Oesophageal manometry: 10-year audit from a specialist centre, and early experience with high-resolution manometry

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Abstract

Background Manometry is the gold standard investigation of innate or acquired motility disorders in the oesophagus. New technology in the form of high-resolution manometry (HRM) may supplant traditional water-perfused manometry and enhance standardisation of manometric interpretation and reporting. This study reports on a 10-year experience of 5,184 consecutive patients using the traditional methods, and an early experience with HRM.

Results Of 5,184 patients assessed, 4,509 (87 %) had both pH and manometry and 675 (13 %) had manometry only. 3,523 (78 %) of the pH /manometry group had normal motility, 635 (14 %) showed ineffective motility (IM), 213 (5 %) a non-specific motility disturbance (NSMD), 42 (0.9 %) achalasia, 58 (1.3 %) nutcracker oesophagus, 22 (0.5 %) hypertensive LOS (HLOS), 8 (0.2 %) diffuse oesophageal spasm (DOS) and 8 (0.2 %) had scleroderma. For those referred solely for manometry only, 324 (48 %) had normal motility, 72 (11 %) IM, 51 (8 %) NSMD, 175 (26 %) achalasia, 16 (2 %) nutcracker oesophagus, 32 (5 %) HLOS, 1 (0.1 %) DOS and 4 (0.6 %) had scleroderma. 92 patients to date have been studied with HRM, with enhanced definition of lower oesophageal sphincter (LOS) function.

Conclusion For patients referred for reflux related symptoms, motility disorders are present in 22 % of the cases. Conversely, of the patients referred for dysphagia, motility disturbances are detected in 52 % of the cases sent for manometry. Our initial experience shows that HRM technology is adding a valuable dimension and clearer understanding of motility patterns in the dysphagic patient.

Keywords Achalasia · Hypertensive LOS (HLOS) · High-resolution manometry · Oesophago-gastric junction

Introduction

Oesophageal manometry has been in common use for approximately 30 years for both the diagnosis and investigation of motility disorders, and as a component of the physiological investigation of patients with gastro-oesophageal reflux disease (GORD). For reflux disease, it has a dual purpose, both to enable precise positioning of pH probes for accurate assessment of acid reflux, and to diagnose acquired and occasionally innate dysmotility which is relevant to treatment planning, particularly where anti-reflux surgery is being considered.

Motility disorders and their manometric features are classified using the British Society of Gastroenterology Guidelines, published in 2001 (Table 1) [1]. Achalasia is a rare oesophageal disorder with a reported incidence of 0.03 and 1 in 100,000 per year [2]. The characteristics of achalasia include absence of peristalsis in the oesophageal body with incomplete relaxation of the lower oesophageal sphincter (LOS). Hypertensive lower oesophageal sphincter (HLOS) is defined by a sphincter pressure (LOSP) above 30 mmHg with normal LOS relaxation and oesophageal peristalsis [3]. Ineffective motility is defined as peristaltic, simultaneous or absent peristalsis with a distal amplitude of <30 mmHg on >30 % of wet swallows [4]. The lower oesophageal sphincter pressure (LOSP) can be normal or hypotensive,

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Table 1 Classification of oesophageal motility abnormalities and manometric features

Achalasia:
Inadequate relaxation of the LOS upon swallow, aperistalsis in the oesophageal body characterized by simultaneous contractions with amplitudes <40 mmHg or by no apparent contractions
Features also characteristic but not needed for diagnosis of achalasia:
Elevated LOS resting pressure (>45 mmHg), elevated oesophageal baseline
Atypical disorders of LOS relaxation:
Often have one or more manometric features that preclude a diagnosis of achalasia:
Some preserved peristalsis
Oesophageal contractions >40 mmHg
Complete LOS relaxation of inadequate duration
Diffuse oesophageal spasm:
Simultaneous contractions on >10 % of swallows
Mean simultaneous contraction amplitude >30 mmHg
Features found but not commonly required for a diagnosis of DOS:
Repetitive multipeaked contractions, intermittent normal peristalsis
Nutcracker oesophagus:
Peristaltic waves with mean distal amplitude of >180 mmHg
LOS resting pressure usually normal range (10–25 mmHg) but can be elevated
Hypertensive LOS:
LOS resting pressure at end-expiratory pressure >26 mmHg
Normal relaxation often with large after contraction
Normal peristalsis
Ineffective oesophageal motility:
Low amplitude waves in distal oesophagus <30 mmHg on at least 30 % of swallows
Simultaneous waves with distal contraction of <30 mmHg with normal LOS relaxation
Failed peristalsis or aperistalsis
Scleroderma:
Basal LOSP low to normal
Low amplitude propagated waves
Aperistalsis
Non-specific motility disturbance:
Patients whose manometric features do not meet the criteria outlined above

Source: Gut 2001 [4]

with complete relaxation. Non-specific motility disturbance is a motility disorder in which oesophageal waveforms do not meet the criteria for any of the recognised motility disturbances. Often this includes a combination of many waveforms including aperistalsis, simultaneous and propagated waves, with normal or hypotensive LOSP and normal relaxation. The diagnostic criteria for nutcracker oesophagus include peristaltic waves with a mean distal amplitude of >180 mmHg using 10 swallows of water [4]. LOS resting pressure is generally normal but a hypertensive LOSP can also be seen in some cases. Diffuse oesophageal spasm is a rare oesophageal disorder characterised by simultaneous often multi peaked contractions with some peristalsis also present. The oesophageal contractions may also be of high amplitude or long duration but this is not necessary for a diagnosis of DOS. Contractions are mainly confined to the distal oesophageal segment and are sometimes referred to as 'distal oesophageal spasm'. LOSP may be normal or hypertensive, with normal relaxation. Barium swallow often reveals unusual patterns such as a 'corkscrew' appearance or severe non-peristaltic contractions.

The above definitions and standards apply to the traditional water-perfused manometric technique, prior to the introduction of high-resolution manometry (HRM) [5]. This new technology is composed of a recording assembly and a catheter which spans from pharynx to stomach with sensor separation less than 2 cm apart. HRM is purported to provide many advantages over conventional manometry, including simplicity, and shorter time as there is no station pull-through technique employed during analysis of the lower oesophageal sphincter (LOS). The sphincter function is also more detailed, distinguishing between LOS and diaphragmatic components of the junction. Moreover, in the upper sphincter, HRM uniquely details dynamic function and allows for the assessment of oesophageal peristalsis as a continuum by the production of spatiotemporal plots which relate contractile pressure, oesophageal clearance and outflow resistance [6]. The Chicago Classification is widely recognised as the definitive classification scheme for oesophageal motility using HRM (Table 2). A key metric used in HRM to detect abnormal OGJ relaxation is the integrated relaxation pressure (IRP). The IRP is the equivalent of LOS relaxation pressure in conventional manometry, and is defined as the mean OGJ pressure measured by an electronic sleeve device, for four continuous or non-continuous seconds of relaxation, in a 10-s window frame in the post swallow period [7]. The 4-s IRP provides an integrated measurement of all the components that effect bolus transit across the oesophago-gastric junction, including LOS pressure, influence of the crural diaphragm and intrabolus pressure [8].

In the Gastrointestinal Physiology Unit at St James's Hospital, large numbers of patients have undergone manometry assessment as a component of studies in patients with GORD, and in patients with suspected primary motility disorders of the oesophagus. The unit has recently begun using HRM for patients with dysphagia. The purpose of this report is to provide a 10-year overview of the activity prior to the introduction of HRM, which has not been done before in an Irish population and to report on our early experience with HRM and its potential applications.

Table 2 Chicago Classification of oesophageal motility

Achalasia	
Type I achalasia	Classic achalasia: mean IRP >15 mmHg, 100 % failed peristalsis
Type II achalasia	Achalasia with oesophageal compression: mean IRP >15 mmHg, no normal peristalsis, paraesophageal pressurization with ≥20 % of swallows
Type III achalasia	Mean IRP >15 mmHg, no normal peristalsis, preserved fragments of distal peristalsis or spastic contractions with ≥20 % of swallows
EGJ outflow obstruction	Mean IRP >15 mmHg, some instances of intact peristalsis or weak peristalsis with small breaks such that the criteria for achalasia are not met
Motility disorders	(Patterns not observed in normal individuals)
Distal oesophageal spasm	Normal mean IRP, ≥20 % premature contractions
Hyper contractile oesophagus (Jackhammer oesophagus)	At least one swallow DCI >8,000 mmHg s cm with single peaked or multipeaked contraction
Absent peristalsis	Normal mean IRP, 100 % of swallows with failed peristalsis
Peristaltic abnormalities	(Defined by exceeding statistical limits of normal)
Weak peristalsis with large peristaltic defects	Mean IRP <15 mmHg and >20 % swallows with large breaks in the 20 mmHg isobaric contour (>5 cm in length)
Weak peristalsis with small peristaltic defects	Mean IRP <15 mmHg and >30 % swallows with small breaks in the 20 mmHg isobaric contour (2–5 cm in length)
Frequent failed peristalsis	>30 %, but <100 % of swallows with failed peristalsis
Rapid contractions with normal latency	Rapid contraction with ≥20 % of swallows, DL >4.5 s
Hypertensive peristalsis (nutcracker oesophagus)	Mean DCI >5,000 mmHg s cm, but not meeting criteria for hyper contractile oesophagus
Normal	Not achieving any of the above diagnostic criteria

Adapted from Bredenoord et al. Neurogastroenterology and Motility [7]

Patients and methods

Patients who are referred to the unit and who are included in this study met indications for oesophageal manometry established by the British Society of Gastroenterology Guidelines [1]. The vast majority of patients that are referred to the unit, present with gastro-oesophageal reflux disease (GORD) and therefore undergo both manometry and 24 h ambulatory pH monitoring. Stationary oesophageal manometry was carried out using a 4-lumen oesophageal catheter with side holes spaced 5 cm apart, radially arranged at 90° angles to each other. This was attached to a low compliance water perfused pump (Mui Scientific, Ontario, Canada) and the data captured on dedicated EsopHogram software (Given Imaging, Germany). After informed consent, the calibrated catheter was passed transnasally and positioned in the stomach. Once comfortable, the patient was placed in a supine position and the probe withdrawn at 1 cm intervals; this is known as the station pull-through technique [1]. The position of the recording site to the nose was documented at each step. As the four recording sites were pulled through the LOS, the change from the negative pressure of the gastric lumen to a positive deflection within the high pressure zone (HPZ) was noted, it is at this level that the LOSP is established. LOSP is measured as end-expiratory pressure at the point of respiratory reversal (Fig. 1). The probe was then re-positioned so that the most distal sensor was placed in the LOS with the proximal three sensors resting in the oesophageal body. Ten test swallows of 5 ml room temperature water were given to the patient to assess contractile activity in the oesophageal body. Manometry traces were analysed according to the criteria of Spechler and Castell [4] (Table 1).

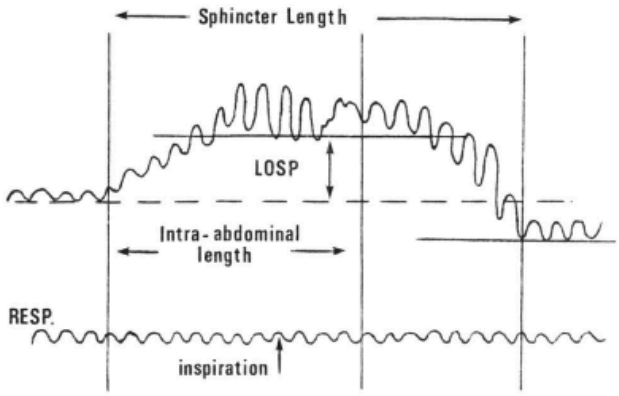

Fig. 1 LOS pull-through in standard manometry

For HRM, the catheter is calibrated to atmospheric pressure as per the protocol for the Manoscan system (Given Imaging, Germany). The probe is then passed trans nasally and positioned so that the upper and lower oesophageal sphincters are visualized on screen. Once this is established the catheter is taped into position. The study is then conducted in a supine position as indicated by the Chicago Classification working group [7]. A 30-s resting period is taken prior to swallow study to help identify

Table 3 Audit of manometry and pH results of 5,184 patients attending St James's Hospital, Dublin, over a 10-year period

Motility classifications	Age range	LOS pressure (mmHg)		LOS length (cm)		Oes length (cm)		Distal amp (mmHg)		pH	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	% +ve	% −ve
Normal motility (n = 3,847)	16–85	10	5.4	4.3	0.8	21	2.6	73	29.7	64	36
IM (n = 707)	16–92	8	4.4	4.2	0.8	21	2.8	24	7.1	75	25
NSMD (n = 264)	15–88	10	5.3	4.4	0.9	22	3.7	37	24.6	61	39
Nutcracker (n = 74)	22–84	15	7.3	4.4	0.9	21	2.2	208	29.4	52	48
Hypertensive LOS (n = 54)	18–81	34	7.4	4.3	0.8	22	2.4	99	2.4	33	67
Achalasia (n = 217)	12–94	25	11.6	4.2	0.9	22	2.8	31	16.6	17	83
DOS (n = 9)	39–64	26	19.9	5	0.6	22	2.4	97	51.1	25	75
Scleroderma (n = 12)	29–72	7.9	3.6	4.5	0.8	22	1.4	12	8.7	88	12

Table 4 Summary results of 4,509 patients referred for both manometry & pH studies over 10-year period at St. James's Hospital, Dublin

Motility classifications	Age range	LOS pressure (mmHg)		LOS length (cm)		Oes length (cm)		Distal amp (mmHg)		pH	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	% +ve	% −ve
Normal motility (n = 3,523)	15–85	10	5.2	4.3	0.8	21	2.6	72	29.3	56	44
IM (n = 635)	16–92	8	4.1	4.2	0.8	21	2.8	23	7.0	75	25
NSMD (n = 213)	15–84	9	5.0	4.3	0.9	21	2.7	36	23.8	61	39
Nutcracker (n = 58)	22–84	14	6.9	4.4	0.9	21	2.2	205	27.8	52	48
Hypertensive LOS (n = 22)	21–81	34	5.7	4.4	0.7	22	2.4	100	64.9	36	64
Achalasia (n = 42)	18–86	25	12.8	4.2	0.9	23	2.9	31	17.4	10	90
DOS (n = 8)	38–64	29	19.7	5.0	0.7	22	2.3	104	51.3	25	75
Scleroderma (n = 8)	29–72	9.0	4.2	4.5	0.9	22	1.5	22	1.5	88	12

landmarks for upper and lower sphincter positioning. Once this is established, ten 5 ml boluses of room temperature water are given, with a 30-s interval between each swallow. Multiple swallows are then given to the patient in the form of a glass of water or 5 × 2 ml boluses of water, with 2-s intervals. This helps to demonstrate peristaltic inhibition and oesophageal clearance. A bread bolus may then be given to assess the response of the oesophagus to a solid bolus. The study is quick and convenient, taking <30 min to complete.

Results

Water-perfused manometry

The majority of patients have routine manometry as a component of 24 h pH studies for GORD (Table 3), or other reflux-related symptoms such as respiratory disorders, hoarseness or halitosis. 5,184 patients were studied, 87 % were referred for pH and manometry studies, and 13 % were referred for manometry only. Of the pH/manometry group, 78 % had normal manometry, in this cohort 56 % had an abnormal pH study defined as a DeMeester score >14 with abnormal upright, supine or combination of both upright and supine periods. Motility disturbances were seen in 22 % of the cases. Ineffective motility in this series was associated with a mean LOSP of 8 mmHg, with mean distal amplitude of 23 mmHg. This type of motility disturbance is commonly seen in patients with GORD which was present in 75 % of the patients in this cohort. For non-specific motility disturbance, the mean LOSP was 9 mmHg, with distal amplitudes of 36 mmHg, and 61 % had an abnormal pH profile (Table 4).

Of the 5,184 patients, achalasia was present in 217 patients (126 male, 91 female) with an age range of 12–94 years, of whom 152 had original manometry traces available for re-review, which included sphincter relaxation profile, oesophageal body motility and oesophageal baseline characteristics. In this series (Table 5) the swallow pattern was either single or multi-peaked simultaneous contractions with incomplete, uncoordinated or intermittent LOS relaxation. It was also noted that the resting pressure in the oesophageal body of patients with multi-peaked

Table 5 Comparison of LOS relaxation in three different swallow types found in achalasia

	Single-peaked simultaneous		Multi-peaked simultaneous		Aperistalsis	
	Male ($n = 54$) (%)	Female ($n = 32$) (%)	Male ($n = 37$) (%)	Female ($n = 28$) (%)	Male ($n = 0$) (%)	Female ($n = 1$) (%)
Incomplete LOS relaxation	69	72	92	86	0	100
Intermittent LOS relaxation	28	25	3	11	0	0
Uncoordinated LOS relaxation	3	3	5	3	0	0
Elevated baseline	30	44	78	79	0	0

simultaneous waves was greater than gastric pressure (70 %) compared with patients with single-peaked simultaneous waves (40 %). In manometry this phenomena is represented by an elevated oesophageal baseline seen during swallow analysis. The increase in oesophageal pressure is thought to be as a result of dilation of the oesophagus due to outlet obstruction. The mean pressure of the LOS in each of these groups was virtually the same with the single peaked group mean LOSP at 24 mmHg and multi-peaked group at 23 mmHg. The distal amplitude in the oesophageal body of the multi-peaked group was slightly higher at 31 mmHg, compared to 28 mmHg in the single-peaked group. None of the patients in the multi-peaked group had high amplitude contractions of >180 mmHg, which is the criteria needed for a classification of vigorous achalasia.

54 patients (32 female, 22 male) with an age range of 18–81 years had a manometry pattern consistent with Hypertensive LOS (HLOS). LOSP in the female population was the same as the male at 34 mmHg and distal oesophageal amplitudes were similar between the sexes (93 and 99 mmHg in females and males, respectively). In most cases relaxation of the LOS was evident with normal propagation in the oesophageal body (Table 6).

Table 6 LOS relaxation in hypertensive LOS patients

Sphincter relaxation	Male ($n = 16$) (%)	Female ($n = 27$) (%)
Normal LOS relaxation	81	81.5
Incomplete LOS relaxation	0	11.1
Uncoordinated LOS relaxation	6	7.4
Intermittent LOS relaxation	13	0

74 patients (33 female, 41 male) with an age range of 22–84 years had a manometry pattern consistent with nutcracker oesophagus, including peristaltic waves with a mean distal amplitude of >180 mmHg using 10 swallows of water [4]. The mean LOSP in the female group was 17 mmHg and the male 13 mmHg, distal oesophageal amplitudes were much the same at 207 and 205 mmHg respectively. LOS relaxation is generally normal in this motility group. There is also evidence of GORD with 52 % of the total group with abnormal pH studies.

In this series, nine patients had a manometry pattern consistent with diffuse oesophageal spasm (3 female, 6 male) with a mean age range of 39–64 years. Mean LOSP in the female group was hypertensive at 32 mmHg, while the male LOSP was 22 mmHg. Incomplete relaxation was noted in 33 % of the female group and 50 % of the male. Mean distal amplitude for both groups were 110 and 89 mmHg respectively. 25 % of the patients with DOS had an abnormal pH study. Oesophageal body contractions show a mixture of multipeaked simultaneous contractions and peristaltic waves which are mainly seen in the distal oesophagus.

Table 7 Summary results of 675 patients referred for Manometry only, over 10-year period at St. James's Hospital (1 patient with DOS not included in the table)

Motility classifications	Age range	LOS pressure (mmHg)		LOS length (cm)		Oes length (cm)		Distal amp (mmHg)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Normal motility ($n = 3{,}523$)	12–88	12	7.0	4.2	0.8	21	2.8	79	30.0
IM ($n = 635$)	18–77	11	5.9	4.2	0.7	21	2.8	25	7.5
NSMD ($n = 213$)	18–88	13	6.0	4.4	0.9	23	2.3	40	28.0
Nutcracker ($n = 58$)	22–78	17	8.2	4.4	0.9	20	2.2	211	34.2
Hypertensive LOS ($n = 22$)	18–76	35	8.4	4.2	0.8	22	2.5	92	51.0
Achalasia ($n = 42$)	12–94	25	11.4	4.4	1.0	22	3.1	30	16.4
Scleroderma ($n = 8$)	45–75	7	1.0	4.5	0.6	23	1.5	14	8.6

12 patients (10 female and 2 male) with an age range of 29–72 years had known systemic sclerosis and had a manometry pattern consistent with scleroderma. The sphincter pressures were hypotensive for both sexes, with mean LOSP for the female group at 8 mmHg, and the male group at 10 mmHg. Mean distal amplitude for the group was 11 and 21 mmHg respectively. The main feature of the oesophageal body was complete aperistalsis in all cases with abnormal pH in 100 % of the scleroderma group. LOS relaxation was normal for all cases.

A subset of patients who were referred for manometry only, had symptoms of dysphagia, globus and non-cardiac chest pain (Table 7). 48 % had normal motility, 11 % ineffective Motility, 8 % non-specific motility disturbance, 2 % nutcracker oesophagus, 5 % hypertensive LOS, 26 % achalasia, and 0.6 % had scleroderma. One patient in this group had diffuse oesophageal spasm. LOSP, LOS length, distal oesophageal amplitude and oesophageal length are comparable between the pH/manometry group and those referred for manometry only.

High-resolution manometry

92 patients were evaluated with high-resolution manometry (46 male, 38 female with an age range of 19–84 years). The patients were selected on the basis that they had dysphagia, globus, chest pain or in some cases their standard manometry proved inconclusive in relation to an evaluation of LOS function. The results were interpreted using the Chicago Classification guidelines for patients in a supine position. 10 (10.8 %) patients had normal motility, LOSP and a normal IRP <15 mmHg. 13 (56 %) patients in the group were found to have oesophago-gastric junction abnormalities indicated by an IRP >15 mmHg and increased intrabolus pressure. These abnormalities showed bolus obstruction or impaired relaxation. Five (5.4 %) had jackhammer oesophagus, one (1.1 %) had nutcracker oesophagus. Frequent failed peristalsis was noted in four patients (4.3 %). Eight (8.7 %) had weak peristalsis with breaks. 14 (15.2 %) of this group had achalasia, (2 = Type I, 8 = Type II and 2 = Type III). Disorders of the upper oesophageal sphincter were identified in seven patients (7.6 %). Post-operative abnormalities were found in 21 (23 %) (Table 8).

Discussion

Manometry has been the gold standard in oesophageal function testing for many decades. Its most common

Table 8 Summary HRM findings and reason for referral

Provisional referral diagnosis	No. (%)	Final diagnosis based on Chicago Classification 2012
Dysphagia/food sticking	24 (26)	2 Jackhammer oesophagus; 2 achalasia Type II
		6 weak peristalsis with break; 3 frequent failed peristalsis
		2 non specific
		6 OGJ Obstruction; 2 normal (1 HH); 1 hypertensive UOS
Achalasia	14 (15.2)	12 achalasia Type I = 2; Type II = 8; Type III = 2
		1 adenocarcinoma; 1 OGJ obstruction
Globus sensation/UOS dysfunction	10 (10.8)	3 hypertensive UOS; 2 OGJ obstruction with poor peristalsis
		2 weak peristalsis with breaks; 1 hypotensive UOS; 2 UOSP depleted due to polio/stroke
Hypertensive LOS	5 (5.4)	3 impaired relaxation with raised intrabolus pressure; 1 frequent failed peristalsis with impaired relaxation; 1 hyper LOS
Chest pain/nutcracker oesophagus	7 (7.6)	3 Jackhammer oesophagus; 1 hypertensive oesophagus
		1 multiphasic waves mid oesophagus
		2 normal studies (1 with HH)
Post fundoplication dysphagia	9 (9.7)	2 slipped wrap; 4 raised intrabolus pressure due to wrap
		1 OGJ obstruction; 2 frequent failed peristalsis
Post Hellers myotomy	5 (5.4)	4 successful myotomy; 1 weak peristalsis with poor clearance
Reflux/regurgitation	5 (5.4)	2 normal motility; 2 OGJ obstruction; 1 HH
Post dilo	5 (5.4)	4 Type II achalasia recurrence post dilo; 1 successful
Others	8 (8.7)	4 normal motility; 1 scleroderma
		1 external compression on the oesophageal body
		2 Post esophagectomy with preserved distal motility

application is as a routine component of investigations of select patients with GORD, aiding both positioning of the pH probe and assessing whether abnormal motility exists. In patients being considered for anti-reflux surgery, the presence of ineffective motility or a non-specific motility disorder may result in more tailored surgery, such as partial fundoplication rather than the 360° Nissen wrap. Manometry may also rarely uncover a primary motility disorder such as achalasia in a patient being investigated for reflux, where again a total fundoplication would be inappropriate. In this large series of over 5,000 cases, the vast majority of patients had normal manometry, and where ineffective motility or non-specific motility disorders are present, it is predominantly in acid refluxers. These motility disorders have now been reclassified using HRM into frequent failed peristalsis (formally ineffective motility) and weak or absent peristalsis with large or small breaks (NSMD).

The large series also highlights that achalasia is the most common primary motility disorder diagnosed, with over 200 patients diagnosed, and that a large spectrum of patterns exist across the LOSP both for this and HLOS, from incomplete, uncoordinated and intermittent relaxation. It is in such primary disorders that from our limited experience to date we have found a wealth of additional information that can be derived from HRM in relation to sphincter function. The classification of achalasia using HRM into subtypes may also prove to be an effective way of tailoring a patient's treatment, based not only LOS impairment, but also the on the dominant feature of the distal oesophageal pressurisation after swallowing. The distinct subtypes are: *Type I* Classic Achalasia, with little or no oesophageal pressurisation; typically this would appear in line tracing as aperistalsis, or low amplitude waves of <30 mmHg and severe oesophageal dilation on barium swallow. *Type II* Achalasia with oesophageal compression shows oesophageal pressurization of >30 mmHg with little or no dilation of the oesophagus (Fig. 2). It is believed that Type II is a forerunner of Type I Achalasia with Type I being a consequence of the long-term effect of outflow obstruction. *Type III* Achalasia with spastic, often lumen obliterating contractions, appears a lot like DOS, but with incomplete relaxation at OG junction [9]. Type II has the best outcome for treatment with pneumatic dilatation (PD) or laparoscopic Heller's myotomy (LHM) than Type I or III. Type III is considered the most difficult to treat, due to the spastic nature of the contractions in the distal oesophagus, that lead to chest pain in the patient. Most study groups have agreed that Type III achalasia responds poorly to all forms of treatment.

For undiagnosed swallowing problems a further advantage of HRM is that it lends itself to provocation studies such as large volume swallows which helps to assess the transit of solid bolus in patients with dysphagia and thus

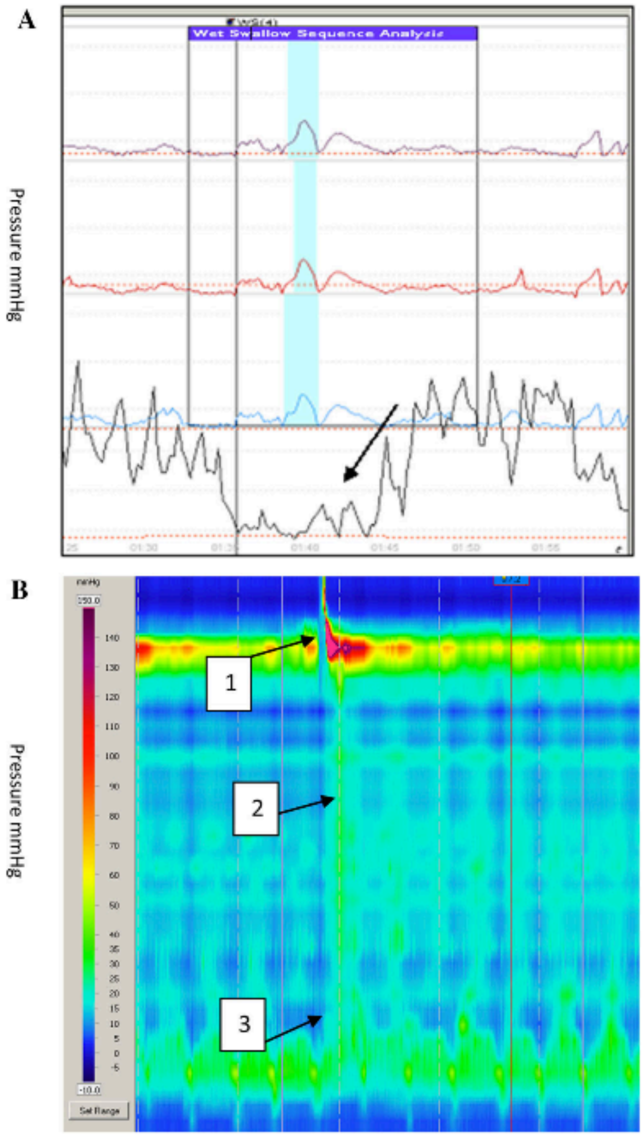

Fig. 2 Conventional line tracing illustrating achalasia vs. HRM plot. **a** Conventional manometry line tracing illustrating simultaneous oesophageal contractions in a patient with achalasia. *Arrows* indicates complete LOS relaxation upon swallow or possible pseudo relaxation. **b** Spatiotemporal plot using HRM illustrating Type II achalasia with compression. *Arrow 1* indicates UOS relaxation, *2* oesophageal compression, *3* incomplete LOS relaxation

provoke symptoms, increasing the diagnostic yield of the procedure [10]. The development of metrics such as the contractile front velocity (CFV), distal contractile integral (DCI) and distal latency (DL) have improved our understanding of the variety of phenotypes that exist in the hypercontractile disorders and disorders of rapid contractions, i.e. DOS. With conventional manometry a diagnosis of DOS was based on the presence of rapid simultaneous contractions with wave velocities of >7.5–8 cm often accompanied by peristaltic waves [4]. Distal latency is measured by taking the time from the start of UOS relaxation to the contractile deceleration point (CDP). The CDP

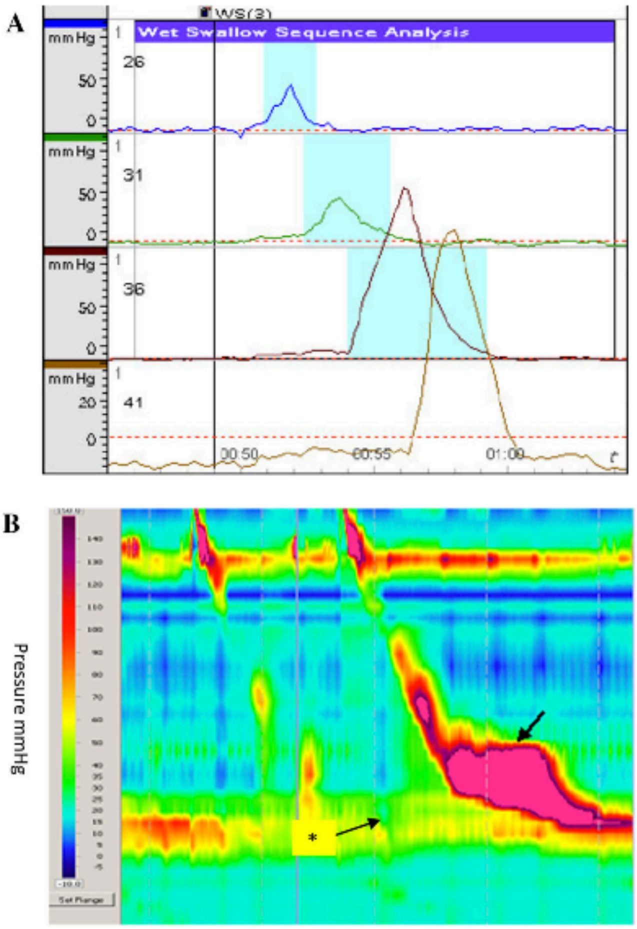

Fig. 3 Conventional line tracing illustrating nutcracker oesophagus vs. HRM plot. **a** Conventional line tracing illustrating nutcracker oesophagus with high amplitude waves in the distal oesophagus. **b** Spatiotemporal plot using HRM illustrating nutcracker oesophagus. *Arrows* indicates increased intrabolus pressure. The *asterisk* indicate a possible outlet obstruction as the sphincter is not relaxing fully and the IRP is >15 mmHg

is the inflection point that indicates the transition from peristaltic activity to the next phase of oesophageal emptying. The lower limit of normal established for the DL is 4.5 s [11]. Pandolfino et al. showed three distinct types of rapid propagation using these metrics: (1) rapid premature contractions with reduced latency, (2) premature contractions and (3) rapid contractions with normal latency which shows the variation in the types of spasm encountered. Under Chicago Classification guidelines, reduced distal latency with $\geq$20 % premature contractions with normal IRP is indicative of DOS. If the IRP is abnormal Type III achalasia may be suspected.

The 4-s IRP has also improved our ability to assess any functional abnormalities of the OGJ. The spatiotemporal plots that are generated by the software allow for a more visual and intuitive study of the swallows in real time, helping to identify any focal points where there may be a disruption to normal peristaltic activity. The main disadvantages are that the startup costs are high, but once established the costs per year are reasonably low and also specialist training is required. However, it is a quick and reliable method of studying motility and would be recommended as a standard in all GI physiology units.

In conventional manometry, nutcracker oesophagus has always been defined by the measurement of the mean amplitude of oesophageal contraction at 3 and 8 cm above the LOS [4]. In HRM not only wave amplitude is measured, but also duration and length of contraction. This is achieved using the distal contractile integral (DCI). The DCI is a measure of amplitude × duration × length of distal oesophageal contraction and is, in essence, a measure of contractile vigor. The Chicago classification working groups have endeavored to redefine the criteria for nutcracker disorders based on the diverse nature of hypercontractile disorders. Therefore two categories of hypertensive peristalsis have been established based on the mean DCI values obtained with 10 swallows. Category 1 is nutcracker oesophagus, where the mean DCI is 5,000–8,000 mmHg s cm and category 2, spastic nutcracker, now more commonly known as 'Jackhammer oesophagus' where the DCI is >8,000 mmHg s cm in just one swallow. The upper limit of 8,000 mmHg s cm was established as values above this have never been recorded in normal controls (Fig. 3).

In conclusion, the spectrum of use of traditional manometry in a specialist centre is highlighted in this series. Many of the limitations of the traditional approach are addressed by HRM, and new terminology is established which may guide treatment. The Chicago Classification group continues their endeavors to classify the varying motility disturbances, especially those that have a high degree of heterogeneity for, e.g. hypocontractile disorders of the oesophagus. This, we hope, will help to tailor treatments to affect a positive outcome for patients with such motility disturbances.

Acknowledgments Some of the data collected for this study were carried out under the guidance of Dr Patrick Byrne PhD before his retirement from St James's Hospital. I would like to extend much gratitude to Dr Byrne for his knowledge, guidance and friendship. The authors thank Given Imaging, Germany, for their permission to reproduce some pressure topography images.

Conflict of interest None.

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