Pressure-Flow Characteristics of Normal and Disordered Esophageal Motor Patterns

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Objective To perform pressure-flow analysis (PFA) in a cohort of pediatric patients who were referred for diagnostic manometric investigation.

Study design PFA was performed using purpose designed Matlab-based software. The pressure-flow index (PFI), a composite measure of bolus pressurization relative to flow and the impedance ratio, a measure of the extent of bolus clearance failure were calculated.

Results Tracings of 76 pediatric patients (32 males; 9.1 ± 0.7 years) and 25 healthy adult controls (7 males; 36.1 ± 2.2 years) were analyzed. Patients mostly had normal motility (50%) or a category 4 disorder and usually weak peristalsis (31.5%) according to the Chicago Classification. PFA of healthy controls defined reference ranges for PFI ≤142 and impedance ratio ≤0.49. Pediatric patients with pressure-flow (PF) characteristics within these limits had normal motility (62%), most patients with PF characteristics outside these limits also had an abnormal Chicago Classification (61%). Patients with high PFI and disordered motor patterns all had esophagogastric junction outflow obstruction.

Conclusions Disordered PF characteristics are associated with disordered esophageal motor patterns. By defining the degree of over-pressurization and/or extent of clearance failure, PFA may be a useful adjunct to esophageal pressure topography-based classification. *(J Pediatr 2015;166:690-6)*.

The Chicago Classification establishes normative values and guidelines for the diagnostic evaluation of esophageal motility by high resolution manometry. The Chicago Classification groups esophageal motor dysfunction into 4 main categories based on esophageal pressure topography (EPT) metrics. In order of severity, these disorder categories are achalasia (category 1), esophagogastric junction outflow obstruction (category 2), disorders never observed in healthy individuals (category 3; absent peristalsis, diffuse esophageal spasm or hypercontractile esophagus), and motor patterns outside the normal range (category 4; weak peristalsis, frequent failed peristalsis, hypertensive peristalsis, or rapid contraction).[1] With available technologies, esophageal motility evaluations are now relatively easy to perform in children. However, important metrics, particularly 4-second integrated relaxation pressure (IRP4s) of the esophagogastric junction and distal latency (DL), are affected by patient age and size.[2] This is problematic for translation of the Chicago Classification to pediatric settings and may lead to over diagnosis of disorders such as esophagogastric junction outflow obstruction and distal esophageal spasm.

Intraluminal impedance can be measured in conjunction with pressure to provide additional information regarding bolus flow (ie, high resolution impedance manometry [HRIM]). The standard approach to the analysis of impedance waveforms has been to use a categorical classification system based on determining the proportion of swallows that completely clears bolus residue.[3] The diagnostic value of intraluminal impedance recording has been potentially enhanced

AIM	Automated impedance manometry	PBS	Peristaltic break size
DCI	Distal contractile integral	PeakP	Peak pressure
DL	Distal latency	PF	Pressure-flow
EPT	Esophageal pressure topography	PFA	Pressure-flow analysis
GERD	Gastroesophageal reflux disease	PFI	Pressure-flow index
HRIM	High resolution impedance manometry	PNadImp	Pressure at the time of nadir impedance
IBP	Intrabolus pressure	Pre-LAGB	Pre-laparoscopic gastric band placement
IR	Impedance ratio	TNadImp-PeakP	Time from nadir impedance to PeakP
IRP4s	4-second integrated relaxation pressure	UES	Upper esophageal sphincter

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by pressure-flow analysis (PFA). This approach may provide additional physiological insights by directly integrating impedance measurements, defining bolus flow, with pressure measurements, defining the forces that drive flow. PFA is readily automated making it simple to perform and has been shown to be reproducible in the hands of experienced and inexperienced users alike.[4]

In patients with dysphagia PFA has identified 2 predominant patterns of abnormality. First, excessive flow resistance during bolus propulsion and second, extreme degrees of bolus retention when bolus transport is incomplete.[5-10] In addition, PFA metrics have been found to correlate with symptom perception and intensity.[5-7] Therefore, PFA may complement routine diagnosis based on the Chicago Classification, as it offers the possibility of quantifying degrees of pressure-flow (PF) dysfunction among individuals who have an equivocal Chicago Classification diagnosis. Alternatively, PFA could provide corroborative evidence of flow resistance which could further support a diagnosis of esophagogastric junction outflow obstruction and, theoretically, guide the need for interventions such as esophagogastric junction dilatation.

The aim of this study was, therefore, to assess the added value of applying PFA to pediatric HRIM recordings. The first step was to perform PFA in a cohort of pediatric patients studied using HRIM; secondly to assess the relationship between EPT metrics and PFA metrics; and thirdly, to correlate both EPT and PFA metrics with the intensity of dysphagia symptoms. We hypothesized that patients within the different Chicago Classification categories would exhibit different PF characteristics and that greater PF abnormalities would be associated with more severe symptoms.

Methods

HRIM recordings of liquid and viscous swallows of pediatric patients <18 years were extracted from a database of studies conducted at the Gastroenterology Unit of the Women's and Children's Hospital, Adelaide, Australia between May 2010 and September 2013. All studies were previously allocated an age-adjusted Chicago Classification.[2] Patient studies were excluded if they were not considered evaluable because of technical or protocol violation reasons. Studies performed in patients studied postachalasia intervention (ie, myotomy or dilatation) were also excluded from analysis. Studies from 25 healthy adult subjects aged 20-50 years and free from gastrointestinal symptoms were also evaluated for comparison (7 males; mean age 36.1 ± 2.2 years). Access to study files of patients who underwent esophageal manometry investigation was approved by the Women's and Children's Hospital Human Research Ethics Committee.

Patients (or their parent guardian) completed a symptom assessment questionnaire, including a validated dysphagia questionnaire modeled on the composite dysphagia score of Dakkak and Bennett.[11] This assessing dysphagia for 9 different food types with increasing viscosity (water to meat; scale 0-45; no dysphagia = 0).

The esophageal motor function of all subjects was assessed using a 3.2 mm diameter solid state manometric and impedance catheter incorporating 25 1 cm-spaced pressure sensors and 12 adjoining impedance segments, each of 2 cm (Unisensor USA Inc, Portsmouth, New Hampshire). Pressure and impedance data were acquired at 20 Hz (Solar GI Acquisition System; Medical Measurement Systems, Enschede, The Netherlands). Patients were intubated after application of topical anesthesia (2% lignocaine spray or gel) and studied sitting or held by a parent in the upright posture. Adult controls were studied in a sitting posture, using the same catheter and methods. If the pressure-impedance sensor array was not long enough to accommodate the entire region from upper esophageal sphincter (UES) to esophagogastric junction, the catheter was positioned with sensors straddling the distal esophagus from transition zone to stomach. Ten liquid and 10 viscous test boluses were administered orally via syringe. Bolus volume ranged from 3-10 mL depending on patient size and bolus tolerance. Controls were given 5 × 5 mL and 5 × 10 mL boluses. The interval between consecutively administered swallows was >20 seconds.

Swallows were excluded from analysis if bolus passage into the proximal esophagus was not clearly discernable on the impedance recording, or if secondary swallows overlapped and inhibited the propagating pressure wave. A minimum of 3 adequately captured individual swallows was considered sufficient for PFA analysis. To perform PFA, raw pressure-impedance data for all swallows were visualized over a 30-second window and exported from the recording system in ASCII text format. Data was then uploaded and analyzed using purposed designed software (AIM*plot* copyright T Omari; MATLAB v 2012a, MathWorks Inc, Natick, Massachusetts). Seven PF variables were derived from the automated analyses: (1) peak pressure (PeakP, mm Hg); pressure recorded at maximum contractile tension; (2) median intrabolus pressure (IBP, mm Hg); IBP recorded during luminal emptying; (3) pressure at the time of nadir impedance (PNadImp, mm Hg); IBP recorded when the esophageal lumen is maximally filled by the bolus; (4) IBP slope (IBP slope, mm Hg s^{-1}); rate of change in IBP recorded during luminal emptying; (5) time interval between nadir esophageal impedance and peak esophageal pressure (time from nadir impedance to PeakP [TNadImp-PeakP], seconds); time interval from maximally full lumen to maximal contractile tension; (6) impedance ratio (IR, NadImp/ImpPeakP ratio); the ratio of nadir impedance to impedance at the time of PeakP as a measure of effective bolus transit; and (7) PF index (PFI); a composite measure of bolus pressurization relative to flow. The PFI is calculated using the formula PFI = (IBP × IBP slope)/(TNadImp-PeakP) and appears to be higher in circumstances of PF abnormality.

PF metrics were derived for the whole esophagus from UES to esophagogastric junction for both liquid and viscous boluses. Unless otherwise indicated, results of PFA are displayed as mean values for the distal esophagus from transition zone to esophagogastric junction. Patient