Evaluation of Gastrointestinal Motility and its Disorders

Uday C. Ghoshal
Editor

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Dedicated to the memory of my parents Shanti Sudha Ghoshal (10.10.1926–12.12.2005) and Nalini Ranjan Ghoshal (7.12.1919–29.11.2012) who taught me everything, particularly Sincerity, Simplicity and Struggling ability.

Preface

Remarkable advances in modern medicine could not have been achieved without the advances in sciences and technologies, which have provided big breakthroughs in our understanding, diagnosis, and management of diseases. Thanks to the development of new technologies, such as endoscopy, ultrasonography, computerized tomography, and magnetic resonance imaging, gastroenterologists are now enlightened by the new concepts and are armed with revolutionary and powerful weapons for diagnosis and management of patients with gastrointestinal (GI) diseases. It is difficult to imagine today the degree of limitation that gastroenterologists had in the past when such technologies were not available, or were only in their primitive stages of development. One example of such technology is the GI motility study and related investigative techniques. These techniques help in evaluating abnormalities in normal GI motility in patients presenting with various functional gastrointestinal disorders, which made remarkable advances in our understanding on GI motility and related disorders. If these investigative techniques were not available, it would not have been possible to demonstrate the abnormalities in physiology in patients suffering from so-called functional GI disorders, which are mistakenly thought to be entirely psychogenic in origin.

We remember the first appearance of the GI manometry system which was equipped with a high-pressure nitrogen tank, low-compliance pneumohydraulic infusion capillaries, external pressure transducers, and a water-perfused catheter. Pressure tracings were recorded on a long paper usually several meters in length. Manual analysis of the pressure tracings took a long time. In those days, it was really time- and effort-consuming work for the motility experts to perform and interpret the manometry studies. With the advance of technology, the long recording paper was replaced by digital recording in a computer, displayed on a monitor. Manual analysis of the pressure tracings was replaced by computer analysis using software. With these technological advances, though the workload of the motility experts was reduced, their understanding enormously improved.

A revolutionary advance of the manometry system appeared in this new millennium with the development of high-resolution manometry (HRM). The difference of HRM from conventional manometry was not a simple change in resolution from an increase in the number of pressure sensors. The HRM system was a great game changer and led our concepts in 2D analog dimension into the 3D digital world. It provided us a new insight in this field and eventually led to a completely new

classification of motility disorders. Development of an impedance measuring technique and its integration into the HRM system provided us another breakthrough in understanding an actual status of the bolus transports with the pressure events.

Ambulatory esophageal pH monitoring system provided us with a confirmatory tool for diagnosis of gastroesophageal reflux, although not perfect. This system combined with impedance sensors could measure movements of the contents and their natures (pH and gas/liquid). This technique enabled us to develop our ideas on the movements of weakly acidic or non-acidic and even gaseous contents which could not have been measured before.

Techniques to evaluate lower GI functions including motility were also developed by pioneers in this field. These are colonic transit study using radio-opaque markers, anorectal manometry and balloon expulsion test, defecography, and hydrogen breath test. Of course, these advances in technologies led us to broaden our understanding in lower GI physiology and pathophysiology, followed by subsequent advances in patient management.

In this book, principles, techniques, interpretations, and clinical applications of these GI motility tests are reviewed and discussed by experts, mostly from Asia, who have enormous expertise in this field. Therapeutic as well as diagnostic strategies in managing patients with GI motility and functional disorders are also discussed by well-known authors who have experience in managing patients with these disorders.

This book is recommended to be included and read as one of the important reference books at GI clinics and motility laboratories in Asia and the rest of the world.

I highly appreciate the efforts of Dr. Uday C. Ghoshal for his excellent weaving and writing of this book and all the authors who willingly agreed to share their up-to-date knowledge and experiences for the meticulous writings of their chapters.

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Contents

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Abbreviations

ARA	Anorectal angle
ARJ	Anorectal junction
ARM	Anorectal manometry
CDP	Contractile deceleration point
CFV	Contractile front velocity
DL	Distal latency
EAS	External anal sphincter
EGJ	Esophago-gastric junction
EMG	Electromyography
GERD	Gastroesophageal reflux disease
GI	Gastrointestinal
HBT(s)	Hydrogen breath test(s)
HRM	High-resolution manometry
IAS	Internal anal sphincter
IBS	Irritable bowel syndrome
IBS-C	Irritable bowel syndrome-constipation
IRP	Integrated relaxation pressure
LES	Lower esophageal sphincter
PCL	Pubococcygeal line
PFD	Pelvic floor dyssynergia
PIP	Pressure inversion point
PPI	Proton pump inhibitor
RAIR	Recto-anal inhibitory reflex
ROC	Receiver operative characteristic
SI	Symptom index
SIBO	Small intestinal bacterial overgrowth
STC	Slow transit constipation
TLESR	Transient lower esophageal sphincter relaxation
UES	Upper esophageal sphincter

Overview of the Manometry Machine

1

Geoffrey S. Hebbard

Abstract

The manometry machine measures pressures from the lumen of the gastrointestinal tract using a catheter placed in the region to be studied. A number of types of manometry systems are available, but all record data digitally to a computer for analysis. The different systems utilize a variety of technologies to record pressure and to transmit the pressure signal to the computer. This determines the cost of the machine and ease of use, but in the end, all record intraluminal and wall contact pressure with acceptable accuracy for clinical diagnosis and physiological investigations, provided the properties of the machine and recording catheter are suited to the physiological and anatomical characteristics of the region to be studied. Factors to be considered include the spacing and orientation of the pressure sensors, the rate of rise of pressure to be recorded, accuracy of pressure measurement, and the rate of digitization of the signal (temporal resolution). In some situations it may be advantageous to record pressures in parallel with other data such as images or intraluminal impedance to allow correlation between pressure and transit.

Keywords

Manometry • Pressure • Catheter • Silicone • Solid state

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Introduction

The purpose of manometry is to record pressures from the gastrointestinal tract in order to either make a clinical diagnosis or to provide data for research studies into the function of the gut. The characteristics of the recording system required to record the pressure data can be defined in terms of the spatial resolution (distance between the recording points), temporal resolution (rate of pressure measurement sampling), and the accuracy with which pressure is measured. These characteristics vary depending on the part of the gastrointestinal system being investigated, determined by the anatomy of the region and the characteristics of the pressures generated.

Over the past 20 years, manometric recording has undergone a revolution in technology based on the use of digital recording techniques, as well as changes in the number and spacing of sensors that can be used to record pressures. Recording systems have evolved from single or low channel count pull-through systems with paper chart recorders to sophisticated digital systems with the ability to record at high resolution and display the resultant pressures as high resolution spatiotemporal plots.

Broadly, there are two general types of manometric recording systems, differentiated by whether the sensors are located within the catheter itself, or externally (in which case pressures are transmitted along a column of water perfused slowly through the catheter). Each of these systems has its advantages and disadvantages, but once the signal is digitized and recorded to the computer, the principles are very similar between the types of recording systems, as shown in Fig. 1.1 and Table 1.1.

Systems utilizing intraluminal transducers (solid state or optical catheters, Fig. 1.1) are simple to operate; the recording catheter is connected and calibrated, then passed directly into the subject. As the transducers are located at the point that the pressure being measured, the dynamic performance of these systems (as measured by the rate of rise of pressure that can be recorded) is excellent. As the solid-state catheter is an electronic device however, individual catheters are expensive and fragile, as well as being generally stiffer and wider than a water-perfused catheter. In addition, these catheters may be sensitive to temperature change, with small changes in temperature causing fluctuations in apparent pressure, which may require temperature compensation measurement, or may lead to "drift" where the recording baseline of individual channels changes with time. An optically based catheter has recently been developed which has the advantage of data being transmitted via a central optical fiber connected to all transducers, meaning that for these catheters, the diameter of the catheter is not related to the number of recording channels, and the catheter remains highly flexible and thin even for up to 96 recording points (Fig. 1.2).

Water-perfused manometry systems (Fig. 1.1) utilize external transducers which are connected to a multi-lumen silicone or PVC catheter. Water is perfused through the transducers, and then through the catheter by a pneumohydraulic pump, with the rate of flow of the water for each channel determined by the resistance of a capillary

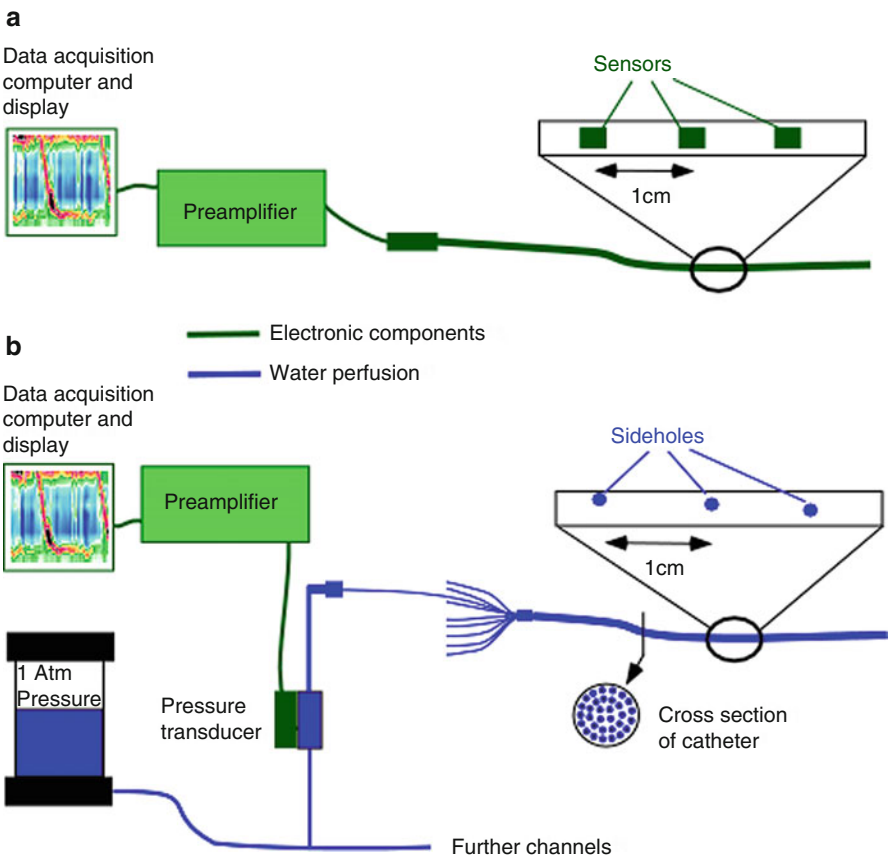

Fig. 1.1 Comparison of different types of manometry machine. (**a**) Intraluminal transducer (solid state or optical sensor); (**b**) water-perfused (silicone or PVC catheter)

Table 1.1 Comparison of intraluminal transducer and water-perfused catheters

Characteristic	Intraluminal transducer	Water-perfused
Cost of catheter	High (US 10–20 k)	Moderate (US 1 k)
Ease of use	Good	Moderate
Catheter material	Plastics/electronic Parts	Silicone/PVC
Site of transducer	In catheter	External
Pressure rise rate	High	Medium
Minimum channel spacing	7 mm	Any
Reprocessing	Chemical	Autoclave (silicone)
Sensor orientation	Unidirectional or circumferential	Unidirectional (circumferential if multiple sideholes)

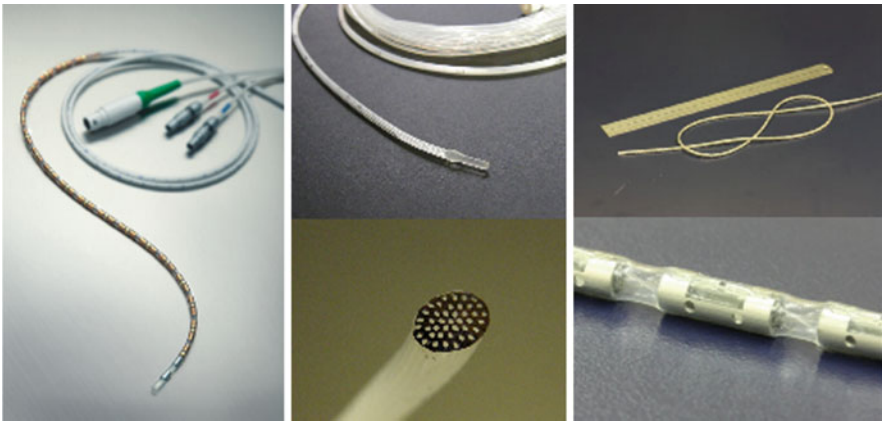

Fig. 1.2 Comparison of different manometric catheters. From *top left* to *far right*: optical catheter, demonstrating flexibility; 16-channel silicone catheter for esophageal manometry; 36-channel solid-state catheter (Image courtesy of Given Imaging). From *bottom left* to *right*: cross-section of 41-channel silicone manometric catheter; close-up of optical sensors

which is placed "upstream" of the catheter. As the catheters do not contain any electronic components, they are considerably cheaper, and generally thinner and more flexible (hence more comfortable for the patient) than the solid-state catheters, however the dynamic performance (pressure rise rate) is not as high, which may be a limiting factor where pressures increase rapidly (e.g., in the pharynx). In addition, the need for a pneumohydraulic pump to perfuse the catheter requires some extra steps to prime the pump with water prior to, and empty the pump after, a series of studies.

Regardless of the mechanism by which the pressure is measured, once the signal is digitized, it is transmitted to a computer for display and recording. Generally, the rate of digitization and number of digitization steps should not be limiting, and a sampling rate of 25 Hz, with a 16 bit analog to digital converter (providing about 65,000 digitization steps) should be adequate for most GI physiology studies, being less limiting in accuracy than the mechanical and other factors described above. The exact details of the digitization, display of the digitized signal, and interpretation is specific to the software and recording system, but the general principles are discussed below.

Spatial Resolution

The general principle to be followed in determining the adequacy of spatial resolution for manometry in the GI tract is that the spacing of sensors should be such that they record all mechanically significant pressure events and, if interpolation between channels is being used to generate a spatiotemporal topographic plot (Fig. 1.3), the channels should be sufficiently closely spaced to ensure that this is a valid

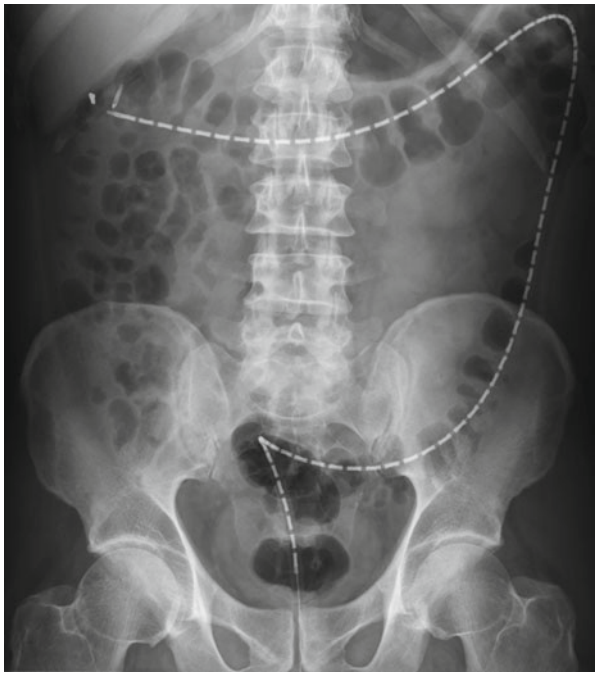

Fig. 1.3 X-ray of a 96-channel optical catheter placed in the colon

assumption. Ideally, pressure would be measured continuously along the manometric catheter, but at present this is not possible, and in all systems available at present, pressure is measured at discrete points, sometimes with a specific radial orientation on the manometry catheter. Generally, recording at 1 cm intervals is considered adequate across the lower esophageal sphincter and in the pharynx. In the body of the esophagus the optimum distance has not been determined, but commercially available systems record at distances of 1–3 cm. The advantage of recording at 1 cm intervals throughout the pharynx and esophagus for esophageal manometry is that the precise position of catheter placement and movement during a study are less critical than if a specific region of the catheter needs to be positioned in the lower esophageal sphincter. In specific regions such as the pylorus or sphincter of Oddi, spacings at less than 1 cm intervals may be required, for example at the pylorus spacings of 3 mm are required to ensure that all mechanically significant pressures are recorded. In the colon, spacings of 5 cm have previously been considered adequate (based on what could be achieved using the available technologies), but more recent studies using more closely spaced sensors have shown that the data obtained with the larger sensor spacings may have significantly misinterpreted the direction of some propagated events. The effects of the radial orientation of the sensor depend on the structure being examined—for example, there is significant radial asymmetry of the upper and lower esophageal sphincters, however, exactly how this should be interpreted, and whether this makes a difference to the interpretation of physiological events or clinical diagnosis, is not certain.

Temporal Resolution

The frequency with which pressure samples are taken and recorded should generally not be an issue, as most current recording systems are capable of sampling at frequencies able to detect the changes in pressure encountered in the upper GI tract. Generally, recording at 25 Hz or above will provide excellent temporal resolution in the measurement of changes in pressure within GI tract.

Accuracy

The accuracy with which pressures are measured is vital to accurate interpretation of physiological events and is affected by a number of factors, including the characteristics and placement of the transducers, mechanical factors, transducer drift, and pressure artifacts. The differences in transducer and catheter measurement characteristics are discussed above. Mechanical factors affecting accuracy in water-perfused systems include changes in the pressure driving the pneumohydraulic pump, as well as the effects of perfusion of bubbles or particles through the capillary resistors, and changes in the resistance of the lumina of the catheter. These factors are preventable by the use of optimal technique, however this is more time-consuming than the use of solid-state catheters.

Transducer drift can affect any type of recording system and relates to instability in the "baseline" pressure recorded by a transducer, usually due to electrical issues with the transducer which may be faulty, or subject to a changing environment (e.g., temperature difference between where the catheter is "zeroed" and the subject in systems using intraluminal transducers). Changes in temperature affect the electrical characteristics of transducers, and intraluminal transducer catheters may need to be "compensated" for the effects of the difference between the ambient temperature and body temperature.

As pressure gradients are being measured along a catheter, an accuracy of 1–2 mmHg is required. The accuracy of pressure measured can be tested in a system by applying a known pressure to the transducers, generally utilizing the manufacturers' system supplied for calibration, and applying known pressures during recording. Pressures should rise in each transducer equally, and should be stable over a recording period of 20–30 min. Catheters can be placed in water baths to simulate placement in the gastrointestinal lumen, and recordings made over prolonged periods to determine whether electrical or mechanical drift is occurring.

Combining with Other Data Streams

One of the longstanding issues in the interpretation of manometry data is that the variable that is measured (pressure) does not directly correlate with transit. Indeed, quite large volumes of intraluminal content can move with minimal pressure change, provided resistance is sufficiently low, and conversely if resistance is

increased, high pressures may be required to move relatively small volumes. This has led to the concept that the value of pressure data can be enhanced by a concurrent measure of transit, and some manometry systems are capable of synchronizing pressure measurement with other data streams such as intraluminal impedance or X-ray images. This data is recorded to the same data file and can be analyzed with the pressure recording, allowing correlation between pressure and the transit of intraluminal contents.

Artifact Detection

The measurement of pressures within the gastrointestinal tract is subject to many potential artifacts. Some of these may arise from mechanical factors within the gastrointestinal tract such as compression by adjacent structures (e.g., vascular or the liver), or the catheter itself impinging on a wall of the gastrointestinal tract as it traverses a bend. Other artifacts are due to mechanical or electrical factors within the recording system, such as a faulty transducer or electronic components, or an incorrect or unstable electrical connection. Generally, artifacts will be recognized when one channel appears to be behaving differently to other recording channels, sometimes with a different baseline pressure, or lack of responsiveness to physiological changes such as coughing (which raises intra-abdominal and intrathoracic pressure, and should increase in the pressure in all transducers in those areas approximately equally). If it is unclear whether the artifact is due to a transducer or to a mechanical factor, the catheter can be repositioned. If the artifact moves with the recording channel, it is due to a problem with the electrical or mechanical factors affecting measurement in that channel; if the artifact changes recording channels, it is likely to be due to mechanical effects from the gastrointestinal tract; and if the artifact disappears with repositioning of the catheter, it is likely to have been due to pressure of the catheter on a mucosal surface.

Recording/Display Software

The function of software during the recording phase of a manometric study is to display the pressures that are being recorded in a way that allows the operator to ensure that the catheter is correctly placed and recording accurately, without artifact. The catheter must initially be calibrated according to the instructions of the manufacturer of the recording system, it is then placed within the subject and positioned by ensuring that the pressure data displayed on the screen allows the identification of particular physiological structures, usually sphincters, as these demonstrate increased pressures (e.g., lower esophageal sphincter in esophageal manometry, anal sphincter in anorectal manometry) that are easily recognizable. Other maneuvers, such as deep breathing, or swallowing during esophageal manometry, or squeezing or coughing during anorectal manometry, can accentuate physiological features such as the position of the diaphragm or a sphincter. The recording

software needs to be able to display these changes in pressure in real time to allow appropriate adjustments of the catheter or other troubleshooting maneuvers to ensure an optimal recording. Generally, the data will be displayed in much the same way as it will be analyzed, usually in the form of a spatiotemporal topographic plot scrolling across the recording screen. Sometimes, it is helpful to visualize pressures as a line plot, or numerically. Once the catheter is positioned and the study commences, the recording software saves the data to a file for subsequent analysis.

Analysis Software

The analysis software used will be specific to the recording system, however the same general principles apply to all systems. Analysis software needs to allow users to move through the recording period, viewing pressures either as absolute pressures with respect to atmosphere, or internally referenced (e.g., to intragastric pressure in the case of esophageal manometry). Pressures are generally displayed as spatiotemporal topographic plots in which the Y axis represents the distance along the recording catheter, the X axis represents time, and pressures are displayed in the Z axis, either as a color plot or a contour plot. Displaying the pressures in this form requires interpolation between the individual pressure points, which must be appropriately spaced (see Spatial Resolution section). Users should be able to move a cursor around in the data to determine pressures at specific points in space and time. Most commercial software for clinical studies includes the ability to measure specific aspects of gastrointestinal function relevant to the region (for example lower esophageal sphincter relaxation), and to classify specific events (e.g., swallowing). Reporting software is included in commercial systems and, again, is specific to be region being examined.

Infection Control

Some catheters are disposable and hence do not need reprocessing. However, the use of disposable catheters will generally be more expensive, and high channel counts are not available. Most manometry catheters will therefore be used on many patients, and it is vital that there are appropriate systems for ensuring that pathogens are not transmitted between patients. The exact method of catheter reprocessing depends on the type of catheter. Water-perfused catheters constructed from silicone can be autoclaved to achieve sterilization, however the electronic components of solid-state catheters are too sensitive to allow the use of steam sterilization, and some form of chemical-based reprocessing, as for gastrointestinal endoscopy, must be used. In addition, some solid-state catheters utilize a sheath to cover the catheter during placement within the patient. The integrity of the sheath is tested afterwards

to ensure that there has been no leakage that might contaminate the catheter. In any case, the method of reprocessing to ensure that pathogens are not transmitted between patients needs to be robust, and in accordance with local policies.

Conclusion

The manometry machine records pressures from the gastrointestinal tract for diagnostic or research purposes; pressure is recorded using catheters (water-perfusion or solid state), transducers that convert physical signals to digital signals, and a computer with software that analyses the data. Different recording systems may have different spatial resolution (distance between the recording points), temporal resolution (rate of pressure measurement sampling), and the accuracy with which pressure is measured. Though the solid-state system, —in which the sensor is located in the catheter itself—has some advantages, such as simplicity in operation and high sensitivity, the catheters are quite expensive, fragile, and often thicker than the water-perfusion catheters and are quite temperature-sensitive, requiring thermal compensation of the recorded data. In both the systems, once the signal is digitized and recorded to the computer, the principles are very similar. Different manometry machines have different recording and analysis software, to which the operator needs to familiarize himself/herself, however, the principles of the most of the recording and analysis software are quite similar. All software currently uses the Chicago system for analysis and reporting of the recorded data.

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High-Resolution Esophageal Manometry: Principles, Technique, and Interpretation

2

Abhai Verma, Asha Misra, and Uday C. Ghoshal

Abstract

There are many upper and lower gastrointestinal (GI) disorders in which either the cause or the result is abnormal motility. Naturally, the study of motor functions of the gut in normal and abnormal conditions is of great help in understanding the pathophysiology and management of these disorders. Motor functions of the GI tract can be assessed by a variety of recording techniques including radiology, scintigraphy, manometry, and most recently intraluminal electrical impedance monitoring. In many instances the techniques are complementary to each other. However, manometry is the most reliable and reproducible method of studying motor functions of the esophagus. In this chapter we will elaborate principles, technique, and interpretation of esophageal manometry.

Keywords

Esophagus • Dysphagia • Motor disorders • Achalasia • Diagnosis

Introduction

There are two basic functions of the esophagus: the transfer of swallowed material into the stomach, and the prevention of gastric contents to reflux back. To accomplish these basic functions the esophagus has been divided into three distinct neuromuscular units: upper esophageal sphincter (UES), esophageal body, and lower esophageal sphincter (LES). The whole purpose of esophageal manometry is to

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examine the functional integrity of these units. Reliable evaluation of esophageal motor functions by manometry started in 1970s [1, 2]. The initial recordings were in the form of two-dimensional line diagrams, what we today call conventional manometry. Later on with further understanding of esophageal motor functions and advancements in technology, high-resolution manometry (HRM) was devised.

Conventional Versus High-Resolution Manometry

Before the advent of HRM, conventional manometry was the only tool available for evaluation of esophageal motor functions. Conventional manometry consists of two-dimensional plots with pressure on y-axis and time on x-axis (Fig. 2.1). Considerable time and expertise are required to obtain adequate and informative data of esophageal functions by this technique. Only a few syndromes have been clearly defined by this method and there are many symptomatic patients, who could not be given any label with this technique. Also, with conventional manometry, assessment of UES is not adequate. Moreover, complete assessment of LES is also difficult, as the exact placement of a port at LES is sometimes difficult (Table 2.1).

Components of Esophageal Manometry System

Manometry systems have undergone significant evolution so that today reasonable ideas can be made about the qualitative and quantitative parameters for the motor functions of the esophagus. Essentially a manometry system consists of two

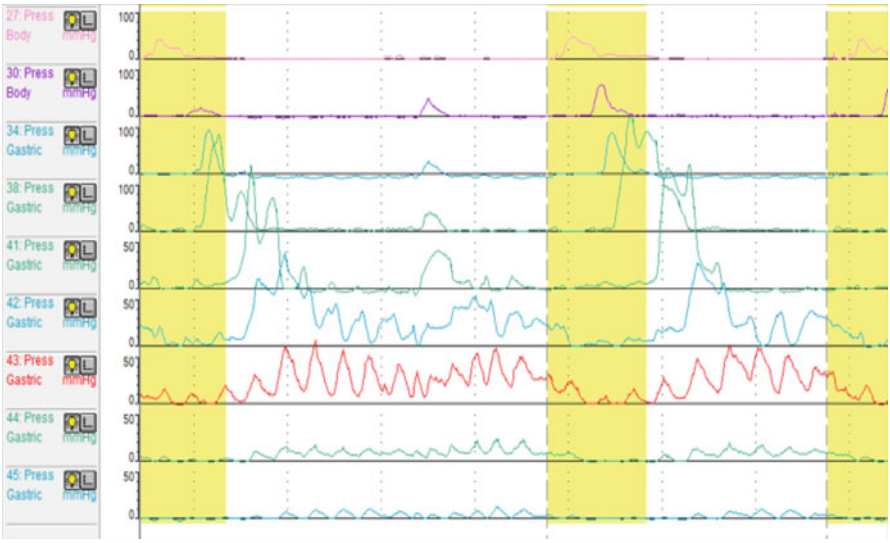

Fig. 2.1 Conventional manometry

components: a catheter, which can sense the pressure changes within the lumen, and a recording device with software, which can store and analyze the information sent to it by the catheter. The catheters [3] can be of two types: water-perfused or solid-state (Fig. 2.2a, b). A water-perfused catheter consists of an assembly of fine plastic tubes, which open distally with side wholes (ports). The tip of each tube is placed at various intervals along the length of the catheter. Water flows through these tubes at a fixed rate to keep the pressure within the tube constant. When the catheter is in the esophagus and peristalsis occurs, the side hole of one of the tubes gets compressed and water flow stops, leading to a change in pressure within that tube which is recorded in the form of a graph or color plot. Usually a catheter can have 8–32 such tubes. More the tubes within the catheter, and the shorter the distance between these, more is the information obtained about the esophageal motor activity.

Table 2.1 Comparison of conventional manometry with HRM

	Conventional manometry	High-resolution manometry
Representation	Two-dimensional	Three-dimensional with colors
Ease of procedure	Takes time	Fast
Interpretation	Requires experience	Easy
LES assessment	Incomplete and difficult	Easy
UES assessment	Difficult	Possible
Cost	Cheap	Expensive

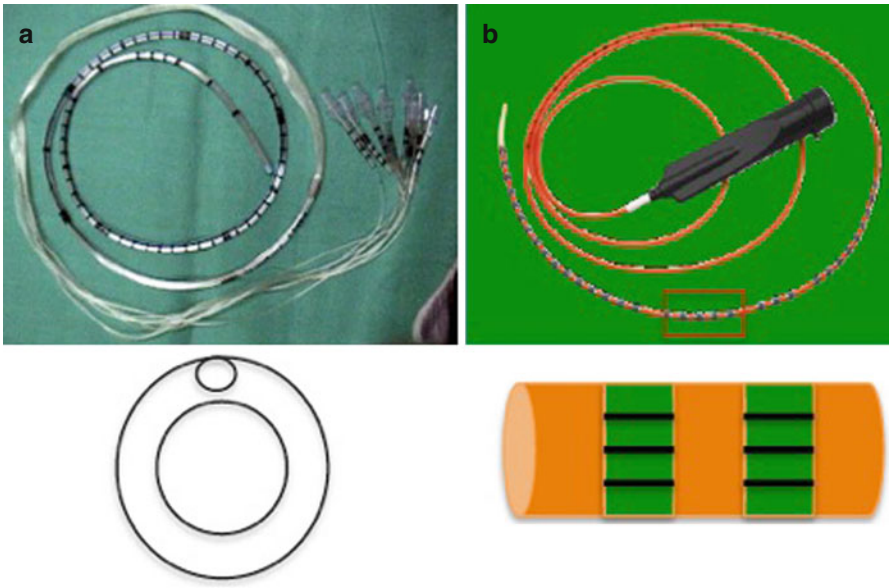

Fig. 2.2 (**a**) Water-perfused and (**b**) solid-state catheters with diagrammatic representation in lower half

The other commonly used sensing device is a linear array of miniature, solid-state strain gauge transducers spaced at regular intervals along a flexible tube. The advantage of solid-state catheters is that they can record pressure changes even within short intervals, i.e., they have a higher frequency response characteristic. This feature of solid-state catheters is extremely handy for evaluation of the upper esophageal sphincter (UES). Also, these catheters are easy to use and require less technical expertise. However, they are costly and more susceptible to damage. The most important factor, which helped in transition from conventional manometry to HRM, was reducing the spacing between two consecutive ports—in other words, increasing the number of ports within the same length of catheter. As shown in Fig. 2.3, this simple technique proved beneficial for evaluating even longer lengths of esophagus. Also, with advancements in computer technology and better software, the information obtained from an increased number of ports can be represented topographically.

Topographic analysis is a method of axial data interpolation derived from computerized plotting of data from multiple, closely spaced recording sites. The interpolated pressure information is plotted as either a 3-dimensional surface plot or a 2-dimensional contour plot in which concentric rings represent pressure amplitude or color gradients with an appropriate scale (Fig. 2.4). The advantage of topographic analysis [4] is that it provides information about pressures at every possible axial location, as opposed to conventional manometry, where only fragmented data is obtained in the form of line tracings.

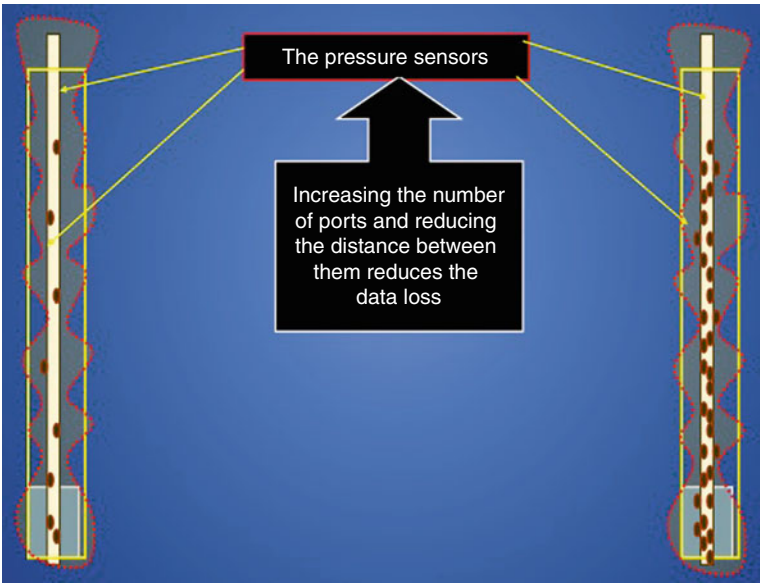

Fig. 2.3 Advantages of increasing the number of ports within same length of catheter

The Procedure

HRM can be done in the supine position in a fasting state, as the values given in the original Chicago Classification [5, 6] are based on the supine position. However, people have tried doing it in the sitting position and data are available regarding normal values in this posture. The catheter tip is placed in the stomach through one of the nostrils (like Ryle's tube). The position of the catheter is adjusted so that both the UES and LES are visible on the color plot simultaneously. This reduces the patient's discomfort and the overall time required to complete the procedure. Also, it allows evaluating the UES, LES, and esophageal body simultaneously. Once the position is secured, some time is allowed so that patient can adjust to the catheter. Then basal recordings are marked for 30-s window during which no swallowing occurs. This will serve for measurements of baseline pressures of UES and esophago-gastric junction (EGJ). Then the patient is asked to swallow 5 ml of water (wet swallow). Again, 30-s uninterrupted recordings are taken before the next wet swallow. This is done so that LES can return to its basal state and deglutitive inhibition does not hinder esophageal motor functions. A minimum of 10 such wet swallow recordings are taken. Care should be taken not to allow any other swallows in between two wet swallows; if it does occur, then the time to the next wet swallow must be reset. This was the

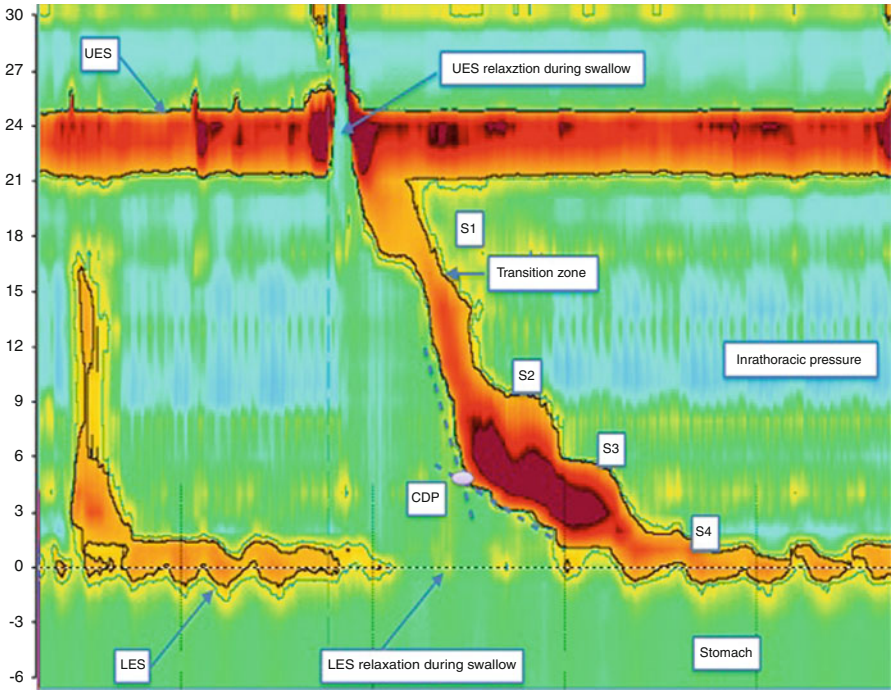

Fig. 2.4 High-resolution esophageal pressure topography (Clouse plot)

protocol used for defining the Chicago Classification for esophageal motor disorders. However, various researchers have used variations of this protocol as and when required. For example, when using a solid-state catheter, the study can be done in supine or sitting posture [7]. Some researchers have also tried esophageal manometry using semisolid swallows, [8] which may reveal additional findings. Technique of esophageal manometry is presented in http://www.spreadhealth.in/videos.php

Metrics Used in HRM

As the technique of esophageal manometry evolved from conventional to high resolution, so, too, did the analysis. New terminology was introduced to better understand and classify the esophageal motor disorders. The new metrics used with HRM are shown in Table 2.2, with reference values in Table 2.3 [9]. These new parameters have better defined the motor abnormalities of the esophagus as seen on manometry. A new classification system evolved, popularly called Chicago Classification, using these metrics (Table 2.4).

To understand Chicago Classification first we need to elucidate the exact meaning and utility of these terms. The key landmark in esophageal HRM is the esophago-gastric junction (EGJ), [10] which is comprised of the LES and crural

Table 2.2 Newer terminology used for analyzing high-resolution esophageal manometry

Metric	Description
Integrated relaxation pressure (mmHg)	Mean EGJ pressure measured with an electronic equivalent of a sleeve sensor for four contiguous or non-contiguous seconds of relaxation in the 10-s window following deglutitive UES relaxation
Distal contractile integral (mmHg-s-cm)	Amplitude × duration × length (mmHg-s-cm) of the distal esophageal contraction >20 mmHg from proximal (P) to distal (D) pressure troughs
Contractile deceleration point [(CDP) (time, position)]	The inflection point along the 30 mmHg isobaric contour where propagation velocity slows demarcating the tubular esophagus from the phrenic ampulla
Contractile front velocity (cm s^{-1}) (Not used now)	Slope of the tangent approximating the 30 mmHg isobaric contour between P and the CDP
Distal latency (s)	Interval between UES relaxation and the CDP
Peristaltic breaks (cm)	Gaps in the 20 mmHg isobaric contour of the peristaltic contraction between the UES and EGJ, measured in axial length

Adapted from Bredenoord et al. [6]

Table 2.3 Normal values for metrics used in HRM

Metric	Normal values
Integrated relaxation pressure	<15 mmHg
Distal contractile integral	450–5000 mmHg-cm-s
Contractile front velocity	<9 cm/s
Distal latency	>4.5 s

diaphragms. When there is resistance in the passage of bolus from the esophagus to the stomach, intra-bolus pressure rises due to an increase in viscous resistance. Integrated relaxation pressure (IRP) denotes the mean EJG pressure during a 4 second window (need not be continuous) after deglutititive UES relaxation. In other words, high IRP distinguishes between normal and impaired EGJ relaxation. To measure IRP, first EGJ should be localized, and then special software tools are applied to estimate its value. First, the deglutitive relaxation window, which stretches for 10 s in the region of EGJ from opening of UES, is marked (Fig. 2.5). Within this window the software gives the lowest mean pressure for 4 continuous or discontinuous seconds. This excludes the pressure rise contributed by crural diaphragm and bolus itself. As in conventional manometry, IRP is referenced to intragastric pressure, i.e., pressure in the stomach is taken as zero. The closest correlate of IRP to conventional manometry is LES pressure during swallowing.

To look at the strength of esophageal contraction, the new metric was devised called distal contractile integral (DCI) [11]. It is called distal because it measures esophageal contraction in the distal segment, which lies between the proximal and distal pressure trough (Fig. 2.6). On conventional manometry the closest correlate of DCI is peristaltic amplitude of the esophageal body. It takes into account the particular length of the esophageal segment and the amplitude and duration of contraction at each point along that length. In other words, it gives us the average

Table 2.4 Chicago classification for esophageal motility disorders

Diagnosis	Criteria
Achalasia	
Type I	Classic achalasia: Mean IRP >ULN, 100% failed peristalsis
Type II	Achalasia with esophageal compression: Mean IRP > ULN, no normal peristalsis, pan esophageal pressurization with 20% of swallows.
Type III	Mean IRP > upper limit of normal, no normal peristalsis, preserved fragments of distal peristalsis or premature (spastic) contractions with ≥20% of swallows
EGJ outflow obstruction	Mean IRP > upper limit of normal, some instances of intact peristalsis or weak peristalsis with small breaks such that the criteria for achalasia are not met
Major disorders of peristalsis	
Distal esophageal spasm	Normal mean IRP, ≥20% premature contractions
Hypercontractile (Jack hammer) esophagus	At least two swallows with DCI > 8000 mmHg-s-cm with single peaked or multipeaked contraction
Absent contractility	Normal mean peristalsis, 100% failed peristalsis (exceeding statistical limits of normal)
Minor disorders of peristalsis	
Ineffective esophageal motility	>50% of swallows with DCI <450 mmHg.s.cm
Fragmented peristalsis	>50% fragmented contractions with DCI >450 mmHg.s.cm

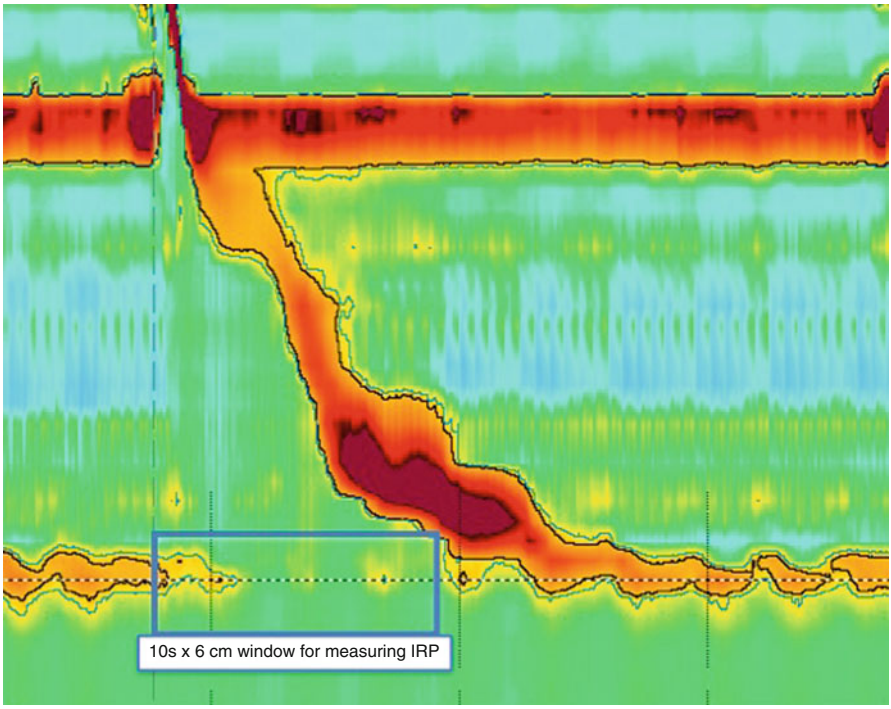

Fig. 2.5 Computation of integrated relaxation pressure involves drawing a rectangle equivalent to 6 cm and 10 s in the region of esophagogastric junction starting from upper esophageal relaxation during swallow

pressure per cm of esophagus per second (mmHg-s-cm). As the bolus moves along the esophagus, it exerts some amount of pressure on the recording probes even if there is no esophageal contraction. Therefore, to exclude the intra-bolus pressure, the first 20 mmHg is ignored. The contractile deceleration point (CDP) [12] is the location in the lower esophagus where the velocity of peristaltic contraction reduces abruptly. It occurs because at certain points along the length of the esophagus, the bolus starts emptying in the stomach. Naturally, due to the resistance at EGJ, the velocity of the peristaltic wave will slow down during esophageal emptying. The time taken from the beginning of UES relaxation to CDP is called distal latency (DL) [13]. It tells us about the peristaltic timing and period of deglutitive inhibition [14]. Contractile front velocity (CFV) is the measure of velocity of peristaltic contractions in the segment of esophagus above CDP. Recently importance of CFV has been underplayed due to its limited utility in diagnosing disorders of esophageal motility. The last concept which needs to be understood is called peristaltic break [15]. It is a measure of peristaltic integrity of the esophagus. First an isobaric contour line of 20 mmHg is drawn and integrity of this line is looked for. 20 mmHg pressure has been chosen to look for peristaltic breaks because

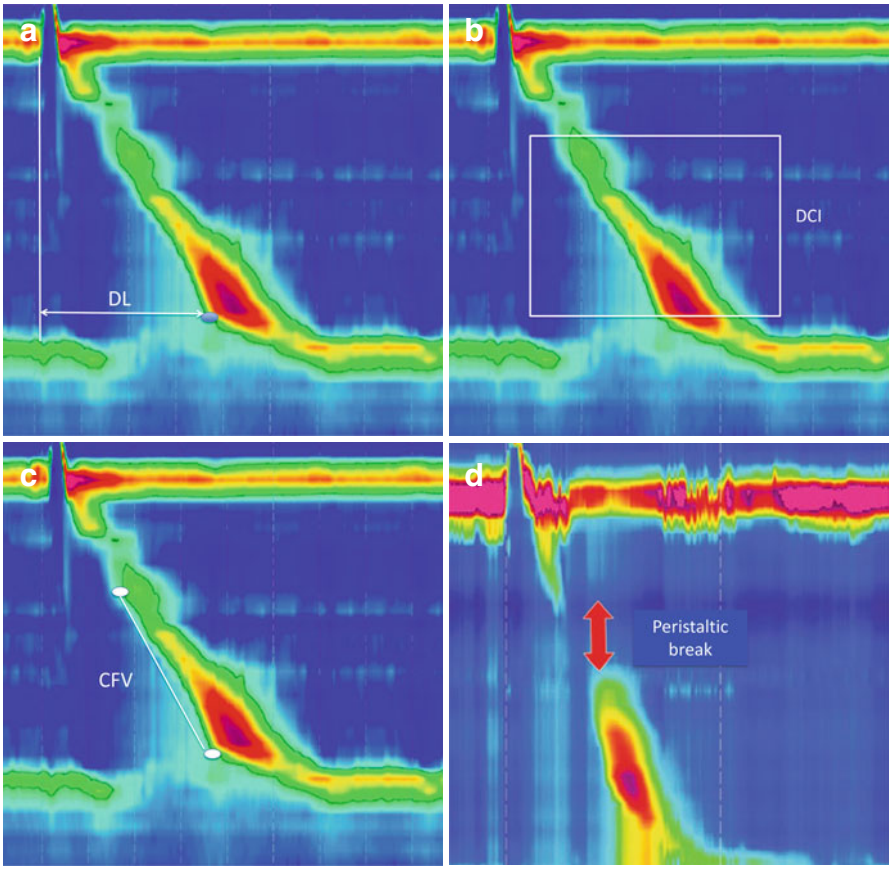

Fig. 2.6 Diagrammatic representation elucidating the concept of (**a**) distal latency; (**b**) distal contractile integral; (**c**) contractile front velocity; and (**d**) peristaltic break

simultaneous fluoroscopic imaging has shown that this is the minimum pressure required for successful transfer of bolus. Breaks along this line signify hypotensive peristalsis causing failed bolus transit. These breaks have been classified as small (2–5 cm) or large (>5 cm).

Analysis

Application of the metrics described above has to be viewed in a stepwise manner to reach any definite conclusion. Although the analysis is mostly software based, basic knowledge of the principles behind these metrics is must. Also, the results should be interpreted in light of other clinical parameters and other investigations.

First we evaluate the characteristics of HRM during the resting phase, when there is no swallowing for 30 s. During this phase two horizontal bands of pressure can be distinctly seen representing UES and EGJ (Fig. 2.4). In the region of EGJ, LES can be identified in the form of a band where the pressure is more or less constant.

Once the position of LES is identified, then we look for the position of the crural diaphragm, which is detected by the pressure inversion point (PIP). PIP is the point where, upon inspiration, the negative intrathoracic pressure becomes positive [16]. The location of PIP signifies the crural diaphragm. Once PIP is localized, one should look for hiatus hernia. Manometrically it is defined as the vertical distance between the LES and PIP [17].

Then one should evaluate the integrity of EGJ. As explained previously, it is assessed by IRP. An increased IRP means resistance to bolus transfer at EGJ. It is important to remember that the value of the upper limit is more important than the lower limit for IRP. After evaluating EGJ, peristaltic integrity needs to be looked for. Esophageal peristalsis is said to be intact if there is no break in 20 mmHg isobaric contour. The length of these breaks have clinical importance. Sometimes there may be a very large break so that there appears to be hardly any intact peristalsis. This is called failed peristalsis and is technically defined as < 3 cm integrity of the 20 mmHg isobaric contour distal to proximal pressure trough.

Once integrity of peristaltic wave has been determined, its propagation should be evaluated. As explained previously, it can be done by CFV. As mentioned previously CFV is of limited value as it adds very little information over what we get from DL. Next look at DCI for evaluating robustness of peristaltic contractions in the smooth muscle esophagus. To calculate DCI, first a box is drawn encompassing all the motor activity in the distal esophagus. Then the software calculates DCI by summing pressures from all of the time/length foci along the 20 mmHg contour line within the box. The last step in analysis is determining the pressurization pattern [18] in the esophagus. Pressurization is recognized as an isobaric pressure bar along varying lengths of esophagus.

Once all the swallows have been looked for these parameters, a systematic algorithm should be followed to reach a definitive diagnosis, as shown in Fig. 2.7. However, there are certain conditions which still can't fit into the Chicago Classification. For instance, belching [19] is manometrically characterized by transient relaxation in the LES with reflux of contents in the esophagus with opening of UES. It can be differentiated from transient lower esophageal sphincter relaxation (TLESR) by focusing on the UES, which essentially remains closed. Also, there is no classification of the disorders involving the UES. In HRM, UES is seen as a horizontal continuous band of pressure during resting phase. During swallow-induced opening of the UES, pharyngeal bolus pressure approximates that in esophageal bolus. However, in the cricopharyngeal bar there is restriction of bolus movement from the pharynx to the esophagus, leading to increased intrabolus pressure in the pharynx.

1	IRP > ULN; 100% failed peristalsis	**Achalasia cardia** (Look at pressurization pattern for type achalasia)
2	IRP > ULN and not achalasia	**EGJ outflow obstruction**
3	IRP normal and short DL or high DCI or 100% failed peristalsis	**DES** >20% DL <4.5 s **Jackhammer esophagus** >20% DCI >8000 mmHg.s.cm **Absent contractility** No scorable contraction
4	IRP normal and >50% ineffective swallows	**Ineffective motility** >50% ineffective swallows **Fragmented peristalsis** >50% fragmented swallows and not ineffective
5	IRP normal and >50% effective swallows	Normal

Fig. 2.7 Algorithm for evaluation of esophageal high-resolution manometry

Conclusion

High-resolution manometry (HRM) is the technique for studying esophageal motor physiology, in normal and diseased state, with much ease for technicians as well as patients. It has enabled us to understand the pathophysiology of esophageal motor disorders in a better way. Now one can recognize and classify certain esophageal motor disorders which were previously not known. It has also helped us in understanding disorders of the UES. It has led to the development of Chicago Classification, which is gradually evolving. More work is required in the area of UES and conditions like belching and TLESRs.

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Colonic Transit Study by Radio-Opaque Markers

3

Yang Won Min and Poong-Lyul Rhee

Abstract

Assessment of colon transit time is the most useful tool to evaluate disorders of colonic motility. It is especially helpful in making a pathologic diagnosis and for planning management in patients with complaints of constipation. Currently, several techniques for assessing colon transit time are available. Assessment of colon transit by radio-opaque markers has been most widely used. This study is simple and inexpensive, as well as reliable. However, it requires good compliance on the part of the patient, produces radiation exposure, and does not measure the transit of a true meal [1–3].

Keywords

Colon transit time • Constipation • Motility • Colonic motility disorders • Radio-opaque markers

Introduction and General Considerations

Colon transit study is indicated to measure total and segmental colonic transit times in patients with complaints of constipation, and may help in evaluating the results of medical or surgical treatment for colonic motility disorders. This study is contraindicated in pregnancy and bowel obstruction.

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Radio-Opaque Markers

Radio-opaque markers can be obtained commercially or can be made by cutting Levine tubes. Commercially prepared markers are plastic beads or rings that are usually ingested in a capsule. Two kinds of radio-opaque markers, Kolomark™ (M.I.Tech., Pyongtaik, Korea) [4] and Sitzmarks® (Konsyl Pharmaceuticals, Fort Worth, TX, USA) [5] are commonly used in Korea. Each single capsule contains 20 or 24 radio-opaque markers, respectively (Fig. 3.1).

Patient preparation

Any special preparation of patients is not required prior to the colon transit study by radio-opaque markers. All contrast material, if any, should be cleared from the colon, and no other study should be scheduled for the duration of the study. Patients should be instructed to continue their usual diet and activities, including their usual medications. Colon transit study, however, should be performed with patients off their usual laxatives, enemas, or other medications known to affect gastrointestinal motility [6].

Methods

After Hinton et al. [7] first described the measurement of gut transit through ingestion of radio-opaque markers in 1961, there have been many methods to assess colon transit time using these markers. The techniques can be divided into two categories: (1) single-capsule technique and (2) multiple-capsule technique.

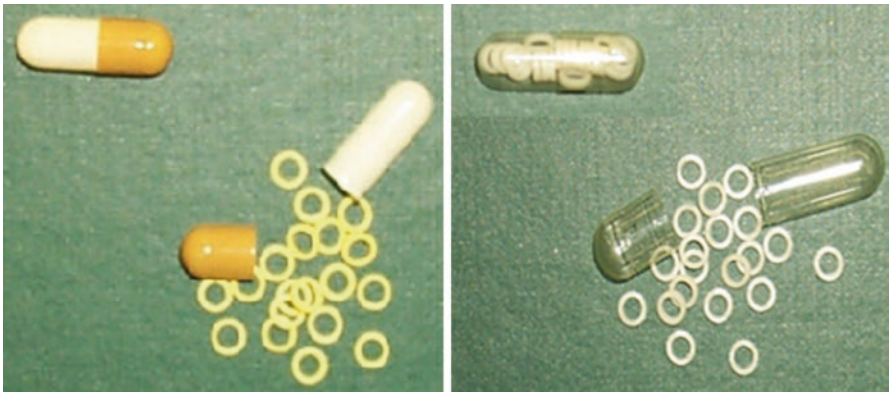

Fig. 3.1 Kolomark™ and Sitzmarks® capsules: 20 or 24 radio-opaque o-ring markers of same size and weight are in the gelatin capsule

Single-Capsule Technique

Subjects are asked to ingest 20 (or 24) radio-opaque markers in a single capsule at a specific time (usually 8 or 9 a.m.). Abdominal X-rays are then taken in supine position at 24-h intervals until all markers are defecated [8]. This method, however, is time-consuming, inconvenient, and produces greater radiation exposure. A simplified method of single-capsule technique involves one abdominal X-ray on day 6, or 120 h after marker ingestion (Fig. 3.2) [9].

Multiple-Capsule Technique

Subjects are asked to ingest capsules containing 20 (or 24) radio-opaque markers daily at a specific time (usually 8 or 9 a.m.) for three sequential days. Abdominal X-rays are taken on day 4 (four-day method) [10], or on days 4 and 7 (seven-day method) [11]. The four-day method is useful in selecting constipated patients with delayed colon transit but it does not give relevant information on severity of delayed transit. The seven-day method can be used in selecting patients with severely delayed transit [12]. An additional abdominal X-ray can be taken on day 10 in those patients with markers still present on day 7 (Fig. 3.3a, b) [13].

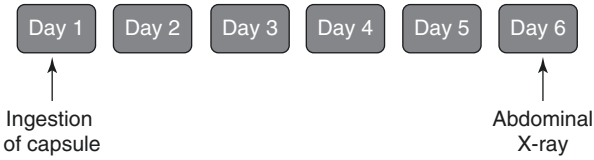

Fig. 3.2 Single-capsule technique

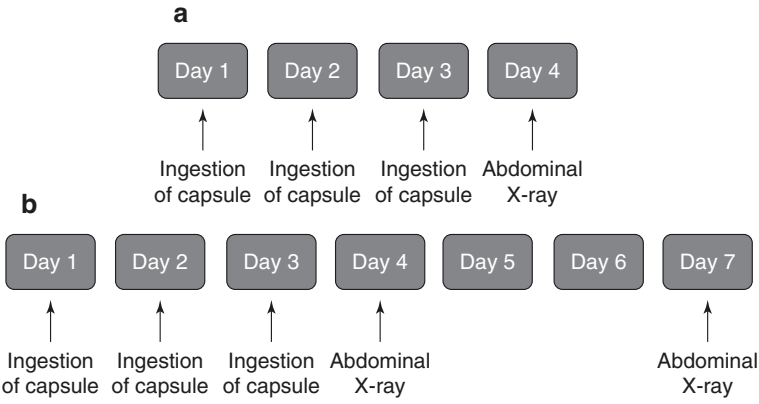

Fig. 3.3 Multiple-capsule technique: (**a**) four-day method; (**b**) seven-day method

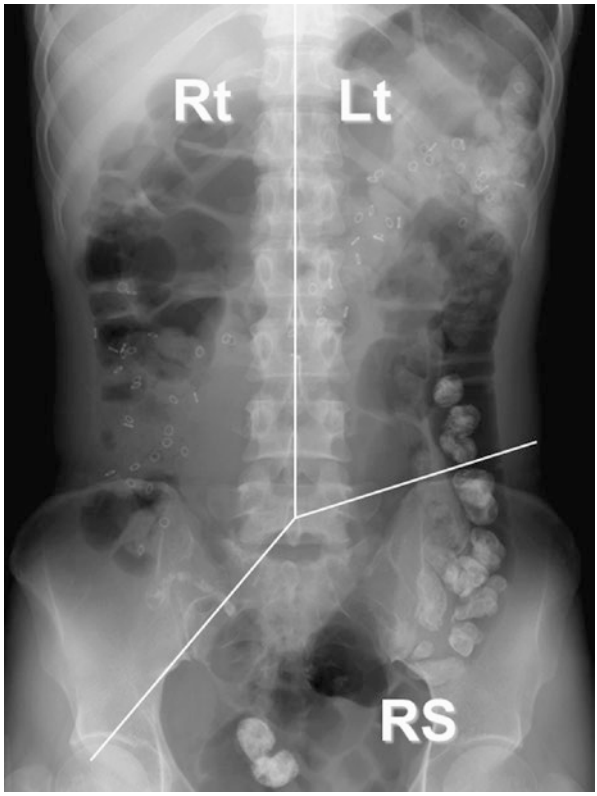

Fig. 3.4 Colonic segments determined by bony landmarks in abdominal X-ray: *Rt* right colon, *Lt* left colon, *RS* rectosigmoid colon

Interpretation

Interpretation is based on the number of markers present in three colonic segments on the abdominal X-ray: right colon, left colon, and rectosigmoid colon. Markers located to the right of the vertebral spinous processes above a line from the fifth lumbar vertebrae to the pelvic outlet are assigned to the right colon. Markers to the left of the vertebral spinous processes and above an imaginary line from the fifth lumbar vertebrae to the anterior superior iliac crest are assigned to the left colon. Markers inferior to a line from the pelvic outlet on the right and the superior iliac crest on the left are assigned to the rectosigmoid colon [8]. Abdominal X-rays should include the diaphragms and the pubis to ensure that all markers in the colon are visualized (Fig. 3.4).

Calculations

Mean transit time of the markers in a single-capsule technique is calculated in the following way [8]:

$$\text{Mean transit time}(\text{hr}) = \frac{1}{N}\sum_{i=1}^{j} n_i \left[\frac{t(i+1)-t(i-1)}{2}\right]$$

where N is the number of given markers, n_i is the number of markers present on abdominal X-ray obtained at time t_i, t is the time elapsed from ingestion of markers to time where abdominal X-ray is taken and $t_0 = 0$, $\left[\frac{t(i+1)-t(i-1)}{2}\right]$ is the time interval between successive abdominal X-rays, and j is the number of abdominal X-rays obtained.

When the single-capsule technique using 20 (or 24) markers in a capsule is performed and successive abdominal X-rays are taken at 24-h intervals, the above formula can be simplified into:

$$\text{Mean transit time}(\text{hr}) = 1.2(\text{or } 1.0) \times (n_1 + n_2 + n_3 \ldots n_j)$$

where n is the number of markers present on each abdominal X-ray, and j is the number of abdominal X-rays obtained.

When the multiple-capsule technique using 20 (or 24) markers in a capsule is performed, the same simplified formula can be used if markers are given at 24-h intervals.

Single-Capsule Technique

Delayed transit is defined when more than 20 % of markers retained on day 6 abdominal X-ray (Table 3.1) [9].

Multiple-Capsule Technique

Mean transit times in each colonic segment and through the entire colon are calculated by multiplying the number of markers by 1.2 (or 1.0 when using a capsule containing 24 markers) (Tables 3.2 and 3.3).

Considerations in Interpretation

The stool pattern and frequency during the study period need to be as usual to show representative colon transit. If not, repeating the study should be considered.

Patients may be found with abnormal transit time for any one colonic segment, but not the total colon. There can be a variation of transit times from day to day in

Table 3.1 The abdominal X-ray five days after ingestion of a single capsule containing 20 radio-opaque markers shows retaining 5 markers (≥ 20 % of markers given) indicating delayed colonic transit

	Number of markers present			
Film	Right colon	Left colon	Rectosigmoid colon	Total colon
Day 6	1	2	2	5

Table 3.2 Calculation of mean transit time by multiple capsules technique (four-day method using a capsule containing 20 radio-opaque markers)

	Number of markers present			
Film	Right colon	Left colon	Rectosigmoid colon	Total colon
Day 4	11	11	12	34

Right colon transit = 1.2 × 11 = 13.2 h
Left colon transit = 1.2 × 11 = 13.2 h
Rectosigmoid colon transit = 1.2 × 12 = 14.4 h
Total colon transit = 1.2 × 34 = 40.8 h

Table 3.3 Calculation of mean transit time by multiple-capsule technique (seven-day method using a capsule containing 20 radio-opaque markers)

	Number of markers present			
Film	Right colon	Left colon	Rectosigmoid colon	Total colon
Day 4	11	11	12	34
Day 7	0	0	2	2
Sum	11	11	14	36

Right colon transit = 1.2 × 11 = 13.2 h
Left colon transit = 1.2 × 11 = 13.2 h
Rectosigmoid colon transit = 1.2 × 14 = 16.8 h
Total colon transit = 1.2 × 36 = 43.2 h

colonic segments and, therefore, delayed transit in one colonic segment can only be considered abnormal if the total colon transit is also delayed [6].

Colon transit appears to be different for different populations, depending upon race, ethnicity, and dietary habit. The method and normative data of one population, therefore, may not be applicable to another population. Colon transit should be standardized and validated for an individual population [14].

Method to Study Colonic Transit in Populations with Faster Colon Transit

In some populations with faster colonic transit, such as among Indian, a conventional method of ingesting a marker every 24 h and then obtaining abdominal radiograph on the fourth day may not be appropriate. Hence, a modified method has been standardized for populations with rapid gut transit. In this method, 20 radio-opaque markers have to be ingested each time at 0 h, 12 h and 24 h. Subsequently, abdominal radiographs are obtained once at 36 h and once at 60 h. Using receiver operative characteristic (ROC) curves, the best cut-off values that differentiated healthy subjects from patients with transit disorders at 36 and 60 h was 30 and 14 markers, respectively. The sensitivity, specificity, positive and negative predictive values, diagnostic accuracy, and area under the ROC curve at 36 h were 90 %, 82 %, 90 %,

82 %, 87 % and 0.9 %, respectively; the corresponding values at 60 h were 95 %, 100 %, 100 %, 92 %, 97 % and 0.99 %, respectively.

Conclusion

Slow colonic transit is an important cause of chronic constipation. Colon transit study by radio-opaque markers is a simple and popular technique to evaluate colon transit time. It not only gives an assessment of transit across the whole colon, but also gives an idea about segmental colon transit. The popular method of assessing colon transit involves administration of multiple radio-opaque markers (typically 20 each time) three times (at 0, 24 and 48 h) and obtaining an abdominal radiograph on the 4th and 7th day. However, in some populations with rapid gut transit time, this protocol may have to be modified to reduce the interval between ingestion of the markers and time of abdominal radiograph.

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Technique, Interpretation and Clinical Application of Anorectal Manometry and Balloon Expulsion Test

4

Kee Wook Jung and Seung-Jae Myung

Abstract

Anorectal manometry and rectal balloon expulsion tests are necessary for the diagnosis of functional defecatory disorders. They can provide comprehensive information about anal sphincter function, rectal sensation, rectal compliance, anorectal coordination during evacuation, and anorectal reflexes. Moreover, they provide new information that may not be detected clinically and can influence the outcome of patients with defecation disorders. Selective tests should be performed based on the potential indication to evaluate each condition. High-resolution manometry based on spatiotemporal plot was developed recently, and it can display the anorectal change during testing with a great resolution, replacing the conventional manometry system.

Keywords

Anorectal manometry • Balloon expulsion • Constipation • Incontinence • Sphincter function • Defacation disorders

Introduction

Anorectal manometry (ARM) provides a means of evaluating various parameters of anal and rectal function, and rectoanal coordinated activity, by measuring the anal resting and squeezing pressures, rectoanal inhibitory reflex, and rectoanal pressure changes during straining [1]. The manometric catheter assembly includes a rectal balloon and either solid-state or water-perfused pressure transducers.

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Indications

The principal indications for ARM are fecal incontinence and constipation, and it is useful in facilitating biofeedback training, assessment of patients before anorectal surgery, and assessment of patients with functional anorectal pain, particularly secondary to pelvic floor dysfunction [2–5]. The indications for ARM are described here:

- Evaluation of refractory constipation
- Evaluation of fecal incontinence
- Facilitation of biofeedback training for dyssynergic defecation
- Facilitation of biofeedback training for fecal incontinence
- Preoperative evaluation before anorectal surgery (anal fissure, anal fistula, anorectal cancer, and reversal of ileostomy/colostomy)
- Postoperative evaluation for reversal of colostomy

Equipment

The ARM system is composed of the following equipment: a pressure-sensing probe, an amplifier/recorder that can convert signals for digital display and storage, a monitor that can display recordings of the signals, and data analysis software.

Probe

The intraluminal pressures can be measured with solid-state microtransducers, water-perfused or sleeve catheters, or water/air-filled balloon catheters [3].

Solid-State Probe with Microtransducers

A thin, flexible tube equipped with microtransducers can sense the pressure directly, unlike with the water-perfused system. Six sensors are typically arranged helically and spaced at 1, 2, 3, 4, 5, and 9 cm from the reference value point [6]. These sensors are usually arrayed at 90° to each other. A balloon is tied to the distal end of the probe; this type of probe can provide an accurate pressure recording [7]. The advantages of solid-state system are that it is user friendly and has a higher fidelity; however, it has disadvantages such as higher cost and fragility, compared with the water-perfused system [7, 8].

Water-Perfused Catheter System

The water-perfused catheter is composed of a thin, plastic tube with 4–9 side holes, and a central channel with a balloon [7]. The catheter connects to a perfusion apparatus, the pneumohydraulic pump, which is set at a pressure of 10–15 psi during testing [7]. Nitrogen gas is used to drive the water. The advantages of the water-perfused system are its simplicity and relatively lower cost [8, 9]. Its major disadvantage is calibration difficulties. Moreover, the water perfused during testing and its contact with the anal mucosa can elicit abnormal reflexes [6, 10].

High-Resolution Manometry

High-resolution manometry (HRM) is a novel, solid-state manometric system [11] that consists of 36 densely spaced sensors at 0.5–1-cm intervals. Each sensor consists of 12 radially dispersed sensing elements that are 2.5 mm long. The software can represent detailed colorful topographical plots of intraluminal pressures [11]. The advantage of the HRM system is greater resolution, based on spatiotemporal plots [12]. However, it is quite fragile and more expensive compared with the conventional system [12].

High-Definition Manometry

High-definition manometry is a novel, solid-state manometric system with more densely arranged sensors than HRM [13]. It has more than 256 pressure sensors arranged in 16 rows, and each row has 16 circumferentially oriented sensors [13]. Each sensor has a 4-mm center linear spacing and 2.1-mm circumferential spacing. The advantage of a high-definition system is more detailed images compared to those obtained with both conventional and HRM. The disadvantage is the catheter stiffness, which may cause more difficulties during testing compared with the conventional or high-resolution system.

Amplifier and Recording Device

These computerized systems amplify signals, record data, and facilitate storage, retrieval, and analysis. Each manufacturer makes these systems with a unique design.

Patient Preparation

The patient should be fully informed about the details of the procedures to enhance their cooperation and comfort. Usually, no bowel preparation is known to be required; [8, 12] however, bowel preparation is sometimes needed when fecal loading is detected on digital rectal examination [8]. An enema of 500 mL of tap water or phosphate is used approximately 2 h before testing [8]. ARM is usually performed with the patient in the left-decubitus position with knees and hips flexed except during the balloon expulsion test. There are no diet restrictions before testing [8, 12].

Digital Rectal Examination

Digital rectal examination consists of three components [14]. First, inspection of the anus and surrounding tissue for fissures, thrombosed hemorrhoids, or skin excoriation should be performed. Second, the perineal sensation anocutaneous reflex should be checked properly. Finally, digital palpation to assess resting and squeeze sphincter tone and assessment of defecation by asking the subject to push and bear down should be conducted. Recent studies show that the digital rectal examination has a high sensitivity and specificity in the detection of dyssynergia [14–16].

Anorectal Manometry Protocol

With the patient in the left lateral position, a lubricated probe is inserted into the rectum. The most distal sensor (at the 1-cm level) should be oriented and located posteriorly from the anal verge.

Assessment of Resting Anal Sphincter Pressure

With this test, the functional anal canal length and its tone can be assessed. The resting anal canal tone predominantly reflects the internal anal sphincter (IAS) function, whereas the voluntary anal squeeze pressure reflects the external anal sphincter (EAS) function.

After probe insertion, a run-in time of at least 5 min is allowed to enable the sphincter to return to its basal levels. Ultra-slow wave activity may be seen as phasic pressure activity at 1–1.5 cycles/min with an amplitude >40 mmHg. This finding is associated with either normal or hypertonic anal sphincter tone [6]. For the conventional manometry system, two methods have been used [7]. The stationary technique is the preferred technique for measuring the resting anal pressure. After probe placement, the highest pressure at any level in the anal canal can be used as the maximum resting sphincter pressure. The mean resting pressure is lower with the stationary technique than with the station pull-through technique. In this alternative technique, the most distal sensor is initially placed 5 cm above the anal margin and withdrawn manually or with an automated device by 5 mm every 30 s. When the sensors straddle the high-pressure zone, a step-up graph can be noted. The length and highest resting pressure can be measured [17]. The disadvantage of the pull-through technique is that the EAS may be excited falsely, which can artificially increase the sphincter pressure [12].

When using the novel HRM system, obtaining the baseline anal sphincter pressure is easier and faster with the help of more densely arranged sensors around the catheter and without the pull-through maneuver [18].

Analysis/Interpretation The maximum resting sphincter pressure is defined as the difference between the baseline pressure (intra-rectal pressure) and the maximum anal sphincter pressure at rest. The maximum sphincter pressure at any level in the anal canal is measured and noted as the maximal resting sphincter pressure. The sphincter length is best measured with the pull-through method. The sphincter zone is defined to be the level at which the resting anal sphincter pressure is at least 5 mmHg above the rectal pressure. The normal length of the anal sphincter ranges from 3 to 5 cm [19]. The length of the anal canal in men is usually longer than that in women [19]. The length of the functional anal canal is usually shorter in incontinent patients than in normal control subjects.

The IAS provides 55–80 % of the resting tone of the anal sphincter. The maximum resting pressure is usually 50–80 mmHg in normal subjects, which is dependent on the manufacturers' systems and catheter sensors [19]. When the resting anal sphincter pressure is decreased relative to the normal value, weakness or disruption of the IAS should be suspected. Symptoms of passive fecal

incontinence are associated with low resting anal tone, which implies IAS weakness [21]. However, a large study showed that assessment of the maximal anal resting tone had a sensitivity of only 32 % for discriminating between continent and incontinent patients, indicating the multifactorial elements determining incontinence [22]. Recently published studies based on HRM showed that those values of female were relatively lower than those of male [23].

Assessment of Squeeze Anal Sphincter Pressure

In this study, the subject is asked to squeeze the anus as long as possible, at least for 30 s. Following a 1-min rest, this procedure is repeated once more. The maximum anal squeeze pressure is defined as the highest sphincter pressure recorded at any level in the anal canal. The contraction of the EAS is associated with the contraction of the puborectalis. EAS contraction elevates the pressure throughout the anal canal, although a pressure increase occurs maximally in the lower canal.

The squeeze pressure shows a biphasic pattern, with an initial sharp rise (maximum sphincter pressure) followed by a drop and a sustained pressure. The latter is important for maintaining continence [7, 24].

Analysis/Interpretation The maximum squeeze pressure is defined as the difference between the intra-rectal and the highest pressure recorded at any level within the anal canal during squeezing.

The sustained squeeze pressure represents the difference between the baseline anal sphincter pressure and the highest anal sphincter pressure value that is sustained for more than 15 s at any level in the anal canal.

The squeeze duration represents the time interval in seconds during which the patient can maintain a squeeze pressure at or above 50 % of the maximum squeeze pressure (Fig. 4.1). In a patient who cannot generate an adequate squeeze, the time interval between the onset of the squeeze response and its return to baseline pressure is measured. The mean squeeze duration ranges from 25 to 31 s, although healthy subjects can maintain squeeze for up to 50 s [24, 25].

A weak squeeze pressure response could be caused by myogenic or neurogenic disorders [25]. Men usually have significantly higher maximal squeeze pressures than women [20, 23, 24]. The maximum squeeze pressure is significantly lower in older subjects when compared to younger subjects [24, 26]. Symptoms of urge- or stress-related fecal incontinence usually correlate with low anal sphincter pressures [21]. In addition, the squeeze duration is reduced significantly in incontinent patients compared with asymptomatic normal controls [27, 28]. Of all standard measures of anorectal function, anal squeeze pressure has been shown to have the greatest sensitivity and specificity for discriminating patients with fecal incontinence from continent patients and controls [29, 30]. Nevertheless, the correlation between the anal canal pressures and incontinence is not perfect [31]. Therefore, it is presumed that there might be multifactorial elements in conferring continence and incontinence.

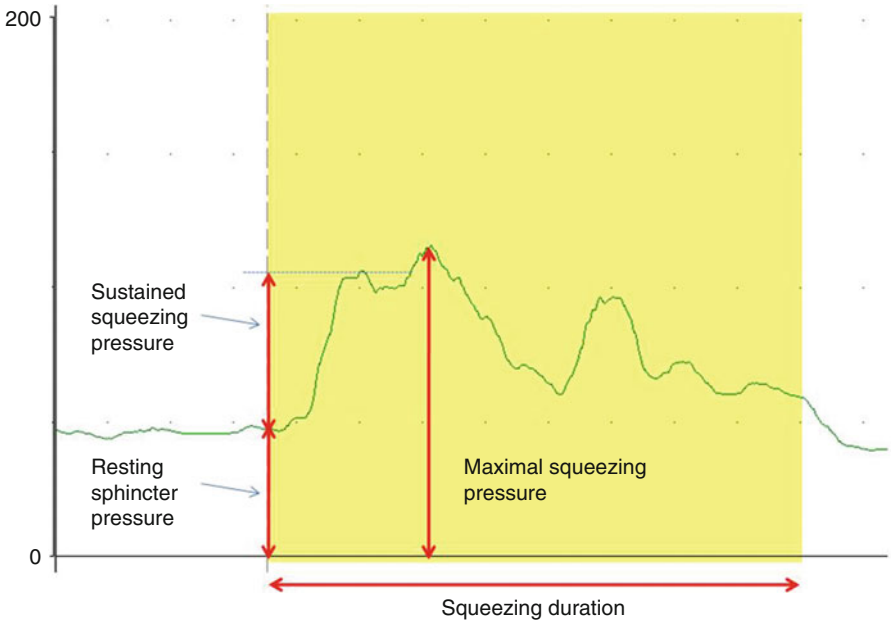


Fig. 4.1 The anal sphincter pressures profiles. The maximum squeeze pressure is defined as the difference between the atmospheric baseline and the highest pressure recorded at any level within the anal canal during squeezing. The sustained squeeze pressure represents the difference between the baseline anal sphincter pressure and the highest anal sphincter pressure value that is sustained for more than 15 s at any level in the anal canal. The squeeze duration represents the time interval in seconds during which the patient can maintain a squeeze pressure at or above 50 % of the maximum squeeze pressure

Abdomino-Pelvic Reflex (Cough Reflex Test)

This test assesses the integrity of the local reflex arc, which is responsible for maintaining continence via an abrupt increase of intra-abdominal pressure. During this test, the subject is asked to either blow up a party balloon or cough.

Analysis/Interpretation An abrupt increase in intra-abdominal pressure evokes a reflex increase in the anal sphincter pressure [25]. This phenomenon is mediated through a local spinal reflex, which is normally intact in patients with upper motor neuron lesions. However, it can be absent or impaired in patients with cauda equine lesions [7]. The difference between the baseline pressure and the highest intrarectal and highest anal pressure are measured as the rectal and anal pressures.

The result of this reflex assessment should be interpreted together with that of the squeeze pressure [25]. An absent reflex along with an absent voluntary squeeze indicates a lower motor neuron lesion (e.g. sacral plexus injury or cauda equina syndrome).

Attempted Defecation (Bearing Down)

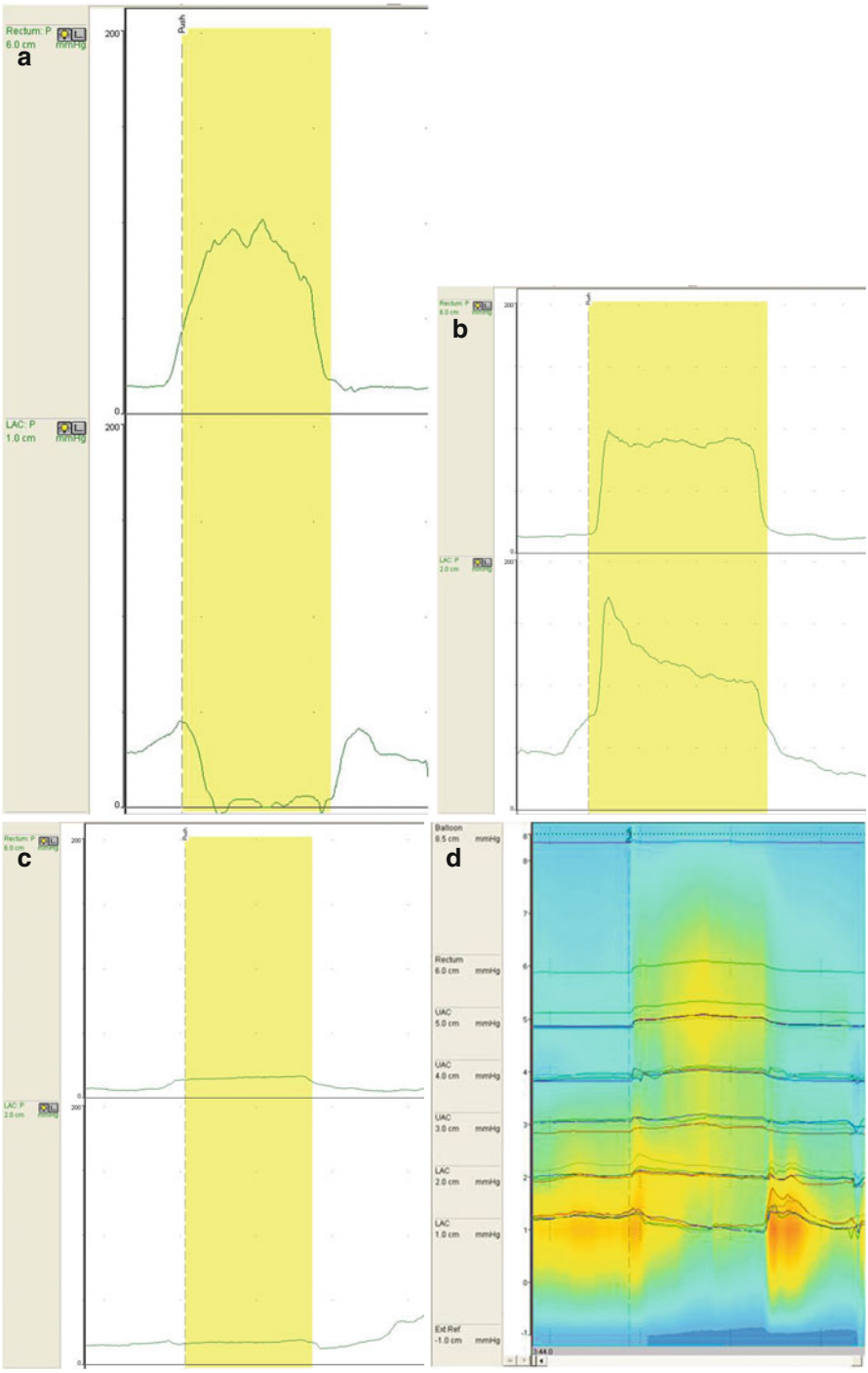
This test assesses the rectal and anal sphincter pressure changes and their coordination during attempted defecation, or bearing down. During attempted defecation, the subject is asked to bear down as if to defecate while lying on the bed [6]. After a 30-s rest, the maneuver is repeated once more.

Analysis/Interpretation The anal residual pressure is defined as the lowest (residual) pressure within the anal canal during attempted defecation [6]. Percent anal relaxation can be calculated using the following formula: percent anal relaxation = anal relaxation pressure/anal resting pressure × 100. The overall index of the changes in the rectal and anal pressure is calculated using the following defecation index: defecation index = maximum rectal pressure while bearing down/minimal anal residual pressure while bearing down [5]. Recently suggested HRM parameters including integrated pressurized volume showed higher prediction of the result of balloon expulsion test than conventional parameters [32].

In normal defecation, an increase in the rectal pressure and a decrease in the anal sphincter pressure occur. When this coordinated maneuver cannot be completed, functional obstruction to the passage of stool occurs, termed dyssynergic defecation. At least three manometric types of dyssynergic defecation have been described [33, 34]. In type I dyssynergia, there is a paradoxical increase in the intra-anal pressure in the presence of adequate expulsive forces (increase in intrarectal pressure). In type II dyssynergia, there is an inability to generate adequate expulsive forces (no increase in intrarectal pressure), together with a paradoxical increase in intra-anal pressure. In type III dyssynergia, the generation of expulsive forces (increase in intrarectal pressure) is adequate, but there is an absent or incomplete (<20 %) reduction in the intra-anal pressure. (Fig. 4.2a–e) [34]. These findings alone, however, are not diagnostic of a functional defecation disorder, which requires further supportive clinical evidence, including the balloon expulsion test [2]. Nonetheless, those patterns might be useful for identifying patients who are amenable to biofeedback therapy [35]. However, even asymptomatic normal control subjects may show these dyssynergia during the test because of embarrassment during testing [36]. Therefore, the overdiagnosis of dyssynergia should be cautioned against. By HRM, the pseudo-relaxation of the anal canal could be easily detected (Fig. 4.3).

Recto-anal Reflex Activity

When the rectum is rapidly distended, mimicking the sudden distension of the rectum with a fecal bolus, the following reflex events occur. After a transient increase in rectal pressure, likely caused by secondary rectal contractions, a transient increase in anal pressure occurs in association with EAS contraction (the recto-anal contractile reflex). Finally, a more prolonged reduction in the anal pressure occurs in association with IAS relaxation (the rectoanal inhibitory reflex).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mmHg
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mmHg
Rectum
6.0 cm
mmHg
UAC
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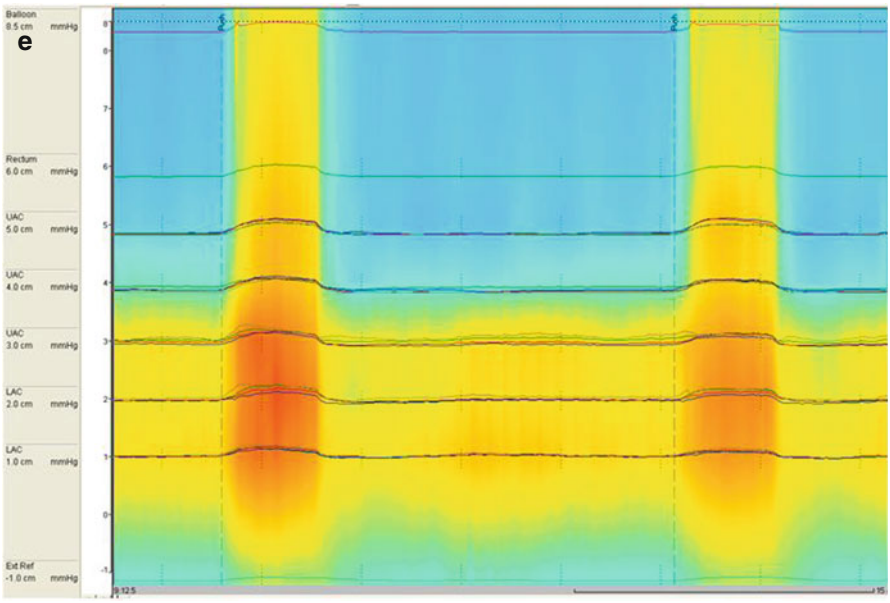

Fig. 4.2 (continued)

Rectoanal Inhibitory Reflex

Using this test, the presence of the local enteric reflex can be assessed. When the intrarectal balloon is inflated, with up to 50 ml of air, anal sphincter relaxation occurs (Fig. 4.4). The lowest balloon volume that induces anal sphincter relaxation is recorded as a cutoff range of recto-anal inhibitory reflex (RAIR) [10].

Analysis/Interpretation Distension of the rectal wall can induce IAS relaxation. This RAIR phenomenon is elicited through the myenteric plexus. A recto-anal contractile reflex is a reflex contraction of the EAS that occurs in response to rectal distension [37]. This reflex is associated with the electrical activity of the EAS.

Fig. 4.2 Normal attempted defecation and dyssynergic defecations. (**a**) In normal defecation, an increase in the rectal pressure and a decrease in the anal sphincter pressure occur. When this coordinated maneuver cannot be completed, functional obstruction to the passage of stool occurs, termed dyssynergic defecation; (**b**) In type I dyssynergia, there is a paradoxical increase in the intra-anal pressure in the presence of adequate expulsive forces (increase in intrarectal pressure); (**c**) In type II dyssynergia, there is an inability to generate adequate expulsive forces (no increase in intrarectal pressure), together with a paradoxical increase in intra-anal pressure; (**d**) High-resolution manometry (HRM) can show the relaxation of the anal canal. The color contour of the anal canal was changed from yellow to green; (**e**) HRM can show the paradoxical contraction of the anal canal

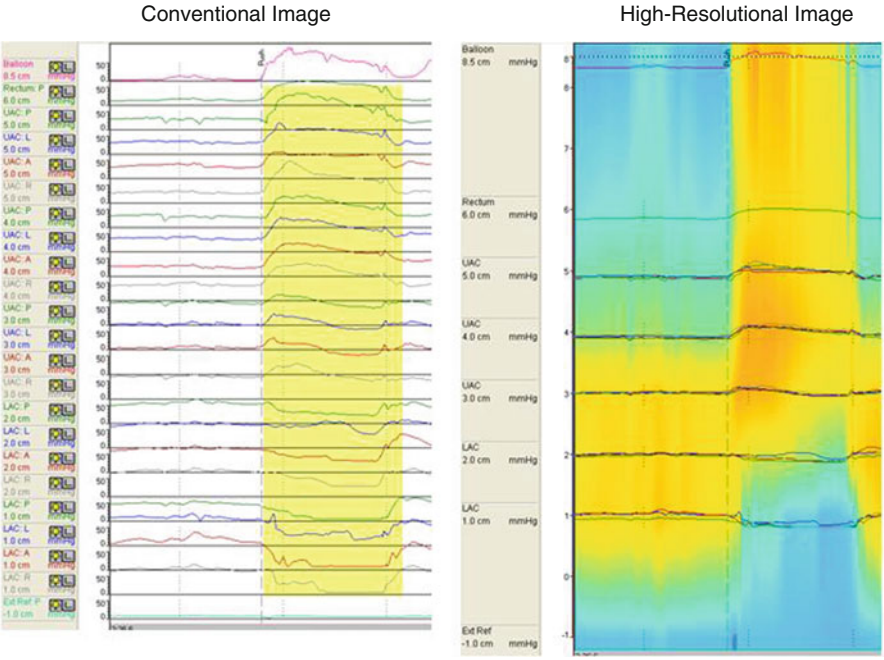

Fig. 4.3 By conventional manometry image, the anal sphincter looked to be relaxed. However, the HRM image showed that the blue color contour during anal relaxation was the same with those of outside of anal canal. Thus, this HRM contour demonstrates an artifact caused by the catheter being pushed out of the anal canal during attempted defecation

The absence of the RAIR is a typical finding in Hirschsprung's disease [38]. However, this diagnosis is rare in adults. Any condition that disturbs this neural arc can alter this reflex (e.g. visceral neuropathies).

Sensorimotor Response

Recently, a new recto-anal activity was described by Rao et al. Rectal distension can elicit a contractile motor response from the anal sphincter around the puborectalis region, termed sensorimotor response [37]. This response is evoked in response to rectal perception, which is usually associated with the desire to defecate [37]. In a 3-dimensional high-definition manometry study, this response was presumed to be associated with the contraction of the puborectalis muscle, which encircles the anal canal [13].

Rectal Sensory Testing

This test assesses the sensory thresholds in response to rectal balloon distension. Latex balloon distension is used for simplicity and economy. The latex balloon is secured to a catheter and inflated with air or water, either manually or assisted by a

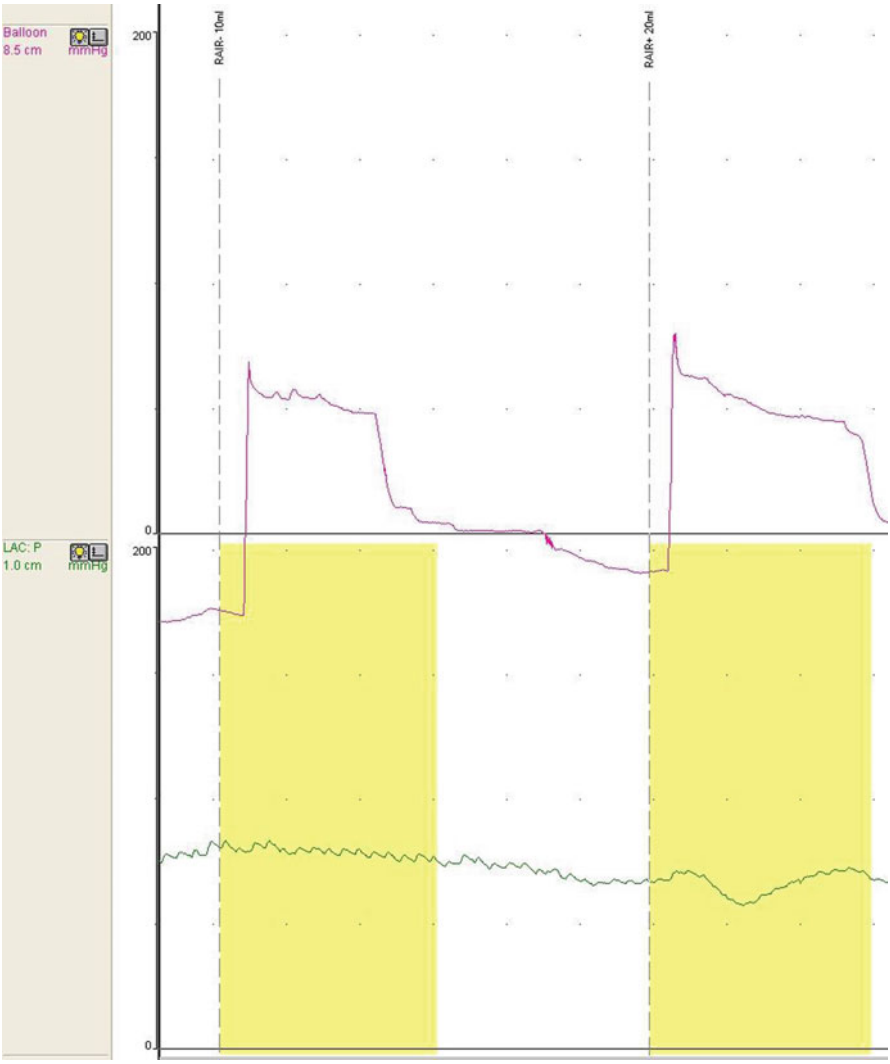

Fig. 4.4 Normal Rectoanal Inhibitory Reflex. Using this test, the presence of the local enteric reflex can be assessed. When the intrarectal balloon was inflated, with up to 10 mL of air, anal sphincter relaxation did not occur. However, when inflation was done up to 20 mL of air, anal sphincter relaxation occurred

pump [6]. Incorporating water-perfused catheters within the rectal balloon can detect the simultaneous acquisition of intraballoon (rectal) pressures and distending volumes. A barostat, which is a computer-driven device with a pneumatic pump, is sometimes used for detection during rectal sensory testing. When a latex balloon is used, two types of inflation are performed, either continual or intermittent, which can be either phasic (volumes injected and then withdrawn) or stepwise (volumes

maintained between inflations) [3, 8]. During intermittent inflation, the rectal balloon is intermittently inflated using a syringe in 10-mL/s increments until the subject can feel and report the first sensation, and then at 30-mL increments up to a maximum volume of 250–320 ml or until the maximum tolerable volume is reached. After each inflation interval, the distention should be maintained for at least 30 s before complete deflation. After a 30-s rest interval, the balloon should be reinflated until the next volume. The rate of inflation should be standardized as 10 mL/s. The five following sensations can be elicited and described [12]:

A. First sensation: A transient sensation of bloating, fullness, or gas; a vague sensation that usually disappears completely.
B. Constant sensation: A constant sensation of fullness, bloating, or gas that persists throughout the entire duration of balloon distension.
C. Desire to defecate: A desire to have a bowel movement that lasts at least more than 15 s.
D. Urgent desire to defecate: An urgent desire to have a bowel movement that could force the subject to stop doing anything else and rush to the bathroom.
E. Maximum tolerable volume: The maximum tolerable volume of distension; often associated with severe urgency and/or pain.

Analysis/Interpretation The reported sensory thresholds vary between laboratories and could differ according to the type, length, and elasticity of the balloon; the method of inflation (intermittent or continuous); and the speed of inflation. Therefore, normative data should be obtained for each laboratory based on its standardized technique.

The definition of rectal hyposensitivity could vary between laboratories; however one study suggested that this condition represents diminished perception of rectal distension for at least two modalities, including first sensation and the urge to defecate [25, 39, 40]. Rectal hyposensitivity can develop in patients with diabetes or Parkinson's disease. In contrast, rectal hypersensitivity, which involves lower thresholds of sensory perception, is noted in patients with irritable bowel syndrome or proctitis [39].

Assessment of Rectal Compliance

This test assesses the distensibility of the rectum and pressure in response to the distending volume. During intermittent inflation of the balloon, the intrarectal pressure is recorded. Initially, the rectum is relaxed by air distension, which allows accommodation of significant increases in volume while maintaining low intraluminal pressures. However, with continued distension, the rectal wall becomes more resistant to stretching because its elastic limit is reached, and the intrarectal pressure is increased. The steady state rectal pressure of each distending volume is calculated by subtracting the intraballoon pressure obtained during balloon inflation in ambient air from the intrarectal pressure during balloon distension [8]. A barostat can be used as an alternative approach for measuring rectal compliance. A highly

compliant balloon is inserted into the rectum, which is connected to a computerized balloon-distending device [41].

Analysis/Interpretation The rectal compliance can be calculated from the slope of the graph describing the relationship between the changes in the intraballoon volume (dV) and the changes in the steady state intrarectal pressure (dP). The formula for compliance is dV/dP mL/mmHg. The single number obtained reflects the average slope of the pressure-volume curve.

The rectal compliance can provide a measurement of the accommodation of the rectal wall, which is dependent on the viscoelastic properties of the rectal wall and adjacent pelvic viscera [25]. Rectal compliance is decreased in older subjects and in patients with chronic inflammatory conditions of the rectum including inflammatory bowel disorders, radiation proctitis, or chronic rectal ischemia. In contrast, increased rectal compliance is noted in cases of megarectum.

Balloon Expulsion Test

This test is performed to evaluate a subject's ability to expel a balloon in cases of suspected dyssynergic defecation [42]. A 5-cm balloon mounted to a short plastic catheter is typically used. The balloon is inflated with 50 mL of tep water, then the subject is asked to sit on a commode and expel the balloon. The time until balloon expulsion is measured [8]. Another method is to assess the amount of weight needed to be hanged on the outer side of tube to help the patient expel the balloon (normal $\leq$200 g).

Analysis/Interpretation Asymptomatic subjects are able to expel the balloon within 1 min. When the subjects cannot expel the balloon, the presence of dyssynergia can be suspected. However, a normal balloon expulsion test cannot exclude dyssynergia [25]. In one study, the balloon expulsion test showed a high specificity, sensitivity, and positive predictive value [42]. Although the balloon expulsion test represents a simple, useful screening test for functional defecation disorders, results should be interpreted alongside those of other anorectal function tests [35].

Standard Anorectal Manometry Report Components

An ideal ARM report should contain the following information:

1. General information
2. Patient demographics
3. Procedure details: indication(s) for test, orientation, number and location of sensors, balloon location and length, documentation of calibration
4. Anal sphincter pressures: resting sphincter pressure (mmHg), squeeze sphincter pressure (mmHg), duration of sustained squeeze (seconds), cough reflex (rectal and anal pressure [mmHg]), attempted defecation (rectal and anal pressure [mmHg]), rectoanal inhibitory reflex (present or absent, minimal volume that elicits the reflex)

5. Rectal sensation: threshold for first sensation (mL), desire to defecate (mL), urgency (mL), maximum tolerable volume (mL)
6. Balloon expulsion test: ability and time taken for expulsion(s)
7. Comments/interpretation/summary: a summary of the findings
8. Diagnosis
9. Identifier/signature

Complications of Anorectal Manometry

There are a few case reports of serious complications of ARM, including colorectal perforation, [43, 44]. Therefore, the probe should be inserted and removed gently [12]. The examiner should monitor the intraluminal pressure during balloon distension. If the subject complains of pain during testing, the balloon should be deflated immediately to prevent rare complications.

Clinical Utility of Anorectal Manometry

ARM, together with adjunctive tests, can confirm a clinical diagnosis and provide new information that may not be detected clinically and can influence the outcome of patients with defecation disorders [5, 18]. Selective tests should be performed based on the potential indication to evaluate each condition. In a prospective study, ARM was considered useful in 88 % of patients [5]. In 12 % of patients, studies were normal. Follow-up manometry after treatment or surgical correction of anorectal malformation or sacral nerve stimulation can prove an objective assessment of improvement [45, 46].

Conclusion

Fecal evacuation disorders causing constipation and fecal incontinence require anorectal manometry and balloon expulsion tests for diagnosis. Testing is also indicated in patients with anorectal pain, and before colorectal surgical procedures to assess sphincter function. Currently, high-resolution manometry has replaced conventional manometry. Anorectal manometry provides comprehensive information about resting anal sphincter pressure (predominantly contributed by internal anal sphincter), squeeze sphincter pressure (predominantly contributed by external anal sphincter), rectal sensation, rectal compliance, anorectal coordination during evacuation, and anorectal reflexes. Selective tests should be performed based on the potential indication to evaluate each condition. Before performing anorectal manometry, a careful digital rectal examination may provide a lot of information. The balloon expulsion test is usually performed with anorectal manometry. It is a simple test to diagnose fecal evacuation disorders with reasonable sensitivity and specificity.

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Defecography: Technique, Interpretation and Clinical Application

5

Ah Young Kim

Abstract

Defecography has been established as one of the primary examinations for patients with defecation disorder because of easy accessibility and cost-effectiveness. This examination enables, in real time, the morphologic as well as functional evaluation of the rectum and anal canal in a physiologic manner by injection of a thick barium paste into the rectum and its subsequent evacuation. Major indications of defecography include chronic intractable constipation, incomplete evacuation, incontinence, unexplainable rectal bleeding or mucous discharge, and suspected rectal prolapse. Technique and interpretation of this examination are outlined in this review.

Keywords

Defecography • Defecation disorder • Constipation • Anorectum • Pelvic floor

Introduction

Evacuation disorders, or pelvic floor dysfunction, are frequently found in elderly patients, especially in multiparous women older than 50 years of age, and is a major health issue impacting on the quality of life. These disease entities, caused by morphologic and functional abnormalities, however, are rarely identified with static imaging techniques.

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Defecography, also called evacuation proctography, dynamic proctography, or voiding proctography, has been established as a particularly useful fluoroscopic examination for patients who suffer from various defecation difficulties. Although there are other common diagnostic tools such as rectal manometry, endoscopic ultrasonography, or MRI for evaluation of the anorectal region, this examination still represents a widely available and cost-effective diagnostic tool because of its easy accessibility and its unique capability of a functional, real-time assessment of the defecation mechanics in a physiologic manner [1–6].

Major indications of defecography include chronic intractable constipation, incomplete evacuation, incontinence, unexplainable rectal bleeding or mucous discharge, suspected rectal prolapse, and perianal pain or discomfort.

Technique

Patient Preparation

Preparation of the bowel with laxatives or enemas is not necessary. In some institutes, however, the patient is asked to take a rectal cleansing enema at home a few hours before the examination because a limited bowel preparation will be more comfortable for the patient and will also provide a more standardized examination.

Before the procedure, it is very important to obtain a complete clinical history of the patient, with particular attention to abdominal or pelvic surgery, clinical conditions (such as diabetes, hypothyroidism, and systemic disorders) and drug consumption. Other clinical history should be recorded as follows: the period of dyschezia, the frequency of defecation per week, the time required for usual defecation, the sense of tenesmus or incomplete evacuation, the specific posture during defecation, the use of specific maneuver (digitalization/laxative/enema).

To perform a correct examination, collaboration of the patient is essential. The entire procedure should be explained to the patient so that the patient follows the actual instructions of the examination correctly, in a relaxed and comfortable condition.

Opacification of Vagina and/or Small Intestine

In female patients, the vagina is usually opacified with a commercially available barium sulfate for oral use. Various agents such as water-soluble contrast agent or radiopaque gel are also used for vaginal opacification.

Sometimes, the small bowel should be opacified with the same barium used for examination of the small intestine in order to differentiate enterocele from other extrinsic indentation. Oral ingestion of 400–600 mL barium suspension is given 45–60 min before the fluoroscopic study. Sometimes, it can take up to 3 h for ingested oral contrast to reach pelvic ileal loops. Contrast opacification of other organs such as sigmoid colon, bladder, or peritoneum can be useful for differential diagnosis, but these techniques are rarely recommended, due to increasing invasiveness and radiation hazard.

Rectal Opacification and Defecation

First of all, the examiner should perform the perineal inspection and rectal digital examination. Before the injection of rectal paste, the digital examination is indispensable in order to confirm the sphincter tone, the presence of rectal intussusception, or unexpected rectal mass.

The next step is transanal injection of barium paste, about 250–300 mL, by using a rectal catheter or a regular caulking gun, after the patient has taken a position of left decubitus. To obtain the accurate examination as under real-life conditions, it is very important to keep the appropriate consistency of barium paste similar to that of stool. In other words, the injection of liquid or thin barium is not physiologic and can stress even a normal continence mechanism, resulting in abnormal contraction of the pelvic floor and anal muscles at rest. In general, commercial formulations or a barium paste prepared with thick barium and potato starch can be used for rectal opacification.

When the patient perceives the stimulus to evacuate, the anal bulb is completely filled and injection can be interrupted. At that time, the fluoroscopic table is tilted vertically and a special commode (Fig. 5.1) is attached to the footboard. The patient is asked to sit on the commode in right lateral projection. When the radiogenic tube is correctly centered on the pelvis, the first radiograph (scout film) is obtained with a marking ruler (rest state). Subsequently, the patient is requested to squeeze (or lift, for maximum contraction of anal sphincters and pelvic floor muscles), cough, strain

Fig. 5.1 Defecography commode. Fluoroscopic table is tilted vertically and a special commode is attached to the footboard with fluid-filled ring pillows

(increase intraabdominal pressure without evacuation), and defecate. The patient must be instructed to empty the rectum completely without interruption. Finally, post-evacuation spot radiograph is also obtained after full evacuation. Without interruption, this process takes less than 30 s in physiologic conditions [7]. The entire examination should be recorded through video fluoroscopy, and static images using a fluoroscopic image capture are obtained at four phases including during rest post-evacuation state.

Interpretation

Parameters for Quantitative Analysis

The anorectal angle (ARA) is defined as the angle between the posterior border of the distal part of the rectum, which is formed by an impression of the puborectalis muscle, and the central axis of the anal canal (Fig. 5.2). Alternatively, if the impression is indistinct or irregular, the posterior rectal wall line can be approximated as parallel to the central longitudinal axis of the rectum [8].

ARA is an indirect indicator of the puborectal muscle activity. At rest, its average value is 95°–96° (physiologic range, 65°–100°) without noticeable differences between men and women [7, 9, 10]. During muscle contraction, ARA becomes more acute, while during relaxing phase it becomes obtuse. Namely, it is more acute with squeezing (75°–90°) and more obtuse (110°–180°) during evacuation.

Another important parameter is "perineal descent," which means craniocaudal shift of the anorectal junction (ARJ) during straining. It can be measured

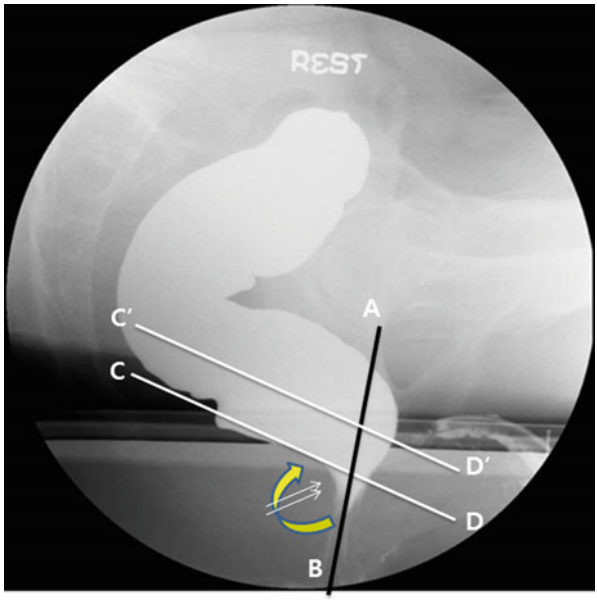

Fig. 5.2 Measurement of anorectal angle. Anorectal angle (*curved arrow*) is measured from the axis of the anal canal (*AB*) to a line either along the posterior wall of the rectum (*CD*) or through the central axis of the rectum (*C'D'*). *Double thin arrows* show the position of the anorectal junction

perpendicularly from the pubococcygeal line (PCL), which extends from the inferior border of the symphysis pubis to the sacrococcygeal joint. PCL usually represents the plane of the levator ani or levator plate [5]. In assessing perineal descent, another reference point, the so-called "bis-ischiatic line" can be used. This is a fixed bony landmark, drawn between the ischial tuberosities.

ARJ is the uppermost point of the anal canal. The craniocaudal migration of ARJ indirectly represents the elevation and descent of the pelvic floor. Normally the pelvic floor is up to 1.8 cm below the PCL and so, in a normal or asymptomatic person, one expects to see little to no downward motion of the pelvic viscera below the PCL with straining or defecation. It can be up to 3.0 cm below the PCL during maximal straining but, if above 3.5 cm, it is considered abnormal. Although the reproducibility and reliability of these two parameters have been confirmed, their clinical significance is still controversial [7].

There are other less frequently used parameters: puborectalis and anal canal length. The former is the length between the anorectal junction and the inferior pubic symphysis. The latter is the distance traversed by the parallel borders of the anal canal before they form the diverging walls of the distal rectum.

Qualitative Analysis

At rest (Fig. 5.3a), the impression of puborectal sling is visible on the posterior wall of caudal rectum and the ARA is about 90°. During voluntary contraction of the pelvic floor (squeezing) (Fig. 5.3b), the ARA decreases to about 75° and the ARJ migrates cranially. The puborectal impression becomes more evident because of the contraction of levator ani. While the patient is asked to strain (Fig. 5.3c), the ARA increases, with partial to complete loss of puborectal impression, and the pelvic floor descends. The degree of caudal migration of ARJ is considered normal when less than 3.5 cm relative to the resting position [11].

During evacuation (Fig. 5.3d), a wide opening of the anal canal and funneling of the anorectum is seen, with near complete loss of puborectal sling impression. The ARA increases with the relaxation of anal sphincter and puborectalis muscle. At the end of evacuation, the rectum is completely empty and its walls collapse. Eventually, the rectum is restored to its original resting condition. Normal evacuation lasts about 30 s and is partly determined by the amount of rectal contents before evacuation.

Classical radiologic findings of normal defecography described by Mahieu P et al. are as follows: increase in the anorectal angle, obliteration of the puborectalis impression, wide opening of the anal canal, evacuation of the rectal contents, and good resistance of the pelvic floor (that is, it does not descend more than 2–3 cm) [2].

Clinical Applications

Rectocele

A rectocele is a focal outpouching of the rectal wall. Most are anterior rectocele and more commonly occur in females because of weakness of the posterior wall of the vaginal canal from obstetric trauma. But these are found in up to 20 % of

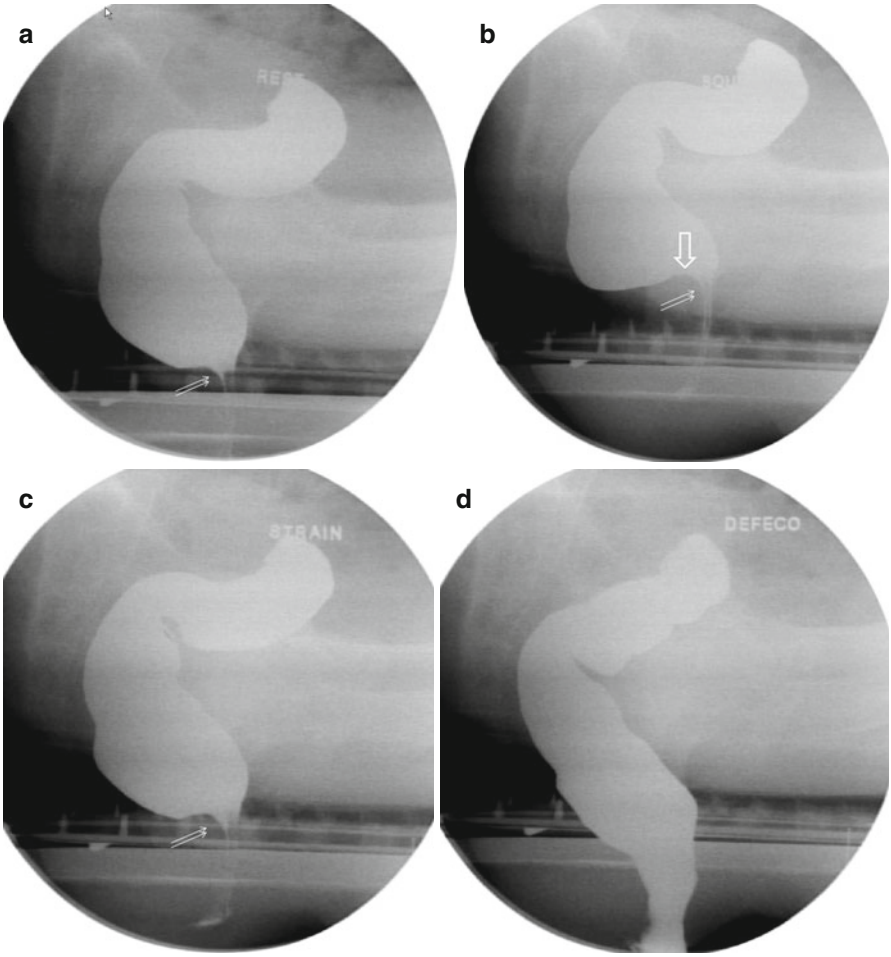

Fig. 5.3 Normal defecography. (**a**) At rest; the deeper impression exerted by the puborectal sling (*open arrow*) is seen. (**b**) The cranial migration of the distal rectum is noted during forced contraction. (**c**) During straining with closed sphincters, caudal migration of the anorectal junction is seen (*double arrows*). (**d**) During evacuation, the anal canal opens with loss of puborectalis impression

asymptomatic women. Although only a rectocele wider than 2 cm in the anteroposterior diameter should be considered abnormal, [6] the significance of the presence of this rectocele at defecography is still not clear. In patients with severe constipation, a rectocele as a solitary finding is rare, and anismus, intussusception, and enterocele are often associated with the presence of a rectocele. Treatment of the rectocele is tailored in symptomatic patients according to other imaging findings. On defecography, an outpouching of the anterior rectal wall bulges and dislocates the opacified vaginal lumen during straining and evacuation (Fig. 5.4).

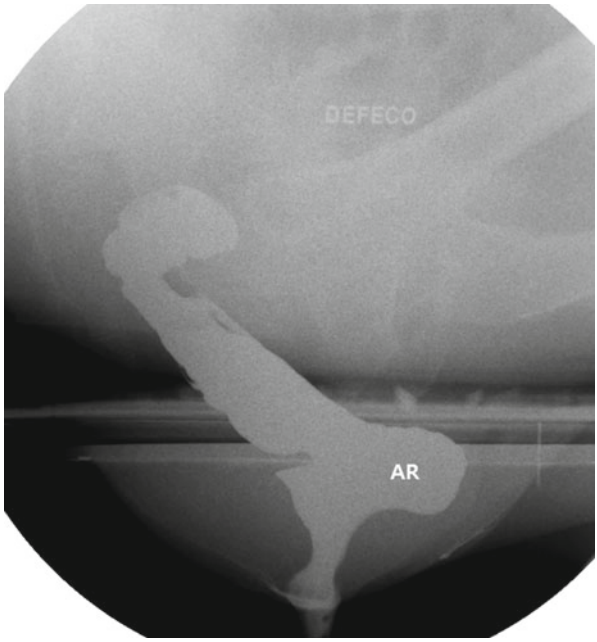

Fig. 5.4 Anterior rectocele. The anterior rectal wall protrudes over the expected position (*AR*) but defecation is not obstructed. Vaginal marking is anteriorly displaced

Although most rectoceles do not necessarily impede evacuation, a large rectocele can interfere with defecation as the force vector is shifted toward the rectocele and away from the anal canal. Retention of stool within a rectocele may lead to a sense of incomplete evacuation and the need for digital maneuver to complete evacuation.

Intussusception and Rectal Prolapse

Rectal intussusception is a concentric invagination of the entire rectal wall toward the anal canal during straining or defecation. It may be classified as intra-rectal, intra-anal, or total rectal prolapse (when the rectum passes through the anal canal). It usually begins 6–8 cm above the anal canal as an invagination of one of the valves of Houston [11]. Such an invagination of the rectal wall does not always occur at entire direction of the rectal wall. The anterior infolding of intussusception occurs in 62 % of patients, annular in 32 %, and posterior in only 6 %. This condition is frequently accompanied with descending perineum syndrome, solitary rectal ulcer, spastic pelvic syndrome, and rectocele.

On defecography, the presence of transverse or oblique infolding of the rectal wall of more than 3 mm thickness, which assumes a funnel or ring-like configuration during straining, represents an intussusception (Fig. 5.5a, b). Minor degrees of infolding of less than 3 mm thickness represents mucosal prolapse and can be seen in a normal person.

Intussusception is unlikely to obstruct defecation directly. It occurs as the rectum collapses, [12] but it can cause a sensation of incomplete emptying or obstructed

defecation in the later phase of evacuation. This is most likely with an intra-rectal, and intra-anal intussusception.

When an intussusception plugs the anal canal, the patient may develop symptoms of obstructed defecation and progress to rectal prolapse. In complete rectal prolapse, dilatation of the anal canal is evident during evacuation, and a circular infolding of the rectal wall invaginates into the lumen. Descent can pass through the anus prolapsing externally (Fig. 5.6). While complete or external prolapses are

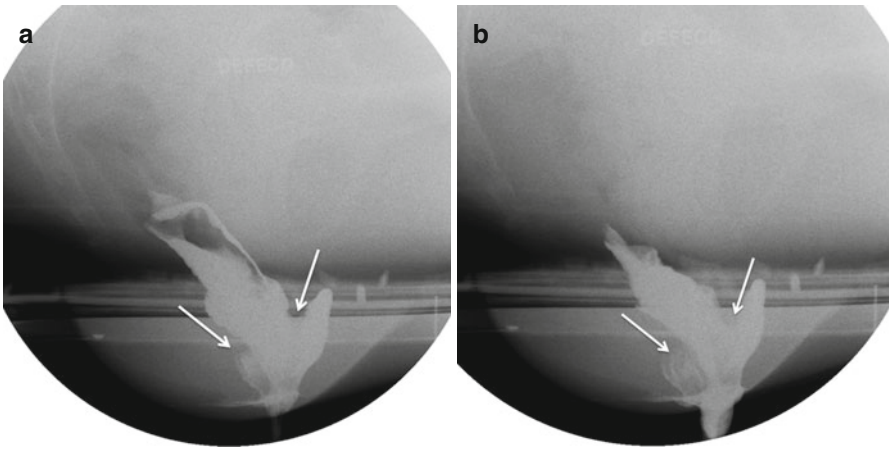

Fig. 5.5 Intussusception. (**a**) An annular infolding of the rectal wall shows a funnel configuration during defecation. (**b**) This intussusception subsequently progresses to intra-anal prolapse (*arrows*)

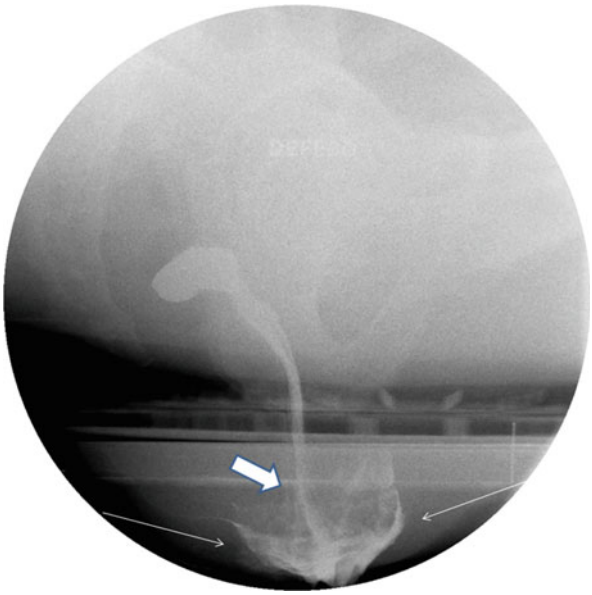

Fig. 5.6 Prolapse. The fluoroscopic image demonstrates complete external prolapse of the rectum (*thin arrows*). Note the thin line of contrast opacification, representing the narrowed lumen of the prolapsed rectum (*thick arrow*)

clinically obvious, depiction of the internal prolapse is not always easy, since it is demonstrated during the end of defecation and sometimes only with straining.

Spastic Pelvic Floor Syndrome

Also known as dyskinetic puborectalis muscle or anismus; this condition is due to an inappropriate contraction of the pelvic floor during defecation. Characteristic findings on defecography include a lack of pelvic floor descent and paradoxical contraction of the puborectalis muscle. Another less specific feature is an aberrantly deep impression of the puborectalis sling on the posterior rectal wall at rest (Fig. 5.7a, b). This is caused by the presence of a hypertrophic puborectalis muscle. But this finding is also seen in some normal individuals [13]. As a result, ARA is decreased or fixed during defecation, and the anal canal frequently shows consistent contraction throughout defecation. In some patients, on the other hand, the puborectalis relaxes during defecation, but the internal or external anal sphincter muscle, or both, fails to open.

Prolonged and incomplete evacuation during defecography remains the specific finding. Evacuation time longer than 30 s is highly predictive of spastic pelvic floor syndrome, having a positive predictive value of 90% [14]. This syndrome is relatively common in patients with normal colonic transit and chronic constipation. Although controversial, it would appear to correlate strongly with symptoms in certain individuals, and is often successfully treated by biofeedback.

Descending Perineum Syndrome

This syndrome is a form of functional outlet obstruction caused by a diffusely weakened pelvic floor. It occurs when there is ballooning of the perineum below the plane of the ischial tuberosities during straining, and can be effectively assessed by defecography.

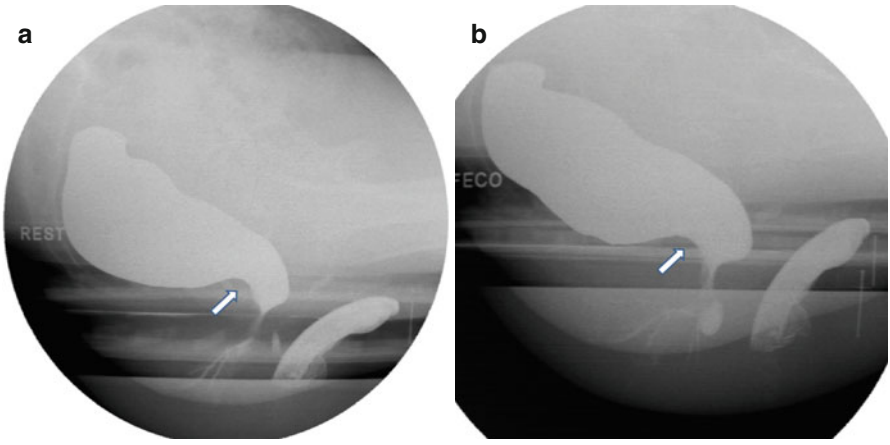

Fig. 5.7 Dyskinetic puborectalis muscle syndrome. (**a**) Note abnormally deep puborectal impression (*arrow*) at the rest. (**b**) During evacuation phase, there is a lack of pelvic floor descent

Excessive pelvic floor descent during defecation is often caused by pudendal nerve injury resulting from a combination of obstetric trauma and chronic straining. This condition is usually found in elderly women [15]. The main radiographic feature is the caudal migration of the anorectal junction more than 3.5 cm during straining. The anorectal angle is more than 130° at rest and increases to more than 155° during straining [16–18]. This perineal descent caused by increased intraabdominal pressure during straining is also associated with relaxation of the puborectalis and pelvic muscles. Repeated stretching of the pelvic floor chronically causes damage to the nervous system, most notably the pudendal nerve, and determines dysfunction of continence, and pain. Incontinence is frequently associated with this syndrome [11]. In such cases, perineal discomfort or pain and a feeling of incomplete evacuation lead to increased straining during defecation, which can, in turn, progress to neuropathic injury to the external anal sphincter, resulting in incontinence. Therefore, this condition should be conservatively treated by means of suppositories to reduce straining during evacuation [6].

Enteroceles and Sigmoidoceles

Peritoneal sac herniations are demonstrated most frequently at the end of evacuation and can be filled with small bowel (enterocele) or sigmoid colon (sigmoidocele). These result from the herniation of the peritoneal sac into the rectovaginal space. Therefore, these are almost exclusively found in female subjects. Pelvic surgical procedures are risk factors for this condition, especially gynecological procedures such as hysterectomy or urethropexy [11]. It is not clear whether enteroceles actually mechanically obstruct defecation, but like intussusceptions, may lead to a sensation of incomplete evacuation. However, protrusion of herniated viscera on the anterior rectal wall frequently causes an associated rectal prolapse [11].

On defecography, the presence of an enterocele can be indirectly suggested when the widening of the space between the rectum and vagina is noted during defecation. When this separation of the space is identified, the examination should be repeated at a later date after the small bowel has been opacified, as described earlier. At that time, the descent of barium-filled ileal loops is evident during evacuation in the space between the rectum and vagina that is widened (Fig. 5.8a, b). Similar to an enterocele, the sigmoid colon infrequently descends through the rectovaginal septum, and then the resulting process is known as a sigmoidocele.

Incontinence

Fecal incontinence is a lack of control over defecation, leading to involuntary loss of bowel contents. Incontinence can result from different causes, and might occur with either constipation or diarrhea. The most common causes are thought to be immediate or delayed damage from childbirth, complications from prior anorectal surgery, and altered bowel habits. It may be associated with other evacuation disorders, such as intussusception and descending perineal syndrome. Its prevalence depends on the age and parity of the patient; it is more common in elderly multiparous women.

Incontinence of solid or liquid stools is evident in approximately 75% of all patients with a full-thickness rectal prolapse [11]. In rectal prolapse, patients are partially incontinent because the intussusception dilates the internal sphincter.

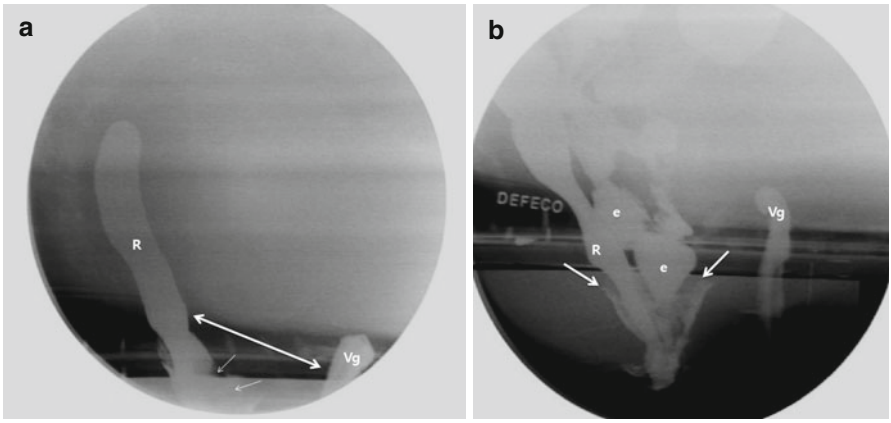

Fig. 5.8 Rectal intussusception with enterocele. (**a**) Rectovaginal space is widened and rectal bulb is compressed. (**b**) On defecogram after opacification of small intestine in the same patient, rectovaginal space widening is demonstrated by the descent of opacified intestine (indicated as "e"), and rectal intussusception is also noted (*arrows*). *R* rectum, *Vg* vaginal marking

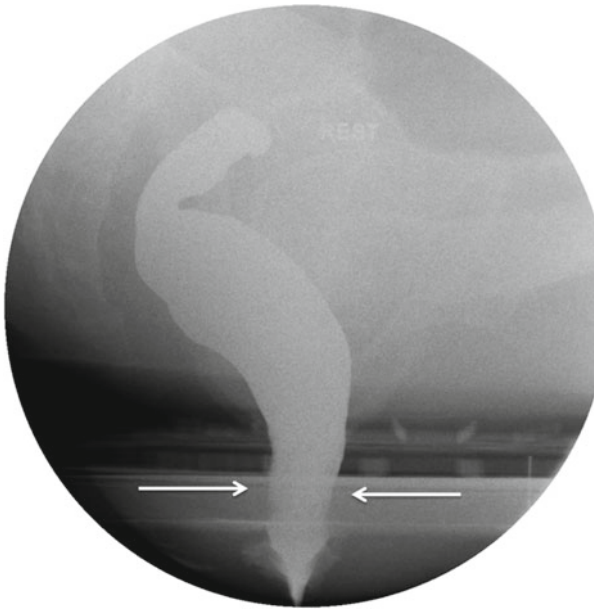

Fig. 5.9 Incontinence. At rest, the widely opened anal canal is seen with expulsion of some barium contents. Wide anorectal angle is also noted

Continuous straining associated with a prolapse may cause pudendal neuropathy, resulting in sensory loss to the anorectum, as well as a motor weakness of the sphincter muscles.

On defecography, the anal canal at rest is seen radiographically as a patulous structure associated with an increase in the anorectal angle (more than 150° at rest) (Fig. 5.9). This wide anorectal angle is not changed, even at straining. Leakage of

barium paste occurs with a slight increase of intra-abdominal pressure (such as cough). The treatment of choice is surgical correction, such as rectopexy or postanal repair.

Conclusion

Defecography is a reliable and reproducible technique, as well as a cost-effective and easily accessible procedure for evaluation of defecation disorders. Although the condition is complex, with overlap of imaging findings between normal and symptomatic individuals, this method has the highest accuracy in diagnosing rectal intussusception, prolapse, and enterocele. It can be used in conjunction with rectal manometry, electromyography, transrectal sonography, and colon transit studies to improve diagnosis and the selection of surgical or medical treatment.

Due to its major limitations—limited projectional planes, radiation risk, and its inability to depict perirectal soft tissue—MR defecography has been suggested as an alternative imaging. However, MR defecography has limited availability in routine practice. Therefore, defecography still represents a unique and basic diagnostic technique for the examination of defecation dysfunctions.

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Therapeutic Application of Manometry: Biofeedback for Management of Fecal Evacuation Disorders

6

Tanisa Patcharatrakul and Sutep Gonlachanvit

Abstract

Anorectal dyssynergia is an important cause of defecation disorder, especially among patients with chronic primary constipation. Patients with this condition have an incoordination of abdominal wall muscles and pelvic floor during bearing down, which results in impaired evacuation. Dietary modification, lifestyle modification, and laxatives—which are the standard treatment of constipation—are not able to correct the pathophysiology of this condition.

Biofeedback has been recommended as the treatment of choice for this condition. It is an instrument-based behavioral learning process and has demonstrated a superior benefit over standard treatment or laxatives in several randomized controlled trials. This treatment improves constipation and overall symptoms, as well as dyssynergic pattern of defecation, and showed a long-term efficacy. To date, the biofeedback treatment protocol has not been standardized and a wide variety of techniques have been reported, with insufficient data to determine the most effective modality. In this review, we focus on a manometry-based biofeedback method which measures the pressure at the rectum that represents the propulsive or pushing force, and anal sphincter pressure that represents the sphincter relaxation or contraction. We thoroughly describe the practical biofeedback technique for dyssynergic constipation patients that has been used in our center. Although only studies of biofeedback therapy from Asian countries have been

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reviewed, the response rate in our center and other centers in Asia was comparable to the western studies.

Keywords
Biofeedback therapy • Constipation • Defecation disorder • Dyssynergic defecation • Evacuation disorder

Introduction

Constipation is a common gastrointestinal symptom worldwide. Population-based studies have reported a wide range of prevalence from 0.7 to 79 % in the general population, depending on how constipation is defined, and the study method [1]. Studies among the patients without organic abnormality, so-called primary chronic constipation, in the referral center where colonic and anorectal physiologic studies were performed revealed that there was no physiologic abnormalities detected in 47–60 % of the patients, and this group of patients commonly had clinical characteristics of irritable bowel syndrome-constipation (IBS-C) [2–4]. Inappropriate contractions of pelvic floor muscles, or dyssynergic defecation which resulted in impaired evacuation, was detected in 27–59 %, followed by a slow colonic transit in 3–47 % of patients. A combination of dyssynergic defecation and slow transit as well as dyssynergic defecation with IBS-C are commonly present [2–4]. Though the symptoms associated with constipation are often intermittent and mild, they may be chronic, debilitating, not respond to simple treatments, and have significant impact on the patient's quality of life [5]. Among the patients with chronic or severe symptoms, investigation to find out the underlying pathophysiology of constipation which leads to specific treatment may not only provide a sustained improvement of symptoms, but also improve quality of life.

Fecal evacuation disorder or defecation disorder in severe chronic constipation is commonly caused by dyssynergic defecation, so called anismus, pelvic floor dysfunction, anorectal dysfunction, pelvic floor dyssynergia, obstructive defecation, paradoxical puborectalis contraction, pelvic outlet obstruction, and spastic pelvic floor syndrome [6]. A careful clinical assessment including digital examination can raise the suspicion of this condition [7]. However, definite diagnosis requires anorectal physiological tests including either anorectal manometry, defecography, or a rectal balloon expulsion test, that reveals an incoordination of abdominal wall muscles and pelvic floor muscles during bearing down, which results in impaired rectal emptying. Dietary modification, lifestyle modification, and laxatives—which are the mainstay of constipation treatment—are not able to correct the pathophysiology of this condition and are commonly associated with treatment failure.

Biofeedback therapy is an instrument-based behavioral learning process that is based on "operant conditioning" techniques. This has been used since 1987 for treatment of spastic pelvic floor syndrome [8]. To date, several randomized controlled trials in chronic constipation patients with dyssynergic defecation demonstrated a superior clinical response over standard treatment including laxatives, and

also showed a long-term efficacy [9–12]. Therefore, biofeedback therapy turns out to be a standard and specific treatment for this condition [13–15]. The principle of biofeedback therapy for dyssynergic defecation is to provide feedback information about how anorectal and pelvic floor muscles are working while the patient is pushing and bearing down. The patient will learn how to relax the anal sphincter muscles and how to push properly to induce adequate rectal propulsive force to overcome anal sphincter pressure. Rectal sensory trainings are also performed in some patients who have impaired rectal sensation (Fig. 6.1). Only a few studies of biofeedback therapy from Asian countries have been published, and the response rate was comparable to the western studies [4, 16, 17]. However, this treatment is readily available only in tertiary care centers.

Although the biofeedback technique has been reported for the treatment of dyssynergic defecation for many years, the technique has not been standardized, and rarely described in practical details. Rao et al. described three phases of the biofeedback therapy for constipation which consisted of (1) patient evaluation/enrollment; (2) active phase of therapy; and (3) reinforcement [18].

In this chapter we describe a practical biofeedback protocol which has been used effectively in our center for several years.

Fig. 6.1 During biofeedback training, the therapist provides feedback information about how anal sphincter and pelvic floor muscles are working, so the patient will learn how to relax anal sphincter muscles and how to push properly by visual and verbal feedback mechanisms

Biofeedback Therapy Devices and Techniques

To date, many varieties of biofeedback training techniques have been reported, with insufficient data to determine the most effective modality, and no uniform treatment protocol established [19–22]. In most centers, a specialized nurse or physical therapist performs this training at an outpatient clinic, however home-based training can also be performed [23, 24]. In the outpatient setting, this therapy generally required four to six sessions every 1–2 weeks, with duration of 30–90 min for each session [4, 9, 12]. Two types of devices have been used, including electromyography (EMG) and manometry, to represent how abdominal muscles, pelvic floor muscles, and the anal sphincter are working.

For manometry-based device, four sensors in a solid-state manometry catheter with a 1 cm interval at the anal sphincter zone and latex balloon at the catheter tip, has been used with software for displaying the manometric data (Fig. 6.2) [4, 25]. The most upper tracing displays the rectal pressure and the other lower tracings display pelvic floor muscles and anal sphincter pressure. The latex balloon, which is placed at the rectum, is used for rectal sensory training. While training with the solid-state catheter, the patient is seated upright in the commode, which is the physiological position for defecation. Use of a water-perfused polyvinyl catheter with a compliant balloon at the tip has also been reported [26, 27]. However, when training is performed in the upright position, this perfusion system may not correctly represent the rectal and anal sphincter pressure while the pelvic floor is descending. Therefore, the training with a water-perfused system is usually performed in the lateral position, which is not a physiologic position, and water dripping out may disturb the patient if training time is prolonged.

For EMG-based device, an anal plug containing longitudinally oriented metal plate electrodes is used. EMG activity is amplified, filtered to eliminate low-frequency EMG signal from the smooth muscle and high-frequency activity representing ambient electric noise, and then averaged and displayed. This recording reflects both the external anal sphincter and puborectalis muscles. A second channel of EMG is recorded from electrodes applied to the skin overlying the rectus abdominis muscles. For this channel, the two active electrodes are positioned in a vertical line with the first situated 2 cm below the umbilicus and the second placed 5 cm below the first one. A reference electrode is placed midway between these two active electrodes. The patient watches a computer monitor displaying the rectus abdominis EMG on

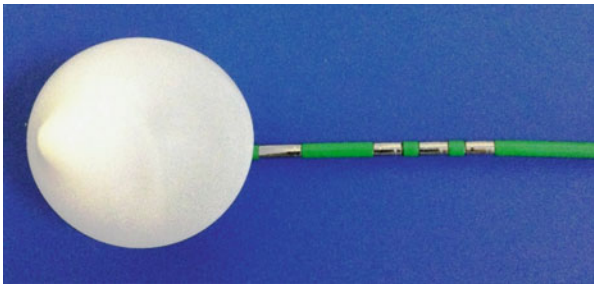

Fig. 6.2 A solid-state manometry catheter (for biofeedback training, a latex balloon is attached at the catheter tip). While training with this catheter, the patient can sit on the commode and training can be performed

the top and the pelvic floor electromyography immediately below it [11]. Commercial software is used to record and display these signals. The rectal balloon cannot be coordinated in the EMG-based system, so rectal sensory training cannot be done. Although there were randomized control studies comparing treatment outcome between different devices, the heterogeneity of these treatment protocols and small sample size make it difficult to detect the difference of outcome [19–22]. In our center, we use solid-state manometry-based devices for training because of the accuracy of pressure measurement and patient preference, as described above, and we always perform rectal sensory training in patients with rectal hyposensitivity.

The frequency of loss to follow-up is 0–30 %, which is similar between different biofeedback techniques and the control group [9, 11, 12, 19–22, 26]. In this review, we only focus on the manometry-based method, which measures the pressure at the rectum that represents the propulsive or pushing force, and anal sphincter pressure that represents sphincter relaxation or contraction. The practical technique that has been used in our center consists of three steps:

Step 1. Provide Education on Anorectal Anatomy and Defecation Physiology

An understanding of normal defecation physiology, including an occurrence of high-amplitude colonic-propagated contractions after meals and awakening, may help the patient learn the sense of defecation and take advantage of these contractions to promote bowel movement and avoid unnecessary straining. The patient should be advised to respond to the sensation of stool and go to the toilet after awakening. An early morning caloric meal or a wake-up meal is usually recommended for patients in our center to promote the sensation of bowel movement. A previous study in Asia suggested that skipping breakfast was associated with constipation in working women in Japan [28].

At this step, the therapist can also elucidate the correlation between toilet-sitting posture and appropriate anorectal anatomy for stool passage, as well as the correlation between intra-abdominal pressure control by abdominal breathing and the effective pushing force. Patient education about anorectal anatomy and normal physiology of defecation can be done after making the diagnosis of defecation disorder. The appropriate toilet-sitting posture, abdominal breathing exercise, and recognition of normal defecation physiology can be practiced at home prior to scheduling the patient for biofeedback treatment. This process should be repeated again at the first session of biofeedback treatment for understanding tracings on the monitor, which represent coordination of abdominal muscles as well as pelvic floor and anal sphincter.

Step 2. Identify and Target Defecation Problem Individually

Because biofeedback therapy is a labor-intensive treatment, patient training by targeting on a specific problem—and not providing universal training—may shorten

treatment duration and create positive reinforcement. The therapist should evaluate whether the patient has specific problem(s) which can lead to dyssynergic defecation. These problems may be divided into three major groups: (1) ineffective rectal propulsive force; (2) paradoxical contraction or inadequate anal sphincter relaxation; or (3) rectal sensory impairment. Treatment should focus on each problem individually (Table 6.1). Preliminary data from our center revealed that among 33 patients with functional defecation disorders by ROME III criteria prior to the biofeedback treatment, 48 % were unable to performed abdominal breathing exercise or hold their breath while bearing down, 70 % had anal sphincter contraction or inadequate relaxation and 57 % of these patients did not recognize this inappropriate anal sphincter contraction. Thirty-six percent of patients did not have urgency sensation when 50 cc. rectal balloon was inflated and 42 % of patients did not recognize the relaxation of anal sphincter during rectal balloon distension. A pathophysiologic mechanisms of dyssynergic defecation described in Table 6.1 should be identified and informed to the patients. During biofeedback training, patient and the therapist should focus on correcting the problem(s).

Ineffective rectal propulsion The problems that are associated with ineffective rectal propulsion are: (i) inappropriate toilet sitting posture; (ii) breathing or exhalation during pushing; and (iii) inappropriate use of muscles during pushing. These problems can be identified by observing the breathing pattern, abdominal wall muscle usage, sitting position, and manometric tracing profiles while the patient is pushing. When asking the patient to bear down, a patient with ineffective rectal propulsive force may exhale or not hold their breath, or cannot contract their diaphragm and abdominal wall muscles appropriately to increase the intra-abdominal pressure [29], which can be observed in the manometric tracing on the computer screen (Figs. 6.3 and 6.4). Among these patients, therapy should emphasize abdominal breathing exercises to strengthen the diaphragm and abdominal wall muscles. Breath holding while bearing down should also be advised, and patients should be advised to keep practicing at home. Appropriate toilet-sitting posture, which includes slight bending forward and increased hip flexion by lifting both feet, may widen the recto-anal angle and let stool come down easily. Looking at the screen under the therapist's supervision will help the patient understand the importance of breath holding and appropriate sitting posture. However, increased pushing effort should be carefully advised, particularly to the patients with paradoxical anal sphincter contraction, because increased pushing force may also increase anal sphincter pressure. During biofeedback training, the appropriate pushing pressure is the level that just overcomes the anal sphincter pressure while the rectal balloon is inflated. Experiences in our center suggest that slowly and gently increasing pushing force can induce anal sphincter relaxation more easily than rapidly increasing pushing force or excessive straining. Between biofeedback sessions, stool softeners—including osmotic laxatives—may be useful in patients who have hard stool. This will help to avoid excessive straining at home during the biofeedback treatment program.

Table 6.1 How to identify defecation problem(s) in dyssynergic constipation patients, and treatment strategy for each problem

Problem	How to identify the problem	Treatment strategy
Inadequate rectal propulsion		
Inappropriate toilet sitting posture Breathing or exhalation during pushing Inappropriate use of muscles during pushing	Observe the patient position during pushing. Observe the patient respiration during pushing (whether the patient does not hold breath during pushing). Cannot or does not use diaphragm or perform diaphragmatic breathing during pushing (abdominal girth does not increase during inspiration before pushing).	Correct posture (mild bending of the body forward and hip flexion during pushing) Advise about breath holding while bearing down Advise the patient to do a halfway inspiration and hold breath before pushing Abdominal breathing exercise training Carefully advise about increasing pushing effort; it should gradually and gently increased after inspiration by diaphragmatic breathing
Paradoxical contraction or inadequate anal sphincter relaxation		
Does not know where the sphincter muscle is Does not know the sensation of sphincter muscle relaxation or contraction Does not know how to control and relax the anal sphincter muscle	Cannot contract the anal sphincter upon request to do so. Ask whether the patient has sensation of relaxation during anal sphincter relaxation in response to rectal balloon distention. If the patient has paradoxical contraction of the anal sphincter during pushing, ask the patient whether the patient experiences the sensation of sphincter contraction. Observe contraction or relaxation of the anal sphincter after asking the patient to squeeze and push.	Let the patient squeeze and observe the tracing displayed on the computer screen to realize that anal sphincter can be controlled. Help the patient to realize and distinguish anal sphincter-relaxing sensation by passive (rectal balloon distention) and active anal sphincter relaxation (pushing). Visual and verbal feedback to help the patient realize the sensation of anal sphincter relaxation and contraction during pushing. Visual and verbal feedback to relax the anal sphincter while pushing and contracting while squeezing.
Impaired rectal sensation	High rectal sensory threshold for first sensation of stool or urgency. Does not know what the sensation of stool or urgency is.	Use rectal balloon distention at a volume that can generate the first sensation of stool or urgency, and then gradually decrease rectal balloon distension to establish the rectal sensation at an appropriate volume. The patient may not have sensation of stool or urgency, but may have other sensation in response to 60–120 ml rectal balloon distention. The therapist should try to change the patient's concept of the sensation of stool/urgency so that response to that sensation is appropriate.

Paradoxical contraction or inadequate anal sphincter relaxation Some patients with dyssynergic defecation are not only unable to contract or relax the anal sphincter, but also do not know where their anal sphincters are and how they are working while bearing down. These patients may not be able to realize contraction and relaxation of anal sphincter as desired and hence, unable to control it.

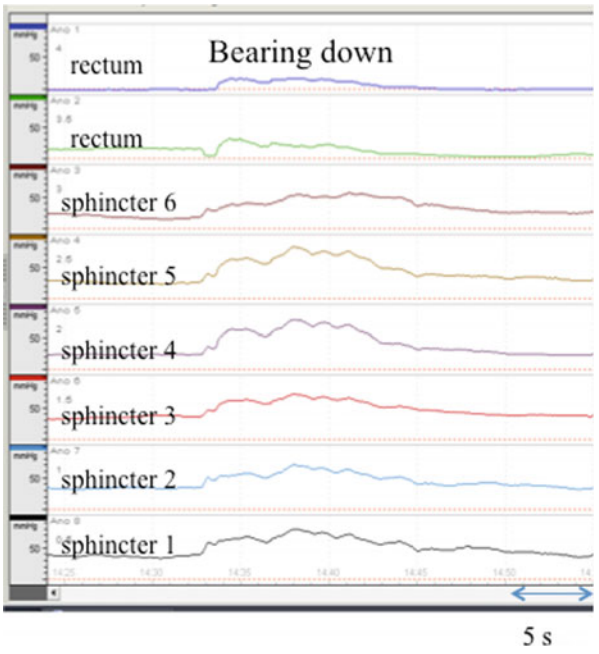

Fig. 6.3 This tracing demonstrates impaired rectal propulsive force from inappropriate use of abdominal muscles without breath-holding. Pushing force is weak but sustained. Paradoxical anal contraction is also shown

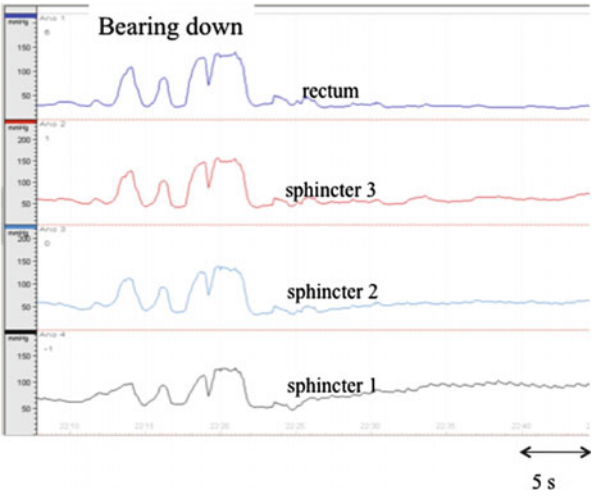

Fig. 6.4 This tracing demonstrates non-sustained rectal propulsive force due to a breath-holding problem

Experiences in our center suggest that patients who cannot realize whether the sphincter contracts or relaxes during pushing will not respond well to the biofeedback therapy, since they cannot maintain appropriate pushing technique learned during the training. Therefore, an initial step for the patients who have paradoxical anal sphincter contraction or inadequate relaxation is to let them realize that anal sphincter can be controlled, and recognize how their anal sphincter is working. During this step in our center, therapists ask patients to squeeze and then quickly relax the anal sphincter without bearing down. The patients will learn how to control the anal sphincter and relationship between and the tracing on the monitor (Fig. 6.5). Then, rectal balloon inflation should be performed to induce more anal sphincter relaxation by activating the recto-anal inhibitory reflex and let patients distinguish difference between the anal sphincter squeezing and relaxing sensations (Fig. 6.6). After the patient knows how to control the anal sphincter and recognize the difference between squeezing and relaxing sensations, the therapist can then ask the patient to push (bearing down) and also watch the tracings in the monitor. If the anal sphincter contracts while the patient is bearing down, the patient should recognize and stop pushing. Each step should be repeated until the patient appreciates each step before performing the next step. The therapist's role is not only to supervise, but also reassure the patient during practicing. Finally, the patient will learn how to relax the anal sphincter while pushing and realize the sensation of the sphincter relaxation by visual and verbal feedback mechanisms. Patients who can relax the anal sphincter and realize whether it relaxes or contracts during pushing usually have a good long-term response to biofeedback therapy.

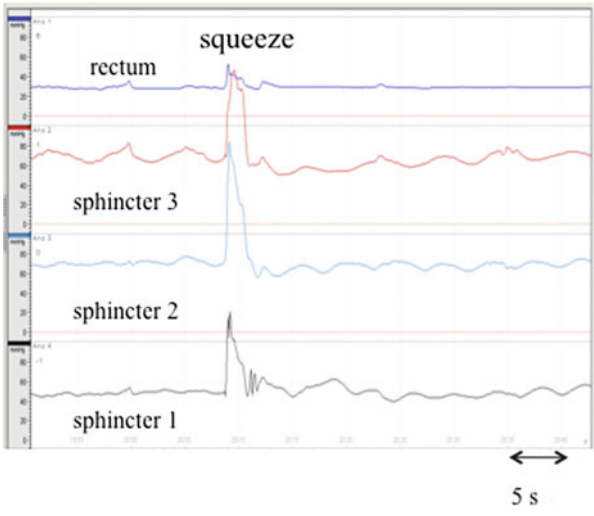

Fig. 6.5 When asking the patient to squeeze and then quickly relax their anal sphincter without bearing down, the patient will learn how to control the anal sphincter and also learn the relationship between patient actions and the tracing on the monitor

Impaired rectal sensation The other important step for the dyssynergic defecation patients—who have high rectal sensory threshold for the first sensation of stool, or for urgency of stool, or even do not know what these sensations are—is sensory training. Previous studies reported that 40 % of patients with dyssynergic defecation also had impaired rectal sensation [30] and this have been reported to be associated with poor biofeedback outcome [4]. This could be explained by either impaired rectal perception for stool urgency that lead to decreased rectal contractility, less sensation of bowel movement or urge to go to the toilet, and as a consequence, result in harder stool and even fecal impaction. This condition may be associated with more severe constipation or megarectum [31, 32]. Although it is unclear whether impaired rectal sensation is the cause or the outcome of severe constipation, there were studies that demonstrated an improvement of rectal perception after biofeedback therapy in patients with constipation [9, 33].

Rectal sensory training aims to promote a better awareness of stool, the volume of which is less than that previously perceived by rectal balloon distension. In this training step, the rectal balloon is gradually inflated until the patient perceives the urge for defecation. After that, the balloon is repeatedly inflated with gradually decreasing volume. By asking the patient to observe the change of tracings which represent the rectal pressure, together with paying attention to the sensation in their rectum, the smaller and appropriate volume of stool can be perceived.

Some patients may not have real sensation of stool or urgency, but have other sensation in response to 60–120 ml rectal balloon distention. In this case, the therapist should try to change the patient concept of the sensation of stool/urgency and teach the patient to respond to that sensation appropriately.

On the other hand, rectal hypersensitivity may also be found in patients with defecation disorders [34]. This condition has been demonstrated to be associated

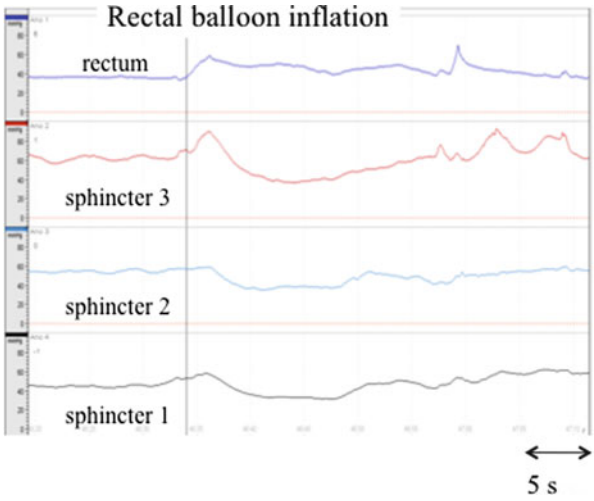

Fig. 6.6 Rectal balloon inflation is performed to induce more anal sphincter relaxation by activating the recto-anal inhibitory reflex, to let patients distinguish the difference between the anal sphincter squeezing and relaxing sensations

with IBS [35, 36]. Our previous study revealed that 58 % of dyssynergic defecation also had clinical features of IBS, and the presence of IBS in dyssynergic constipation patients does not affect the outcome of the biofeedback therapy [4]. However, the effect of rectal hypersensitivity on biofeedback treatment outcome has not been well established, as seen in Table 6.1.

Step 3. Maintenance

Standard treatments of constipation such as adequate fiber intake, exercise, not neglecting stool call, and timed toilet after wake-up or breakfast, should always be advised, and patients should be encouraged to keep practicing at home including abdominal muscle exercise, avoiding excessive straining, and sitting in the correct posture. Dyssynergic constipation patients without delayed colonic transit who can achieve all biofeedback training tasks or overcome all identified physiologic problems usually have a good long-term response without any laxative uses.

However, laxatives can be used when stool is hard, especially in patients with concomitant delayed colonic transit, but enema and maneuver to help defecation should be discarded. Asking the patient to keep a stool diary in which he or she records stool form, defecation time, and laxative or maneuver usage, may help the therapist to evaluate training outcomes more precisely. During each training visit, overall symptoms, as well as specific constipation symptoms during the training interval, should be assessed and therapy should be re-evaluated for each problem discussed above in Step 2 in every session.

Efficacy of Biofeedback Therapy

The efficacy of biofeedback therapy varies between 44 and 100 % [37]. Recent randomized control trials in refractory chronic constipation patients with dyssynergic defecation reported superior benefits over placebo or laxatives with 70–80 % response rate after EMG or manometry-based treatment for four to six sessions [9, 11, 12]. This treatment significantly increased the number of spontaneous bowel movements and improved overall symptoms, constipation symptoms, and dyssynergic pattern of defecation, as well as colonic transit time (Fig. 6.7a, b). Long-term studies also shown these benefits over standard treatment at 1-year follow-up [10, 12]. The protocol in a recent long-term study was six sessions of 1-h manometry-based biofeedback treatment, simulated defecation training, and sensory training. Follow-up schedule was every 3 months, and patients received biofeedback reinforcement at their returning visit [10]. Biofeedback therapy also provides benefits for chronic constipation patients who have combined anorectal dyssynergia and slow transit [3, 4], as well as IBS constipation with evidence of anorectal dyssynergia [4]. One uncontrolled study evaluating biofeedback treatment on isolated slow transit constipation revealed no benefit [38]. Most studies defined treatment failure after four to six sessions, and factors associated with treatment failure included

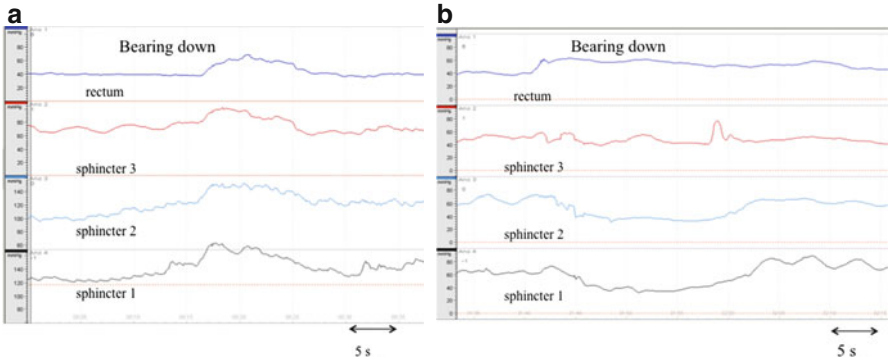

Fig. 6.7 (**a**, **b**) Comparison of anorectal manometry tracing (**a**) before and (**b**) after biofeedback treatment. After treatment, a paradoxical anal sphincter contraction can relax appropriately during bearing down

severe constipation symptom, digital facilitation of defecation, slow transit constipation, impaired rectal sensation, and increased anorectal angle during squeeze [1, 5, 6]. The impact of biofeedback treatment on quality of life or psychological state have not been assessed (Table 6.2).

Conclusion

Chronic constipation patients, especially those who have failed standard therapy, should undergo anorectal function tests to identify the potentially treatable condition of dyssynergic defecation. Biofeedback therapy is the highly effective and preferred treatment. During biofeedback therapy, physiologic problem(s) of defecation should be carefully identified and corrected individually.

Table 6.2 The randomized control studies of biofeedback therapy on dyssynergic defecation

Study	Comparison(n)	Technique	Primary outcome	Loss to follow-up	Follow-up duration	Result
Chiarioni 2006 [12]	Biofeedback (54) *vs.* polyethylene glycol (55) after 30 days run in	EMG, 5 weekly, 30 min/session	Global symptoms improvement	2/54 (3.7 %) *vs.* 4/55 (7.3 %)	24 months	**Favor biofeedback** Major global symptom improvement 80 % *vs.* 22 %, $P<0.01$ More pelvic floor relaxation, improved balloon evacuation and urge threshold; *vs.* polyethylene glycol, $P<0.01$
Heymen 2007 [11]	Biofeedback (30) *vs.* diazepam (30) or placebo pill (24) after 30 days run in	EMG, 6 biweekly, 50 min/session	Adequate relief of constipation	7/30 (23.3 %) 7/30 (23.3 %) 4/24 (16.7 %)	3 months	**Favor biofeedback** Adequate relief of constipation 70% *vs.* 23 % and 38 %, $P<0.01$ More pelvic floor relaxation *vs.* diazepam and placebo, $P=0.001$
Rao 2007 [9]	Biofeedback (28) *vs.* sham feedback (25) or standard treatment (24)	Manometry, 6 biweekly, 1 h/ session	Complete spontaneous bowel movements (CSBMs), global bowel satisfaction	7/28 (25 %) 4/25 (16 %) 1/23 (4.3 %)	3 months	**Favor biofeedback** Global bowel satisfaction 75 % *vs.* 48 % and 63 %, $P<0.01$ Higher CSBMs ($P<0.05$), corrected dyssynergia ($P<0.0001$), improved defecation index ($P<0.0001$), and decreased balloon expulsion time ($P<0.05$) *vs.* sham, standard treatment
Farid 2009 [26]	Biofeedback (24) *vs.* botulinum injection 500 unit (24)	EMG, 8 biweekly, sessions duration not defined	Not clearly defined	3/24 (12.5 %) *vs.* 0 %	1 year	**Similar efficacy** Overall satisfaction 25 % vs. 33 %, $P>0.05$ Both treatments significantly improved dyssynergic pattern and balloon expulsion time, but were not significantly different between groups

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Approach to Patients with Refractory Constipation

7

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Abstract

A review of relevant publications revealed that the criteria for defining refractory constipation were ill-defined. Common treatment for constipation includes osmotic, stimulant, and enterokinetic agents. Prucalopride is a new enterokinetic agent that has been shown in clinical trials to produce significant improvements in bowel functions, gastrointestinal symptoms, and quality of life. Patients who fail pharmacological treatment should be referred to specialized centers for physiological laboratory evaluation like transit studies, balloon expulsion, anorectal manometry, and defecography. Potential pathophysiology of refractory constipation include physiological disturbances like pelvic floor dyssynergia and slow transit constipation. Physical defects such as rectocoele and internal prolapse are uncommon. Psychological disturbances have been linked to persistent GI symptoms. Non-pharmacological treatments to consider include biofeedback and behavioral therapy. More studies are needed before surgery can be recommended. There is the possibility that a wider acceptance of the use of

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laxatives may substantially reduce the number of patients with refractory constipation.

Keywords
Constipation • Laxative • Biofeedback • Psychological • Surgery • Bowel

Introduction

Before embarking on the work-up and management of refractory constipation, the clinician must ask, what is refractory constipation? Situations where patients may be considered to have refractory constipation are when patients are subjected to clinical trials of new pharmacological agents or referred for total colectomy. A review of relevant publications revealed that the criteria for defining refractory constipation were ill-defined. The majority of studies reported duration of constipation, and simply that laxatives had been unsuccessful. No information was available to determine the type of laxatives, dosing, and duration of treatments. In a recent review by the Asian Neurogastroenterology & Motility Association, a pharmacological non-responder was defined as failure to respond to bisacodyl at 10 mg every night for at least 4 weeks, with consideration given to a total treatment period of up to 12 weeks if access to specialized centers is limited, or prucalopride at 2 mg daily for up to 12 weeks, and combining a stimulant or prokinetic agent with an osmotic agent may also be considered [1]. This is based on recent high-quality clinical trials which demonstrated improvement in quality-of-life scores in patients on daily treatment with either of these agents for 4 weeks (bisacodyl or picosulfate) to 12 weeks (prucalopride) [2–6]. Contrary to popular belief, patients who had received active treatment with bisacodyl were able to reduce their dosage with time [6].

Prucalopride is a new enterokinetic agent that has been shown in clinical trials to produce significant improvements in bowel functions, gastrointestinal symptoms, and quality of life, with improvements maintained on continued use for up to 24 months [2–4, 7]. Based on secondary endpoint analysis of data derived from the pivotal studies, it appears that prucalopride may be particularly effective at improving bloating [8].

Other treatments that may be explored in the future are lubiprostone and linaclotide, which belong to a new class of pharmacological agents known as colonic secretagogues. Table 7.1 serves as a guide to the feasibility of maximizing pharmacological agents before labeling a patient as having refractory constipation. The information on dosing ranges and treatment durations is based on those used in clinical trials of these agents. However, it is unclear if such an extended treatment can produce durable improvement.

Patients who fail pharmacological treatment should be referred to specialized centers for physiological laboratory evaluation (see Fig. 7.1).

Table 7.1 Summary of the various agents of chronic constipation

Category	Laxative	Population	Range of dosage	Duration of treatment
Osmotic	PEG	Adults	13–39 g/day	Up to 6 months
		Children	1–1.5 g/kg/day (disimpaction dose) 0.3–0.8 g/kg/day (maintenance dose)	Up to 7 days Up to 6 months
	Lactulose	Adults	15–60 ml	1–12 weeks
		Children (11–18 years)	15 ml twice daily	4 weeks
		Children (6–10 year)	10 ml twice daily	4 weeks
		Children (1–5 years)	5 ml twice daily	4 weeks
	Magnesium hydroxide	Elderly (>65 years)	25 ml/day	8 weeks
Stimulant	Bisacodyl/ picosulfate	Adults	5–10 mg/day	4 weeks
		Children (6–14 years)	2.5–5 mg/day	No data[a]
Enterokinetics	Prucalopride	Adults (>65 years)	1 mg/day	12 weeks
		Adults (18–65 years)	2 mg/day	12 weeks

Reproduced with permission from Gwee et al. [1]

[a]For children, bisacodyl/picosulfate was only used as part of preparation to cleanse bowel

Potential Pathophysiology of Refractory Constipation

Physiological Factors

The two main physiological disturbances associated with refractory constipation are pelvic floor dyssynergia (PFD) and slow transit constipation (STC). Pelvic floor dyssynergia (alternative terms are anismus or obstructed defecation disorder) refers to paradoxical contraction or inadequate relaxation of the pelvic floor muscles during attempted defecation; this is believed to be an acquired behavioral disorder of defecation. Slow transit constipation is also referred to by its old name of colonic inertia, and refers to the inability of the colon to modify stool to an acceptable consistency and move the stool from the cecum to the rectosigmoid area. An alternative definition is prolonged colonic transit time that cannot be normalized even by the consumption of large amounts of dietary fiber. There is a wide variability of methodology used to measure colonic transit times, and the reproducibility of these tests is not high, and especially so for slow transit times [9]. Studies of patients referred to tertiary centers in Korea and Thailand (for presumed refractory constipation), reported PFD in 30–35 %, STC in 13–20 %, and PFD combined with STC 11–27 %, but a substantial proportion had normal transit constipation (13–47 %) [10, 11]. Similar to studies from the west, these Asian

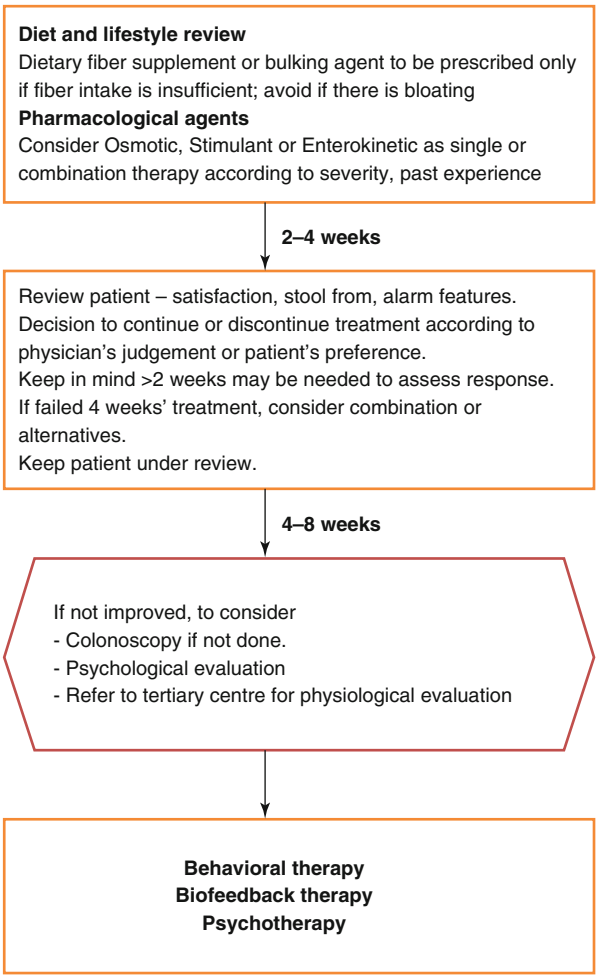

Fig. 7.1 Chronic Constipation Treatment Algorithm

studies suggest that symptoms alone cannot distinguish the different constipation subtypes.

Anatomical Factors

Physical defects such as rectocoele (herniation of the rectal wall with retention of stool in the hernia after defecation) and internal prolapse are uncommon, reported in less than 1 %, even in tertiary centers [12]. At least one study has reported that biofeedback can help more than half of these patients to overcome their constipation without the need for surgical repair [13].

Psychological Factors

An important aspect that is frequently overlooked is the psychological one. Numerous studies had shown the association of abuse history, in particular sexual and childhood abuse, with functional gastrointestinal diseases. Depression is not uncommon, especially in the elderly. In young women with severe constipation, the possibility of an eating disorder should be considered [14]. The possibility of a past history of sexual and physical abuse should be kept in mind [15]. In a referral-based clinic, Drossman et al. reported that of 206 women with functional gastrointestinal disorders, 44 % reported a history of sexual abuse or physical abuse in childhood or later in life. However, only 17 % had informed their doctors about the abuse. As these women may be psychologically predisposed to submit themselves to surgery, it is especially important for the physician to ask specifically for a history of abuse before contemplating a referral to a surgeon [15–17]. There is a strong possibility that psychological factors are a major reason for refractory constipation. Psychological disturbances have been linked to persistent GI symptoms and frequent health-seeking behavior as well as failure to respond to tertiary-level treatment [18, 19].

Non-pharmacological Treatments

Biofeedback and Behavioral Therapy

Biofeedback is a training technique which aims to teach patients to relax, instead of contracting, their pelvic floor muscles during straining at stool. There are several variations of the method; some involve the use of visual or auditory signals, from surface or electromyographic electrodes or anal probes, to inform patients whether they are performing the appropriate muscular action. In its most basic form, patients may also be trained to evacuate rectal contents by using a balloon, or even oatmeal porridge in the shape of a stool, introduced into the rectum to simulate defecation [20, 21]. Currently, biofeedback therapy is applied primarily to patients with PFD. Overall, biofeedback is a safe treatment which may produce durable improvement beyond the active treatment period. Randomized control trials in refractory chronic constipation patients with PFD have reported 70–80 % success rates for up to 1 year [22–24]. Improvement was reported for constipation symptoms and overall symptoms, as well as dyssynergic pattern of defecation. However, the impact on quality of life or psychological state has not been fully assessed. As many as two-thirds of patients referred for biofeedback could have diagnosable psychiatric disorders, and those patients with a higher degree of quality-of-life impairment due to psychological distress are less likely to respond to biofeedback treatment [25].

Surgery

The scientific rationale for surgical treatments has not been clearly articulated. When contemplating a surgical referral, the following reservations should be

considered. Initially promising results with small numbers of highly selected patients may not be replicated when extended to larger series with longer term follow-up. Surgical treatments have not been evaluated to the same rigorous degree that modern pharmacological agents are subjected to. Non-destructive treatment approaches may become available or prove to be more effective. An example is that in the 1970s and 1980s an operation known as anorectal myectomy was advocated for adult patients with outlet obstruction. However, longer term follow-up revealed that in the majority of patients, the improvement was not sustained, and there was a high incidence of incontinence [26, 27]. In its place, biofeedback is now offered to patients with outlet obstruction. Similarly, for sub-total colectomy with ileo-rectal anastomosis, which is advocated for colonic inertia, initial series comprising 6–30 patients followed up for up to 6 years reported satisfactory results in 60–100 %, but when one of these studies was extended for another 3 years and expanded to include 44 patients, the proportion of patients who were able to maintain normal bowel function fell to 50 %, while 71 % continued to experience abdominal pain, 39 % required further surgery, and almost a quarter required psychiatric treatment for severe psychological disturbances [28–31]. A number of studies have also in the past demonstrated that when bisacodyl was instilled into the colon of patients classified as colonic inertia, as many as 60–90 % achieved high amplitude propagated contractions [32–34]. This suggests that if high enough levels of the stimulant agent could be delivered, some of these colons could have been salvaged.

The possibility of a Munchausen phenomenon should be seriously considered in patients willing to subject themselves to an ablative procedure like colectomy. Patients with a history of sexual abuse had a ten-fold increased risk of surgery prior to their colectomy, and had a high probability of seeking medical care for abdominal complaints after their colectomy [35–38].

A number of recent studies found that the majority of patients with severe STC had evidence of small bowel motor abnormalities and are at risk of intestinal obstruction post-colectomy [39–43]. Our position is that any patient with functional constipation who is being considered for surgical intervention must undergo a formal psychiatric evaluation and an evaluation of GI motility with, at the minimum, measurement of small intestinal transit time.

Conclusion

The management of refractory constipation remains a challenge, not least because criteria for refractoriness has not been clearly defined. On the one hand, there is much prejudice regarding the use of laxatives that is not evidence based, while on the other hand, there is much uncritical acceptance of the effectiveness of fiber treatment that is poorly substantiated. There is the possibility that a wider acceptance of the use of laxatives may substantially reduce the number of patients with refractory constipation. The main challenge appears to be to identify and recognize the role that psychological disturbances play in refractory constipation. More attention to psychologically directed treatments, including biofeedback, with greater accessibility to these treatments, may help to reduce the number of patients who are driven to the treatment of last resort, ablative surgery.

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Overview of Hydrogen Breath Tests in Gastroenterology Practice

8

Uday C. Ghoshal

Abstract

Hydrogen breath tests are quite popular for diagnosing carbohydrate malabsorption such as lactose and fructose malabsorption, and small intestinal bacterial overgrowth (SIBO). The lactulose hydrogen breath test is also used for estimation of mouth-to-cecum transit time. These are easy to perform and are noninvasive. With growing recognition of food intolerance as the cause of symptoms in patients with irritable bowel syndrome (IBS), and importance of SIBO in pathogenesis of a subset of patients with IBS, the importance of some noninvasive tests for diagnosis of these conditions can't be overestimated. However, diagnosis of SIBO using hydrogen breath tests have limitations. Though the glucose hydrogen breath test is highly specific, it is quite insensitive. In contrast, double-peak criterion on the lactulose hydrogen breath test is very insensitive and early-peak criterion is quite non-specific. The lactose hydrogen breath test using 25-g lactose is quite sensitive and specific for diagnosis of lactose malabsorption. Techniques and interpretation of various hydrogen breath tests are reviewed in this chapter.

Keywords

Breath tests • Functional bowel disease • Irritable bowel syndrome • Lactose intolerance • Small intestinal bacterial overgrowth

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Introduction

Hydrogen breath tests (HBT) are cheap, non-invasive and popular methods for diagnosis of different types of carbohydrate malabsorption such as lactose and fructose malabsorption and small intestinal bacterial overgrowth (SIBO) [1, 2]. These conditions are being increasingly gaining importance in clinical practice. For example, dietary manipulation such as withdrawal of high fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAP) foods is gaining importance in management of irritable bowel syndrome [3, 4]. Recent studies have suggested the role of SIBO in a subset of patients with IBS and therapeutic manipulation of gut microbiota using probiotics and antibiotics in its treatment [5]. Hence, importance of techniques to diagnose SIBO and carbohydrate malabsorption can't be overestimated. Though various other methods are available for diagnosis of these conditions such as jejunal aspirate culture for small SIBO [1, 6], and genetic tests for lactose malabsorption [7], hydrogen breath tests are being employed widely in clinical practice. However, in spite of simplicity of performance, there is lack of uniformity about interpretation of various HBTs. Therefore, technique and interpretation of commonly used HBTs are reviewed here.

Principles of Hydrogen Breath Tests

In glucose hydrogen breath tests (HBTs), if there is bacterial overgrowth in the small bowel, glucose is fermented by the bacteria before it is absorbed from the small intestine. The principle of HBT is outlined in Fig. 8.1. Hydrogen produced by bacterial metabolism is absorbed from the small bowel, carried to the lungs by circulating blood, exhaled with breath, and detected by a gas chromatograph [2]. Of the various breath test machines available, some measure only hydrogen (e.g., Bedfont®, Bedfont Scientific Ltd, England) and the others measure methane and CO_2 in addition to hydrogen (Quin Tron Breathtracker™ Digital Microlyzer, QuinTron Inc, Milwaukee, WI, USA). CO_2 is used to correct for inadequacy of collection of breath sample. In lactose and lactulose HBT, bacteria, especially anaerobic, colonizing the large bowel in health produces hydrogen by fermentation of unabsorbed disaccharide. A large amount of hydrogen is produced if lactose is not digested in the small bowel due to lack of brush border lactase. During lactulose HBT, since this disaccharide is not digested in the small bowel, it reaches the colon, where it is fermented by bacteria to produce hydrogen. Therefore, the time since ingestion of lactulose and rise in breath hydrogen above threshold value is a measure of mouth-to-cecum transit time [2]. About 15–30 % of people have gut flora that contain *Methanobrevibacter smithii*, which converts four atoms of hydrogen into one molecule of methane [8]. These subjects may not exhale much hydrogen in the breath despite having SIBO or carbohydrate malabsorption, as excess hydrogen produced inside them is converted into methane. In these patients, measurement of methane in the breath by in addition to hydrogen by is useful.

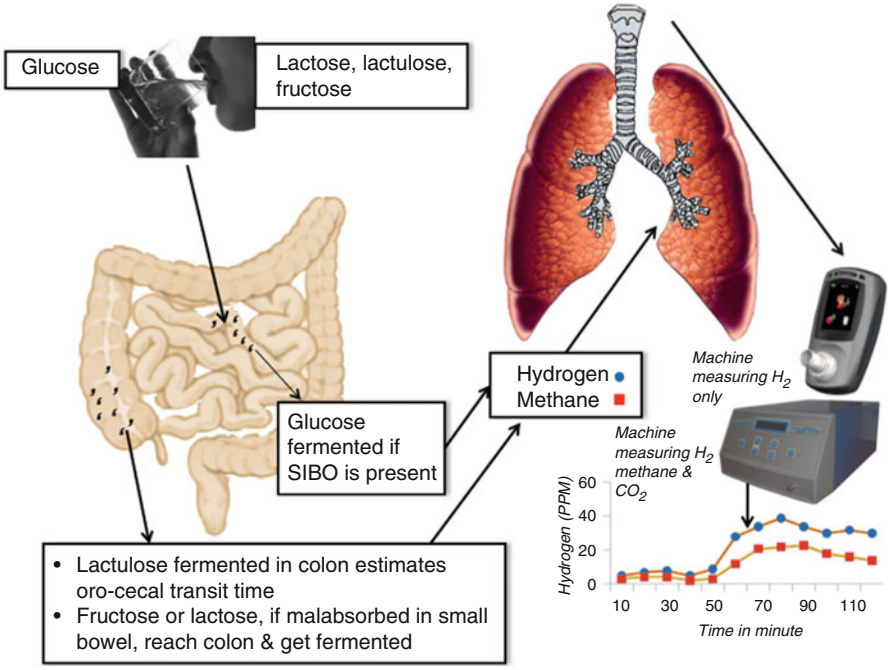

Fig. 8.1 A schematic diagram that shows the principles of the hydrogen breath test. *Abbreviations used*: *SIBO* small intestinal bacterial overgrowth, *PPM* parts per million

Breath Test Procedure

The patient must be prepared for the breath test. He or she is advised to avoid complex carbohydrates (like bread and potato) and fiber in their diet the previous night, as these may result in high basal breath hydrogen, which might cause discontinuation of HBT [6]. Cigarette smoking and exercise are avoided 2 h before and during the test, as hyperventilation can cause changes in breath hydrogen content [6]. Drugs that alter gut motility such as prokinetics, anticholinergics, opiates, and those altering gut flora such as antibiotics, probiotics, and proton-pump inhibitors, should be discontinued weeks before performing breath tests.

On the day of HBT, the patient is asked to come in a fasting state. It is advisable that the patient brushes his or her teeth well and rinses his/her mouth with antiseptic mouthwash, which eliminates an early hydrogen peak due to action of oral bacteria on test sugars [6]. Breath samples are collected either in bags or syringes. Initially, three to four fasting readings of breath hydrogen are obtained, the average of which is taken as the basal breath hydrogen. Subsequently, the subject ingests a fixed amount of the test sugar (10 g lactulose, 100 g glucose, 25 g lactose or 25 g fructose). Several authors recommended a dose of 50 g lactose for performing lactose HBT; however, this is a non-physiological dose. Also, a recent study showed that a positive test using 25 g lactose is more predictive of symptom resolution following

its withdrawal than 50-g dose [7]. Following ingestion of the substrate, hydrogen with or without methane is estimated every 10–15 min for 2–4 h and the values are recorded. Reproduction of symptoms following ingestion of the substrate is important and should be recorded [7, 9]. A lactose tolerance test, which involves estimation of blood sugar in fasting state and 30-min after ingestion of lactose, is usually combined with a lactose hydrogen breath test. [10]

Interpretation of Breath Tests

High basal breath hydrogen Average basal value of breath hydrogen more than 16 parts per million (PPM) is considered high value [11]. Generally, if basal breath hydrogen is high, the breath test is repeated on a later day with better preparation. Some investigators used high basal breath hydrogen to be suggestive of SIBO [12], though evidence available is contradictory [11]. Hence, it is important to reiterate that high basal breath hydrogen must not be considered as a criterion for diagnosis of SIBO. Figure 8.2a–f show some typical HBT graphs without the data on methane [2].

Diagnosis of SIBO on glucose and lactulose hydrogen breath test Persistent rise in breath hydrogen (at least two consecutive readings) 12 PPM above basal is diagnosed as SIBO on glucose HBT [2]. This criterion has been validated against quantitative culture of upper gut aspirate. In patients with malabsorption syndrome, the sensitivity and specificity of this criterion to diagnose SIBO are 40 % and 80 %, respectively [6]. In patients with IBS, however, sensitivity of this criterion is low (27 %), though specificity was as high as 100 % [13]. This might be related to the fact that the patients with IBS may have a lower colony count of bacteria in the small bowel than patients with malabsorption syndrome. This suggests that though glucose HBT has a high negative predictive value for diagnosis of SIBO, its positive predictive value is low.

Lactulose HBT has also been used to diagnose SIBO. Conventionally, SIBO is diagnosed on LHBT if there are two peaks: one early rise from the small bowel due to SIBO, and the other from the colon [6]. Among patients with malabsorption syndrome, sensitivity and specificity of lactulose HBT to diagnose SIBO using this conventional criterion are 31 % and 86 %, respectively, considering quantitative culture of jejunal aspirate (bacterial colony count $\geq 10^5$ colony forming unit per ml) as gold standard. [6] However, with the same gold standard, sensitivity and specificity were 0 % and 98 %, respectively among patients with IBS [13]. The differences in sensitivity might be related to the fact that patients with IBS are expected to have a lower colony count of bacteria in the small bowel than patients with malabsorption syndrome.

Pimentel et al., suggested that a rise in breath hydrogen 20 PPM above basal levels within 90 min after ingestion of lactulose should be considered diagnostic of SIBO (early-peak criterion) [14], with a presumption that mouth-to-cecum transit

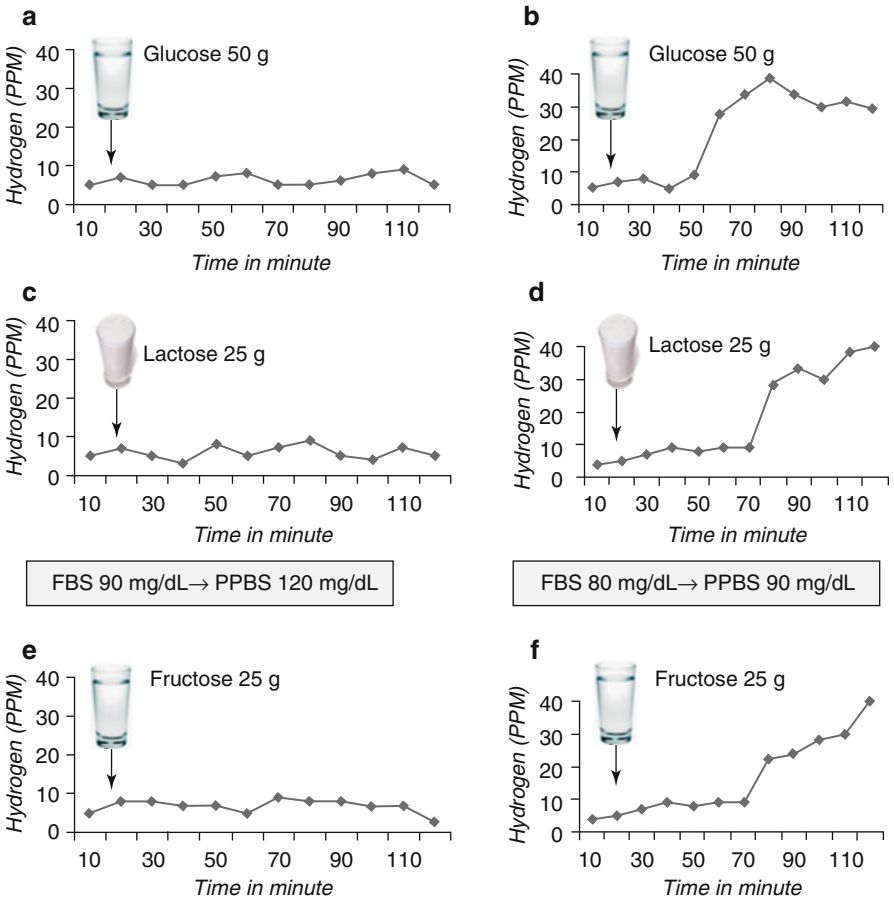

Fig. 8.2 (**a**–**f**) Some typical hydrogen breath test graphs are shown. (**a**) Shows a glucose hydrogen breath test negative for small intestinal bacterial overgrowth (SIBO); (**b**) A graph on glucose hydrogen breath test positive for SIBO; (**c**) A lactose hydrogen breath and tolerance test negative for lactose malabsorption; (**d**) A lactose hydrogen breath and tolerance test positive for lactose malabsorption; (**e**) A graph negative for fructose malabsorption; (**f**) A graph positive for fructose malabsorption. *Abbreviations used*: *PPM* parts per million, *FBS* fasting blood sugar, *PPBS* post-prandial blood sugar (Reproduced with permission from Ghoshal [2])

time is always greater than 90 min, so that a peak in breath hydrogen within 90 min after lactulose ingestion must be due to bacterial fermentation in the small bowel. This is a fallacious presumption. Mouth-to-cecum transit time may be quite short in a population with fast gut transit time [5]. For example, in our study, median mouth-to-cecum transit time in 12 healthy Indian subjects was 65 min (range 40–110 min) [15]. In a study of 45 healthy Taiwanese, mean mouth-to-cecum transit time was 85 min (standard deviation 37) [16]. Even in a Western population, recent studies that used radionuclide to study gut transit during lactulose HBT showed that the

early peak in hydrogen often comes after radionuclide reached cecum [17]. Hence, the early-peak criterion proposed by Pimentel et al. is fallacious and is often false positive [13].

Limitations of HBT to Diagnose SIBO

There are several limitations of HBT for the diagnosis of SIBO. As described above, lactulose HBT is not useful to diagnose SIBO; early peak criterion on lactulose HBT is non-specific, and double-peak criterion insensitive. Therefore, lactulose HBT can't be recommended for diagnosis of SIBO. An important limitation of glucose HBT is its inability to detect bacterial overgrowth in the distal small bowel such as in ileum, as glucose is absorbed completely in the upper small intestine [18]. One has to realize, however, that quantitative culture of jejunal aspirate, which is considered as the "gold standard," has limitations, as only 30 % of gut bacteria are culturable [18]. However, in spite of all the limitations, glucose HBT may be better than lactulose HBT, as early peak criterion in the latter is often false-positive double peak criterion insensitive [6]. However, a better noninvasive test for diagnosis of SIBO is needed, as glucose HBT is also quite insensitive, as evidenced by:

1. In individuals with slow gut transit time, if a standard testing period is undertaken, the diagnosis may be missed.
2. It was earlier believed that in subjects with predominant methanogenic or hydrogen sulfide-producing gut flora, only hydrogen estimation may miss the diagnosis of SIBO [8]. Estimation of methane may be useful in such a situation. However, in a recent study, we found that measurement of methane is not useful to diagnose SIBO [13]. Methane is a marker of constipation [19]. There is no commercially available machine currently available that measures hydrogen sulfide.
3. A positive HBT may not always mean that a patient's symptoms are caused by SIBO. The only way to establish whether the symptoms are caused by the intestinal disease or by the SIBO is to treat and eradicate SIBO. If the symptoms disappear, it is likely that SIBO, rather than the underlying disease, is responsible for the symptoms.

Lactulose HBT to Estimate Oro-cecal Transit Time

The time needed to have a peak in hydrogen production by 20 PPM above basal following ingestion of lactulose is a measure of oro-cecal transit time [2]. In contrast to a cut-off value of peak in breath hydrogen by 12 PPM above basal arising from the small bowel in patients with SIBO, peak arising from the colon is higher (20 PPM above basal) [2]. This is possibly related to the fact that the colony count of bacteria is generally lower in the small bowel even in patients

with SIBO than in the colon of healthy subjects. Therefore, for measurement of oro-cecal transit time and lactose malabsorption using lactulose and lactose HBT, cut-off value is 20 PPM above basal. Recently, in a study in which the lactulose HBT was compared with radionuclide scintigraphic method for estimation of oro-cecal transit time, the former is shown to have reasonable accuracy for this purpose [17].

Lactose HBT for Diagnosis of Lactose Malabsorption

Lactose malabsorption is diagnosed when hydrogen rises by 20 PPM above basal after ingestion of lactose. Previously, 50 g lactose was used for lactose HBT. However, 50-g lactose is equivalent to one liter of milk, which is rarely ingested; hence, this is a non-physiological dose of lactose. Recently, it has been found that a dose of 25-g lactose is as sensitive and more specific than 50-g lactose. This study also showed that exclusion of lactose based on a positive lactose HBT using 25-g lactose was more predictive of symptom resolution [7]. Failure of blood sugar to rise by 20 mg/dl 30 min after ingestion of lactose is considered as a positive lactose tolerance test, which is indicative of lactose malabsorption [9, 10].

Interpretation of Fructose HBT

Rise in hydrogen by 20 PPM above basal after fructose ingestion is considered positive fructose HBT [20].

Clinical Importance of Breath Gas Profile

Some data suggest that basal breath hydrogen, both in the fasting state and following ingestion of a substrate, is higher among patients with irritable bowel syndrome, particularly those with diarrhea-predominant disease, than in controls [21]. In contrast, people with constipation may have high methane [8]. Therefore, hydrogen may be a biomarker for diarrhea, and methane a biomarker for constipation [11, 19, 21]. Hence, a reduction of methane by rifaximin may improve constipation [19].

Conclusion

Hydrogen breath tests are easy to perform and are noninvasive. These may be useful to understand abnormal pathophysiology such as SIBO and carbohydrate malabsorption that contributes to symptoms in patients presenting with irritable bowel syndrome. Diagnosis of SIBO, however, using just HBT have limitations. Glucose HBT, though specific, is quite insensitive. In contrast, double-peak criterion on lactulose HBT is very insensitive and early-peak criterion is quite nonspecific. The lactose hydrogen breath test, using 25-g lactose, is quite sensitive and specific for diagnosis of lactose malabsorption.

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Catheter-Based 24-h pH-Metry and Impedance: Technique, Interpretation, and Clinical Application

9

Uday C. Ghoshal and Rajan Singh

Abstract

Gastroesophageal reflux disease (GERD) is a common condition in gastroenterology practice. Classical techniques like endoscopy and 24-h pH-metry are often used to diagnose patients with symptoms related to GERD. Although these techniques have been useful over the years both for diagnosis and therapeutic guidance, there are still many patients with typical or atypical GERD symptoms with normal endoscopy and pH-metry who do not respond adequately to anti-secretory therapy. 24-h impedance combined with pH is a new technique and currently considered as the gold standard for diagnosis of GERD. It offers greater sensitivity for the detection of all reflux episodes, and allows us to establish their nature (liquid, gas, mixed), composition (acidic, non-acidic), and clearance. This chapter describes basic principles, technique, interpretation, and clinical application of 24-h pH impedance monitoring.

Keywords

Esophageal pH monitoring • Gastroesophageal reflux • Electrical impedance • pH-metry • Atypical symptoms

Introduction

Gastroesophageal reflux disease (GERD) is a common problem in Gastroenterology practice. 24-h pH-metry was considered as the gold standard for diagnosis of GERD in the past. However, 24-h pH-metry does not pickup reflux of neutral or alkaline content from the stomach. Therefore, it has a lower sensitivity to diagnose GERD

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and hence, this has been replaced largely by 24-h impedance pH-monitoring. It has more sensitivity for detection of all reflux episodes and confirms their nature (liquid, gas, mixed), extent, composition, and clearance.

Intraluminal impedance is based on the measurement of electrical impedance between closely arranged electrodes during a bolus passage, using a probe. Cylindrical shaped metal electrodes are mounted on a thin plastic catheter. Each neighboring pair of electrodes (impedance segment) is connected to an impedance voltage transducer, which measures the resistance between the two neighboring electrodes. Impedance refers to electrical resistance and is represented by Z. The impedance is inversely proportional to the electrical conductivity of the luminal contents and the cross-sectional area between the two electrodes [1, 2]. In the absence of swallow or reflux within the esophagus, the impedance is identified by the electrical conductivity of the inner wall and it is relatively stable, and is known as baseline impedance value [3]. Since air has a low conductivity, gaseous reflux during belching results in an increase in impedance value; in contrast, swallowed or refluxed liquid would result in a drop in impedance due to higher electrical conductivity of liquids. Bolus movement recorded by impedance monitoring are either retrograde and ante-grade (Fig. 9.1). Retrograde bolus movements denote reflux, whereas ante-grade bolus movement is due to swallow [4]. The pH sensor during impedance monitoring classifies reflux episodes as acid (<4) and non acid (>4) [5].

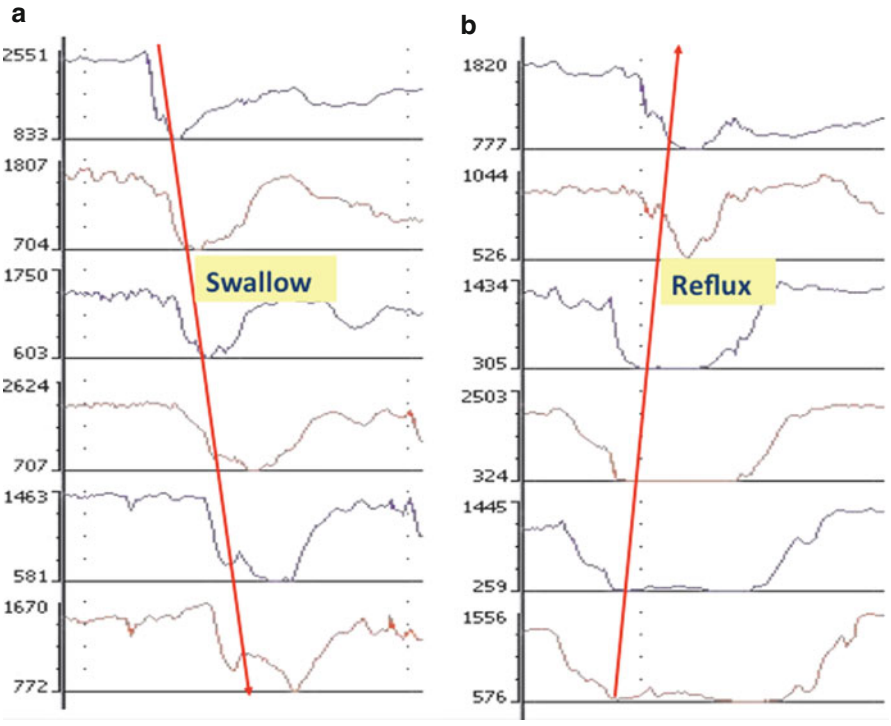

Fig. 9.1 Antegrade (**a**) and retrograde (**b**) bolus movement

Impedance of Various Boluses

Conductivity of empty esophageal lumen is relatively stable (baseline impedance value 2000–4000 Ω).

Liquid reflux retrograde drop in Z by 50 % of the baseline value, as the ionic content of the liquid bolus increases electrical conductivity.

Gaseous reflux retrograde rise in Z by ~5000 Ω, as gas is a poor conductor of electricity.

Mixed bolus is recognized by change in impedance both on upward and downward direction from baseline indicating presence of air as well as liquid in the bolus.

pH Monitoring

pH monitoring is performed commonly using two pH sensors made up of either glass or antimony electrodes, the proximal sensor placed 5 cm above manometrically located upper border of lower esophageal sphincter (LES) zone and the distal sensor (15 cm below the proximal sensor) placed in the stomach to assess the degree of gastric HCl secretion. Two types of reflux on 24-h pH monitoring include [4]:

- *Acidic reflux*: Reduction in pH <4
- *Non-acidic reflux*: pH ≥ 4

Reflux Detection by 24-h Combined Impedance pH-Monitoring

Since the current technology permits evaluation of gastroesophageal reflux events by a combination of both impedance and pH monitoring techniques, which is superior to the conventional technology, 24-h pH-impedance monitoring has replaced pH-metry alone for diagnosis of GERD. Reflux events (liquid or gaseous) are detected by impedance monitoring while the acidity of the refluxate is determined by simultaneous pH monitoring [6].

Indications

Indications for 24-h impedance pH-monitoring include (a) confirmation of the diagnosis of GERD, particularly in patients with atypical symptoms; (b) before-surgical or endoscopic anti-reflux treatment; (c) assessment of response to treatment, including nocturnal acid breakthrough in patients on proton pump inhibitor (PPI) and (d) assessment of efficacy of surgical and endoscopic therapy. In such clinical situations, impedance testing is able to assess non-acid reflux as well [7–10].

Equipment

The equipment consists of a pH-impedance catheter, data logger (Fig. 9.2) with flash card, and computer with software,. Catheters are long, flexible tubes made of polyurethane in a variety of diameters and lengths. The catheters have multiple impedance sensor pairs along their length and one or two pH sensors made of either glass or antimony (Figs. 9.3 and 9.4) [11]. The standard pH-impedance catheter has

Fig. 9.2 Data logger

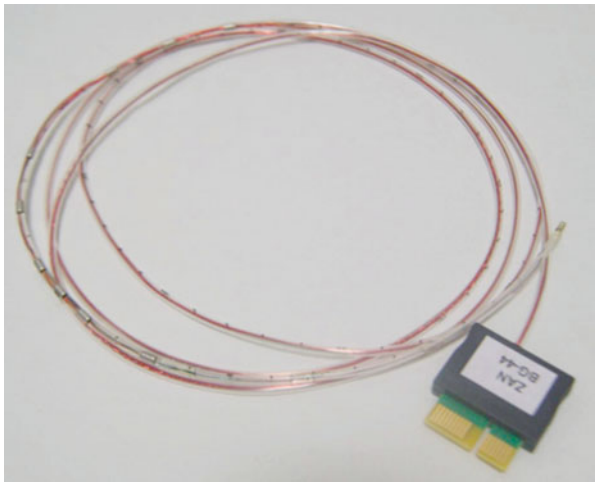

Fig. 9.3 pH-impedance catheter

six to eight pairs of impedance sensors that collect data 3, 5, 7, 9, 15, and 17 cm proximal to the LES [5].

Technique

Steps to be taken prior to and during the monitoring are discussed here.

Patient Preparation

24 h pH-impedance monitoring is done after an overnight fast. All drugs that could affect esophageal motility must be discontinued at least 72 h before the study. Often, the study is done while the patient is off anti-secretory agents including PPI. However, to assess response to anti-secretory treatment or nocturnal acid breakthrough, the

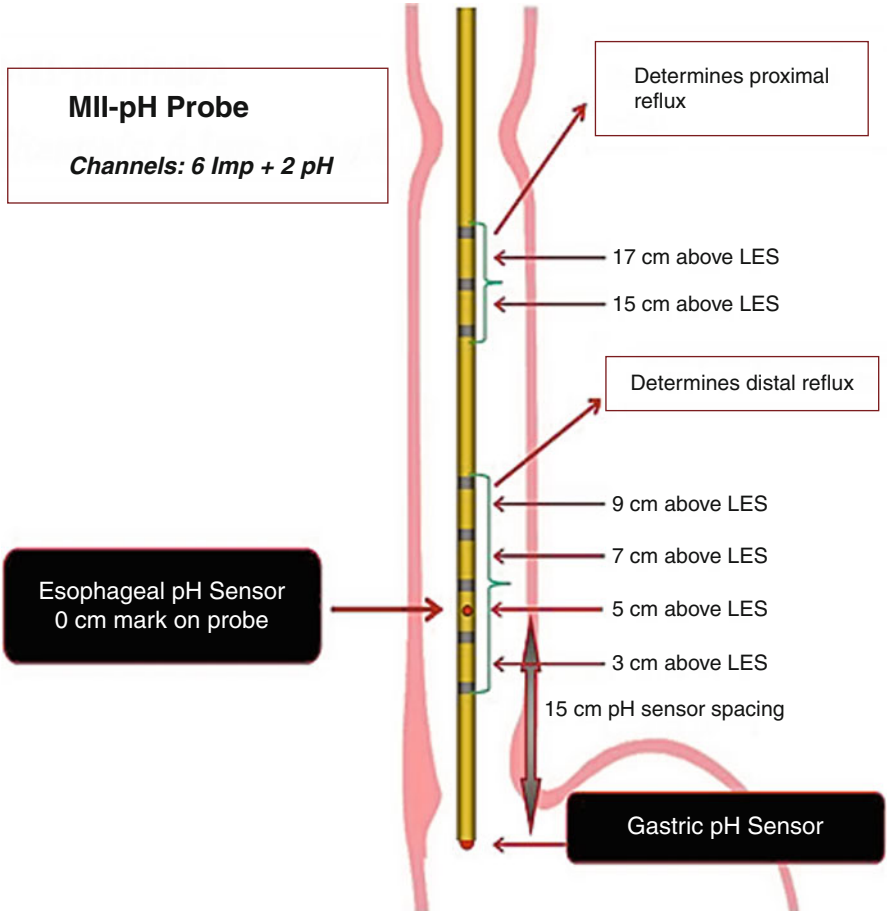

Fig. 9.4 pH-impedance probe description

study has to be done while the patient is on therapy [12]. The procedure must be adequately explained to the patient.

Entering Patients Details into the System

Since 24-h pH impedance monitoring is an ambulatory procedure, the recorded data are collected in a flash card, which is a component of the data logger. Hence, the flash card is inserted into the computer with the pH impedance monitoring software and is fed with the patient's details, such as name, hospital number, age, and gender. There are three event keys which are selected for symptoms (such as event key 1 for heartburn, key 2 for regurgitation, and key 3 for chest pain). Subsequently, the flash card is re-inserted into the data logger and then the procedure is initiated.

Electrode Calibration

Electrodes must be calibrated before each study, as failure to do so may lead to gross inaccuracy. Calibration is performed with both an acidic and neutral buffer of known pH (usually pH 4 and 7) [11, 12]. Usually, the probe is dipped in pH 4 solution first, then in pH 7 for calibration after washing in between with distilled water.

Positioning of the Catheter

The catheter is positioned into the esophagus through transnasal route. Initially, both the pH electrodes (proximal and distal) are placed deep inside the stomach and then the catheter is pulled gradually to position the proximal port 5 cm above the manometrically determined upper margin of LES zone. Since the change in the pH from stomach to esophagus (acid drift) can be seen in real time, this parameter also helps in placement of the pH sensor. The proximal pH electrode needs to be placed 5-cm above the upper border of LES, determined on manometry. The distal pH electrode is kept in the stomach to record gastric acidity [12]. The proximal end of the catheter emerging from the patient's nose is affixed to the face with tape during the study period (Fig. 9.5).

24-h Monitoring

The data logger is hung from the patient's shoulder throughout the 24-h study period. A diary is given to the patient with instructions to record the time of meal, symptoms, and body posture. The patient is also instructed to press the pre-defined event markers in the data logger for all such events such as a meal, lying down, getting up, and symptoms. The patient is instructed to continue usual daily activities and diet, including those activities known to precipitate symptoms, as changes in typical routines may affect data interpretation. The patient is asked to avoid acidic drinks during the study period. Once the study is completed, the catheter is removed. Subsequently, the flash card is inserted into the computer with software and the signal files are downloaded and analyzed.

During the analysis, the signal is visually scanned for adequacy of recording including events marks, gastric pH, and presence of reflux (Fig. 9.6). All reflux

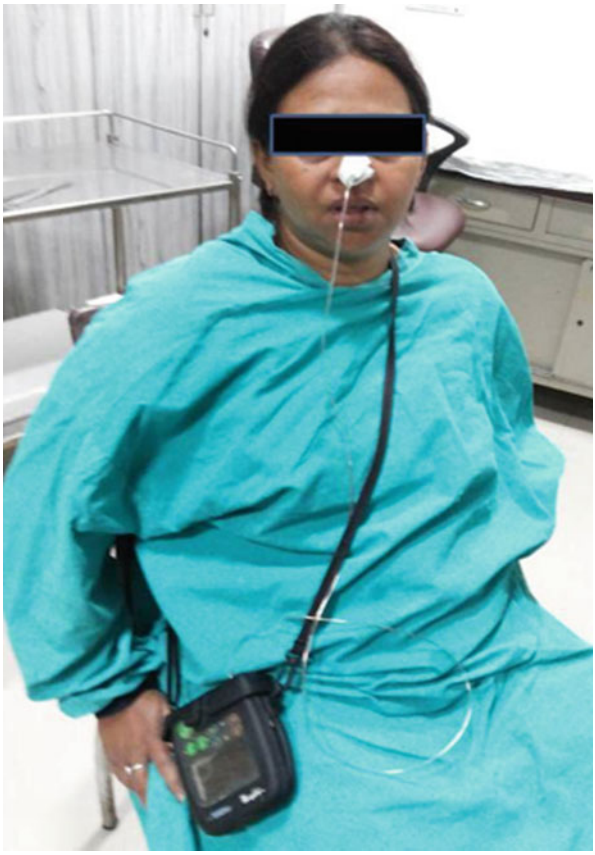

Fig. 9.5 Patient undergoing 24-h impedance pH-monitoring

events are analyzed during the total recording period, in upright and supine phases. From the impedance-pH recordings, the parameters of acid and bolus exposure are analyzed using the software (Tables 9.1 and 9.2) [4]. The standard cut-off values of percentage time of 24-h recording period, esophageal pH below 4, and of bolus exposure are used to diagnose abnormal gastroesophageal reflux, as shown in Tables 9.1 and 9.2. Based on whether the abnormal reflux occurred during supine or upright period during 24-h recording, patients are further diagnosed as having supine, upright, or combined refluxers.

Definition of Esophageal Reflux Parameters

***Acid exposure* (%)** Defined as the total time during which the lower esophageal pH was below four divided by the duration of monitoring.

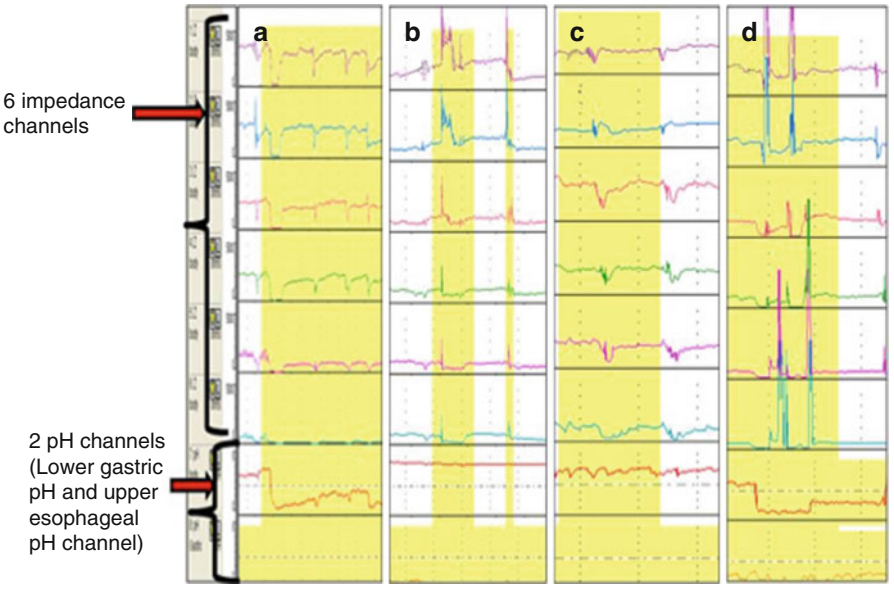

Fig. 9.6 Some pH-impedance recording signals using impedance and pH sensors. (**a**) Acidic liquid reflux. (**b**) Non-acidic gas reflux. (**c**) Non-acidic liquid reflux. (**d**) Acidic mixed reflux

Table 9.1 Normal values for 24-h pH impedance monitoring; acid exposure and bolus exposure

Parameters	Upright	Recumbent	Total
Acid exposure (pH)			
Percent Time Clearance pH	<6.3	1.2	4.2
Bolus exposure (impedance)			
Median bolus clearance time (sec)	<43	<51	<44
Acid percent time	<1.7	<0.8	<1.1
All reflux percent time	<2.1	<0.7	<1.4

Table 9.2 Composite score analysis (DeMeester)

Parameters	Normal threshold
Upright time in reflux	<8.4
Recumbent time in reflux	<3.5
Total time in reflux	<4.5
Episodes over 5 min	<3.5
Longest episode	<19.8
Total episodes	<46.9
[a]Composite score	<14.7

[a]Patient values for composite score are normalized for 24 h

***Bolus exposure* (%)** Defined as being analogous to acid exposure by adding the duration of all reflux defined by impedance, and dividing this value by duration of monitoring.

Symptom index (SI) Defined as the number of symptoms associated with reflux divided by the total number of symptoms. A value of SI ≥50 % is abnormal and is considered to diagnose GERD (i.e., at least half of symptoms are associated with reflux).

Normal Values of Reflux Parameters

Normal values for impedance-pH monitoring off acid-suppression therapy have been determined from studies on healthy volunteers [13–15]. Based on the 95th percentile as the upper limit of normal, the proposed normal value of total distal reflux is ≤73, percentage time distal esophageal pH ≤4.2 (pH parameter), and percentage bolus exposure ≤1.1 (impedance parameter) (Table 9.1).

Published data on normal values for impedance-pH monitoring while on acid-suppression therapy are lacking. Such studies are important for interpreting esophageal impedance pH monitoring studies while on acid-suppressive treatment, as persistent symptoms of gastroesophageal reflux while on acid-suppression therapy is not uncommon. A study by Vela et al. reported that PPI therapy reduced the number of acid reflux episodes with a proportional increase in non-acid reflux, the net result of which was an unchanged total number of reflux episodes on or off therapy as observed during post-prandial studies [16]. The normal range of reflux episodes "on therapy" (<73) has been determined by extrapolating the data from healthy volunteers "off therapy" [13] and by assuming that PPI primarily changes the pH of the refluxate without affecting the total number of reflux episodes [16]. This presumption, however, may not be entirely correct.

Interpretation

During assessment of pH- impedance tracings, the impedance channels are used to detect the occurrence of reflux, and pH changes help to classify the reflux episodes as acid (pH<4) or non-acid (pH>4) [9]. Data analysis is performed on the liquid and mixed reflux episodes during the upright, supine, and total phases of measurement. Parameters recorded during pH-impedance monitoring include: (a) total reflux (liquid and gaseous) percent time and those in upright and recumbent postures; (b) acidic and non-acidic reflux in upright, recumbent, and both postures; (c) duration of esophageal pH<4 in upright, recumbent, and both the postures; (d) acid exposure percent time in upright, recumbent, and both the postures; (e) mean acid clearance time; and (f) symptom correlation to reflux (acidic and non-acidic) [11].

Clinical Utility

In contrast to pH-metry alone, impedance-pH metry can detect non-acid and gas reflux in addition to acidic reflux [5, 7, 17]. Therefore, it may be used to diagnose

reflux even while the patient is on treatment with acid-lowering drugs [18, 19]. In this condition, impedance testing is intended to assess whether non-acid reflux is the cause of ongoing symptoms. In the pH-impedance technique, proximal extent of reflux can be assessed, the type of refluxate be determined (gas, mixed, or liquid), and a calculated SI may help to evaluate whether the ongoing symptoms correlate with reflux events [20].

A number of studies have evaluated the utility of impedance testing in GERD patients both on and off PPI therapy. Moreover, in patients with repeated belching, impedance monitoring may help to determine whether the belching is gastric or supra-gastric in nature, and whether there is associated GERD.

A study of 60 patients on PPI treatment reported higher SI with 24-h impedance-pH monitoring compared with pH testing alone (77.1 % vs 66.7 %, $p < 0.05$). Another study of 150 patients with non-erosive reflux disease undergoing 24-h impedance-pH monitoring (off PPI therapy) found that 87 patients (58 %) had a normal esophageal acid exposure. However, 15 % of them had a positive SI for acid, 12 % for non-acid, and 5 % for both. Two studies aimed to evaluate genesis of symptom development following reflux reported that a higher proximal extent, greater reduction in pH, prolonged acid clearance time, and mixed reflux (air and liquid) were more likely to be associated with symptoms. These studies suggest that 24-h impedance-pH monitoring (off PPI therapy) in patients with typical symptoms is more sensitive than pH testing alone [21–24].

In a study of 168 patients with persistent GERD symptoms despite twice-daily PPI therapy, 86 % were found symptomatic during the 24-h impedance-pH monitoring test; however, more than half of the symptomatic patients had a negative SI (e.g., symptoms did not correlate with a reflux event). Of the 69 patients with a positive SI, acid reflux was the cause of symptom in 11 % and non-acid reflux in 37 %, which was only detectable by impedance. In another multicentric study of 150 patients, a positive SI was found in association with non-acid reflux in 32 %. Thus, these studies suggest that 30–40 % of patients with persistent symptoms on PPI therapy have non-acid reflux as a cause, and this can currently only be identified with impedance testing.

24-h impedance-pH monitoring is useful to investigate patients with atypical symptoms (cough, hoarseness) of GERD [25–31]. In a study of 22 patients with unexplained chronic cough who underwent impedance-pH monitoring, 30.6 % of coughing episodes were associated with reflux. Another study of 100 patients with unexplained chronic cough underwent impedance-pH monitoring. They found that chronic cough was temporally associated with a reflux event in almost 50 % of patients. These studies suggest that 24-h impedance-pH monitoring may diagnose GERD as a cause of chronic cough in some patients that would be missed with only pH testing.

Advantages of impedance-pH metry, therefore, may be summarized as:

- Nature (liquid, gaseous or mixed), movement, and extent of reflux in the esophageal lumen can be detected
- Efficacy of the PPI therapy can be checked

- This technique has a higher yield in identifying patients with cough due to reflux compared to pH monitoring alone
- Analysis of the relationship between symptoms and all types of reflux events, both acid and non-acid

However, the disadvantages include:

- pH-impedance technique cannot estimate the volume of the refluxate
- Costly and time-consuming procedure
- Interpretation of non-acid reflux episodes has a high inter-observer variability
- Automatic analysis considers only a drop of impedance of $\geq 50\,\%$ as a reflux episode; however, a drop of 49 % also can contribute to a reflux episode
- The recordings are complex and filled with artifacts; a thorough (and time-consuming) review of the recordings, episode by episode, is still required

Conclusion

Though all patients with GERD may not need physiological testing for confirmation of abnormal gastroesophageal reflux, these tests are essential in a subset of patients. Catheter-based 24-h impedance pH monitoring scores over conventional 24-pH metry. In expert hand, 24-h pH impedance monitoring is easy to perform and analyze. These physiological tests are also useful to assess response to pharmacological and non-pharmacological treatment for GERD, when indicated.

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Summary of Criteria for Diagnosis of Motility Disorders

10

Rajesh Sainani

Abstract

High-resolution manometry, a novel technology, has revolutionized the ease of performing, interpreting, and applying gastrointestinal motility tests in clinical practice. Moreover, the recent introduction of Chicago classification has paved a new way by which motility disorders like achalasia are diagnosed and classified, and has introduced a new clinical dimension to select patients with different sub-types of achalasia to different therapeutic modalities. Moreover, high-resolution manometry also helped us to understand which sub-type of achalasia respond best to the first-line treatment like endoscopic pneumatic dilation. Introduction of newer parameters such as integrated relaxation pressures, distal contractile integral, contractile deceleration point, and distal latency, potentially helped in diagnosis of various clinical entities more objectively.

Keywords

Motility • Achalasia • Distal esophageal spasm • Jackhammer esophagus • Chicago classification • Esophageal manometry • Anorectal manometry • Cricopharyngeal bar • Dyssynergic defecation • Fragmented peristalsis

Introduction

High-resolution manometry has changed the way motility tests are performed and interpreted. The Chicago classification has changed the way motility disorders like achalasia are diagnosed, and for the first time given a management guidance as to

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which patients will benefit from the different modalities of treatment. There are newer parameters being measured like integrated relaxation pressures, distal contractile integral, contractile deceleration point, and distal latency, which make the diagnosis of various clinical entities more objective.

Esophageal Manometry

The Chicago classification [1–3] has laid down criteria for diagnosis of esophageal motility disorders. We must define the various measurable parameters on high-resolution manometry before we sub-classify them into various clinical diagnoses.

Normal Peristalsis

The swallow begins with relaxation of the upper esophageal sphincter (UES), which is associated with simultaneous relaxation of the lower esophageal sphincter (LES) (Fig. 10.1). The peristalsis is progressive and ends with augmentation of the lower esophageal sphincter. The thoracic pressures are negative (blue) and become deeper blue (more negative) on deep inspiration as compared to gastric pressures, which are positive (green).

Integrated Relaxation Pressure (IRP)

IRP [2, 3] is measured in mmHg and defined as mean of the 4 s of maximum deglutitive relaxation in the 10 s window beginning at UES relaxation. The contributing times can be contiguous or non-contiguous and referenced to gastric pressures (Fig. 10.2).

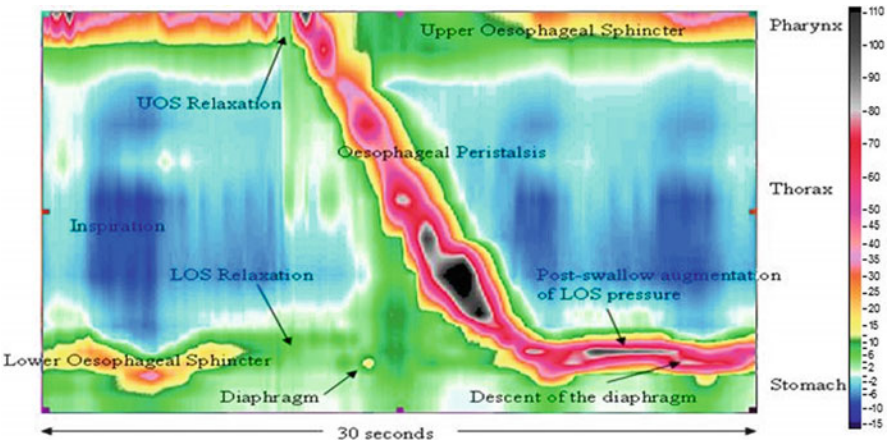

Fig. 10.1 Normal esophageal peristalsis (Used with permission from Hebbard Geoff. A Primer of High Resolution Manometry & Spatiotemporal Analysis)

Distal Contractile Integral (mmHg-s-cm) (DCI)

DCI [2, 3] is defined as amplitude x duration x length of the distal esophageal contraction >20 mmHg from the transition zone to the proximal margin of the LES (Clouse 2nd and 3rd contractile segments) (Fig. 10.3).

Contractile Deceleration Point (CDP)

CDP [2, 3] is the inflection point along the 30 mmHg isobaric contour [or pressure greater than intrabolus pressure in instances of compartmentalized pressurization] at which propagation velocity slows, demarcating peristalsis from ampullary emptying. The CDP must be localized within 3 cm of the proximal margin of the LES (Fig. 10.4).

Contractile Front Velocity (cm s^{-1}) (CFV)

CVF [2] is the slope of the tangent approximating the 30 mmHg isobaric contour between the proximal trough of the distal esophageal contraction and the contractile deceleration point (see Fig. 10.4). (This parameter is not used in the Chicago v3.0)

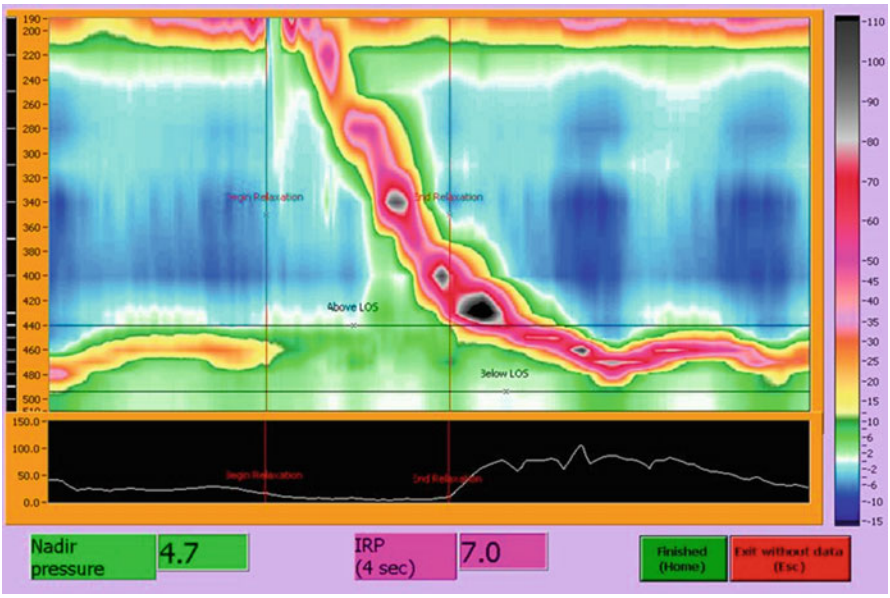

Fig. 10.2 Integrated relaxation pressures (Used with permission from Hebbard Geoff. A Primer of High Resolution Manometry & Spatiotemporal Analysis)

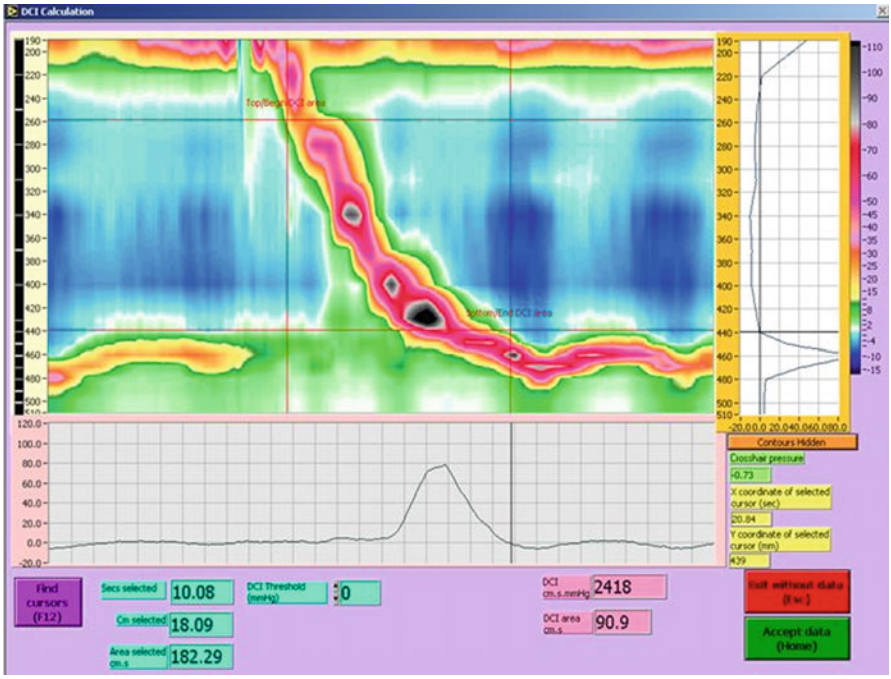

Fig. 10.3 Distal contractile integral (Used with permission from Hebbard Geoff. A Primer of High Resolution Manometry & Spatiotemporal Analysis)

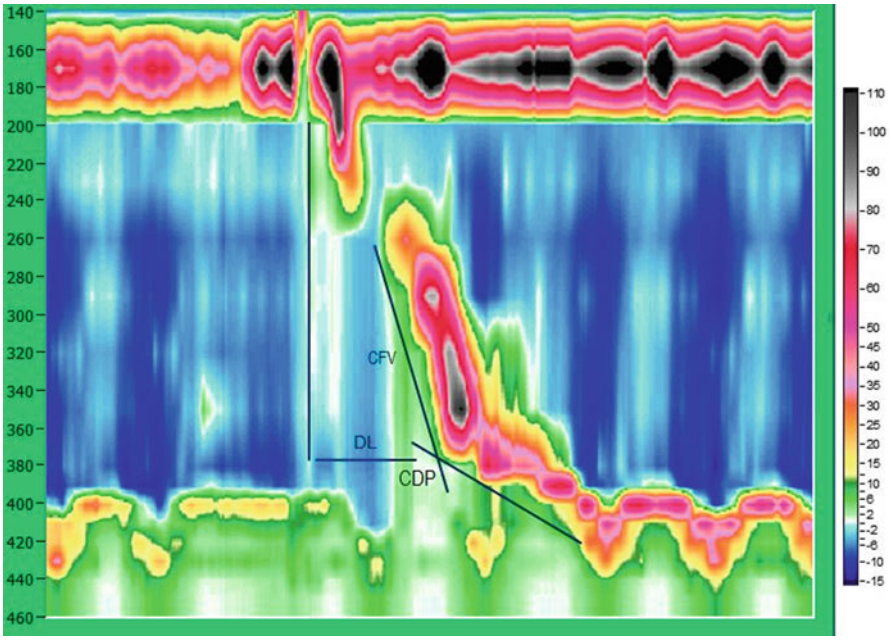

Fig. 10.4 Contractile deceleration point, Contractile front velocity, Distal latency

Distal Latency (DL)

DL [2, 3] is the interval between the upper esophageal sphincter relaxation and the contractile deceleration point (see Fig. 10.4). In a normal peristalsis the distal latency is >4.5 s. Distal latency is less (<4.5 s) in distal esophageal spasm.

Characterization of Esophageal Contractility

The characterization of esophageal contractility [3] is based on contraction vigor, contraction pattern, and intrabolus pressure patterns. The contraction pattern is not scored for ineffective swallows (DCI <450 mmHg-s-cm).

The contraction vigor is of the following types:

1. Failed peristalsis is DCI < 100 mmHg-s-cm (Fig. 10.5).
2. Weak peristalsis is DCI > 100 mmHg-s-cm but <450 mmHg-s-cm (Fig. 10.6).
3. Ineffective peristalsis is failed or weak peristalsis.
4. Normal peristalsis is DCI > 450 mmHg-s-cm BUT <8000 mmHg-s-cm (Fig. 10.1).
5. Hypercontractile peristalsis is DCI >8000 mmHg-s-cm (Fig. 10.7).

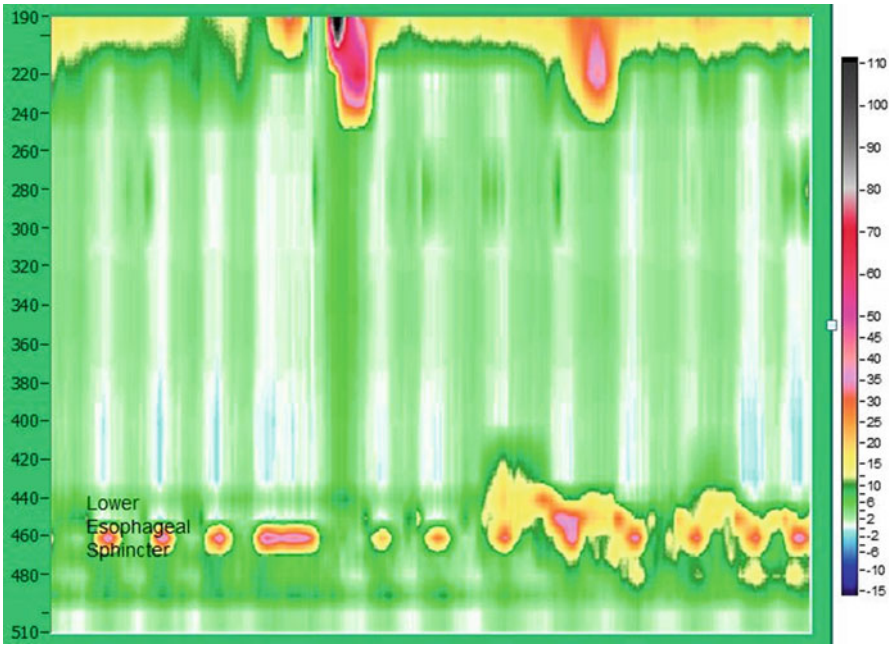

Fig. 10.5 Failed peristalsis

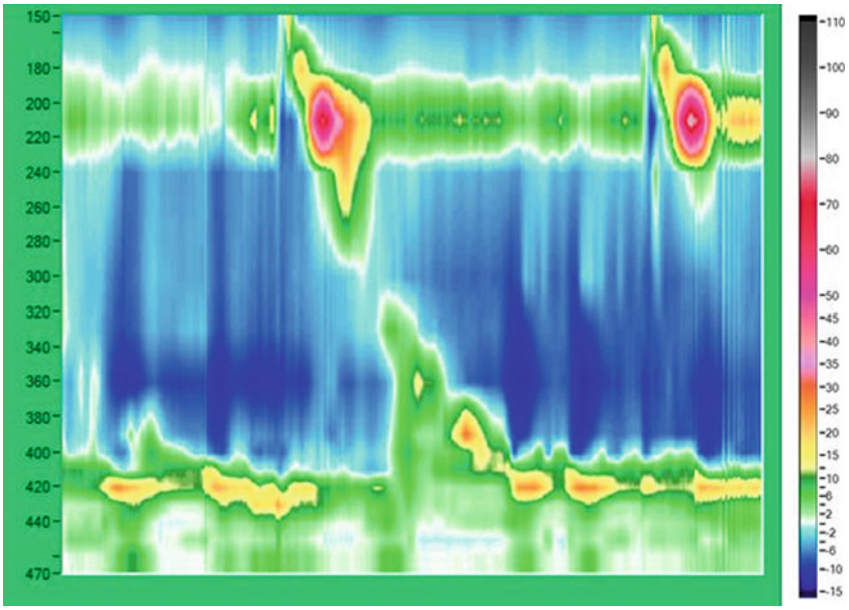

Fig. 10.6 Weak Peristalsis

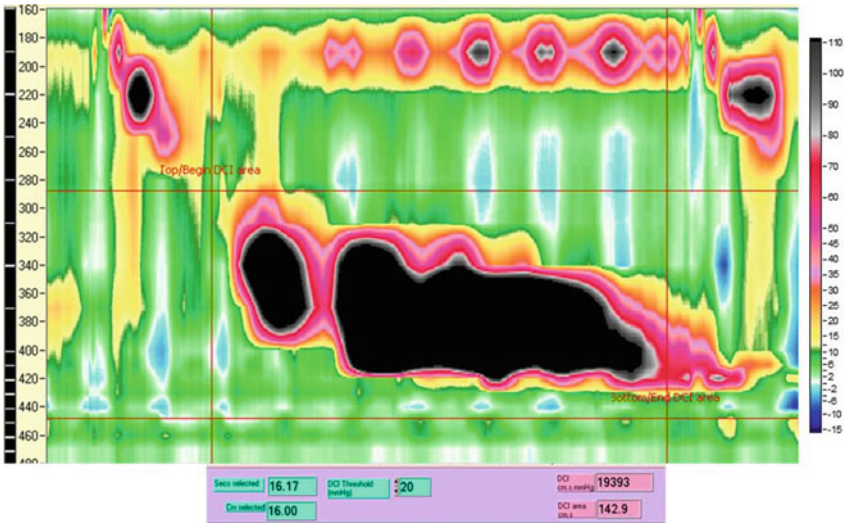

Fig. 10.7 Jackhammer esophagus

The contraction pattern is of the following types:

1. Premature contraction is distal latency <4.5 s (Fig. 10.8).
2. Fragmented contraction is a large break [>5 cm] in the 20 mmHg isobaric contour with DCI >450 mmHg-s-cm (Fig. 10.9).
3. Intact peristalsis is a swallow not achieving the above criteria (Fig. 10.1).

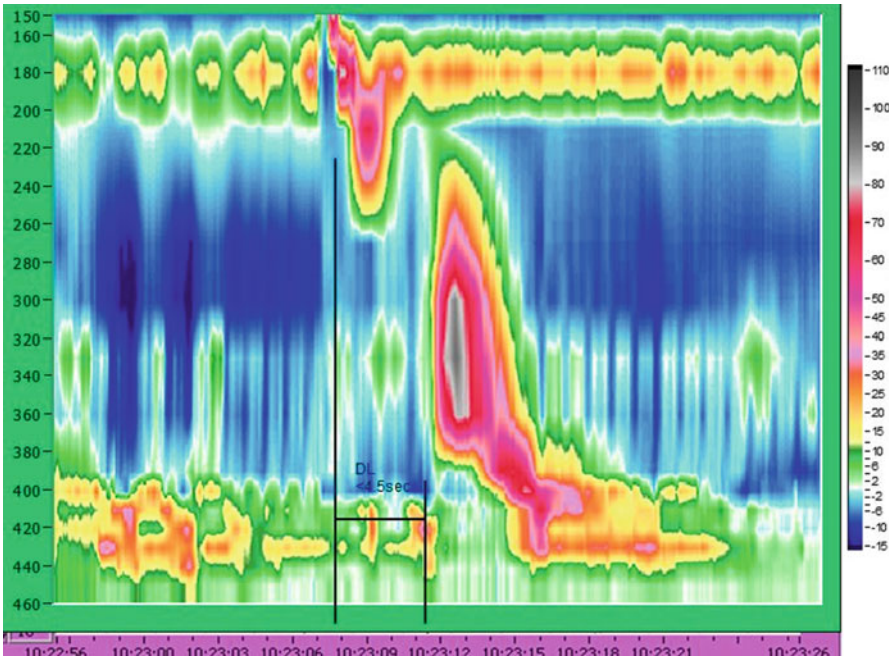

Fig. 10.8 Premature contraction, distal esophageal spasm

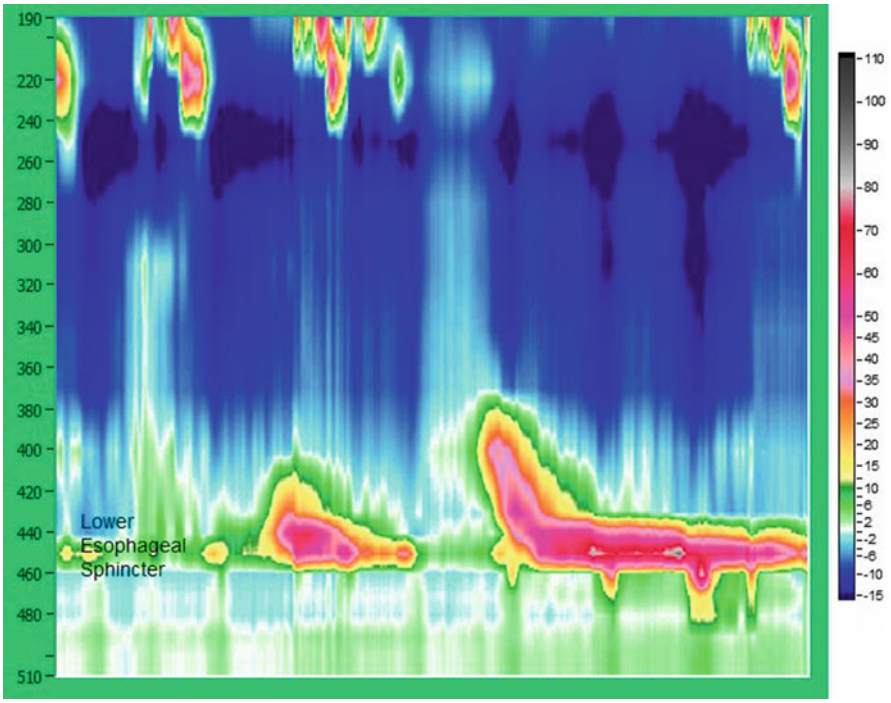

Fig. 10.9 Fragmented peristalsis

The various patterns esophageal body contractility are as follows:

1. Panesophageal pressurization is defined as uniform pressurization of >30 mmHg extending from the upper esophageal sphincter (UES) to the esohago gastric junction (EGJ) (Fig. 10.10).
2. Compartmentalized esophageal pressurization is defined as pressurization of >30 mmHg extending from the contractile front to the EGJ (Fig. 10.11).
3. Esophago Gastric Junction (EGJ) pressurization is the pressurization which is restricted between the lower esophageal sphincter (LES) and crural diaphragm in conjunction with the LES-CD separation.
4. Normal swallows have no bolus pressurization of >30 mmHg (Fig. 10.1) (Table 10.1).

Other Conditions Not Separately Classified By Chicago Classification

Hiatus Hernia

There is a normal peristaltic wave which ends in the lower esophageal sphincter (smooth muscle). There is an axial dissociation between the lower esophageal sphincter and crural diaphragmatic pressures which gets augmented on deep inspiration (deep blue intrathoracic pressures) as seen in Fig. 10.12.

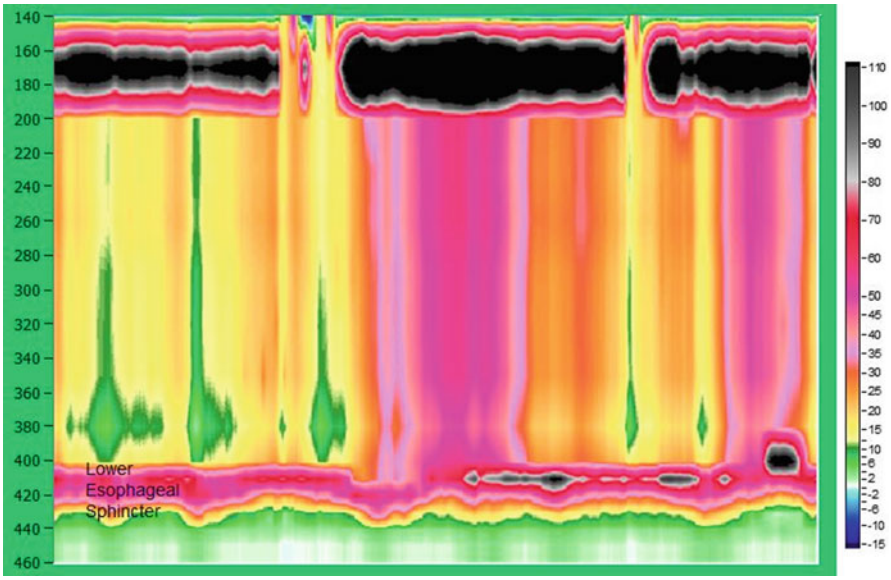

Fig. 10.10 Achalasia, type 2

The esophago gastric junction (EGJ) morphology [3] is classified into three types:

Type I: There is a complete overlap of the crural diaphragm (CD) and LES components with single peak on the spatial pressure variation plot.

Type II: There is a double-peaked pressure zone with the interpeak nadir pressure greater than gastric pressure and a separation of 1–2 cm between peaks. This can vary or be present intermittently in which case the report should mention the range of observed LES-CD separation.

Type IIIa: There is a double-peaked pressure zone with the interpeak nadir pressure less than or equal to gastric pressure, but the pressure inversion point remains at the CD level. The range of observed LES-CD separation is required to be reported.

Type IIIb: There is a double-peaked pressure zone with the interpeak nadir pressure equal to gastric pressure and the pressure inversion point at the LES level. The range of observed LES-CD separation is reported.

Scleroderma

This condition usually presents with low lower esophageal sphincter pressures, absent peristalsis in the lower two-thirds of the esophagus (smooth muscle) with present peristalsis in the upper third of the esophagus (skeletal muscle). These findings are not specific for scleroderma and may also be seen in gastroesophageal reflux disease. As per the Chicago classification, this would get classified as a failed peristalsis (Fig. 10.13).

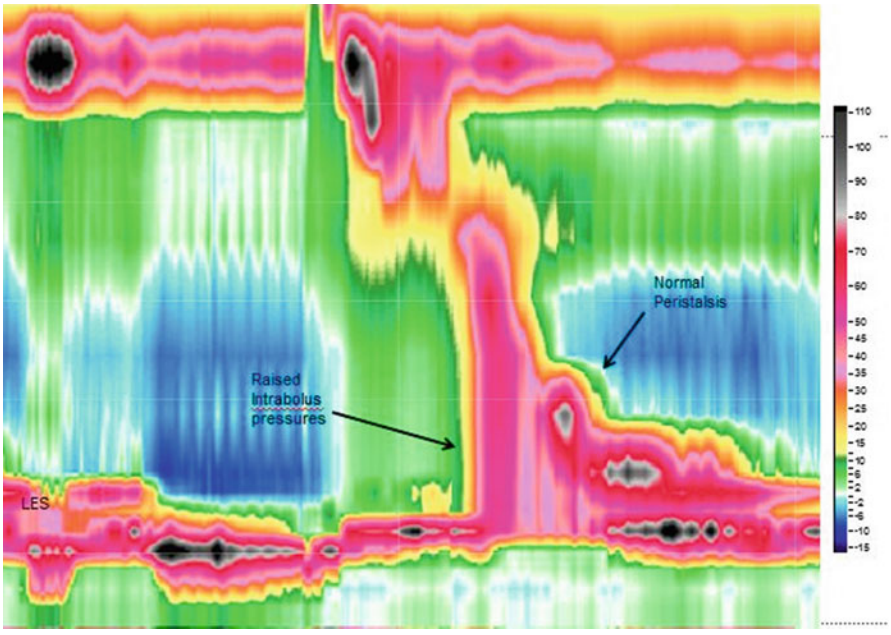

Fig. 10.11 Esophago Gastric Junction outflow obstruction

Table 10.1 Manometric features of esophageal motility disorders (Chicago classification v3.0)

Motility disorder	Lower Esophageal Sphincter [LES]	Esophageal body
Achalasia type I (Classic Achalasia) (Fig. 10.27)	Median IRP > 15 mmHg (median IRP > upper limit of normal)	100 % failed peristalsis (DCI <100 mmHg-s-cm)
		Premature contractions with DCI <450 mmHg-s-cm satisfy criteria as failed peristalsis
Achalasia type II (with esophageal compression) (Fig. 10.10)	Median IRP > 15 mmHg (median IRP > upper limit of normal)	100 % failed peristalsis, panesophageal pressurization with ≥20 % of swallows
Achalasia type III (spastic achalasia) (Fig. 10.28)	Median IRP > 15 mmHg (median IRP > upper limit of normal)	No normal peristalsis, premature (spastic) contractions (DL <4.5 s) with DCI >450 mmHg-s-cm in ≥20 % of swallows
Esophago Gastric Junction (EGJ) outflow obstruction (Fig. 10.11)	Median IRP > 15 mmHg (median IRP > upper limit of normal)	Sufficient evidence of peristalsis such that criteria of achalasia type I–III are not met
Distal Esophageal Spasm (Fig. 10.9)	Median IRP <15 mmHg (normal median IRP)	≥20 % premature contractions (DL <4.5 s) with DCI >450 mmHg-s-cm
Hypercontractile esophagus (Jackhammer) (Fig. 10.7)	Median IRP <15 mmHg (normal median IRP)	At least two swallows DCI > 8000 mmHg-s-cm (hypercontractility may involve or be localized to LES)
Absent contractility (Fig. 10.5)	Median IRP <15 mmHg (normal median IRP)	100 % of failed peristalsis
		Premature contractions (DL <4.5 s) with DCI <450 mmHg-s-cm satisfy criteria as failed peristalsis
Fragmented peristalsis (Fig. 10.9)	Median IRP <15 mmHg (normal median IRP)	≥50 %, fragmented peristalsis (large break >5 cm in the 20 mmHg isobaric contour with DCI >450 mmHg-s-cm)
Ineffective esophageal motility (Figs. 10.5 and 10.6)	Median IRP <15 mmHg (normal median IRP)	≥50 %, ineffective swallows (weak or failed with DCI <450 mmHg-s-cm)
Normal esophageal motility (Fig. 10.1)	Median IRP <15 mmHg (normal median IRP)	Not fulfilling any of the above classifications

IRP Integrated relaxation pressure, *DL* Distal latency, *DCI* Distal contractile integral
Adapted with permission from Mehta [14]
Modified from the Chicago Classification [1–5]

Upper Esophageal Manometry

The normal upper esophageal sphincter (UES) relaxes to swallows with the pressures falling to intraesophageal pressures (Fig. 10.14). In cricopharyngeal achalasia, there is a failure of the upper esophageal sphincter to completely relax, and can

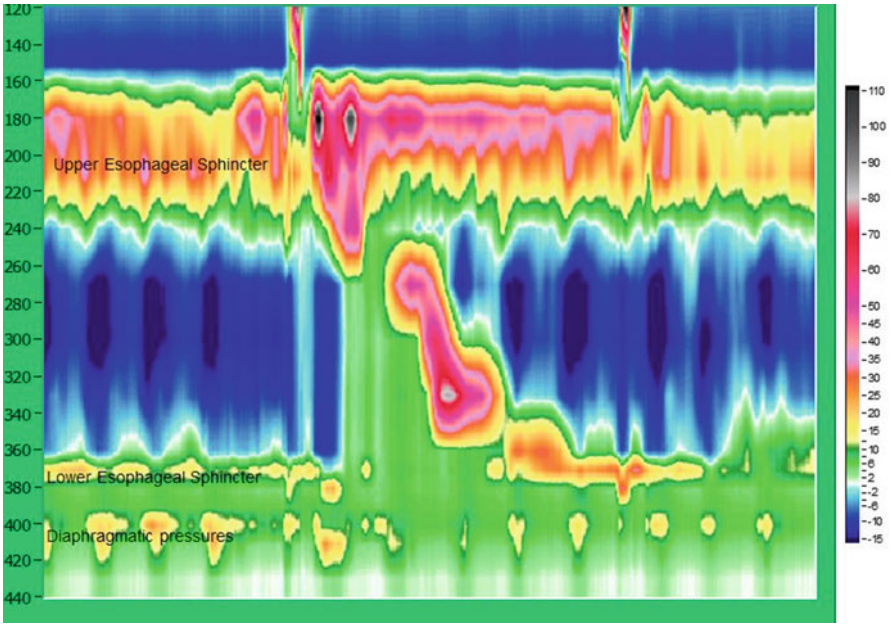

Fig. 10.12 Hiatus hernia

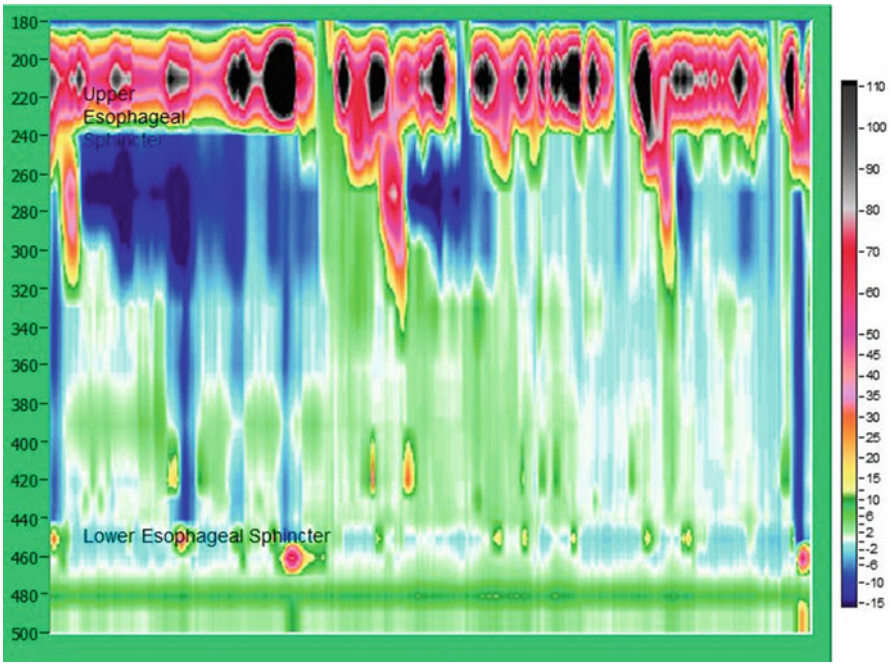

Fig. 10.13 Scleroderma

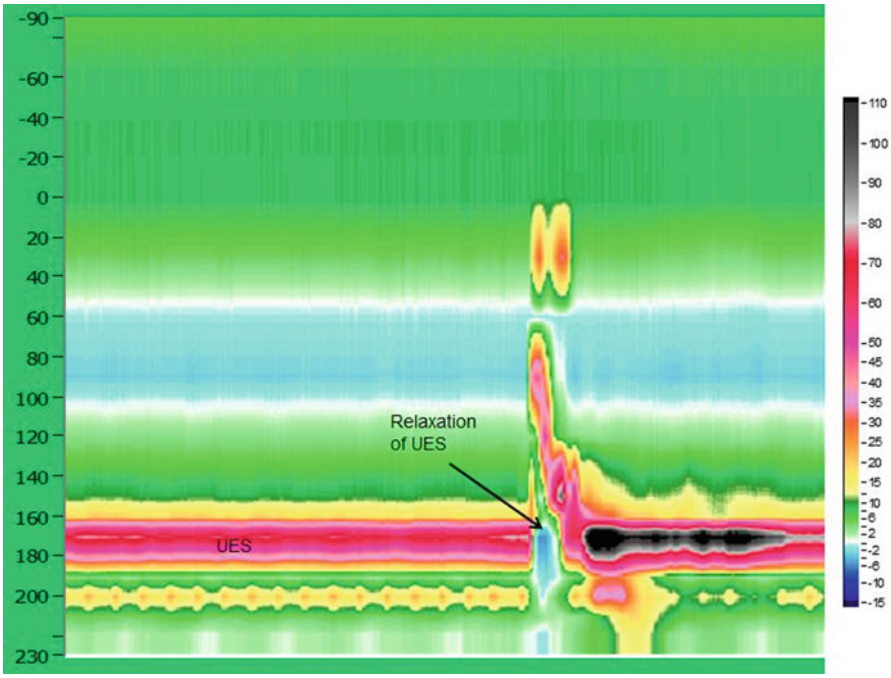

Fig. 10.14 Upper esophageal sphincter relaxation, normal

be visualized on high-resolution manometry. The same is observed on simultaneous videomanometry as a cricopharyngeal bar (Fig. 10.15) (Table 10.2).

Anorectal Manometry

Anorectal manometry is performed in the same way as conventional manometry, but with the advantage that movement artifacts due to catheter displacement does not affect its interpretation. A high-resolution anorectal manometry catheter is used with a balloon attached to its tip. After insertion of the anorectal catheter, the basal resting pressure of the anal sphincter is measured. Then squeeze pressures and rectoanal inhibitory reflex are recorded. This is followed by rectal sensory testing for first sensation to balloon distension, desire to defecate, and discomfort or urgency to defecate, to various volumes of balloon distension. This is followed by asking the patient to strain to expel the balloon to look for anal sphincter relaxation and to measure the anorectal balloon expulsion time.

The following parameters need to be measured during anal manometry using high-resolution manometry.

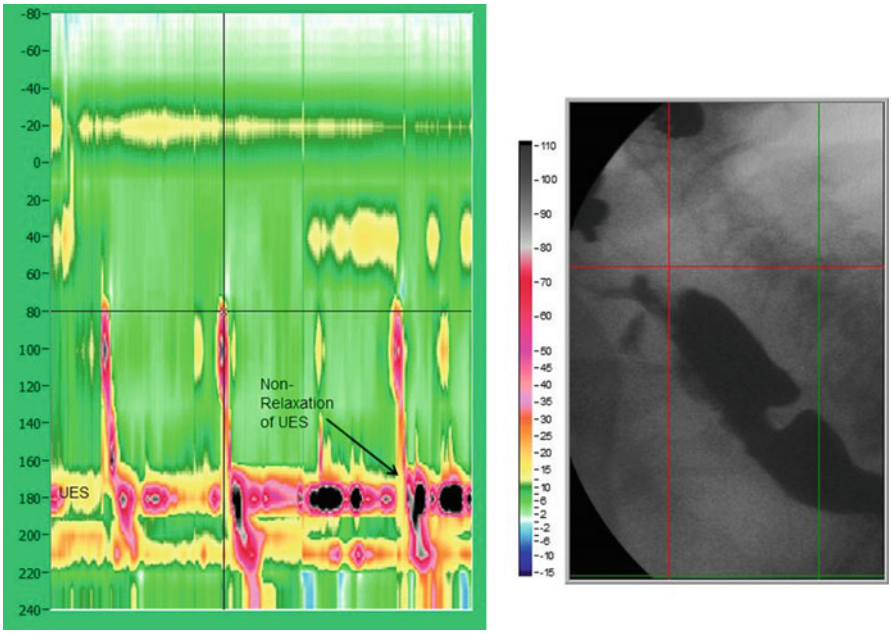

Fig. 10.15 Cricopharyngeal Achalasia, Cricopharyngeal Bar. Incomplete relaxation of the upper esophageal sphincter suggestive of cricopharyngeal achalasia, cricopharyngeal bar on simultaneous videomanometry

Table 10.2 Normal values upper esophageal sphincter manometry

Pharyngeal contraction amplitude	Mean 71–134 mmHg
Resting upper esophageal sphincter (UES) pressures	73 ± 29 mmHg
Nadir of UES Relaxation (Fig. 10.14)	– 0.8 to +4 mmHg

Adapted with permission from Mehta [14, 6, 7]

Anal Pressures [8–10]

Resting anal pressure is the difference between intrarectal pressure and the maximum anal sphincter pressure at rest. For normal range of anal sphincter pressures in men and women, see Table 10.3 and Fig. 10.16.

If the resting anal pressures are low (<40 mmHg) then the anal sphincter is hypotensive in nature (Fig. 10.17). These patients may have fecal incontinence. If the resting pressures are >100 mmHg they are usually considered to be elevated (Fig. 10.18).

Table 10.3 Normal values for anorectal manometry

	Women	Men
Length of anal canal cm	4 ± 1	4 ± 1
Resting anal canal pressures mmHg	50 ± 13	63 ± 12
Maximal squeeze pressures mmHg	100–134	126–200
Recto anal inhibitory reflex (RAIR)	Present	Present
Balloon distention-first sensation cc	16–24	11–29
Balloon distention – desire to defecate cc	85–127	78–140
Balloon distention – discomfort to distension cc	156–200	139–231
Anal valve- normal	Relaxation during defecation	Relaxation during defecation
Dyssynergic defecation	Paradoxical Contraction of anal sphincter during defecation	Paradoxical Contraction of anal sphincter during defecation
Hirschsprung's disease	RAIR absent	RAIR absent

Adapted with permission from Mehta [14]
Normal values will vary from laboratory to laboratory due to differences in types of catheters and sizes of balloons used [6, 7, 10]

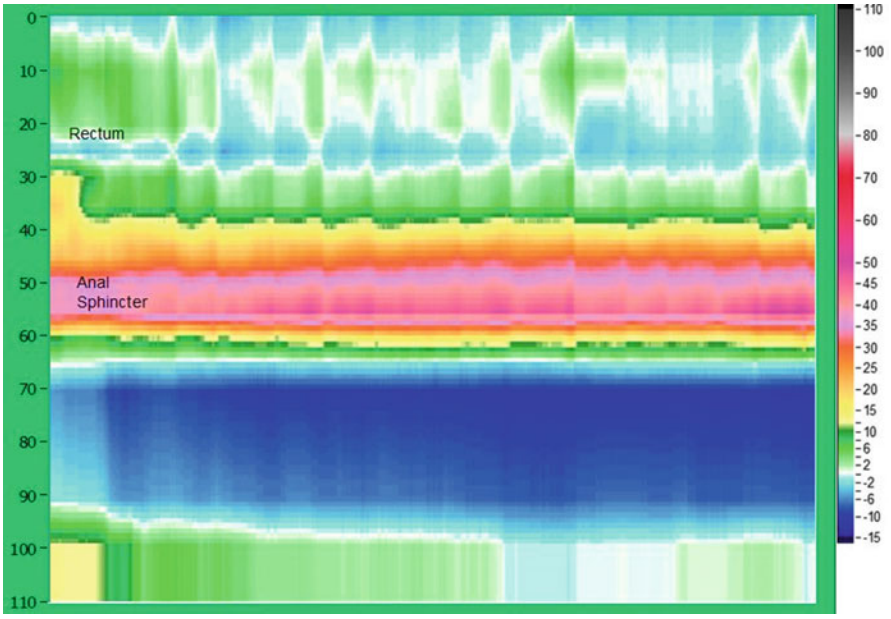

Fig. 10.16 Anal sphincter, resting pressures, normal

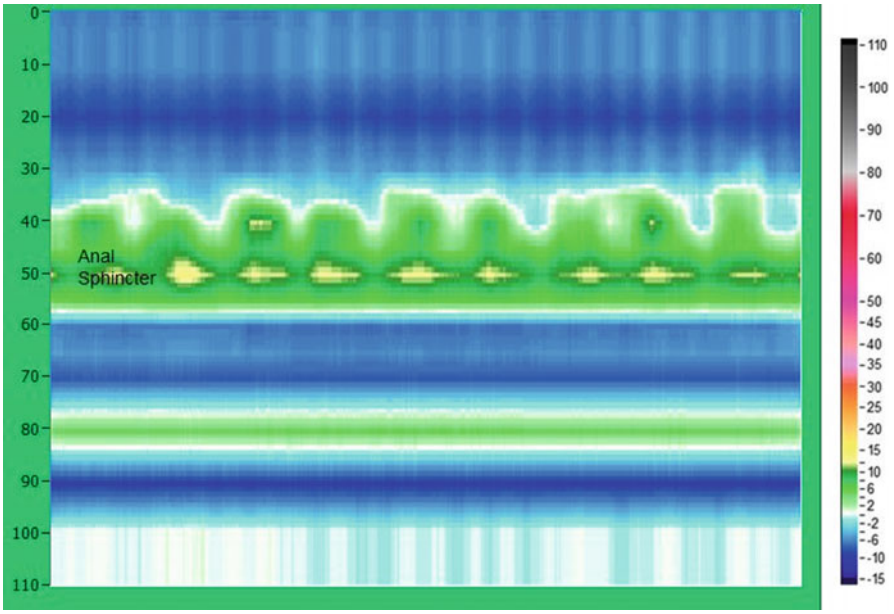

Fig. 10.17 Anal sphincter, resting pressures, low

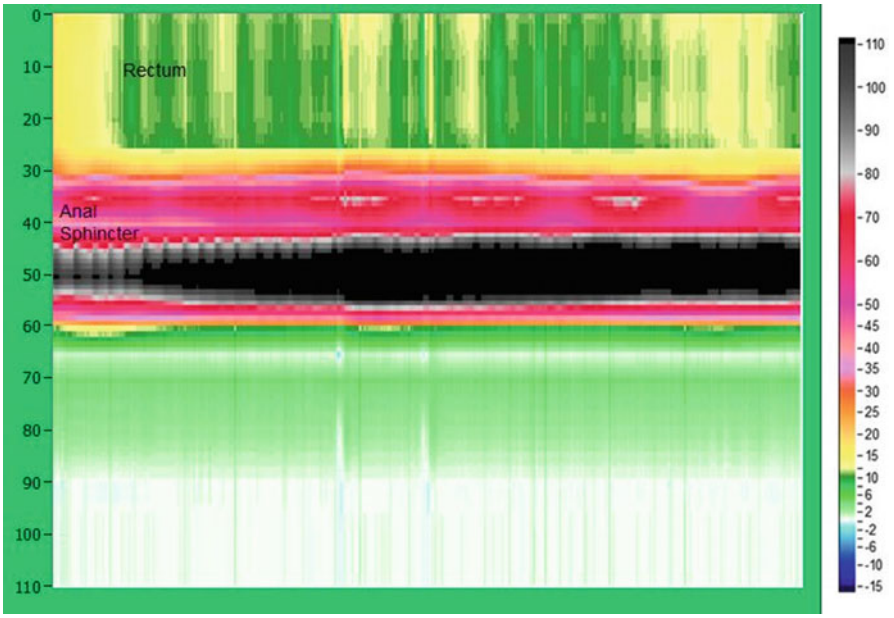

Fig. 10.18 Anal sphincter, resting pressures, elevated

Maximum squeeze pressure is the difference between the intrarectal pressure and the maximum anal sphincter pressure at any level during the squeeze maneuver (Fig. 10.19).

Duration of sustained squeeze is defined as the interval in seconds during which the patient can maintain the maximum squeeze pressure or 50 % of the maximum squeeze pressure.

Measurements for Rectal Sensation

Evaluation of rectal sensation is performed by placing a balloon catheter above the anorectal ring. The balloon is gradually inflated with air.

First sensation is the minimum rectal volume perceived by the patient. It is a transient sensation of fullness or bloating or gas; a vague sensation that disappears completely.

Desire to defecate/urge sensation is the volume associated with the initial urge to defecate. This desire to have a bowel movement lasts > 15 s.

Maximum tolerated volume is the volume at which the patient experiences discomfort and an intense desire to defecate.

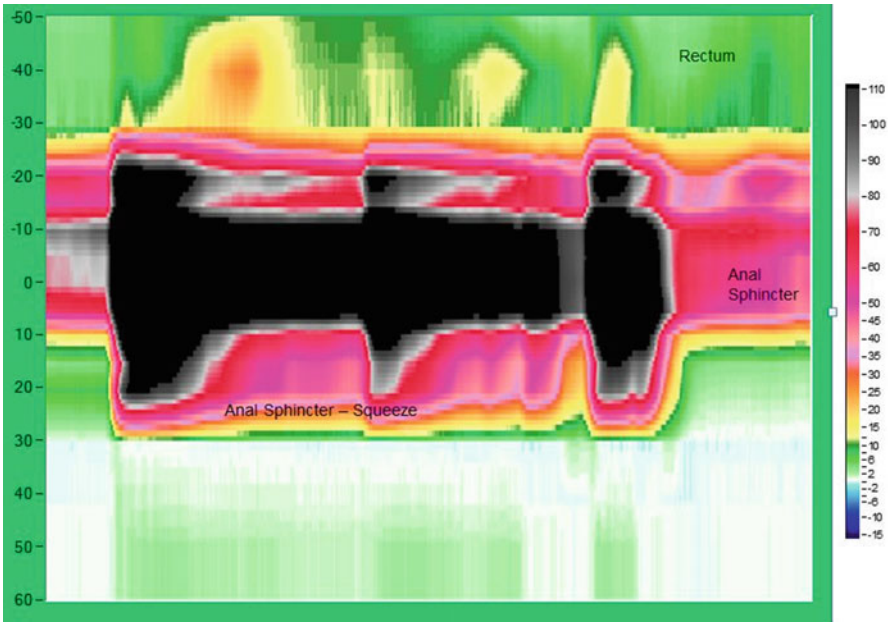

Fig. 10.19 Anal sphincter, squeeze

Rectoanal Inhibitory Reflex (RAIR)

Rectoanal inhibitory reflex is the transient decrease in resting anal pressure by >25 % of basal pressure in response to rapid inflation of a rectal balloon, with subsequent return to baseline (Fig. 10.20).

The presence of anal sphincter relaxation after a balloon is rapidly distended with 50ml air in the rectum is suggestive of a preserved RAIR. If RAIR is not demonstrable with 50 ml of air, a higher volume, up to 250 mL, should be used. The presence of RAIR confirms the integrity of the myenteric plexus between the rectum and anal canal. The reflex is absent in Hirschsprung's disease. At times, the absent RAIR may show a paradoxical increase in the anal sphincter pressures after balloon inflation (Fig. 10.21).

Balloon Expulsion Test

The balloon expulsion test measures the ability of the patient to expel a balloon inflated with 50 ml of water. The time required to expel the balloon is <1 min. If weight is used, a normal person is able to expel the balloon with no weight or less than ≤200 g weight.

Normal Defecation Pattern

During straining in an attempt to pass stools, there are forward rectal propulsive forces (>45 mmHg) and simultaneous relaxation of the anal sphincter >20 % as shown in Fig. 10.22.

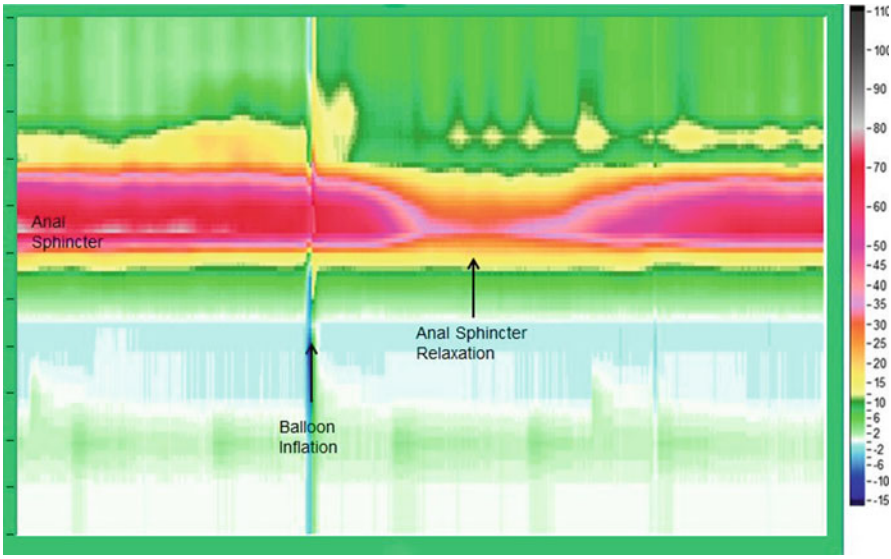

Fig. 10.20 Recto-anal inhibitory reflex (RAIR), normal, present

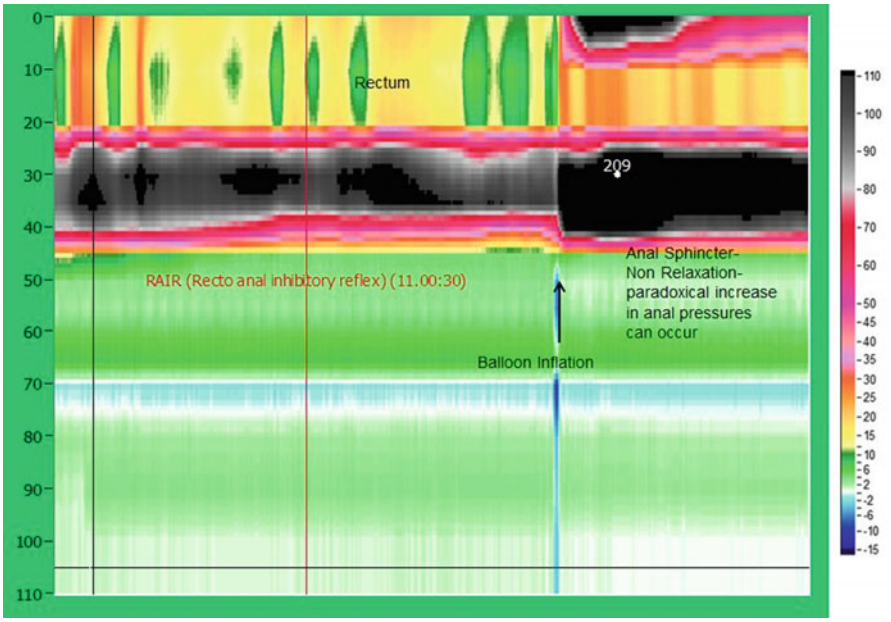

Fig. 10.21 Rectoanal inhibitory reflex (RAIR), abnormal, absent

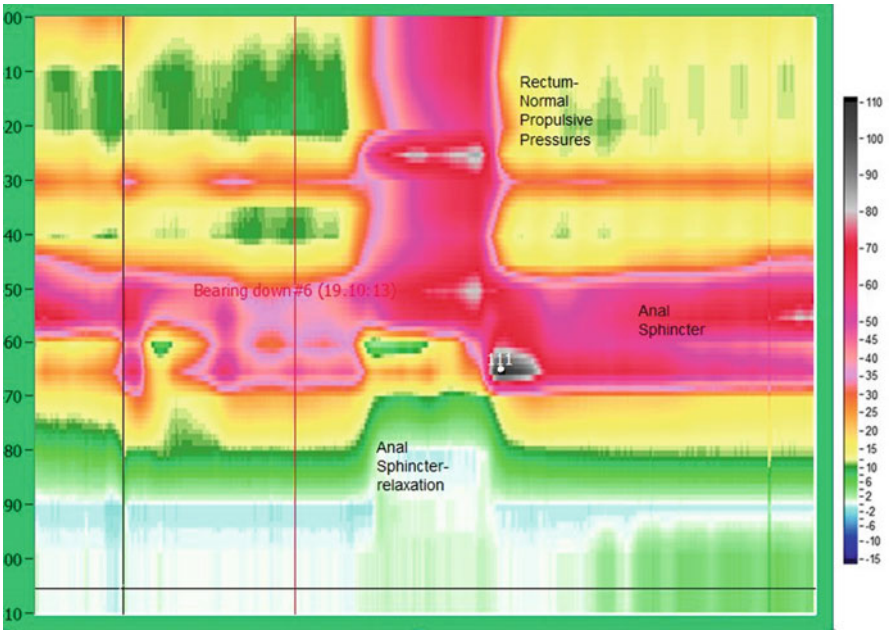

Fig. 10.22 Anal sphincter, relaxation during attempted defecation

Paradoxical Contraction/Non-relaxation of the Anal Sphincter

This non-relaxation is the failure of the levator and external sphincter muscles to relax during straining. This paradoxical contraction is suggestive of dyssynergic defecation, which is classified in four types: [10–12].

- *Type I dyssynergia:* the patient can generate an adequate propulsive force (increase in intra-rectal pressure ≥45 mmHg) with paradoxical increase in anal sphincter pressure (Fig. 10.23).
- *Type II dyssynergia:* the patient is unable to generate an adequate propulsive force (intra-rectal pressure <45 mmHg) and there is paradoxical anal contraction (Fig. 10.24).
- *Type III dyssynergia:* the patient can generate an adequate propulsive force (increase in intra-rectal pressure ≥45 mmHg) but there is either absent relaxation or incomplete (≤20 %) relaxation of anal sphincter (Fig. 10.25).
- *Type IV dyssynergia:* the patient is unable to generate an adequate propulsive force (intra-rectal pressure <45 mmHg) and there is an absent or incomplete (≤20 %) relaxation of anal sphincter (Fig. 10.26).

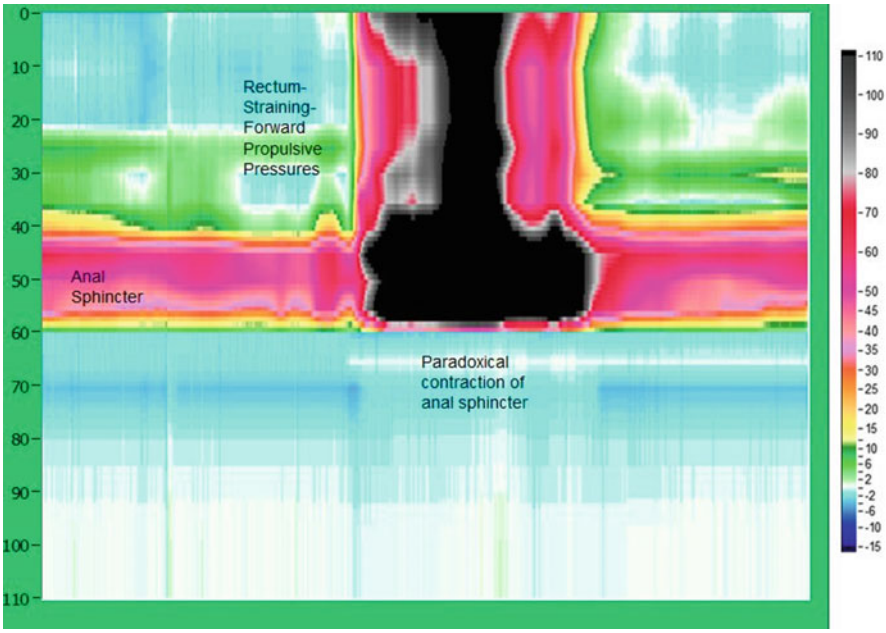

Fig. 10.23 Dyssynergia Type 1

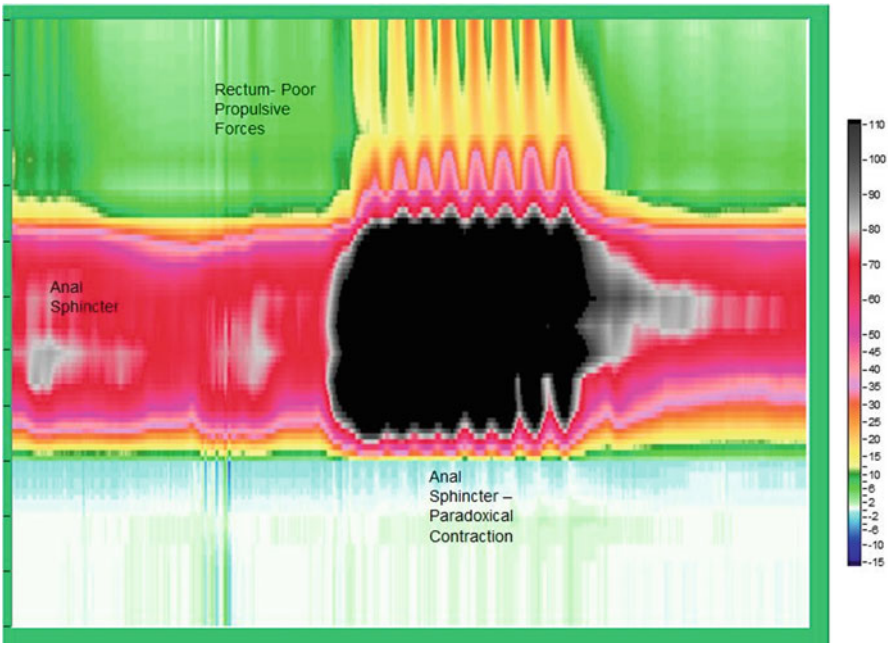

Fig. 10.24 Dyssynergia Type 2

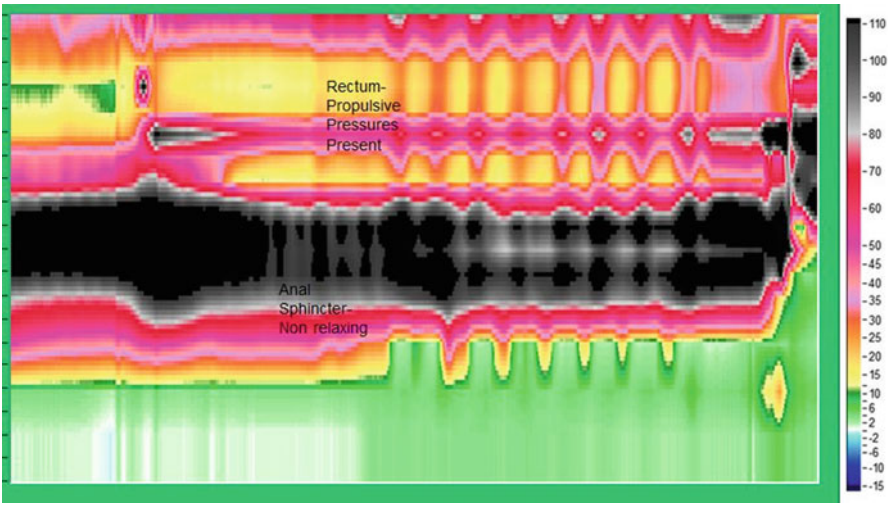

Fig. 10.25 Dyssynergia Type 3

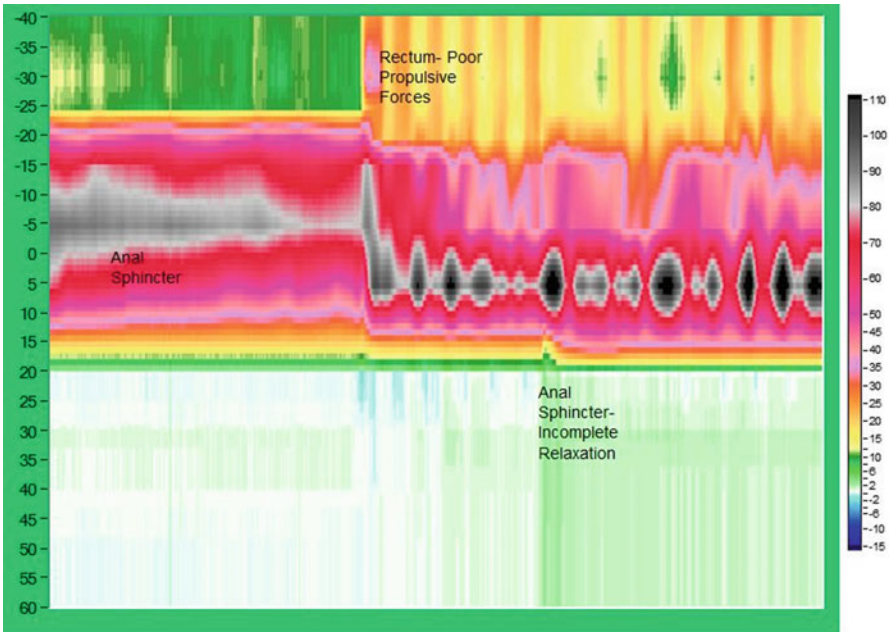

Fig. 10.26 Dyssynergia Type 4

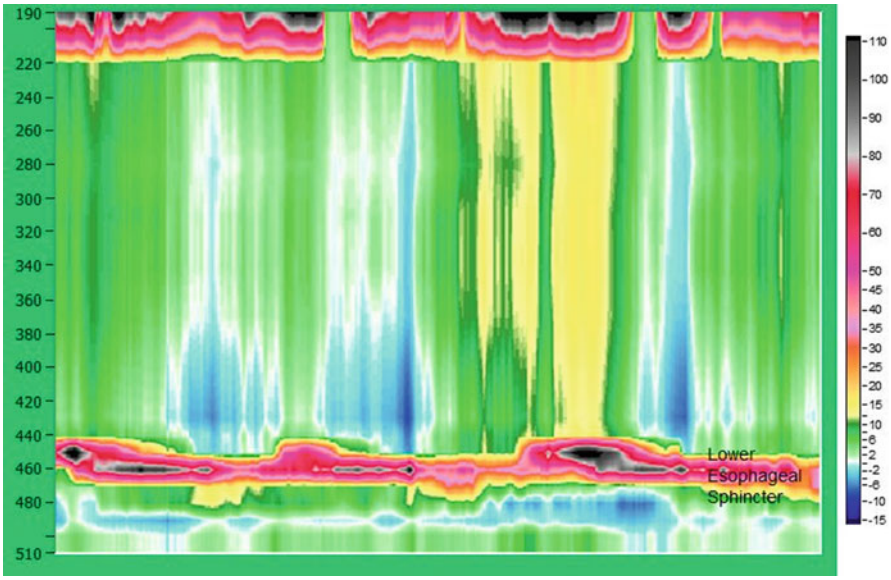

Fig. 10.27 Achalasia, type 1

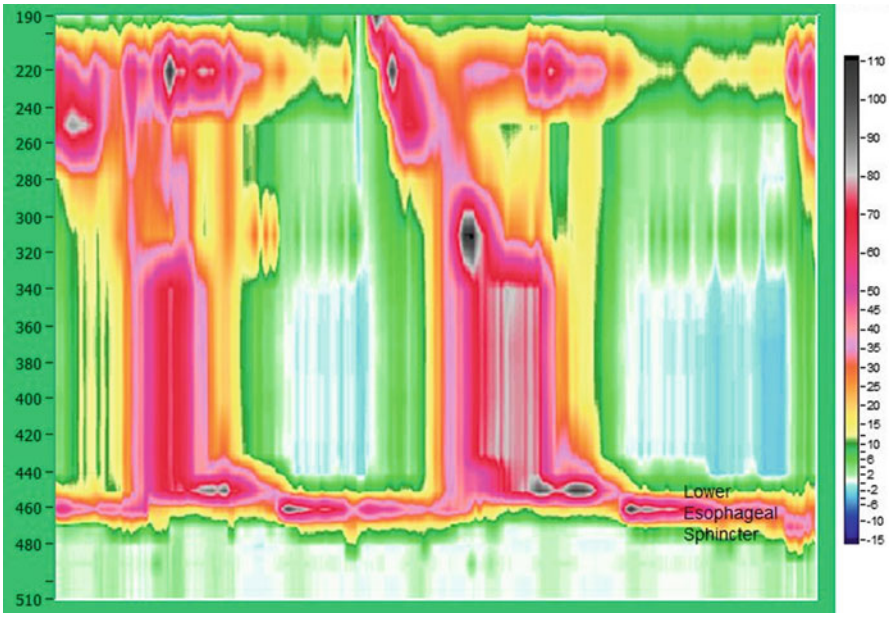

Fig. 10.28 Achalasia, type 3

Diagnostic Criteria* for Functional Defecation Disorders [13]

1. The patient must satisfy diagnostic criteria for functional constipation (mentioned below).
2. During repeated attempts to defecate must have at least two of the following:
   (a) Evidence of impaired evacuation, based on balloon expulsion test or imaging
   (b) Inappropriate contraction of the pelvic floor muscles (i.e., anal sphincter or puborectalis) or less than 20 % relaxation of basal resting sphincter pressure by manometry, imaging, or EMG
   (c) Inadequate propulsive forces assessed by manometry or imaging

* Criteria fulfilled for the last 3 months with symptom onset at least 6 months prior to diagnosis.

Functional defecation disorders are further sub-classified into two categories:

(a) *Diagnostic Criteria* for Dyssynergic Defecation.* Inappropriate contraction of the pelvic floor, or less than 20 % relaxation of basal resting sphincter pressure with adequate propulsive forces during attempted defecation (see Figs. 10.23 and 10.25).
(b) *Diagnostic Criteria* for Inadequate Defecatory Propulsion.* Inadequate propulsive forces with or without inappropriate contraction, or less than 20 %

relaxation of the anal sphincter during attempted defecation (see Figs. 10.24 and 10.26).

* Criteria fulfilled for the last 3 months with symptom onset at least 6 months prior to diagnosis.

Diagnostic Criteria* for Functional Constipation

1. Must include two or more of the following:
   (a) Straining during at least 25 % of defecations,
   (b) Lumpy or hard stools at least 25 % of defecations,
   (c) Sensation of incomplete evacuation at least 25 % of defecations,
   (d) Sensation of anorectal obstruction/blockage at least 25 % of defecations,
   (e) Manual maneuvers to facilitate at least 25 % of defecations (e.g. digital evacuation, support of the pelvic floor),
   (f) Fewer than three defecations per week.
2. Loose stools are rarely present without the use of laxatives.
3. There are insufficient criteria for IBS.

* Criteria fulfilled for the last 3 months with symptom onset at least 6 months prior to diagnosis.

Conclusion

High-resolution manometry has brought a revolution in evaluation of patients with gastrointestinal motility disorders. It has brought several new assessment parameters such as IRP, DCI, CDP that evaluate esophageal motility disorders with higher sensitivity and clinical utility. However, there are still limitations in the current Chicago system, as it does not define and classify all the esophageal motor disorders encountered in clinical practice. Therefore, the existing Chicago system is being updated to overcome these limitations. Unfortunately, the current Chicago classification does not include disorders of anorectal manometry, which are no less important than esophageal motility disorders. In spite of these limitations, the criteria and classification systems available currently are of reasonable accuracy to diagnose and classify various motility disorders of the gastrointestinal tract.

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Manometry Report Format

11

Sanjeev Sachdeva and Asha Misra

Abstract

Gastrointestinal (GI) manometry has evolved prodigiously during the last decade. The introduction of high-resolution manometry (HRM) has been a true innovation in the field of gastrointestinal physiology. HRM has greatly simplified the job of acquisition, analysis and interpretation of motility related data. As with conventional manometry, there is a need for minimum standards for reporting in the case of HRM as well. Standardized reporting formats for GI manometry would be useful for (a) streamlining day-to-day functioning in GI physiology laboratories; (b) providing a standard template for collection, analysis, and publication of data from across the globe; and (c) providing benchmark resources to young gastroenterologists planning to set up a new manometry laboratory. This chapter provides a description of standard reporting formats for esophageal, antroduodenal, and anorectal manometry.

Keywords

High-resolution manometry (HRM) • Esophageal manometry report • Antroduodenal manometry report • Anorectal manometry report

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Introduction

Gastrointestinal (GI) manometry has progressed enormously in the last decade with the advent of state-of-the-art high-resolution manometry (HRM) [1–3]. HRM has remarkably eased the task of acquisition, analysis, and interpretation of motility related data [4–6].

The field of HRM has witnessed a great deal of research in esophageal manometry. High-resolution esophageal pressure topography is an advanced technology which integrates HRM and pressure topography plots pioneered by legendary RE Clouse [7]. Chicago classification has been the first HRM classification which aims at an accurate assessment of esophageal motility disorders using well-defined objective parameters [8–10]. HRM has enabled the clinician to have a comprehensive insight into hitherto difficult to analyze regions like the upper esophageal sphincter [11, 12] and proximal transition zone [13, 14]. HRM also offers superior insight into recording of antroduodenal manometry. Refined assessment of motility data from the pyloric region is now feasible with the use of the antroduodenal HRM catheter [15]. HRM has also proven its merit in the evaluation of anorectal disorders [16, 17].

As with conventional manometry, there is a need for minimum standards for reporting in the case of HRM. There is perceptible lack of uniformity with regard to performance, analysis, and reporting of motility studies. There are only a limited number of published articles on the components of standard GI manometry report format [18–20]. Standardized reporting formats would be helpful for (a) streamlining day-to-day working in GI physiology laboratories; (b) providing a standard draft for collection, analysis, and publication of data from across the world; and (c) providing precious resources to emerging gastroenterologists planning to set up a new manometry laboratory. Standard manometry report should include [21]:

- general information (patient particulars, indication of manometry, history and other clinical details, previous investigations, details of the manometry equipment, catheter and analysis software used, particulars of referring medical practitioner and the investigator performing the motility study)
- brief description of the procedure (including mention of the local anesthesia, patient position, catheter placement) and the study protocol
- the results of the motility recording
- mention of any artifacts or technical difficulty encountered during the procedure
- summary of salient findings on manometry
- specific comments including study limitation (if any), and final impression or diagnosis. Representative manometry tracings: The normal/reference, the patient (Figs. 11.1–11.3)

This chapter provides a description of standard reporting formats for esophageal, antroduodenal, and anorectal manometry.

Example: Esophageal Manometry Report

Name of the Institution, Department, Laboratory

General Information
Manometry Equipment System:
Analysis Software:
Catheter (Type & Configuration):
Referring Medical Practitioner:
Investigation date:
Investigator:
Nurse/Medical Technician:

Patient Information:
Patient Name: Date of Birth: Gender:
Address:
Telephone No:
Patient ID/OPD No:

Clinical Diagnosis/Indication:
Clinical history:
Previous investigations (Upper GI endoscopy, barium swallow, others):
Any medications/surgeries:

Patient preparation: Overnight/6-h fasting

Procedure:
- Local anesthesia (nasal application of 2 % lignocaine gel)
- Catheter placement
- Patient position for the study (Upright/Supine/Both)
- Water swallow protocol (Ten 5-ml swallows at interval of at least 20–30 s)
- Provocative bolus challenge (if any e.g., viscous liquid, solid food)

Results
Upper esophageal sphincter (UES)
Proximal border: _____ (cm)
Distal border: _____ (cm)
UES length: _____ (cm)

UES Basal/Resting pressure: _____ (mmHg)
UES Residual/Nadir pressure: _____ (mmHg)
UES % relaxation: _____%
UES Relaxation Interval (RI): _____ (s)
Integrated Relaxation Pressure (IRP) (0.2 s) _____ (mmHg)
Integrated Relaxation Pressure (IRP) (0.8 s) _____ (mmHg)
Mean pharyngeal contractionamplitude_____ (mmHg)
UES co-ordination with pharyngeal contractions _____ %
Median intrabolus pressure (mIBP) during RI _____ (mmHg)
Deglutitive sphincter resistance (DSR = mIBP/RI) ____ (mmHg/s)

Proximal Transition Zone (PTZ)

- PTZ length _____ (cm)
- PTZ duration _____ (s)
- PTZ Mean pressure _____ (mmHg)
- Length of Proximal contractile segment _____ (cm)
- Length of Distal contractile segment _____ (cm)
- Average contraction amplitude above PTZ _____ (mmHg)
- Average contraction amplitude below PTZ _____ (mmHg)

Esophageal Body (Analysis and average of ten water swallows)

- Mean contraction amplitude (upper esophagus) _____ (mmHg)
- Mean contraction amplitude (mid esophagus) _____ (mmHg)
- Mean contraction amplitude (lower esophagus) _____ (mmHg)
- Mean contraction duration (upper esophagus) _____ (s)
- Mean contraction duration (mid esophagus) _____ (s)
- Mean contraction duration (lower esophagus) _____ (s)
- Mean Onset velocity _____ (cm/s)
- Mean Peak velocity _____ (cm/s)
- Contractile front velocity (CFV) _____ (cm/s)
- Distal Latency (DL) _____ (s)
- Distal contractile integral (DCI) _____ (mmHg.s.cm)
- Peristaltic breaks _____ (cm)
- Peristaltic integrity (% Intact/Failed*/Weak**)
  - [*Minimal (<3 cm) integrity of 20 mmHg isobaric contour distal to PTZ]
  - [**Presence of either small (2–5 cm) or large (>5 cm) break in the 20 mmHg isobaric contour]
- Contraction pattern (for intact or weak peristalsis with small breaks) (% Normal/Rapid*/Premature**/Hypercontractile***)
  - [*CFV > 9 cm/s]
  - [**DL < 4.5 s]
  - [***DCI >8000 mmHg.s.cm]
- Intrabolus pressure pattern (30 mmHg isobaric contour) (%Normal/Pan esophageal/Compartmentalized/EGJ type)

- Any other comments related to esophageal contractions (Aperistalsis, repetitive contractions, synchronous/simultaneous contractions, focal/generalized failure)

Lower esophageal sphincter (LES)

Proximal border: _____ (cm)
Distal border: _____ (cm)
LES length: _____ (cm)
Pressure inversion point (PIP position): _____ (cm)
Any evidence of hiatus hernia: _____ (Yes/No)
LES Basal/Resting pressure: _____ (mmHg)
LES Residual/Nadir pressure: _____ (mmHg)
LES relaxation: _____ (Complete/Incomplete/Absent)
LES % relaxation: _____%
Integrated Relaxation Pressure (IRP) (4 s) _____ (mmHg)

Summary of Ten Wet Swallows

Swallow No.	Peristaltic integrity	Peristaltic breaks (cm)	Contraction pattern	Intrabolus pressure pattern	DCI mmHg. s.cm	Onset velocity (cm/s)	Peak velocity (cm/s)	CFV (cm/s)	DL (s)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
Average									

Any artifacts (e.g., Cough, sneeze, belch, vomiting, hiccoughs, extrinsic transmitted pulsations)

Any technical difficulty encountered (e.g., Patient intolerance, equipment malfunction, problems with catheter positioning or function)

Salient Findings/Comments:

Impression:

Signature of the Investigator:
Date:

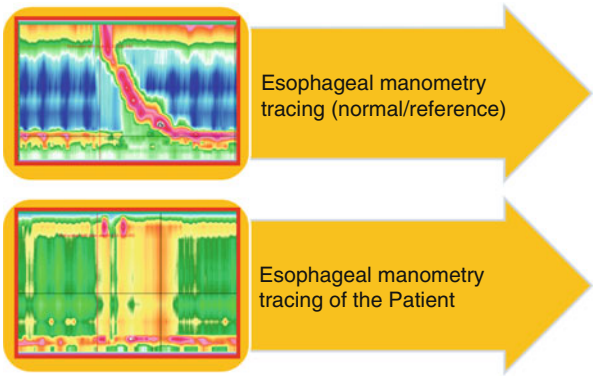

Fig. 11.1 Esophageal manometry tracings

Example: Antroduodenal manometry Report

Name of the Institution, Department, Laboratory

General Information
Manometry Equipment System:
Analysis Software:
Catheter (Type & Configuration):
Referring Medical Practitioner:
Investigation date:
Investigator:
Nurse/Medical Technician:

Patient Information:
Patient Name: Date of Birth: Gender:
Address:
Telephone No:
Patient ID/OPD No:

Clinical Diagnosis/Indication:
Clinical history:
Previous investigations (Upper GI endoscopy, barium meal follow through, radionuclide based gastric emptying study, others):
Any medications/surgeries:

Patient preparation: Overnight/12-h fasting

Procedure:
- Local anesthesia (nasal application of 2 % lignocaine gel)
- Catheter placement and confirmation of position under fluoroscopy

- Patient position for the study (semi-recumbent)
- Study protocol
  - Motility recording in fasting state (3–4 h)
  - Standardized test meal (At least 400 kcal, 20–25 % protein, 20–25 % fat, 50–55 % carbohydrate)
  - Post-Prandial (Fed-state) motility recording for at least 2 h
  - Provocative challenge (Injection Octreotide 50 μgm intravenous) followed by motility recording for 30 min
  - Any other provocative challenge (e.g., Injection Erythromycin 50 mg intravenous)

Results

Total study time period _____ (min)
Fasting motility recording time period _____ (min)
Time period of test meal intake (start meal to end meal) _____ (min)
Post-prandial motility recording time period _____ (min)
Post-Injection Octreotide motility recording time period _____ (min)
Any artifacts observed (e.g., Cough, retching, vomiting, rumination, extrinsic compression)

Fasting motility

- Spontaneous Migrating Motor Complex (MMC) _____ (Present/Absent)
- Total No. of MMC observed over the entire fasting period _____
- Overall MMC cycle duration _____ (min)
- Percent duration of MMC cycle phases (I, II, III) _____
- MMC (Phase III) duration _____ (min)
- MMC (Phase III) aboral (antrum to duodenum) propagation _____ (Present/Absent)
- MMC (Phase III) aboral propagation velocity _____ (cm/min)
- MMC (Phase III) wave amplitude (Antrum) _____ (mmHg)
- MMC (Phase III) wave amplitude (Duodenum) _____ (mmHg)
- MMC (Phase III) wave Frequency (Antrum) _____ (/min)
- MMC (Phase III) wave Frequency (Duodenum) _____ (/min)
- Amplitude of contraction (Antrum) _____ (mmHg)
- Amplitude of contraction (Proximal Duodenum) _____ (mmHg)
- Amplitude of contraction (Distal Duodenum) _____ (mmHg)
- Motility Index (Antrum) _____ (mmHg)
- Motility Index (Proximal Duodenum) _____ (mmHg)
- Motility Index (Distal Duodenum) _____ (mmHg)
- Average Fasting Pyloric pressure _____ (mmHg)
- Fasting Pressure gradient across the pylorus (pressure difference at distal most antral port & proximal most duodenal port) _____ (mmHg)

Post-Prandial (Fed-state) motility

- Conversion of fasting to fed pattern _____ (Yes/No)
- Contraction wave Frequency (Antrum) _____ (No./min)

- Contraction wave Frequency (Proximal Duodenum) _____ (No./min)
- Contraction wave Frequency (Distal duodenum) _____ (No./min)
- Amplitude of contraction (Antrum) _____ (mmHg)
- Amplitude of contraction (Proximal Duodenum) _____ (mmHg)
- Amplitude of contraction (Distal Duodenum) _____ (mmHg)
- Motility Index (Antrum) _____ (mmHg)
- Motility Index (Proximal Duodenum) _____ (mmHg)
- Motility Index (Distal Duodenum) _____ (mmHg)
- Average Postprandial Pyloric pressure _____ (mmHg)
- Postprandial Pressure gradient across the pylorus (pressure difference at distal most antral port & proximal most duodenal port) _____ (mmHg)

Post-Injection Octreotide motility

- Motility response (MMC) _____ (Present/Absent)
- MMC duration _____ (min)
- MMC Frequency _____ (No./min)
- MMC Amplitude (Proximal duodenum) _____ (mmHg)
- MMC Amplitude (Distal duodenum) _____ (mmHg)

Other observations during any period of motility recording

- Any abnormal contraction patterns (e.g., clustered contractions, Bursts, Sustained incoordinated pressure activity, Giant migrating contractions, Retrograde giant contractions)
- Any other abnormalities (e.g., tonic elevation of pyloric sphincter pressure, isolated pyloric pressure waves)
- Any symptoms during the test and their correlation with manometric events
- Any technical difficulty encountered (e.g., patient intolerance, equipment malfunction, problems with catheter positioning or function)

Salient Findings/Comments:

Impression: The antroduodenal (AD) motility study is suggestive of one of the following:

☐ Normal AD manometry
☐ Myopathy related dysmotility
☐ Neuropathy related dysmotilty
☐ Neuromyopathy related dysmotility
☐ Mechanical subocclusion/pseudo-obstruction
☐ Antralhypomotility
☐ Post-vagotomydysmotility
☐ Other disorder

Signature of the Investigator:
Date:

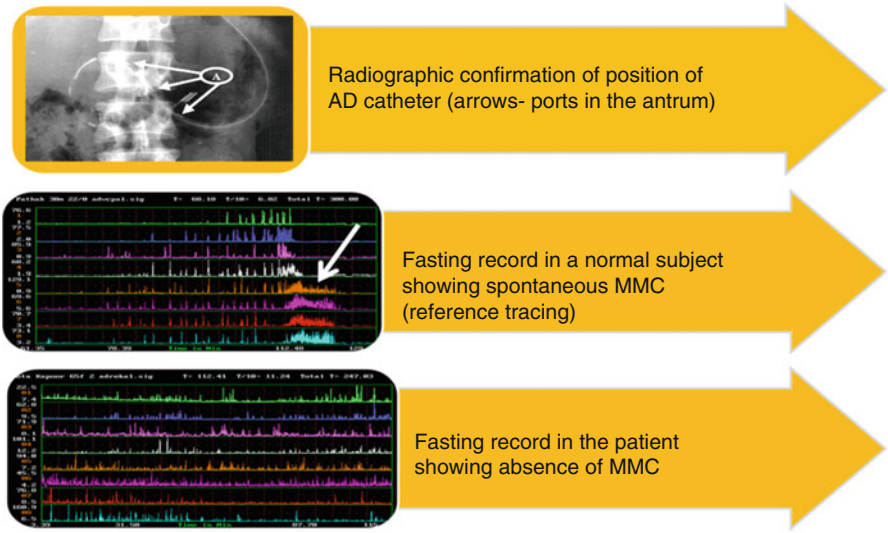

Fig. 11.2 AD catheter position and AD manometry tracings

Example: Anorectal manometry Report

Name of the Institution, Department, Laboratory

General Information
Manometry Equipment System:
Analysis Software:
Catheter (Type & Configuration):
Type & length of the balloon used:
Referring Medical Practitioner:
Investigation date:
Investigator:
Nurse/Medical Technician:

Patient Information:
Patient Name: Date of Birth: Gender:
Address:
Telephone No:
Patient ID/OPD No:

Clinical Diagnosis/Indication:
Clinical history:
Digital rectal examination:

Previous investigations (Colonoscopy, barium enema, defecography, anal electromyography, radio-opaque marker based colonic transit study, endoanalultrasound/MRI, rectal barostat, others):
Any medications/surgeries:

Patient preparation:

- Bowel preparation: Optional
- Subject is asked to empty his/her bowel before the test; but if digital rectal examination reveals presenceof stools, enema is given to achieve stool evacuation

Procedure:

- Local anesthesia (2 % lignocaine gel)
- Patient position (Left lateral with hips and knees flexed)
- Manometry catheter placement
- After catheter placement, a rest of 5 min is allowed to give the subject time to relax
- Study protocol
  - Measurement of anal sphincter pressures (basal and squeeze) and length
  - Cough reflextest
  - Attempted defecation test
  - Rectoanal inhibitory reflex (RAIR) by balloon inflation method
  - Testing of rectal sensation by balloon inflation method
  - Rectal compliance (Measurement of rectal pressure-volume relationships [dV/dP] using graded balloon distension method)
  - Balloon expulsion test (BET) [Method 1: Left lateral decubitus; Method 2: Sitting]

Results

Anal sphincter parameters

- Length of anal sphincter high pressure zone (HPZ) _____ (cm)
- Resting/basal sphincter pressure _____ (mmHg)
- Squeeze sphincter pressure _____ (mmHg)
- Anal squeeze increment _____ (mmHg)
- Duration of anal squeeze _____ (s)

Cough Reflex:

- Present/Absent _____, If present___ (Normal/Weak)
- Rectal pressure _____ (mmHg)
- Anal pressure _____ (mmHg)

Attempted defecation test (Average of at least 3 attempts):

- Maximal intrarectal pressure when straining _____ (mmHg)
- Anal relaxation pressure _____ (mmHg)

- Minimal anal residual pressure _____ (mmHg)
- Percent Anal relaxation (Anal relaxation pressure ÷ anal resting pressure × 100) ___%
- Defecation Index (Maximal intrarectal pressure when straining ÷ minimal anal residual pressure when straining) _____
- Dyssynergic defecation _____ (Present/Absent), If present, specify Type ___

Rectoanal inhibitory reflex (RAIR)

- Present/Absent _____
- RAIR Threshold _____ (ml)

Rectal sensation

- Threshold for first Sensation: ____ (ml)
- Threshold for desire to defecate ____ (ml)
- Threshold for maximum tolerable volume (MTV) _____ (ml)

Rectal compliance

- Calculated by plotting the relationship between balloon volume (dV) and the steady state intrarectal pressure (dP) [Compliance = dV/dP = _____ml/mmHg]

Balloon Expulsion test (BET)

- **Method 1:**
  - Could expel/could not expel _____
  - Amount of weight required to expel _____ (gm)
- **Method 2:**
  - Could expel/could not expel _____
  - Time taken for expulsion _____ (s)

Any Artifacts:

Any technical difficulty encountered (e.g., Patient intolerance, equipment malfunction, problems with catheter positioning or function):

Salient Findings/Comments:

Impression:

Signature of the Investigator:
Date:

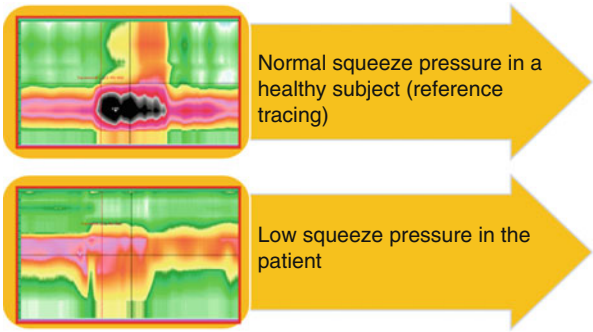

Fig. 11.3 Anorectal manometry tracings

Conclusion

HRM has brought a revolution in evaluating gastrointestinal motor activity and diagnosis of its disorders. HRM has simplified acquisition, analysis, and interpretation of gastrointestinal motility studies. However, for keeping uniformity, avoiding the overlooking important parameters, and providing a standard template for collection, analysis, reporting, and publication of data from different laboratories, it is important to have a standard reporting format. Such a reporting format would be particularly important for the beginners. However, even for experienced persons, it is a good practice to follow a standard format. This chapter has attempted to present a broad outline of the parameters that should be included in a manometry report. However, it is important to mention that this should be considered only as a guide, and each laboratory can add more parameters depending upon their need. Moreover, with time, as the technology evolves and newer parameters get added to the currently used parameters, the format may need to be revised.

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