High resolution manometry and multichannel intraluminal impedance oesophageal manometry in clinical practice

Inder Mainie

Correspondence to
Dr I Mainie, Belfast City Hospital,
The Belfast Trust, Lisburn
Road, Belfast BT9 7AB, UK;
indermainie@gmail.com

Accepted 11 December 2009
Published Online First
31 March 2010

The past decade has seen new technological advances in the investigation of oesophageal motility disorders. Multichannel intraluminal impedance monitoring has been used as an adjunct to conventional manometry in the assessment of oesophageal function, independent of radiography. High resolution manometry provides additional information over conventional manometry, and its topographic analysis makes interpretation of studies easier. Both utilities in non-obstructive dysphagia have been used ultimately in research; however, more studies are addressing their clinical application.

Introduction

Conventional manometry has been the standard modality in the investigation of oesophageal motility disorders for more than 50 years and the primary indications are as follows¹:

- (1) non-obstructive dysphagia;
- (2) unexplained chest pain;
- (3) evaluation of gastro-oesophageal reflux—prior to antireflux surgery, excluding scleroderma and prior to placement of (impedance)/pH probe; and
- (4) exclude a gastrointestinal motility disorder.

Oesophageal manometry provides information on the amplitude and velocity of the peristalsis but until recently bolus transport could only be investigated by radiological studies.² The 21st century has seen new technological advances in the clinical setting of oesophageal testing, including multichannel intraluminal impedance (MII) testing and high resolution manometry (HRM).

Multichannel intraluminal impedance

Impedance is opposition to current flow and is the measurement of resistance in an alternating current. It is inversely related

to the electrical conductivity of an organ's wall and contents; if conductivity is low, there is high impedance. Air has a much lower conductance than refluxate and therefore much higher impedance. When bolus changes from refluxate (liquid or mixed (liquid and gas)) to air, the electrical conductivity decreases and impedance increases.

Intraluminal impedance testing has increased since the start of the decade and is used as a clinical tool in the assessment of bolus transport, both antegrade and retrograde. Since its introduction by Silny in 1991, many studies have validated its application. Studies using simultaneous time recordings during impedance and video fluoroscopy have shown strong correlation between both.^{3–5}

Impedance changes are observed over a single pair of measurement rings separated by 2 cm. A rapid increase in resistance is noted when air travelling in front of the bolus head reaches the impedance measuring segment followed by a decrease in impedance once higher conductive bolus material passes the measuring site (figure 1). Lumen narrowing produced by the contraction transiently increases the impedance above baseline. Bolus entry is considered at the 50% decrease in impedance from baseline relative to nadir, and bolus exit is considered at the 50% recovery point from nadir to baseline.

The pressure transducers and impedance measuring segments are placed 5 cm apart. While the patient is in the supine position, the catheter (figure 2) is placed transnasally so that the distal circumferential pressure transducer is located in the high pressure zone of the lower oesophageal sphincter (LOS), with the additional pressure transducers at 5, 10, 15 and 20 cm above the LOS. The LOS is located using a stationary pull-through technique.

Figure 1 Bolus entry is considered at the 50% decrease in impedance from baseline relative to nadir and bolus exit is considered at the 50% recovery point from nadir to baseline.

Figure 2 Schematic representation of the nine channel catheter used in multichannel intraluminal impedance-oesophageal manometry. LOS, lower oesophageal sphincter; P, pressure transducer (circumferential transducers represented by bars, unidirectional transducers represented by circles); Z, impedance measuring segment (each measuring segment is made up of two impedance rings, placed 2 cm apart).

The catheter is connected to a computer that continuously records the manometry and impedance signals at 50 Hz. The tracings obtained during the study are interpreted using a dedicated software program (Bioview Analysis; Sandhill Scientific, Denver, Colorado, USA). The patients are then given 10 liquid swallows (5 ml of 0.9% saline solution) and 10 viscous swallows (5 ml OFT viscous; Sandhill Scientific).

The liquid swallows consist of saline as it is universally available and because its salt content decreases the impedance level. The viscous fluid is of apple sauce consistency and has a standardised impedance value (Sandhill Scientific). The swallows are spaced 20–30 s apart to allow oesophageal body and LOS recovery.

Tutuian *et al* studied the effect of position on oesophageal function. There was an almost perfect inverse linear correlation between angle of inclination

and bolus transit time.⁶ Srinivasan *et al* studied the total bolus transport time (TBTT) of liquid, semisolid (apple sauce) and solid (different size marshmallows) boluses. TBTT of liquid was found to be constant whereas TBTT of semisolid and solid were volume dependent and longer than liquids.⁷ An example of normal and abnormal bolus transit is shown in figure 3.

Normal has been defined as: distal contraction amplitudes (5 and 10 cm above the LOS) are both above ≥ 30 mm Hg and distal velocity is <8 cm/s. Manometric measurements can be classified as follows:

- (1) ineffective if one contraction amplitude (5 or 10 cm above the LOS) is <30 mm Hg and
- (2) simultaneous if contraction amplitudes (5 and 10 cm above the LOS) are both above 30 mm Hg but distal velocity is >8 cm/s.

Bolus entry is seen at the most proximal site (20 cm above the LOS) and exits at all three impedance measuring sites (5, 10, 15 and 20 cm) above the LOS. Normal bolus transit values can be classified as follows⁸:

- (1) complete bolus transit for liquid $>80\%$ of swallows and
- (2) complete bolus transit for viscous $>70\%$ of swallows.

In 2004, Tutuian *et al* published results on 350 patients using MII-EM. All patients with a diagnosis of achalasia or scleroderma had abnormal bolus transit whereas half of the patients with a manometric diagnosis of ineffective oesophageal motility (IOM) and distal oesophageal spasm (DOS) had a normal bolus transit. Almost all patients ($>95\%$) with normal oesophageal manometry, nutcracker oesophagus, poorly relaxing LOS, hypertensive LOS and hypotensive LOS had normal bolus transit. Using impedance as an adjunct to manometry, the authors concluded that patients with LOS abnormalities were unlikely to have abnormal bolus transit and MII may help further categorise those patients with an abnormal manometric diagnosis.

In the 70 patients with a manometric diagnosis of IOM, 48% of liquid swallows and 38% of viscous swallows showed complete bolus transit, with one-third showing normal bolus transit for both. The results of this study found that using three or more weak or failed peristaltic controls as the manometric diagnosis of IOM was too sensitive but lacked specificity. The authors concluded that using combined MII-oesophageal manometry (MII-OM) could help better characterise these patients with IOM into normal (those with normal bolus transit for both liquid and viscous), moderate (those with abnormal bolus transit for liquid or viscous) or severe (those with abnormal bolus transit for both liquid and viscous).⁹

Another study from the same group analysed 71 patients with DOS in more detail.¹⁰ As already mentioned, half of the patients with a manometric diagnosis of DOS had normal bolus transit for both liquid and solids. Patients

Figure 3 Two examples of tracings from multichannel intraluminal impedance-oesophageal manometry (MII-OM) testing are shown. (A) MII-OM in a normal patient. The impedance portion demonstrates bolus clearance with entry and exit at each site above the lower oesophageal sphincter (LOS). The manometry portion demonstrates normal oesophageal body contractions at each site with normal LOS relaxation. (B) MII-OM in a scleroderma patient. The impedance portion demonstrates incomplete exits in all three sites (ie, 15, 10 and 5 cm above the LOS). The manometry portion demonstrates normal contraction amplitude in the most proximal site but low contraction amplitudes in the remaining sites. OS relaxation pressure is also lower than normal.

presenting with chest pain had higher contraction amplitudes and were more likely to have normal bolus transit compared with patients with dysphagia or atypical gastro-oesophageal reflux disease symptoms. Using combined MII-OM, the authors concluded that appropriate medical therapy may be different for those patients with a diagnosis of DOS and normal bolus transit compared with DOS patients with abnormal bolus transit.

For patients with a diagnosis of achalasia, impedance provides no additional benefit over the manometric investigation. These patients already have fluid stasis and therefore a low impedance baseline. We studied 20 patients with achalasia and 15 with scleroderma using MII-OM, and while the overall bolus transit was impaired in both groups, patients with scleroderma showed normal regional pressure and bolus transit in the proximal oesophagus.^{10,11}

Oesophageal manometry is an accepted part of the preoperative evaluation prior to antireflux surgery.¹² Patients may experience persistent postoperative dysphagia following surgery.¹¹ Using technetium-99m jello to assess bolus transit, Hunt *et al* studied 26 patients preoperatively and were able to detect a subtle functional motility disorder that predisposed

to postoperative dysphagia and hence predict surgical outcome.¹³ Yigit *et al* showed that MII after fundoplication was more commonly abnormal in patients with abnormal fundoplication anatomy and/or dysphagia but more recently the same group looked at MII as a predictor of postoperative dysphagia after laparoscopic Nissen fundoplication and found that it was not predictive.^{14,15}

Rumination

Rumination syndrome is characterised by effortless and repeated regurgitation of small amounts of food from the stomach into the mouth. The combination of MII-OM can identify the sequence of events by placing the distal pressure transducer within the stomach. The increase in intragastric pressure is recorded by the pressure transducer and the refluxate in the oesophagus by the impedance rings.¹⁶ As well as using MII-OM to identify rumination, it can be then used in biofeedback as a treatment modality.

High resolution manometry

Conventional manometry uses between five and eight transducers over the length of the catheter. In 1991, Clouse and Staiano made several technological

advances on conventional manometry by using micro-manometry on a water perfused system and creating up to 12 miniature transducers at each centimetre, thus giving an average pressure over this area. This created multiple circumferential sensors over the entire length of the catheter, 1 cm apart.

Measurements from a single pressure sensor may be misleading and using a sleeve sensor measures the highest pressure over a 5–6 cm area. In HRM a virtual sleeve is constructed, therefore observing local changes of pressure and location within this area that are impossible with conventional techniques. The 'gold standard' conventional manometry uses a pull-through technique to identify the resting pressures of the LOS and upper oesophageal sphincter (UOS). The new HRM can be either water perfused or solid state catheters with up to 36 sensors, 1 cm apart, allowing for easy LOS location and assessment compared with the conventional LOS stationary pull-through which can be time consuming. A study by Sadowski *et al* showed that there was a time saving of 26% comparing HRM and conventional manometry and no difference in discomfort between the two groups.¹⁷

Both sphincters can be accurately assessed and quantified due to the high concentration of pressure sensors overcoming difficulties of movement of the sphincters during relaxation, oesophageal shortening, the presence of a hiatus hernia, crural changes during respiration and the intrabolar pressure. HRM has demonstrated that the pressure inversion point is caused by sliding of the high pressure zone along pressure sensors rather than by movement from the abdominal cavity into the thoracic cavity.¹⁸

The typical 'double high pressure zone' or 'double hump' seen during the conventional stationary manometric pull-through can also be seen as two pressure peaks with HRM.^{19–20} However, when using conventional manometry, the high pressure zone created by the diaphragm can be mistaken for the LOS and therefore cause inaccurate placement of the (impedance) pH/catheter.²⁰ HRM is also comparable with conventional manometry in the characterisation of transient lower oesophageal relaxations.²¹

The high density of transducers across the catheter generates a large amount of information which is converted into a spatiotemporal plot displaying a colour topographic image. The data are presented in isocontour plots as a space–time continuum with time on the x axis, axial position of the pressure sensors on the y axis and pressure magnitude on the z axis scaled by colour intensity. The final presentation of the data makes interpretation easier and more understandable.

The final topographic analysis of each swallow demonstrates that normal oesophageal peristalsis is not seamless but made up of four separate pressure segmental events and three pressure troughs. The first segment represents the striated muscle in the proximal

oesophagus and extends from the UOS to the first pressure trough. The first trough is located in the region of the aortic arch and represents the transition zone. The second and third segments compromise the smooth muscle portion of the oesophagus and are divided by the second trough. The final pressure segment follows after the third trough and is the LOS (figure 4).²²

With the presence of transducers from the pharynx to the stomach, the UOS opening and transphincteric flow can be accurately assessed. A study by William *et al* compared pharyngeal swallows using HRM and video fluoroscopy simultaneously. They concluded that HRM was accurate at defining the pharyngo-oesophageal segment space–time–pressure and movement across the UOS during a normal swallow.²³

Fox *et al* compared HRM, conventional manometry and video fluoroscopy in healthy volunteers and patients. They demonstrated that HRM was more accurate at predicting abnormal bolus transport than conventional manometry and identifying motor dysfunction compared with manometry and video fluoroscopy. They estimated that HRM could give a definite diagnosis to endoscopic negative dysphagic patients in approximately 10% of patients with a non-diagnostic conventional manometry.²²

The Chicago group has published extensively on HRM and the Chicago classification refers to data accumulation and analysis of 75 normal subjects and 400 patients. Table 1 contains the most recent modifications.²⁵

Using their subclassification of achalasia, the investigators evaluated treatment response for each group. Type II patients were significantly more likely to respond to any therapy (Botox (71%), pneumatic dilation (91%) or Heller myotomy (100%)) than type I (56% overall) or type III (29% overall) patients. They concluded that classifying achalasia patients into the various subtypes could determine the appropriateness of their treatment.²⁵

The advantage of HRM over conventional manometry is the additional information of the patterns of the pressure topographic plots. Measurement of peristaltic amplitude with conventional manometry poorly

Figure 4 An example of a normal high resolution manometry spatiotemporal plot. The final topographic analysis of each swallow demonstrates that oesophageal peristalsis is not seamless but made up of four separate pressure segmental events and three pressure troughs. Courtesy of Pandolfino and colleagues²² (modified). LOS, lower oesophageal sphincter; UOS, upper oesophageal sphincter.

Table 1 The most recent modification to Chicago classification of oesophageal motility disorders

Disorder	Criteria
With normal OGJ relaxation (mean IRP <15 mm Hg)	
Absent peristalsis	100% swallows with absent peristalsis
Hypotensive peristalsis	
Intermittent	More than 30% of swallows with hypotensive or absent peristalsis
Frequent	≥70% of swallows with hypotensive or absent peristalsis
Hypertensive peristalsis	Normal CFV _{fast} , mean DCI >5000 and <8000 mm Hg/s/cm or LOS after contraction >180 mm Hg
Spastic nutcracker	Normal CFV _{fast} , mean DCI >8000 mm Hg/s/cm
Distal oesophageal spasm	Spasm (CFV _{fast} >10 cm/s) with ≥20% of swallows
Segmental	Spasm limited to S2 or S3
Diffuse	Spasm involving both S2 and S3
With impaired OGJ relaxation (IRP ≥15 mm Hg)	
Achalasia	
Classic achalasia (type I)	Mean IRP ≥15 mm Hg, absent peristalsis
Achalasia with oesophageal compression (type II)	Mean IRP ≥15 mm Hg, absent peristalsis and panoesophageal pressurisation with ≥20% of swallows
Spastic achalasia (type III)	Mean IRP ≥15 mm Hg, absent peristalsis and spasm (CFV >10 cm/s) with ≥20% of swallows
Functional OGJ obstruction*	Normal CFV _{fast} , IBP _{esoph} ≥30 mm Hg with ≥30% of swallows compartmentalised above OGJ with type I OGJ
Functional LOS obstruction*	Normal CFV _{fast} , IBP _{esoph} ≥30 mm Hg with ≥30% of swallows compartmentalised above the LOS with type II or III OGJ
Functional CD obstruction	Normal CFV _{fast} , IBP _{esoph} ≥30 mm Hg with ≥30% of swallows compartmentalised above the CD with type II or III OGJ

*May represent an achalasia variant.

CD, crural diaphragm; CFV, contractile front velocity; DCI, distal contractile integral; IBP, intrabolus pressure; IRP, integrated relaxation pressure; LOS, lower oesophageal sphincter; OGJ, oesophagogastric junction.

predicts oesophageal clearance. Oesophageal clearance is dependent on the balance between peristaltic integrity and outflow obstruction at the oesophagogastric junction. HRM can simultaneously track peristaltic clearing wave pressure, intrabolus pressure and residual oesophagogastric junction pressure during the postdeglutitive period, thereby quantifying the time during which the intraluminal pressure gradient favours outflow (flow permissive time). Flow permissive time >2.5 s is strongly correlated with complete oesophageal clearance, as verified by concurrent fluoroscopy.

Combined HRM impedance testing is the new kid on the block. This new technology is a combination of both HRM and impedance testing on the one catheter. Its utility is still in its infancy but it should provide us with both contractility and bolus transit dynamics.

Conclusions

These two evolving technologies have improved the assessment of oesophageal function providing greater detail and information. MII-OM provides the investigator with oesophageal function independent of radiation and the benefits of impedance have also been shown in the assessment of non-acid reflux.

Currently HRM has focused on new horizons regarding the transition zone and the complexities of the LOS. The unique concentration of transducers has made placement both quicker and easier and new analytical software has made interpretation easier and faster than conventional manometry. Future studies may help in the clinical setting in how to treat the various types of achalasia and those with non-obstructive dysphagia.

Competing interests None.

Provenance and peer review Commissioned; externally peer reviewed.

References

- Pandolfino JE, Kahrilas PJ. American Gastroenterological Association medical position statement: clinical use of esophageal manometry. *Gastroenterology* 2005;128:207–8.
- Massey BT, Dodds WJ, Hogan WJ, *et al.* Abnormal esophageal motility. An analysis of concurrent radiographic and manometric findings. *Gastroenterology* 1991;101:344–54.
- Silny J. Intraluminal multiple electric impedance procedure for measurement of gastrointestinal motility. *J Gastrointest Motil* 1991;3:151–62.
- Silny J, Knigge KP, Fass J, *et al.* Verification of the intraluminal multiple electrical impedance measurement for the recording of gastrointestinal motility. *J Gastrointest Motil* 1993;5:107–22.
- Imam H, Shay S, Ali A, *et al.* Bolus transit patterns in healthy subjects: a study using simultaneous impedance monitoring, videoesophagram, and esophageal manometry. *Am J Physiol Gastrointest Liver Physiol* 2005;288:G1000–6.
- Tutuian R, Elton JP, Castell DO, *et al.* Effects of position on oesophageal function: studies using combined manometry and multichannel intraluminal impedance. *Neurogastroenterol Motil* 2003;15:63–7.
- Srinivasan R, Vela MF, Katz PO, *et al.* Esophageal function testing using multichannel intraluminal impedance. *Am J Physiol Gastrointest Liver Physiol* 2001;280:G457–62.
- Tutuian R, Vela MF, Balaji NS, *et al.* Esophageal function testing with combined multichannel intraluminal impedance and manometry: multicenter study in healthy volunteers. *Clin Gastroenterol Hepatol* 2003;1:174–82.
- Tutuian R, Castell DO. Combined multichannel intraluminal impedance and manometry clarifies esophageal function

- abnormalities: study in 350 patients. *Am J Gastroenterol* 2004;**99**:1011–19.
10. Tutuian R, Mainie I, Agrawal A, *et al.* Symptom and function heterogeneity among patients with distal esophageal spasm: studies using combined impedance-manometry. *Am J Gastroenterol* 2006;**101**:464–9.
 11. Mainie I, Tutuian R, Patel A, *et al.* Regional esophageal dysfunction in scleroderma and achalasia using multichannel intraluminal impedance and manometry. *Dig Dis Sci* 2008;**53**:210–16.
 12. Pandolfino JE, Kahrilas PJ. AGA technical review on the clinical use of esophageal manometry. *Gastroenterology* 2005;**128**:209–24.
 13. Hunt DR, Humphreys KA, Janssen J, *et al.* Preoperative esophageal transit studies are a useful predictor of dysphagia after fundoplication. *J Gastrointest Surg* 1999;**3**:489–95.
 14. Yigit T, Quiroga E, Oelschlager B. Multichannel intraluminal impedance for the assessment of post-fundoplication dysphagia. *Dis Esophagus* 2006;**19**:382–8.
 15. Montenovo M, Tatum RP, Figueredo E, *et al.* Does combined multichannel intraluminal esophageal impedance and manometry predict postoperative dysphagia after laparoscopic Nissen fundoplication? *Dis Esophagus* 2009;**22**:656–63.
 16. Tutuian R, Castell DO. Rumination documented by using combined multichannel intraluminal impedance and manometry. *Clin Gastroenterol Hepatol* 2004;**2**:340–3.
 17. Sadowski DC, Broenink L. High-resolution esophageal manometry: a time motion study. *Can J Gastroenterol* 2008;**22**:365–8.
 18. Bredenoord AJ, Weusten BL, Roelofs JM, *et al.* The gastro-oesophageal pressure inversion point revisited. *Scand J Gastroenterol* 2003;**38**:812–18.
 19. Agrawal A, Tutuian R, Hila A, *et al.* Identification of hiatal hernia by esophageal manometry: is it reliable? *Dis Esophagus* 2005;**18**:316–19.
 20. Bredenoord AJ, Weusten BL, Carmagnola S, *et al.* Double-peaked high-pressure zone at the esophagogastric junction in controls and in patients with a hiatal hernia: a study using high-resolution manometry. *Dig Dis Sci* 2004;**49**:1128–35.
 21. Bredenoord AJ, Weusten BL, Timmer R, *et al.* Sleeve sensor versus high-resolution manometry for the detection of transient lower esophageal sphincter relaxations. *Am J Physiol Gastrointest Liver Physiol* 2005;**288**:G1190–4.
 22. Pandolfino JE, Ghosh SK, Rice J, *et al.* Classifying esophageal motility by pressure topography characteristics: a study of 400 patients and 75 controls. *Am J Gastroenterol* 2008;**103**:27–37.
 23. Williams RB, Pal A, Brasseur JG, *et al.* Space-time pressure structure of pharyngo-esophageal segment during swallowing. *Am J Physiol Gastrointest Liver Physiol* 2001;**281**:G1290–300.
 24. Fox M, Hebbard G, Janiak P, *et al.* High-resolution manometry predicts the success of oesophageal bolus transport and identifies clinically important abnormalities not detected by conventional manometry. *Neurogastroenterol Motil* 2004;**16**:533–42.
 25. Staiano A, Clouse RE. Detection of incomplete lower esophageal sphincter relaxation with conventional point-pressure sensors. *Am J Gastroenterol* 2001;**96**:3258–67.