, we also feel that motility interpretation starts with identification of single swallow patterns, and that this is a critical first step in interpretation. Second, typical and classic abnormalities were tested, and only normal motility and broad groups of motor disorders were included. While we have shown that HRM improves identification of these broad groups of disorders, further interpretation is frequently required when subtleties are seen. The findings therefore need to be considered in the context of the presenting symptoms and the indications for the study, both of which were not provided to the learners. It has been established that even experienced motility readers disagree on final designations 12–20% of the time.¹⁶ Further studies are needed using a broader selection of motor abnormalities and larger groups of interested participants to evaluate whether our findings remain consistent. Finally, bias could have been introduced with the tutorial in favour of HRM. We recognise that teacher bias is difficult to eliminate completely from this setting. However, all participants completed both line tracings and HRM education and interpreted both modalities at each assessment session. The advantage in diagnostic accuracy with HRM at the second assessment (with no preceding tutorial) was consistent with the first, suggesting that HRM itself may have imparted some interpretative benefits.

In conclusion, our results add to the growing body of literature demonstrating the value of HRM in the evaluation of oesophageal motor disorders. Building on previous literature, we demonstrate that pattern recognition with HRM provides both novice and intermediate learners with durable interpretation skills, which all groups of learners favour over conventional line tracings. Finally, our study implies that the teaching of oesophageal pathophysiology may benefit from the incorporation of HRM Clouse plots in medical school curricula and teaching formats at postgraduate levels. The appeal and ease of use of this technology hopefully will result in more widespread understanding of oesophageal motor physiology and pathophysiology among gastroenterologists, and enrich future education and research in this field.

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Significance of this study

What is already known about this subject?

- ▶ High resolution manometry (HRM) provides spatiotemporal colour plots of motor phenomena.
- ▶ Specific recognisable HRM patterns are seen in oesophageal motor disorders.
- ▶ Diagnosis of abnormal relaxation of the lower oesophageal sphincter is more sensitive and specific with HRM.

What are the new findings?

- ▶ Understanding of oesophageal physiology and pathophysiology is low in learners.
- ▶ HRM diagnostic accuracy is substantially higher than with line tracings in learners.
- ▶ Learners retain HRM interpretation better than line tracing interpretation over time.
- ▶ Learners prefer HRM to line tracings.

How might it impact on clinical practice in the foreseeable future?

- ▶ Utilisation of HRM for education of medical students, residents and other learners.
- ▶ Shift in oesophageal motility testing to HRM-based systems.
- ▶ Understanding of the value of pattern recognition in HRM interpretation.

Figure 1.

Comparison of understanding of oesophageal motor pathophysiology, oesophageal motility interpretation in terms of line tracings and high resolution manometry (HRM) prior to the tutorial provided as part of the study. Although gastroenterology fellows reported higher values for all categories, only their self-reported prior understanding of HRM was statistically higher than the other groups. Data are shown as mean $\pm$ SEM values from the 10 cm visual analogue scale (* p <0.05).

Figure 2.

Percentage gain in diagnostic accuracy of high resolution manometry (HRM) over line tracings, for each of the two evaluations performed. Gains were consistently seen across motor patterns. Incremental gains seen at the second evaluation suggest more prominent decline in diagnostic accuracy of line tracing interpretation over the 4-month interval between evaluations. LES, lower oesophageal sphincter.

Figure 3.

Comparison of learner preference of high resolution manometry (HRM) versus line tracings in terms of ease and speed of interpretation. These were assessed using visual analogue scales (VAS), anchored by line tracings at one end and HRM on the other, which were depicted horizontally on the actual questionnaire. Data are shown as median values and IQR on the 10 cm VAS scales.

Table 1

Percentage of correct responses among all learners by category of motor disorders

	HRM		Line tracings	
	1st evaluation	2nd evaluation	1st evaluation	2nd evaluation
Aperistalsis	93.4	95.8	68.4	61.0
Hypermotility	90.9	83.2 [*]	84.0	74.0 [*]
Hypomotility	88.5	76.2 [*]	60.7	53.0
Normal	82.7	76.5	74.4	84.7 [†]
Body overall	87.9	82.0 [*]	71.7	67.7
LES overall	73.1	69.3	60.5	54.8
Composite body and LES	60.6	57.0	42.3	36.0 [*]
Achalasia	61.7	56.9	51.7	36.4 [*]

Each comparison between HRM and line tracings was statistically significant at both evaluations.

^{*} p<0.01 for decline in diagnostic accuracy compared with first evaluation.

[†] p<0.001 for increment in diagnostic accuracy compared with first evaluation.

HRM, high resolution manometry; LES, lower oesophageal sphincter.