5

Introduction to Methods of Anorectal Physiology Evaluation

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Introduction

Pelvic floor disorders are a common group of heterogeneous pathologies that range from being inconvenient to extremely debilitating. Although it is essential to complete a thorough history and physical examination in patients with functional pelvic disorders, specialized tests can greatly assist in the evaluation, diagnosis, and management of these complex patients. In recent years, major advances in anorectal physiology testing and imaging have provided a better understanding of pelvic floor disorders. The methods used in evaluating anorectal function are evolving, becoming more sophisticated, and providing more clinically relevant data.

This chapter will focus on a brief introduction to the methods of anorectal physiology testing including

- Endoanal ultrasound
- Cinedefecography
- Magnetic resonance imaging (MRI)
- Anorectal manometry
- Electromyography
- Pudendal nerve assessment
- Colonic transit study

Some of these exams will be detailed in a separate chapter of this book.

Endoanal Ultrasound

Anatomic evaluation of a patient with a functional pelvic floor disorder often begins with a endoanal ultrasound. Ultrasound uses sound waves that are transmitted to and reabsorbed by an ultrasound probe. Different tissues will appear differently based on its echogenicity. Tissues with high water content such as muscle will reflect the ultrasound waves less and appear hypoechoic. Tissues with less water content such as connective tissue and fat will reflect ultrasound waves more and appear hyperechoic.

The main utility of endoanal ultrasound plays an essential role in evaluating the structural integrity of the anal sphincter complex and determining surgical candidacy for sphincteroplasty, artificial anal sphincters, sacral nerve stimulation, and injectable biomaterials [1–5].

To perform the procedure, patients are instructed to self-administer enemas to evaluate stool from the rectal vault the day of the proce-

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dure. While the patient is in left lateral decubitus, a lubricated ultrasound probe is placed into the upper anal canal. The anal canal can be divided into three levels. In the upper anal canal, the horseshoe-shaped, hyperechoic puborectalis and the hypoechoic internal anal sphincter (IAS) will be visualized (Fig. 5.1). In the mid anal canal, the concentric rings of the hyperechoic external anal sphincter (EAS) and the hypoechoic IAS will be visualized (Fig. 5.2). In the lower anal canal, the IAS terminates, and the EAS appears thick (Fig. 5.3).

Upon reviewing the images of endoanal ultrasound, abnormalities in the structural integrity of the sphincter complex can be seen. Scarring, thinning, or disruption of the sphincters can be visualized (Fig. 5.4).

Although endoanal ultrasound has the advances of low cost, convenience, and accessibility, the main drawback of endoanal ultrasound is that its accuracy depends on operator experience [6–9]. However, diagnostic accuracy and resolution of the ultrasound can be improved with the use of 3D ultrasound and dynamic ultrasound, which are beyond the scope of this chapter.

Cinedefecography

Cinedefecography also known as evacuation proctography is a fluoroscopic study that is used to investigate the physiology of defecation. Using this modality, morphological changes in the rec-

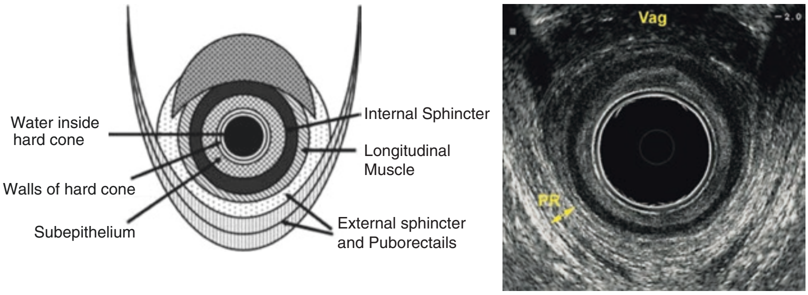

Fig. 5.1 Endoanal ultrasound of the upper anal canal showing the puborectalis muscle. Schematic representation and axial image. (Reused with permission © Springer Nature)

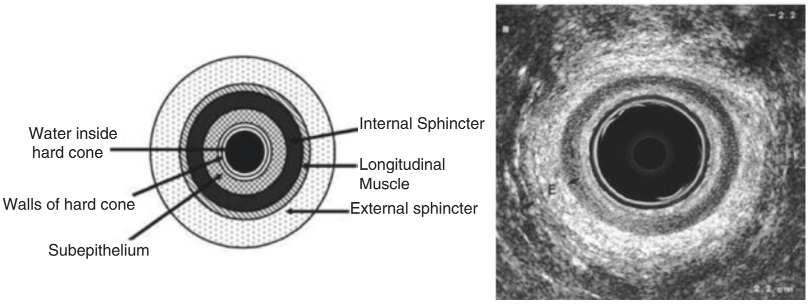

Fig. 5.2 Endoanal ultrasound of the mid anal canal showing the two concentric sphincter muscle rings. Schematic representation and axial image. (Reused with permission © American Gastroenterological Association)

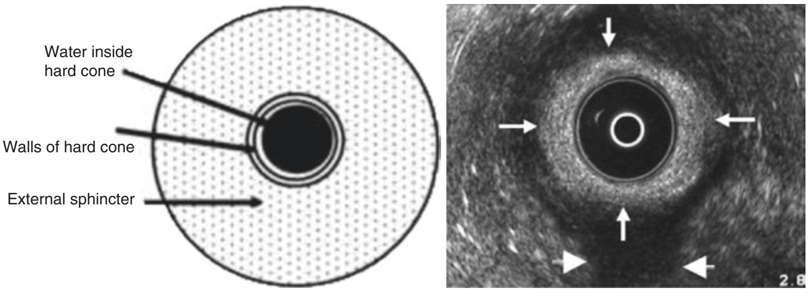

Fig. 5.3 Endoanal ultrasound of the lower anal canal showing the only the EAS. Schematic representation and axial image. (Reused with permission © John Wiley and Sons)

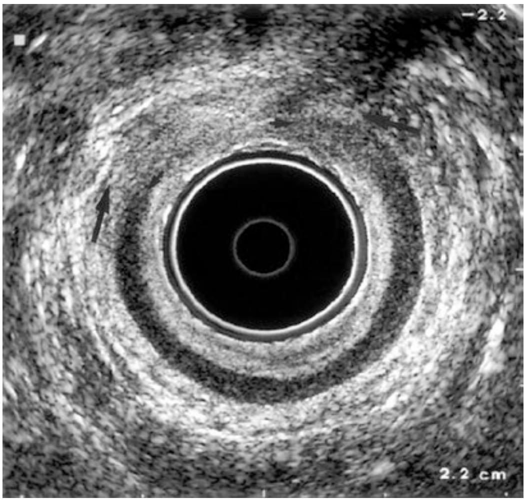

Fig. 5.4 Endoanal ultrasound image of an anterior EAS damage due to obstetrical injury. (Reused with permission © American Gastroenterological Association)

tal wall, anal canal, vagina, and pelvic floor are simultaneously visualized [10–12].

The patient is prepared for the study by administering phosphate enemas prior to the study. Then, the patient is placed in left lateral decubitus, and 50 mL of liquid barium is instilled into the rectum with a catheter followed by insufflation of a small amount of air. Also, 100–200 mL of barium paste is injected into the rectum until the patient feels rectal fullness. This study can be modified by simultaneous instillation of vaginal contrast/radiopaque tampons and bladder contrast for dynamic pelvicography [13]. The patient then sits on a radiolucent commode (Fig. 5.5), and standard fluoroscopic equipment is used to take images and video of the patient in rest, squeeze, push, evacuation, and post-evacuation phases (Fig. 5.6). Three important data points obtained from this study are measured including the anorectal angle, perineal descent, and puborectalis length.

The anorectal angle can be defined as the angle between the axis of the anal canal and the tangential line of the posterior rectal wall. As expected, the anorectal angle changes during the different phases of defecation. It approximates 90 degrees at rest. During the squeezing phase, puborectalis contraction makes the angle more acute at 75 degrees resulting in elevation of the anorectal junction. Normally, the puborectalis relaxes during straining thereby changing the angle to 110–180 degrees allowing the anorectal junction to descend to a maximum of 3.5 cm. Lack of these dynamic changes during relaxation can be interpreted as paradoxical contraction of the pelvic floor during defecation [14–16].

The pubococcygeal length or line is the distance from the tip of the coccyx to the pubis. It can be used as a surrogate to delineate the degree of puborectalis relaxation, and failure of the pubococcygeal length to change during resting and pushing phases suggests non-relaxation of the puborectalis muscle [15].

Perineal descent is in reference to the degree of the rectum that is below the pubo-

Fig. 5.5 Radiolucent commode. (Wiersma, T. 2006. Rectum-Dynamic Evaluation. Retrieved from http://www.radiologyassistant.nl/en/p4412ca5e2c21a/rectum-dynamic-examination.html. Accessed Nov 2017)

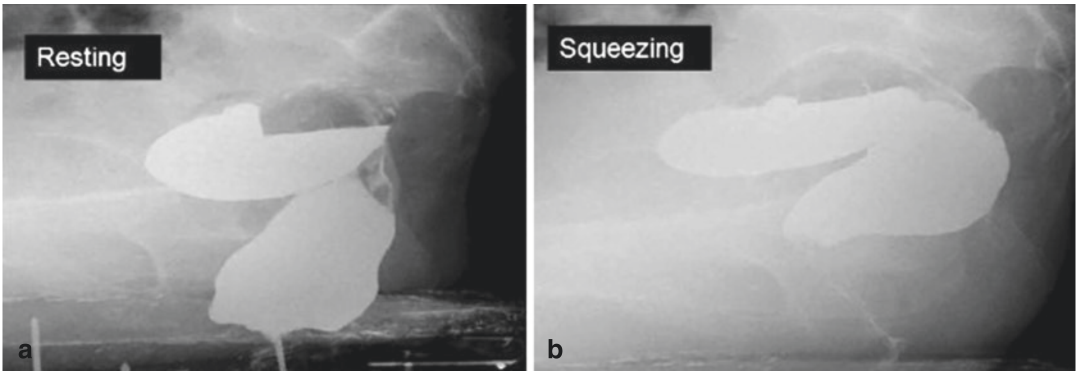

Fig. 5.6 Appearance of normal defecography phases. (**a**) Resting. (**b**) Squeeze. (**c**) Straightening of anorectal angle. (**d**) Post defecation. From: Kumar et al. [14]

coccygeal line during the study. If the rectum is more than one-third below the pubococcygeal line, radiologists interpret this as pelvic organ prolapse.

The main advantage of cinedefecography is that it gives dynamic imaging of a patient's defecatory function under normal physiologic conditions [12]. For instance, if the patient required

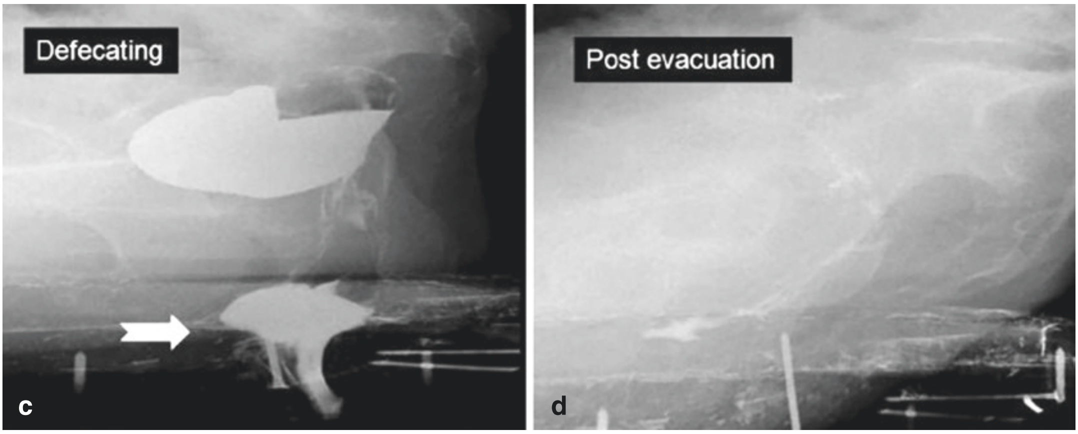

Fig. 5.6 (continued)

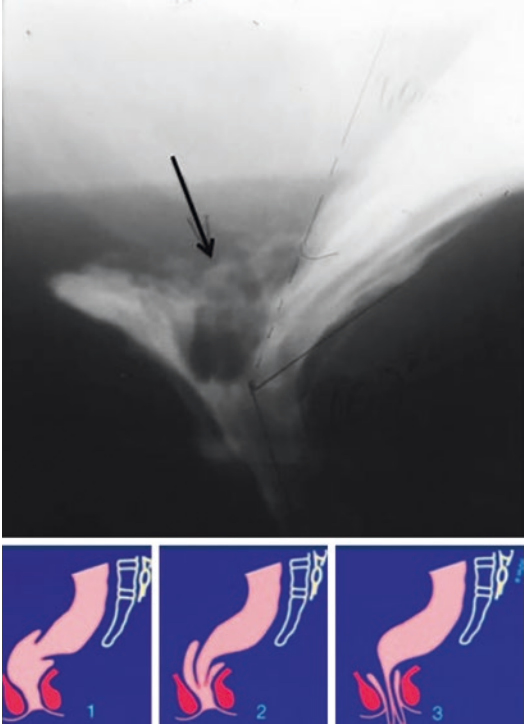

Fig. 5.7 Rectal Intussusception. (Wiersma, T. 2006. Rectum-Dynamic Evaluation. Retrieved from http://www.radiologyassistant.nl/en/p4412ca5e2c21a/rectum-dynamic-examination.html. Accessed Nov 2017)

digitation to evacuate stool, this can be imaged as well. It also provides anatomic detail of mucosal prolapse, intussusception (Fig. 5.7), rectocele, and enterocele.

However, the findings from this study must be interpreted in conjunction with symptomatology because it can demonstrate findings of questionable clinical significance [17, 18].

Magnetic Resonance Imaging

Another modality in anatomic evaluation of the pelvic floor is magnetic resonance imaging (MRI). High-resolution cross-sectional images are obtained either by an external-phased array coil or and endoanal coil. MRI has been used extensively in the evaluation of fecal incontinence [10]. Dynamic evaluation of the pelvic floor can be accomplished with magnetic resonance defecography. While the patient is in a sitting position, rectal contrast is instilled into the rectum. Parameters measured are similar to cinedefecography described above. This modality has the advantage of providing great spatial resolution and soft tissue details (Fig. 5.8). However, this exam is not easily accessible.

Anorectal Manometry

Anorectal manometry enables objective evaluation of the sphincter complex of pelvic floor (Fig. 5.9) [19]. It provides a comprehensive

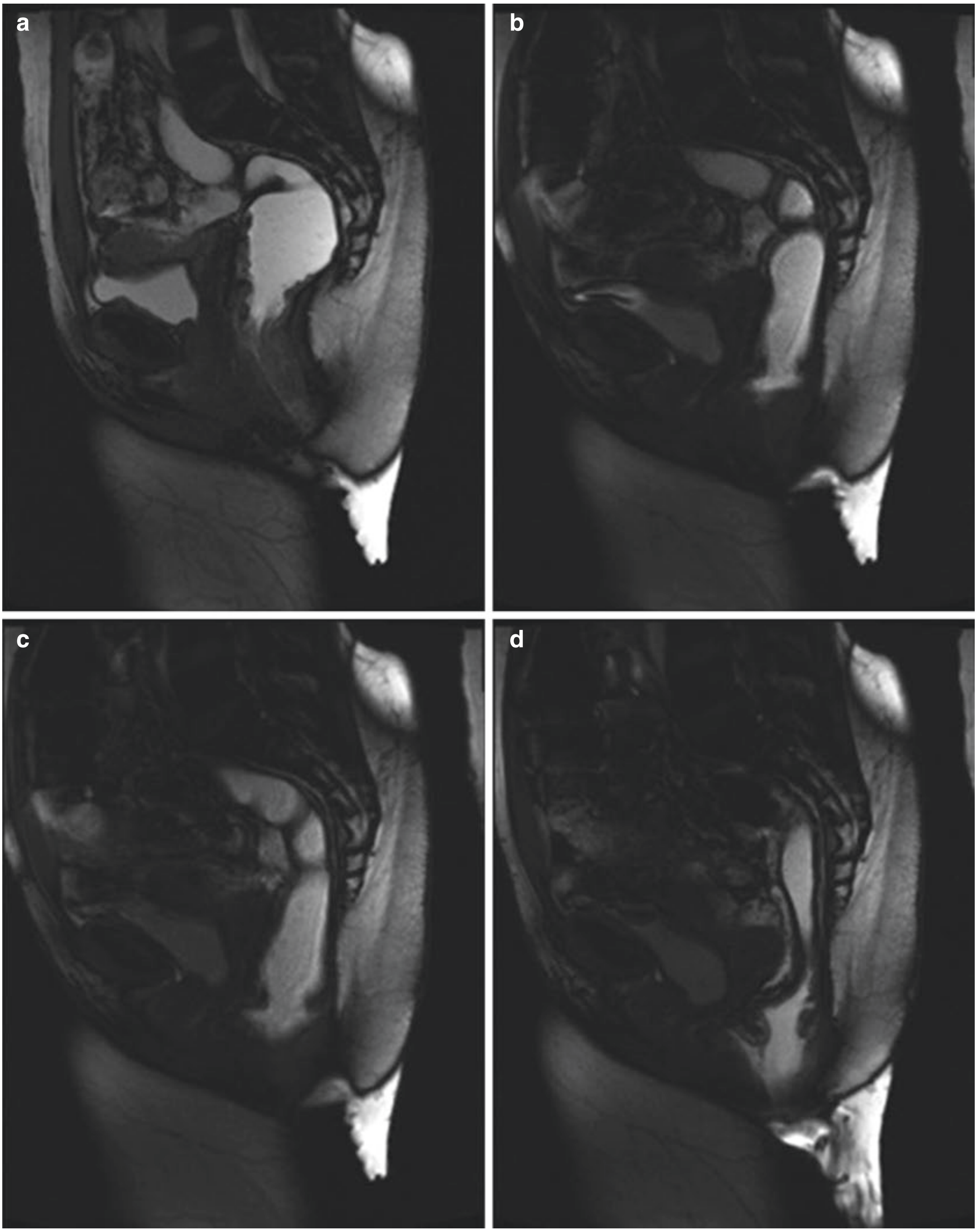

Fig. 5.8 Normal MR defecogram. Normal position of the anorectal junction at rest (arrow in **a**) with mild pelvic floor lift on squeeze (**b**). On straining (**c**) and defecation (**d**), there is mild descent of the anorectal junction, with the rectum and anal canal aligned in almost a straight line. The broken white line in (**d**) is the pubococcygeal line. The broken black line is the "H line" corresponding to the anteroposterior dimension of the hiatus. The solid black line is the "M line" which is the perpendicular distance between the pubococcygeal line and the posterior anorectal junction. (Reused with permission © Thieme)

Fig. 5.9 Anorectal physiology lab set up and equipment

picture of the anorectal sphincter function by measuring parameters such as resting pressure, squeeze pressure, cough reflex pressure, Valsalva pressure changes, rectoanal inhibitory reflex, and rectal capacity. Clinically, this information can help in the diagnosis and management of disorders such as fecal incontinence, constipation, anal pain, and Hirschsprung's disease.

In order to be useful, data gathered from anal manometry must be compared to a standard of normal values that is specific to the institution performing the study. These normal values must undergo routine calibration and standardization to minimize inter-examiner variability allowing for accurate interpretation of the data.

Several systems and probes exist to perform anorectal manometry, each with its advantages and disadvantages; however, these systems require two basic components: a catheter and a transducer. The pressure measured by the system is generated by the resistance to the flow of perfusion through the catheter channels. Measured pressures are transmitted to specialized software which produces a polygraph. A large amount of data can be acquired from multiple channels to further enhance the study. Much of the software currently available for these studies allows for easy interpretation of the data.

Knowledge of normal pelvic floor anatomy as well as possible dysfunction is essential for evaluation of this complex patient population. The anal canal measures 2–5 cm and is surrounded by the internal and external anal sphincters. Importantly, there are gender differences in canal length, and it is well known that the anal canal is longer in men than it is in women [18]. The IAS is about 0.15–0.5 cm thick and consists of involuntary muscle that is innervated by the autonomic nervous system. The IAS is contracted at rest and is responsible for 50–85% of resting pressure. The external anal sphincter is made of striated muscle that is under voluntary control via the somatic innervation, specifically, the inferior branch of the pudendal nerve (S2–S3) and perineal branch of S4. When contracted, it is responsible for about 20% of the resting anal canal pressure.

Anal Manometry Systems and Techniques

Perfusion Systems

This system was originally developed by Arndorfer et al. [11] and uses a combination of flexible or rigid small catheters with ranging in diameter of 2.5–7 mm. These catheters have multiple channels or lumens that are arranged radially around the main axis of the catheter. Distilled water is infused through these catheters

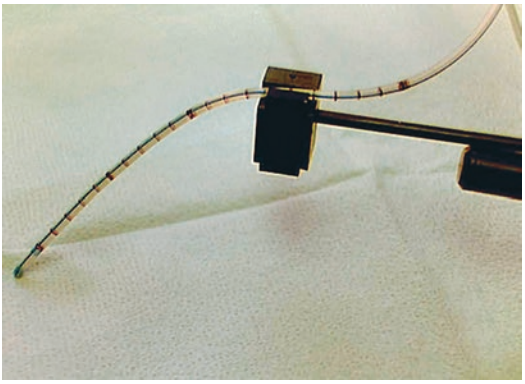

Fig. 5.10 1A de Coller® manometry catheter

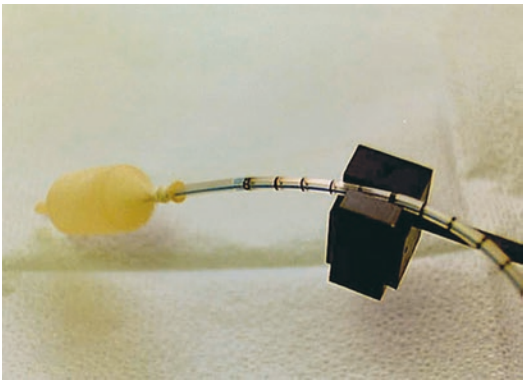

Fig. 5.11 B3 de Coller® manometry catheter

by a pneumohydraulic pump used to attain a consistent perfusion rate of 0.2–0.4 mL/min [20, 21].

Occlusion of the channels increases intraluminal pressure and produces resistance to the flow of water. This resistance is measured by transducers and interpreted as compliance of the tissue. Different types of catheters are available and allow the measurement of distinct parameters. Although many anal physiology labs use four channel systems, the author's lab utilizes an eight-channel system (Narco Biosystem, Austin, Texas).

In fact, the authors use two different catheters for the collection of data. Our first catheter is a Coller type 1A catheter (Fig. 5.10), and it has eight channels radially aligned into a single catheter. This catheter is used to measure the resting and squeeze pressure with a technique of continuous withdrawal. It is withdrawn from the anal canal at a velocity of 1 mm/s. The circumferential pressure differentiates are recorded eight times. Also, anal canal pressures can be measured at stationary intervals of 0.5 cm resulting in 64 recordings. At intervals of 1 cm, only 32 recordings are measured. In contrast, a 4-channel catheter measures only 32 and 12 pressure recordings at 0.5 and 1 cm intervals, respectively.

The second catheter we use is a Coller type B3 (Fig. 5.11) which has channels aligned in a linear orientation. Moreover, it is equipped with a balloon whose capacity is about 60 mL. It features a central channel that measures intrarectal pressure. Also, it measures the rectoanal inhibitory reflex (RAIR) and other parameters of rectal volumetrics (first sensation, desire to evacuate, and maximal tolerable volume).

Perfusion manometry systems have the advantage of wide availability and low cost. However, they are limited by artifacts during acquisition of data related to the number of channels utilized, the velocity of perfusion, and the left lateral decubitus position.

As inferred by the above discussion, there are two commonly used techniques for the evaluation of anorectal pressure by the perfusion manometry systems: continuous withdrawal and withdrawal at intervals.

The continuous withdrawal (pull through) method allows pressure readings to be made of the length of the anal canal, from the rectum to the anal margin. To perform this study, the catheter is gently introduced into the rectum with the most distal channel positioned above 6 cm proximal to the anal margin, and it is withdrawn at a speed of 1 mm/s via a motorized or computer-controlled arm. As the channels in the catheter pass over the high-pressure zone (HPZ), a pressure spike should be recorded. This method allows one to evaluate the resting and squeeze pressure, determination of the HPZ, and sphincter dysfunction/asymmetry. To minimize artifacts from this method, adequate lubrication and maintenance of constant withdrawal velocity are required.

The interval withdrawal method is performed by advancing the catheter 6 cm into the rectum so that the most distal channel is adjacent to the HPZ. Next, it is withdrawn at intervals of 0.5–1 cm every 30 seconds between withdrawals to allow stabilization of pressures. Static measurements at rest and squeeze are taken at these intervals. Although this method provides reliable pressure recordings at these intervals, it is hard to get a complete picture of sphincter function.

Microtransducer Systems

This system uses catheters with fine and flexible pressure sensors and microtransducers. These microtransducers consist pressure-sensitive diaphragms with semiconductors. This type of catheter allows the pressure sensor to come in direct contact with the area being investigated thereby providing direct measurements of pressures in the anal canal. A unique feature of this system is that it can be used in any patient and even while the patient is ambulating. Currently, this is the only system that allows for continuous ambulatory evaluation; however, its use is limited by greater fragility and high cost.

Balloon Systems

The largest evidence for use of balloon systems in manometry is from Shuster et al. [20] who used a system with two to three balloons filled with air. The device consisted of a small hollow cylinder surrounded by a latex balloon to create two compartments. The two parts of the balloon are connected to pressure transducers. The catheter is positioned in the anal canal and the balloon inflated until it is fixated in the rectum. The internal balloon measures the internal pressure of the anal canal, while the outer balloon measures the pressures of the anal sphincter. A modification can be made where a third balloon is placed in the proximal portion of the cylinder to measure pressures in the rectum.

High-Resolution Anorectal Manometry (HR-ARM)

Since its initial introduction in 2007, high-resolution anometry catheters are increasingly used in clinical practice. There are two types of catheters utilized: high-resolution anorectal manometry (HR-ARM) and high-definition anorectal manometry (HD-RAM). Unlike earlier catheters which have up to six unidirectional sensors, HR-ARM and HD-ARM catheters contain several closely spaced circumferential sensor elements along the longitudinal axis with the pressure-sensing element varying among different systems.

High-resolution anometry catheters provide several advantages over traditional catheters. These systems provide a continuous and dynamic spatio-temporal mapping of anorectal pressures allowing for easier and more detailed data interpretation [22]. Patient comfort with the procedure is also improved with HR-ARM because the time needed for the exam is much shorter because the catheters do not require pull-through and a topographic display enables rapid positioning of the probe [23].

The main disadvantage of this system is that the catheters are expensive, fragile, and are less durable [23]. Also, these catheters are temperature-sensitive, which require a thermal compensation algorithm built into the software [24–26]. While pressures recorded with HR-ARM and traditional manometry correlate well, anal sphincter pressures at rest and squeeze are often higher with HR-ARM. It is thought that this is due to improved sensitivity of measurements with sensors in the high-resolution probe [27].

Like traditional anorectal manometry, HR-ARM are either water-perfused or solid state. A brief review of these catheters will be given here. Given Imaging HR-ARM systems are solid-state catheters (ManoScan AR catheters) with an outer diameter of 4.2 mm. There are two different types of probes. The regular probe (AAN) has 12 circumferential sensors, including tensors at 5 mm intervals along the anal canal and 2 sensors in the rectal balloon. The balloon is 3.3-cm-long and has a maximum capacity of 400 mL. In contrast, the small probe (APN) has 8 circumferential sensors and 1 balloon sensor. The balloon is again 3.3-cm-long and has a maximum capacity of 300 mL. Either of these catheters have 36 circumferentially oriented, pressure-sensing elements that acquire data at 35 Hz. These 36 sector pressures are averaged to yield a single value. The data acquired are displayed using ManoScan AR analysis software.

The eSleeve option in the software produces a single value derived from all the recorded pressure across the anal value. This eSleeve value is used to calculate the average and maximum anal resting pressure and the maximum squeeze pressure over 20 seconds during these maneuvers. During simulated evacuation, the eSleeve identifies the rectoanal gradient between over a 20-second interval [25].

Sandhill HR-AM (Denver, CO, USA) system uses a 4-mm-diameter probe that has eight directional solid-state sensors. The sensors are spaced at 1 cm intervals in the following locations: rectal balloon (1), rectum (1), anus (5), and external to anal verge (1). The pressures recorded are averaged to provide a mean sphincter pressure and analyzed by the InSight system (Sandhill Scientific) [25].

Medical Measurement Systems uses a 12G catheter probe that incorporates eight directional sensors along its axis. Six of these eight sensors are equidistant from each other and span 5 cm. The proximal sensor is located within the rectal balloon and is spaced 2.5 cm proximal to the other sensors. The most distal sensor is 2 cm below the most distal anal sensor and is used as an external reference. This catheter requires submersion in water for about 3 minutes to pre-wet the sensors and then zeroed to atmospheric pressure. Data is analyzed using the Solar GI HRM software (MMS, Enschede, the Netherlands) [25].

Given Imaging's HD-ARM (Yokne'am Illit, Israel) catheter is 6.4 cm in length with an outer diameter of 10.75 mm. The sensing segment is composed of 256 sensing elements that are arranged in 16 rows which are circumferentially oriented. The spacing between the sensors is 3 mm axially and 2 mm radially. Unique to this probe is that it displays pressures recorded by individual sensors around the circumference. Manometry and topographic images are displayed using the Motility Acquisition AR System (Given Imaging). The probe is calibrated immediately before the procedure by placing it in a calibration chamber, where it is zeroed to atmospheric pressure and set to a range of pressures up to 300 mmHg [25].

The sophisticated software provides the clinician with an intuitive color topographic analysis of anal canal pressures [26]. Cool colors (blue and green) correlate with low pressure. Warm colors (red and yellow) correlate to higher pressures (Fig. 5.12). This can lead to improved understanding of anal canal function.

Parameters Measured with Anal Manometry

Anorectal manometry measures the following parameters listed in no particular order:

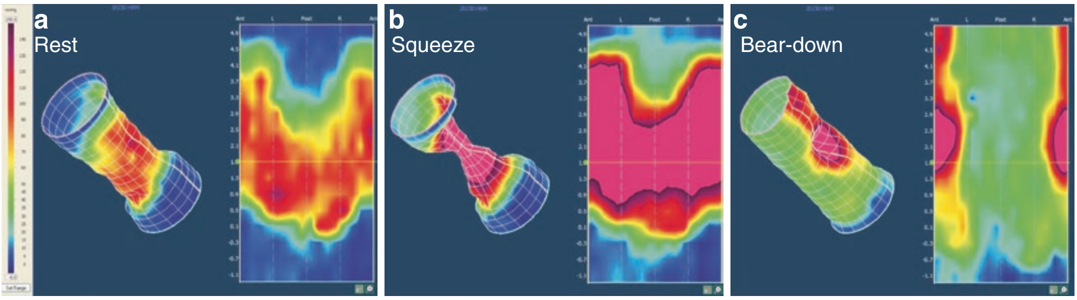

Fig. 5.12 High-definition anorectal manometry in a healthy individual. (**a**) Rest frame shows that the high-pressure band is seen in the middle of the image. (**b**) Squeeze frame shows an "λ" shape on 2-D mapping indicating normal functioning of the EAS muscle. (**c**) Bear-down frame shows a green low-pressure zone appearing in the end (i.e., a low-pressure area in the distal posterior wall of the anorectum). (Reused with permission © The Korean Society of Neurogastroenterology and Motility)

- Anal sphincter function including resting and squeeze pressures
- Anal canal length
- Anal motility
- Rectal sensation and compliance
- Pressures during forced evacuation
- Anorectal reflexes

Resting Anal Pressure

The normal sphincter rest pressure reflects the sum of the tone of the internal and external anal sphincters. Resting anal pressure is defined as the difference between intrarectal pressure and anal canal pressure. It is important to remember that measures of pressures vary according to gender, age, and technique used. In general, these pressures are higher in men and younger individuals. In our institution, normal resting pressure usually varies between 65 and 85 mmHg above rectal pressure at 1 cm intervals. At typical longitudinal profile of normal anal sphincter, resting pressure is shown in Fig. 5.13.

The proximal portion of the sphincter is determined by an increased pressure of at least 5 mmHg compared to intrarectal pressure, and it is considered the zero point. The HPZ is defined as the length of the anal canal over which the pressure is greater than half the maximum resting pressure [28]. In men, it measures about 3–3.5 cm in length, and in women it is about 2–2.5 cm in length. The distal end of the anal canal is determined when the pressure abruptly reduces to zero. Defects in the anal sphincter musculature can be clearly observed in a longitudinal profile as seen in Fig. 5.14.

It is important to recognize that the sphincter muscles have longitudinal and radial asymmetry. The pressure is typically higher in the posterior portion of the anal sphincter and then increases distally. Cross-sectional measurements of the sphincter can create a 3-D image such as Fig. 5.15**.** An example of a right anterior sphincter defect in an obstetric patient can be seen in Fig. 5.16**.**

Squeeze (Contraction) Pressure

The evaluation of the external sphincter may be better demonstrated as the pressure during vol-

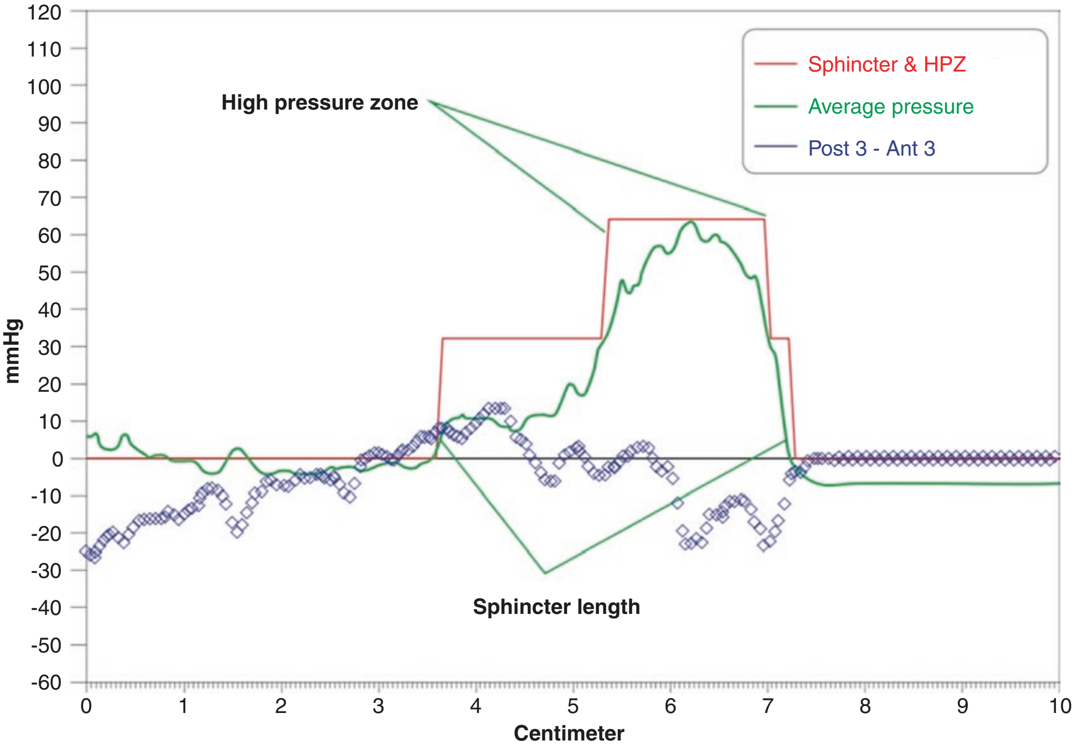

Fig. 5.13 Manometric graph showing a longitudinal profile typical of the pressure at rest

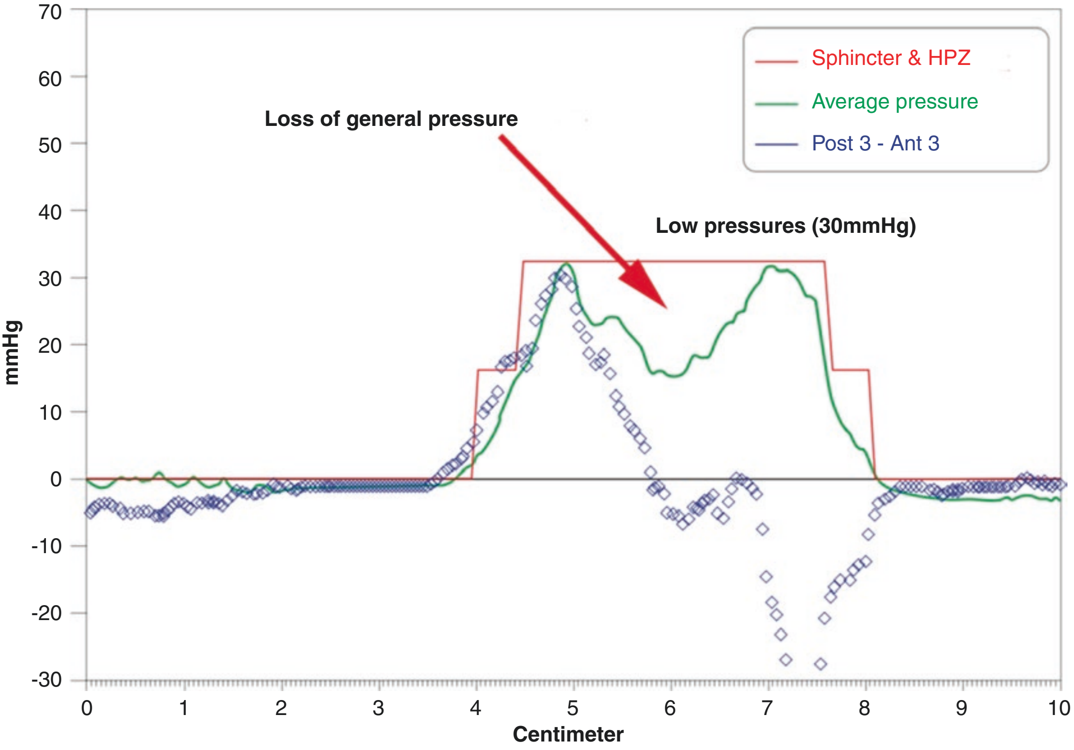

Fig. 5.14 Manometric graph showing the high-pressure zone

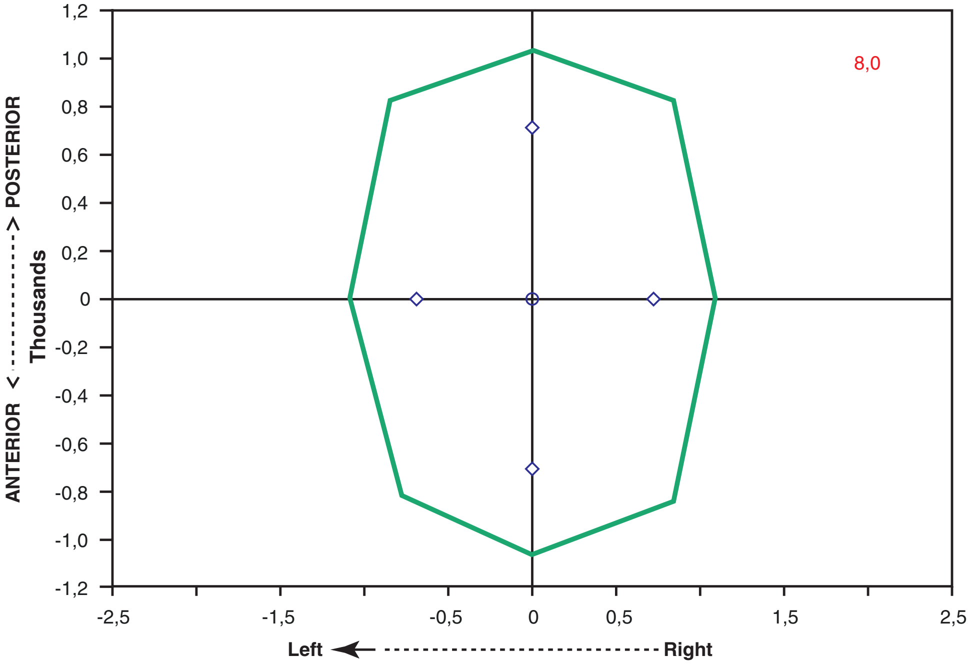

Fig. 5.15 Three-dimensional graph showing sphincter symmetry

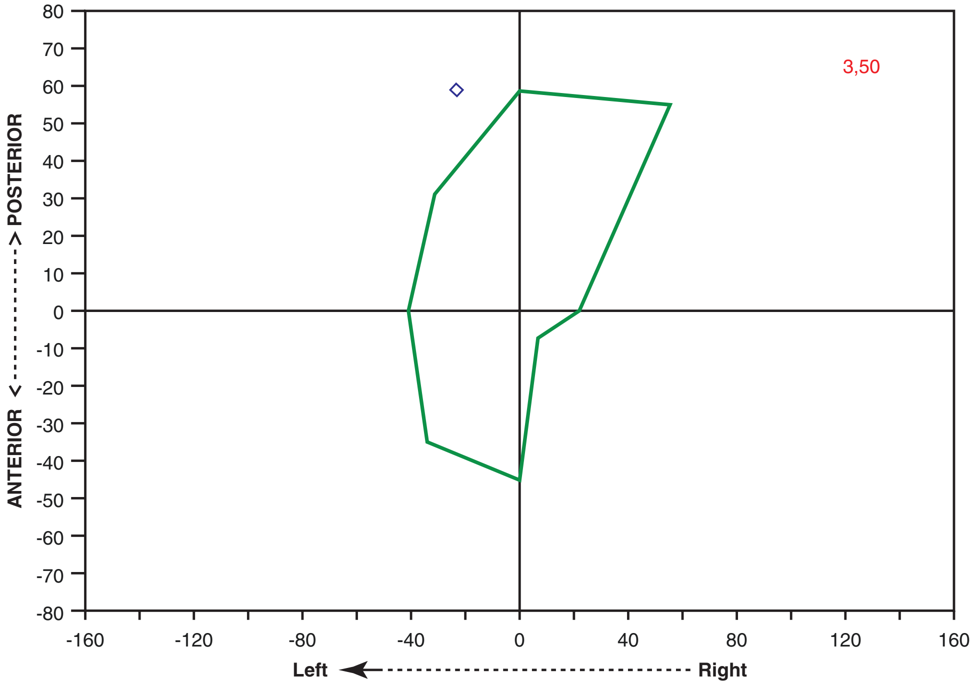

Fig. 5.16 Sphincter asymmetry in a patient with defect in the right anterior quadrant

untary contraction. As the perfusion catheter is continuously pulled through the anal canal, the patient instructed to contract their external anal sphincter which is measured as an increased pressure. The contraction pressure maximum is up to 155 mmHg in normal controls; however, incontinent patients have averages that are well below these values [29]. Importantly, there is a large variation in the average squeeze pressure due to a variety of factors. Figures 5.17 and 5.18 demonstrate normal voluntary squeeze pressures during continuous or stationary techniques, respectively. A diminished contraction pressure can be an important parameter in incontinent patients and could indicate sphincter deficiency, neurologic dysfunction, or low rectal compliance.

Normally, patients can maintain maximum contraction tone for about 45–50 seconds which is followed by a refractory period. The muscle fiber complement in the external anal sphincter determines the duration of maximum contraction until fatigue. Types I and II muscle fiber complement in the external anal sphincter changes with age. The duration of squeeze and fatigue index has been shown to be much lower in patients with incontinence [30–34].

Anal Motility

Internal anal sphincter resting tone is fundamentally different from other muscles because there is evidence that there are cyclical variations in the electrical activity. Analysis of the configuration of the IAS tone demonstrates short, ultrashort, and intermediate waves.

The frequency of the short wave ranges from 9 to 15 cycles per minute (CPM), with an amplitude of 0 to 40 mmHg (Fig. 5.19). The shortwave frequency in the IAS is greater than any other gastrointestinal muscle and is highest in the most distal portion of the sphincter. The tonal frequency depends on factors such as prandial vs. postprandial state and awake vs. asleep states. Although the shortwave pattern is present in most patients and is the most frequently present wave, its clinical significance is not none.

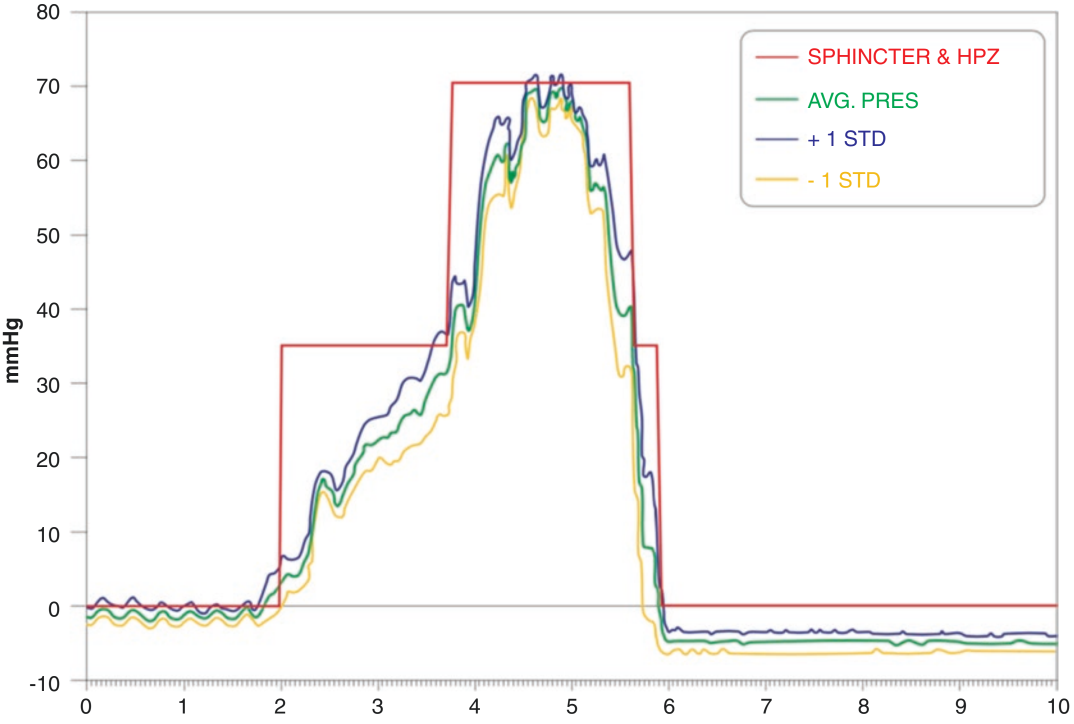

Fig. 5.17 Pressure profile in manometry performed with continuous withdrawal method

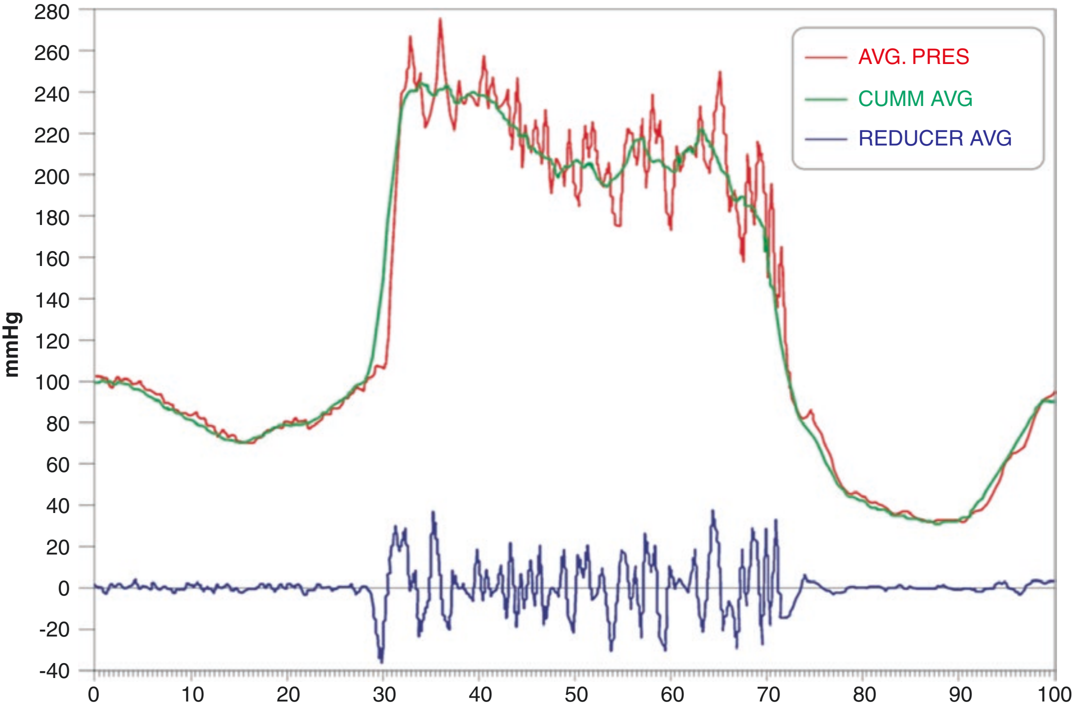

Fig. 5.18 Manometric tracing with stationary withdrawal technique

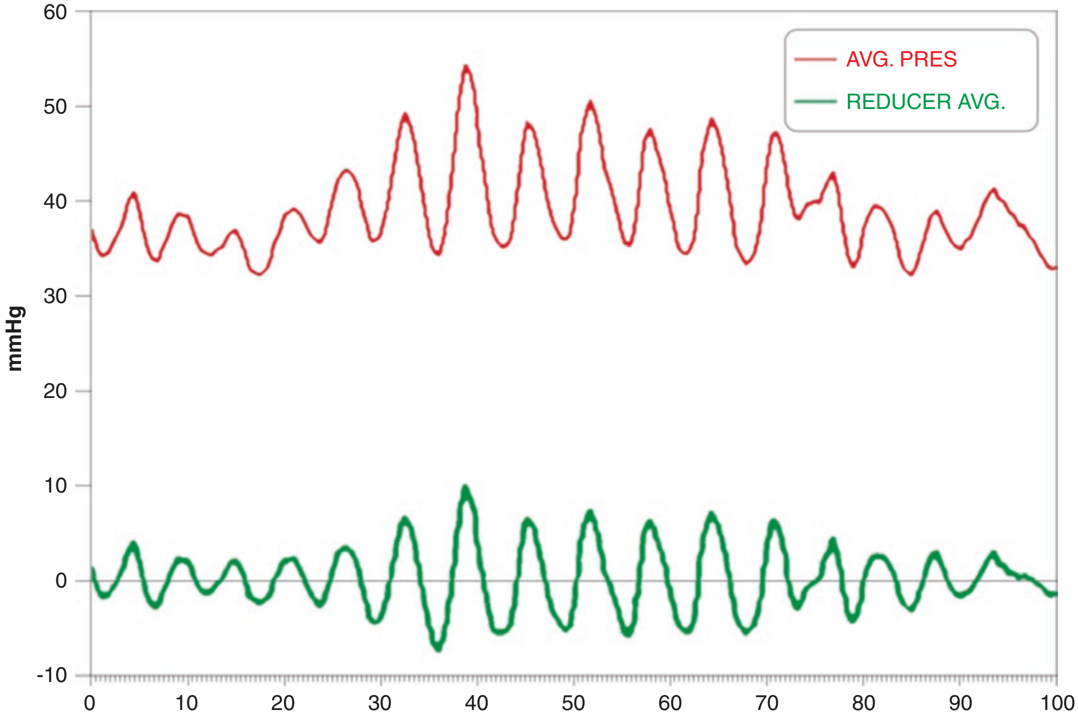

Fig. 5.19 Manometric tracing showing resting pressure with short and ultrashort waves

Ultrashort waves vary in frequency from 0.5 to 1.5 CPM and present a wider range reaching about 100 mmHg (Fig. 5.20). It is believed that these waves originate from the IAS and can be seen in patients with anal fissures and hemorrhoids. Although shortwaves and ultrashort waves can be attributed to the IAS, a correlation with patients with continence has yet to be demonstrated.

The intermediate waves are slightly faster than short waves and range from 4 to 8 CPM and present with pressures reaching about 3 to 70 mmHg (Fig. 5.21). We believe that they relate to intrinsic fasciculations in the IAS and can be observed in patients with neurogenic fecal incontinence and those with ileoanal anastomosis [29].

Volumetric Measurements

Rectal Sensation

The ability of the rectum to distend in response to increasing rectal volume enables it to store substantial quantity of stool before defecation. Gradual intrarectal balloon distension enables accurate measurement of rectal sensation. The first sensation measured refers to the threshold of rectal sensitivity, and it can be described to the patient as the first sensation of cold or nuisance. The second sensation recorded is the urge to defecate. Finally, the third sensation recorded is the maximum tolerable volume.

Mucosal receptors in the rectum are innervated by nerves in the pelvic fascia and pelvic floor musculature through S2 to S4 nerve roots [35]. Patients can have a hypo- or hypersensitive rectum which correlates to increased or decreased rectal capacity.

Rectal Compliance

The ability of the rectum to distend and accommodate stool is rectal compliance. This is calculated as the change in rectal pressure with the change in volume. Rectal compliance can be altered in conditions such as proctitis or external beam radiation.

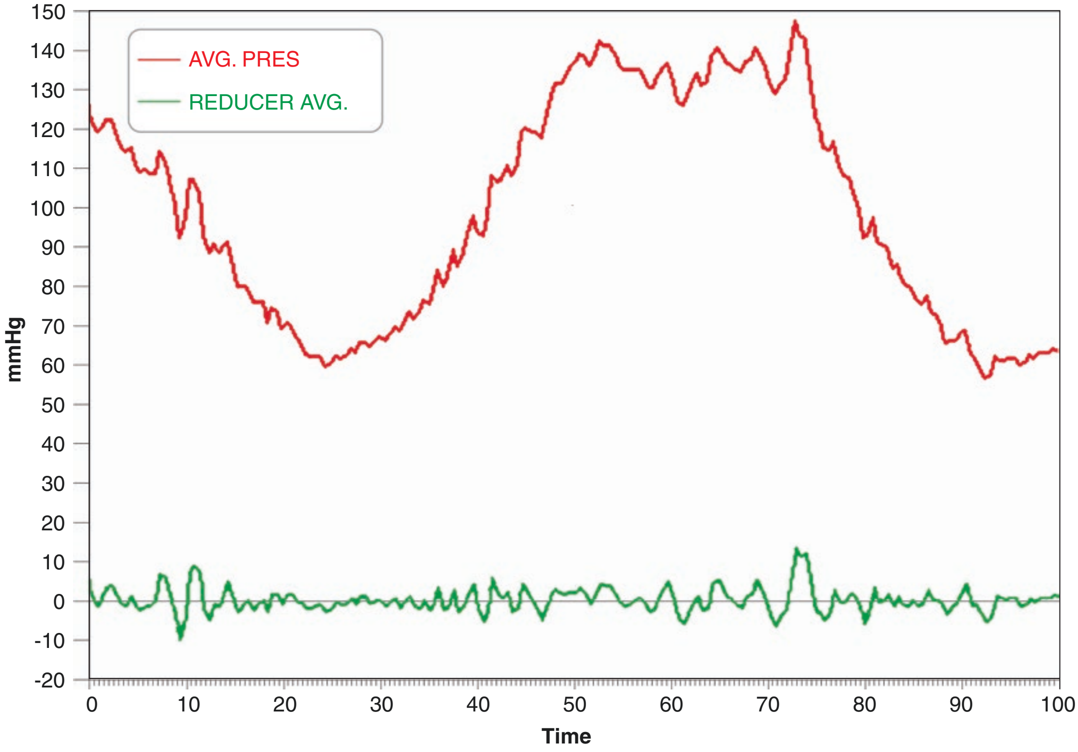

Fig. 5.20 Graphic showing ultrashort waves

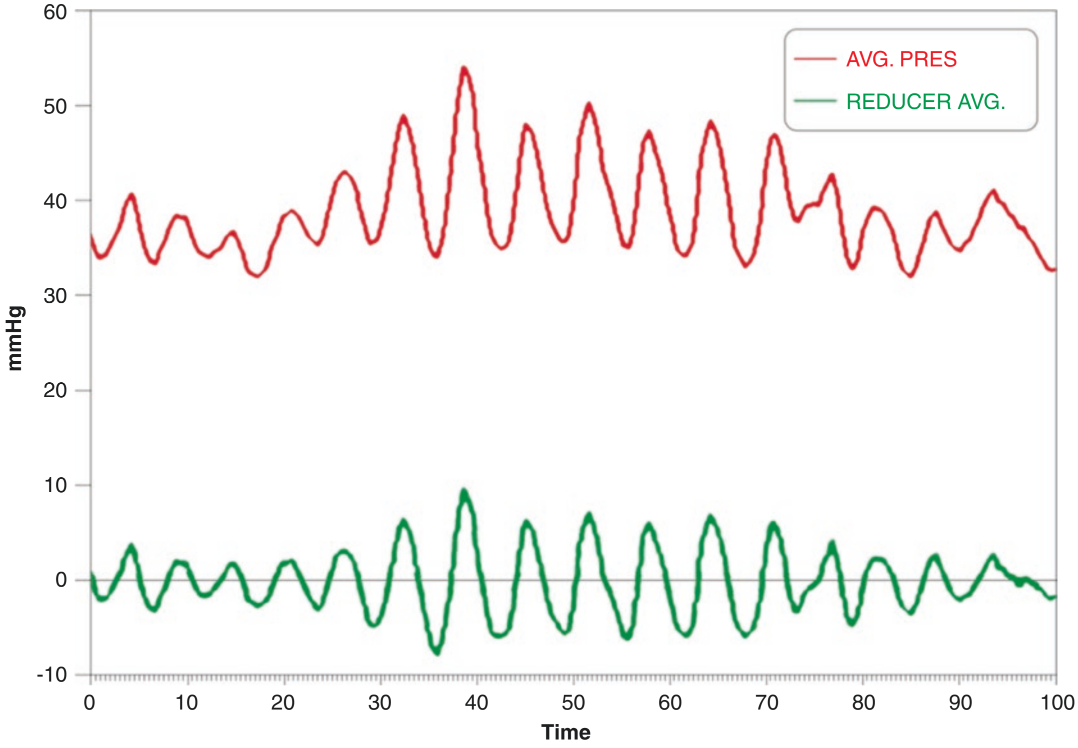

Fig. 5.21 Manometric tracing showing giant short waves

Balloon Expulsion Test

The balloon expulsion test is used to evaluate forced evacuation. This test is performed by placing a 4 cm rectal balloon into the rectum. Next, the patient is asked to expel the balloon while time is recording. The ability to expel the balloon and time taken to expel the balloon are recorded. This is clinically significant in patients with normal-transit constipation and megarectum as they are often unable to expel the inflated balloon.

Rectoanal Inhibitory Reflex (RAIR)

The rectoanal inhibitory reflex is defined as the relaxation of the IAS during rapid rectal distension [32]. This reflex allows the anal epithelium to sample rectal contents enabling one to discern between liquid and solid stool [33].

On manometry, the RAIR is demonstrated as a steep drop in IAS tone when rectal balloon is inflated to 50–100 mL of air (Fig. 5.22). The degree of RAIR stimulation and inhibition as well as time needed for the curve to return to baseline are analyzed. Volumes larger than 100 mL are required in condition such as megarectum and hyposensitivity. The magnitude of the pressure reduction depends on the volume in the balloon used to distend the rectum. In fact, the IAS tone can be totally inhibited at a certain rectal volume. With time, the IAS pressure returns to normal because it adapts to the increased rectal volume.

The RAIR is mediated by the enteric nervous system composed of myenteric plexi with input from the autonomic nervous system. Its absence is pathognomonic of patients diagnosed with Hirschsprung’s or rectal Chagas disease. Of note, the RAIR is still present after head, spinal cord, and hypogastric nerve trauma. However, it is affected by low colorectal or coloanal anastomoses. In addition, fecal constipation and incontinence and have been associated with altered patterns of the RAIR [34].

Valsalva

Normally, the external anal sphincter relaxes during the Valsalva maneuver to allow stool

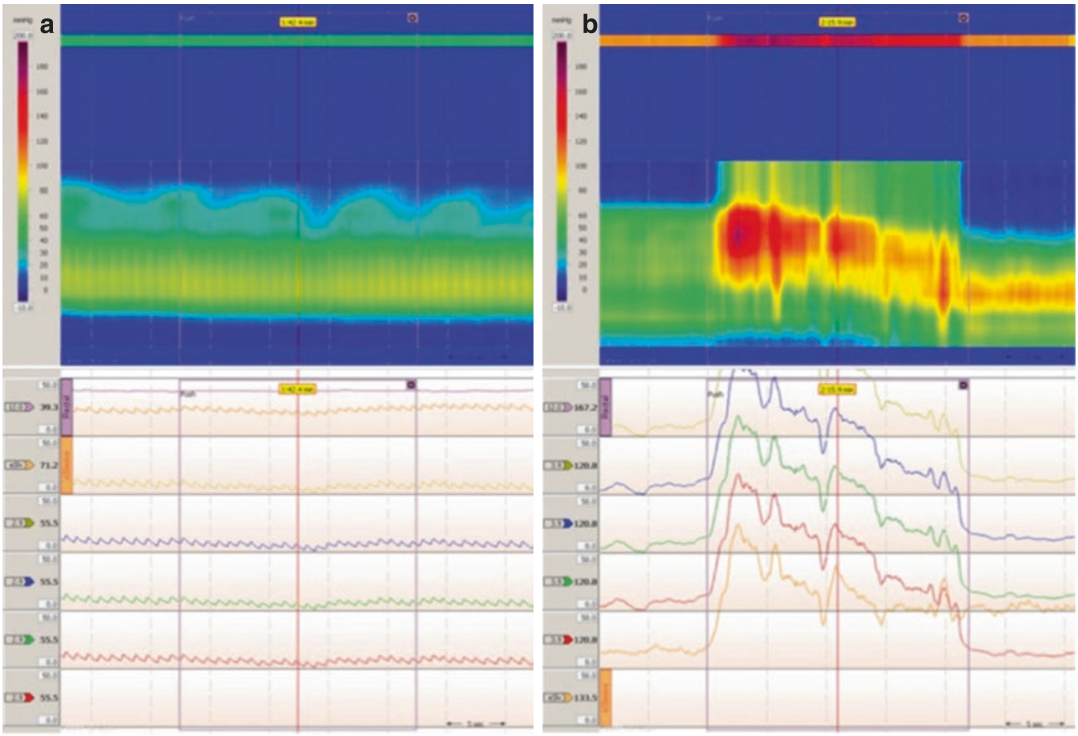

Fig. 5.22 Appearance of Valsalva on high-resolution manometry. (**a**) Normal relaxation. (**b**) Paradoxical contraction. (Reused with permission © Springer Nature)

evacuation. On manometry, this is demonstrated by an increase in intrarectal and a decrease in anal canal pressures (Fig. 5.23). However, puborectalis and/or EAS contraction can lead to outlet obstruction–induced constipation [31]. Anal manometry can detect paradoxical contraction of these muscles and diagnose dyssynergic defecation (Fig. 5.23). Like other manometry studies, these findings must be interpreted in the context of the symptomatology and examination of the patient because paradoxical sphincter contraction can be a finding in healthy patients as well.

Neurophysiologic Examination

Electromyography

Anal electromyography quantifies the electrical activity of the external anal sphincter and puborectalis muscles by providing measures of amplitude as well as duration of action potentials. The study provides a global evaluation of each motor unit and can be used to assess the functional activity of pelvic floor muscles during rest, squeeze, and attempted defecation. Before widespread use of endoanal ultrasound,

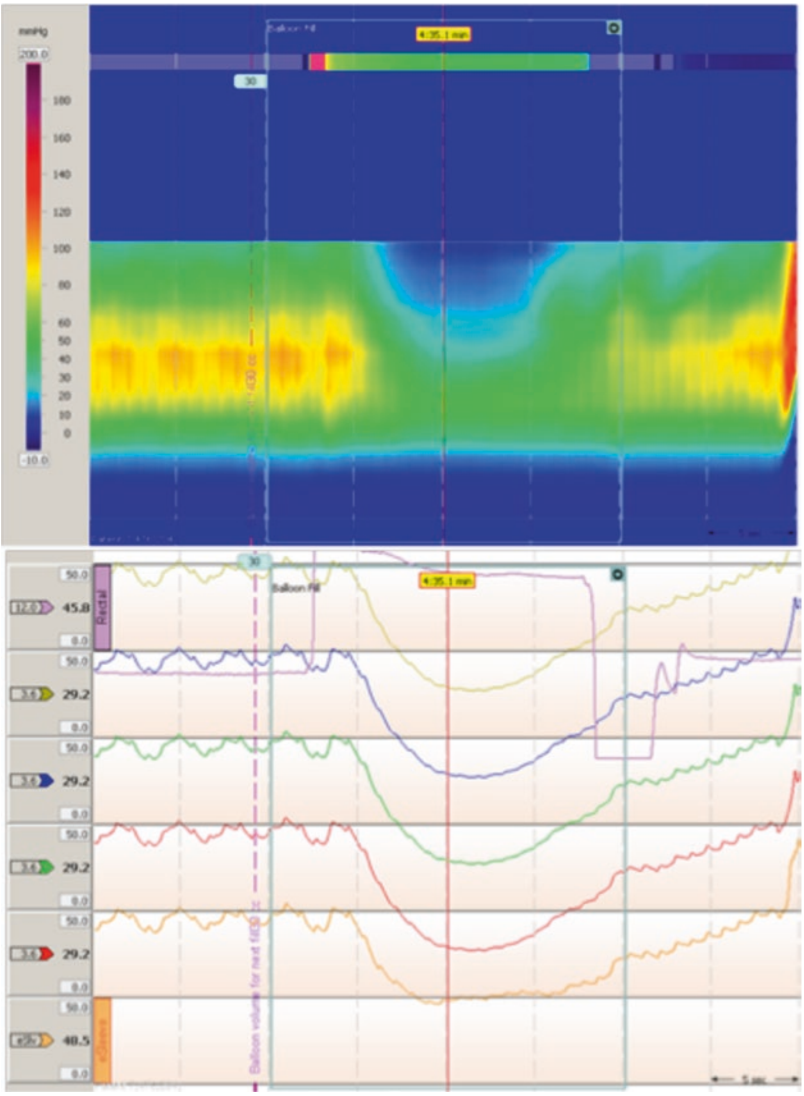

Fig. 5.23 Appearance of RAIR (rectoanal inhibitory reflex) on high-resolution manometry. (Reused with permission © Springer Nature)

EMG was the used primarily for evaluating anal sphincter defects [36]. Currently, EMG can still be helpful in mapping sphincter defects when there is dense scarring that can cause artifact on ultrasound.

The study can be performed via three methods: a needle electrode, a surface electrode on the perianal skin, or a cone-shaped plug in the anal canal. Needle electrodes come in two varieties: a concentric needle and a monopolar wire. Using this device, the clinician can precisely assess motor unit function by each quadrant. The number of motor units recruited during voluntary contraction correlates with sphincter pressures. For example, incontinent patients may have areas of sphincter damage that will display prolonged or absent action potentials. Also, disorganized polyphasic responses can be seen in motor units that have undergone reorganization and reinnervation [37]. Unfortunately, this study is not well tolerated due to the pain associated with this exam.

On the other hand, surface and anal plug electrodes are painless and well tolerated; however, it only provides a global assessment of motor function instead of each quadrant of the external anal sphincter. The anal canal responses during voluntary contraction are recorded. In constipated patients, failure to decrease or increase motor unit recruitment during attempted defecation can signal anismus or paradoxical contraction of the puborectalis respectively [38]. This information can be used therapeutically during biofeedback sessions.

Pudendal Nerve Terminal Motor Latency

Pudendal nerve fibers originate from the nerve sacral nerve roots of S2, S3, and S4; then, they traverse Alcock's canal and terminate in the fibers of the levator muscle and external anal sphincter. Due to its anatomic location, the pudendal nerve is vulnerable to traumatic injuries to the pelvic floor, particularly those related to forceps-assisted vaginal childbirth. Other causes of pudendal nerve damage include chronic rectal prolapse, perineal descent, and other conditions associated with intestinal constipation,

First described in 1984 at St. Mark's Hospital [39], pudendal nerve terminal motor latency (PNTML) is a test that assesses the integrity of the pelvic floor innervation via conduction through the pudendal nerve [40]. A neurogenic sphincter injury can be demonstrated as prolonged PNTML. This test has effectively replaced concentric needle EMG in the evaluation of patients with incontinence [41].

To perform this test, an electrode mounted to a gloved finger is introduced into the rectum (Fig. 5.24). After palpating the coccyx, the finger is slid laterally and positioned over the ischial spine which serves as a landmark for the pudendal nerve. Next, 5–15 mA impulses are delivered by the fingertip electrode, and responses are captured by another electrode at the base of the finger. The interval between nerve stimulation and muscle contraction at the level of the external anal sphincter corresponds to the PNTML, and normally it is less than 2.2 milliseconds. Values above 2.2 milliseconds are abnormal and can indicate neuropathy (Fig. 5.25a, b).

Of note, the reliability of this test is operator-dependent because proper placement of the fingertip electrode over the pudendal nerve is critical [42]. However, the test is reproducible with low intra- and inter-observe variability [43].

Colonic Transit Study

Colonic transit studies are used to assist in the evaluation of patients with intestinal constipation due to slow transit or colonic inertia [44].

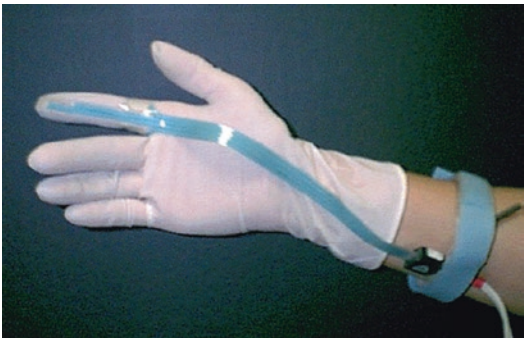

Fig. 5.24 St. Mark's electrode

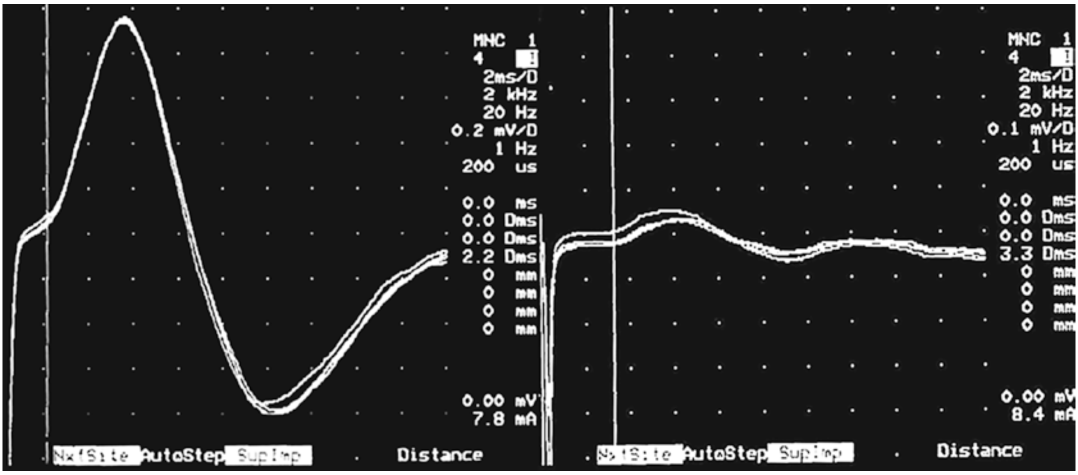

Fig. 5.25 Graph showing normal latency time of the pudendal nerve (**a**). And prolonged latency time of the pudendal nerve (**b**)

Fig. 5.26 Sitzmarks® Radiopaque Markers

Although there are many methods to assess colonic transit, this chapter will review only the main studies currently used in clinical practice.

Single-Capsule Technique

In the single-capsule technique (Fig. 5.26), 24 radiopaque markers are administered to the patient as a single capsule (Sitzmarks® Konsyl Pharmaceuticals, Fort Worth, TX, USA). Plain anterior–posterior (AP) abdominal films are on day 5 (120 hours) post-ingestion to visualize the location and distribution of the markers. A normal study should have less than 20% or less than five of the markers remaining in the colon. When a patient retains more than five markers, the distribution of the markers is important. For instance, patients with colonic inertia will have the markers spread out through the colon. On the other hand, patients with outlet obstruction will have most of the retained markers in the rectosigmoid [45–47].

The main advantage of this technique is its ease of administration, tolerability, and reduced radiation exposure; however, it does not permit exact quantification of transit time nor does it assess segmental transit time. Also, it is important to counsel the patient to stop all laxatives 48 hours prior to the study.

Multiple-Capsule Technique

In the multiple-capsule technique, a patient ingests a Sitzmarks capsule daily for 3 days consecutively. A plain AP radiograph is obtained on day 4 and day 7. Total and segmental colonic transit times are calculated using a specialized formula. The average total colonic transit time is about 35 hours (95% eliminate by 68 hours), and average segmental transit time is about 12 hours (95% have segmental transit by 26 hours). The main advantages of this technique is quantification of total transit time and segmental transit time at the cost of increased radiation exposure.

Summary

Pelvic floor disorders are a common group of heterogeneous pathologies that range from being inconvenient to extremely debilitating. Although it is essential to complete a thorough history and physical examination in patients with functional pelvic disorders, specialized tests can greatly assist in the evaluation, diagnosis, and management of these complex patients.

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