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DOI: 10.17235/reed.2018.5705/2018

Link: [PubMed \(Epub ahead of print\)](#)

Please cite this article as:

Ciriza de los Ríos Constanza, Mínguez Miguel, Remes-
Troche Jose Mariaí, Lacima Glòria. High-resolution and
high-definition anorectal manometry: rediscovering
anorectal function . Rev Esp Enferm Dig 2018. doi:
10.17235/reed.2018.5705/2018.



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High-resolution and high-definition anorectal manometry: rediscovering anorectal function

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ABSTRACT

Anorectal motor and functional disorders are common among the general population. Anorectal manometry allows the study of anorectal motor activity both at rest and mimicking different physiological situations. High-resolution anorectal manometry (HR-ARM) and high-definition anorectal manometry (HD-ARM) are increasingly used in clinical practice. In comparison with the conventional technique, HR-ARM and HD-ARM catheters provide a higher number of recording points because of their many, closely packed circumferential sensors. This allows time-space visualization (topographic or 2-3-plane mode) as spatially continuous measurements are obtained by interpolation

between near sensors. HR-ARM and HD-ARM allow a more standardized, reproducible technique, and a better assessment and understanding of the functional anatomy of the sphincter complex. Newer specific parameters are now being developed for use with these systems. They are being currently assessed by multiple research teams, and many of them remain unavailable for clinical practice as of today. However, they provide highly relevant information, which is now prompting a redefinition of anorectal anatomy and physiology. The goal of the present review was to describe the currently available HR-ARM and HD-ARM techniques, to discuss the normal values so far reported, and to analyze the newer parameters that may be assessed with these techniques, and which will likely be highly useful for clinical practice in the upcoming future.

Key words: High-resolution anorectal manometry. High-definition anorectal manometry. Equipments and catheters. Normal values. New parameters.

INTRODUCTION

Anorectal disorders affect 15-20% of the population, and most result from neuromuscular changes in the pelvic floor and adjacent structures (1,2). Neurophysiological testing to assess anorectal function provides highly significant information on the pathophysiological mechanisms involved in the genesis of fecal incontinence, pelvic floor dyssynergia, rectal hypo- or hypersensitivity, and pelvic neuropathy (3).

Anorectal manometry (ARM) is a technique that, by simultaneously recording intraluminal pressure changes at multiple levels, allows to assess anorectal motor activity both at rest and mimicking multiple physiological situations (rectoanal inhibitory reflex, retention effort, defecation maneuver, Valsalva reflex).

While barostats represent the golden standard in the evaluation of rectal sensitivity, ARM may also assess it provided the device is fitted with a distensible rectal balloon. This technique, together with balloon expulsion testing, is used in standard clinical practice for the diagnosis of defecatory disorders in patients with constipation refractory to standard therapy with hygienic-dietary measures and laxatives (4), in the

assessment of patients with fecal incontinence (5), to administer biofeedback therapy to patients with constipation and/or fecal incontinence, in the assessment of anorectal pain syndromes (proctalgia), and even for the preoperative and postoperative evaluation of ileorectal anastomoses (6).

High-resolution anorectal manometry (HR-ARM) and high-definition anorectal manometry (HD-ARM), available since 2007, are increasingly used in clinical practice. In comparison to the conventional technique, HR-ARM and HD-ARM catheters provide a greater number of recording points thanks to their multiple, closely packed circumferential sensors. This allows time-space visualization (topographic or 2-3-plane mode) as spatially continuous measurements are obtained by interpolation between near sensors, as well as a clearer assessment of anal/rectal pressure changes, without interference from catheter shifting with pelvic floor movements (7) (Fig. 1). The technique is more intuitive and reproducible, and has better inter-observer agreement when compared to the conventional procedure (8,9). It is also easier to perform, as the whole study may be carried out without catheter mobilization, and more accurate regarding the relationship between balloon distension and motor response. It reduces errors from pelvic floor movements (artifact minimization), and allows ongoing recording on balloon inflation for cases with short or low-pressure anal canal, which may be challenging with conventional manometry. However, the benefit of HR-ARM over standard manometry in clinical practice is less obvious in the anorectal area as compared to the esophagus (10). Furthermore, equipments are expensive, and catheters more fragile (7).

The technique has few contraindications, particularly serious medical or psychological conditions that may preclude patient cooperation during the procedure, presence of anal or rectal disorders that may impede catheter insertion (stricture, anorectal obstruction), and infectious diarrhea (10).

OBJECTIVE

To review the equipments and technical characteristics of novel anorectal manometry modalities, emphasizing the values observed in the healthy population (reference) and discussing the newly available measurement parameters.

METHODOLOGY

A narrative literature review was performed using the MEDLINE database. Search terms included: *anorectal manometry, anorectal manometry AND sensitivity OR specificity, high-resolution anorectal manometry, anorectal manometry AND solid-state OR water-perfused catheters, anorectal manometry AND 3D high-definition OR high-resolution*. Only texts in English or Spanish were analyzed.

EQUIPMENTS AND CATHETERS

As with conventional manometry, HR-ARM may use either continuous perfusion systems with external transducers and open-end catheters with side holes, or systems incorporating pressure microtransducers in the exploring probe, which directly record intraluminal pressure changes (10).

Perfusion systems have the drawback of requiring ongoing catheter perfusion with bidistilled water, which leads to continuous water outflow into the anal canal and rectal ampulla. Furthermore, increasing the number of recording points with perfusion systems only may be done longitudinally, never covering the entire circumference in the axial plane. These limitations are minor when catheters with solid-state microtransducers are used (11). Currently, the most commonly employed HR-ARM devices are those manufactured by Medtronic® (previously Sierra® and Given Imaging®), Medical Measurements®, and Diversatek® (previously Sandhill®), whereas HD-ARM devices are only available from Medtronic®.

Catheters vary in outer diameter and number of sensors, usually oscillating between 8 and 12, capturing pressure data in the rectum, anus, and atmosphere.

Medtronic® High-Resolution Manometry System

It includes an adult catheter with an outer diameter of 4.2 mm, and has 12 circumferential sensors – of these, at least 8 are to be placed in the anal canal – 2

usually remain outside (external reference) – and 2 in the rectum within a 3.3 cm-long balloon with a capacity of 400 mL. These catheters use a novel solid-state technology for pressure transduction (tactile array sensors) to capture data at 35 Hz, and provide one mean pressure value for the whole circumference at 6-mm intervals all along the anal canal, thus obviating the need for station withdrawal. These sensors are very sensitive to temperature changes, which results in pressure measurements; it is for this reason that thermal compensation is required on test completion to correct this deviation. On extraction, the catheter must be kept at room temperature for a few seconds, without bringing pressure to bear on its sensors. As regards durability, a mean service life of 200 procedures is guaranteed (7).

The system's software is similar to that of high-resolution esophageal manometry, and includes a data acquisition module (ManoScan AR; Medtronic®) and a data analysis module (Manoview AR; Medtronic®). It also includes the "eSleeve" option, a data processing tool that simplifies the data sequence of selected sensors to a single pressure value for all pressures recorded in the anal canal. At rest, during voluntary contraction, and during rectal distension the "sleeve" identifies the highest pressure recorded by the sensors at each point in the anal canal. This accounts for the fact that pressures obtained by HR-ARM are higher than those recorded by standard manometry. During the defecation maneuver the "sleeve" identifies the difference in more positive or less negative pressure between the rectum and the anus over a period of 20 seconds (12).

Medtronic® High-Definition System

Its catheter has a length of 6.4 cm with an outer diameter of 10.75 mm, and includes 256 sensors, which provide true recordings with individualized circumferential measurements. The space between sensors is 4 mm axially and 2 mm radially. The rectal balloon is 3.3 cm long and has a maximum capacity of 400 mL.

The software allows volumetric representations of the anal canal in addition to 2D visualization and standard line tracings. The 3D pressure map allows rotation of the pressure cylinder to assess the entire morphology and more easily identify asymmetries. The program also permits to open the cylinder longitudinally to examine

selected pressure areas; thus, any point in the anorectal pressure morphology may be clearly assessed (13).

Medical Measurement® High-Resolution System

The catheter has an outer diameter of 4 mm and includes 8 directional sensors. Six of them are equidistant from each other by 5 cm. The most proximal sensor is located within the rectal balloon (3.3 cm in length, maximum capacity of 400 mL) and 2.5 cm away from the other sensors. The most distal sensor serves as external reference. The data acquisition and analysis software is the es Solar GI HRM package (v 9.1; MMS, Enschede, the Netherlands) (13). Perfusion catheters with 8 sensors and holes 0.5 or 1 cm apart are also available.

Diversatek® (previously Sandhill®) High-Resolution System

It includes a catheter 4 mm in outer diameter and 8 directional, solid-state sensors. The most proximal sensor is located inside the rectal balloon; distal to this a sensor is placed in the rectum, 5 sensors 10 mm apart from each other are placed in the anal canal, and an external reference sensor is placed outside the anal margin. The pressures recorded in the anal canal are averaged to obtain a mean value. The balloon is 3.3 cm long, with a maximum capacity of 400 mL. Data are analyzed with the Bioview Analysis software (InSIGHT G3 HRIM or InSIGHT Ultima system; Sandhill Scientific) (13). The superiority of solid-state catheters over perfusion catheters for the assessment of abrupt pressure changes in the anal canal during maneuvers such as voluntary contraction or cough has been recently confirmed (14).

Another aspect to consider is whether HR-ARM and HD-ARM are comparable, and the longitudinal analysis seems to show good agreement between both techniques in the assessment of resting pressure and voluntary contraction (15).

PROCEDURE

While not physiological for bowel voiding, the procedure is usually performed with the patient in the left lateral decubitus position for technical convenience, and standardized normal values are available for this setting. The procedure starts after a

period of patient adaptation to the probe for 3-5 min (10,16). In every exploration the following is assessed:

- Anorectal resting pressure: usually recorded over 20 seconds, except when ultra-slow waves (1-1.5 cycles/min) are detected, where the period is extended to at least one minute (10,13,17). These waves may be previously identified during the stabilization period.
- Maximum voluntary contraction pressure: three maneuvers, each lasting 20-30 seconds followed by a resting lapse of at least 30 seconds (10,17). It was recently suggested that, in addition to sustained contraction, rapid voluntary contractions may also be assessed, but the clinical usefulness thereof remains uncertain (18).
- Cough maneuver (cough reflex, three iterations) to assess extrinsic nerve supply integrity. It is performed on a deflated balloon and after 50-mL inflation.
- Defecatory maneuver (three attempts): performed on a deflated balloon and after 50-mL inflation with air, the interval between maneuvers being 30 seconds (10,13).
- Anorectal inhibitory reflex and rectal sensitivity: simultaneously recorded, internal anal sphincter relaxation is gradually assessed during rectal balloon distension in increments of 10-20 mL; distension perception threshold, defecatory urgency, and maximum tolerable volumes are assessed. The examination may be completed by exploring other reflexes and performing a balloon expulsion test (17).

DATA ANALYSIS AND INTERPRETATION

Graphic visualization modes (topography, line tracing) may be alternated to facilitate the analysis of ARM recordings. Parameters developed for conventional manometry and later adapted to the newer systems are usually assessed.

TRADITIONAL PARAMETERS

Anal canal resting pressure

Similarly to conventional manometry, normal resting pressure values depend on both patient-related factors (e.g., age, gender, parity, and more uncertainly body mass

index and race) and equipment-related factors (17,19-21). Values obtained with the Sandhill® system are lower than those recorded by other devices (22). As with conventional manometry, higher pressures are usually recorded in patients with anal fissure or pain (because of striated or smooth muscle spasm) (23), and lower pressures are seen in patients with impaired internal anal sphincter and fecal incontinence (24). However, variability is high among healthy individuals (20), probably because sample size remains small in studies with healthy subjects. According to catheter type, resting pressure may be considered as related to either a rectal or external reference value. Importantly, measured values must be assessed using atmospheric pressure as their reference, as this generally assesses the structures making up the anorectal unit, and biases, variations, and artifacts are less common. While it is an expert recommendation, no evidence is found in the literature assessing the actual difference between absolute and atmospheric values in anorectal structures within a clinical context.

High-resolution perfusion devices always use an intrarectal reference.

High pressure zone length

The length of the mean pressure profile within the resting pressure frame, defined as: [rectal pressure + (anal resting pressure - rectal pressure) x 0.25] (17,19). Short anal canals have been seen to be associated with fecal incontinence (18).

Maximum voluntary contraction pressure

As with resting pressure, this parameter is dependent on factors such as age, gender, and measuring equipment (17,19,20,22). Absolute maximum voluntary contraction pressure and pressure increases from resting pressure should both be assessed (13). As with resting pressure, some systems allow using intrarectal or atmospheric pressure as reference.

A low pressure measurement usually reflects a hypotonic external anal sphincter (EAS) because of muscle or nerve injury (24).

Voluntary contraction duration

The most widely accepted criterion to assess this parameter is considering the period (in seconds) the patient is able to sustain voluntary contraction pressure until its fall by more than 50%. A short voluntary contraction suggests fatigue or skeletal muscle injury.

Cough maneuver (cough reflex)

The abrupt increase in abdominal pressure associated with cough induces the contraction of the EAS. This maneuver allows to indirectly assess the sacral reflex arc, which is a spinal reflex. While no significant differences have been previously reported between HR-ARM and the standard technique (16), it has been recently shown that solid-state catheters seem superior in assessing abrupt pressure changes in the anal canal (14). A maximum anal canal pressure higher than the maximum rectal pressure is deemed to be normal.

Defecatory maneuver

Normal defecation involves a sufficient increase in rectal pressure that is coordinated with anal sphincter and pelvic floor muscular relaxation. During the defecatory maneuver the eSleeve tool identifies the most positive (or less negative) difference in pressure between the rectum and anus over 20 seconds (17,19). The parameters assessed in a normal defecatory maneuver include intrarectal pressure (mmHg), residual anal pressure (mmHg), anorectal pressure (mmHg) or rectoanal gradient, percent anal relaxation, and defecatory index. Importantly, these parameters were developed for conventional systems, and their adaption to HR-ARM and HD-ARM has been challenging.

Rectoanal gradient is defined as rectal pressure minus residual anal pressure, hence a positive gradient indicates a normal defecatory maneuver using the standard approach. However, when using HR-ARM or HD-ARM this gradient is negative in a large proportion of healthy subjects(17,19,25), particularly when the maneuver is performed on a deflated balloon. Therefore, it does not seem to be a good index to discriminate between healthy individuals and patients with dyssynergic defecation. Furthermore, rectoanal gradient results are dependent on the position adopted

during the defecation maneuver (lateral decubitus or sitting), and balloon inflation status (26,27).

Percent anal relaxation is defined as anal relaxation pressure divided by anal resting pressure and multiplied by 100. Values of at least 20% are considered normal.

Defecatory index results from dividing maximum rectal pressure by residual anal pressure during the defecation maneuver. A value higher than 1.5 is considered normal.

Based on these parameters defecatory dyssynergia has been categorized in at least 4 subtypes (28):

- Type I: adequate propulsive forces (intrarectal pressure > 45 mmHg) but with increase in anal pressure.
- Type II: inability to generate adequate expulsive forces (intrarectal pressure < 45 mmHg) together with paradoxical increase in residual intra-anal pressure.
- Type III: adequate propulsive forces with absent or inadequate baseline pressure relaxation (< 20%).
- Type IV: inability to generate adequate expulsive forces, that is, without increase in intrarectal pressure, and absent or inadequate baseline pressure relaxation (< 20%).

Types I and III are classically described as pelvic floor dyssynergia, whereas types II and IV involve inadequate defecatory propulsion. Recently, identifying these subtypes has been reported to be feasible and easier using HR-ARM (29,30) (Fig. 2).

The fact that conventional manometry provided few recording points, and many of the defecatory maneuvers that were deemed normal might be the result of a shifting catheter, must be borne in mind. In the study by Sauter et al (12) false relaxations were seen in up to 55% of cases because of catheter shifts, which is considerably reduced when using HR-ARM.

Anorectal inhibitory reflex

This reflex is deemed to be present when internal anal sphincter relaxation is > 25% as compared to baseline pressure in the anal canal (17). Amplitude and duration depend on distension volume in the rectum. This reflex is absent in Hirschsprung's disease.

Rectal sensitivity

It is assessed using balloon rectal distension, considering the perception of said distension (first sensation, urgency, and maximum tolerated volume). During each distension, the percentage of anal relaxation is calculated as $[(1 - \text{residual anal pressure} / \text{resting anal pressure}) \times 100]$ (17,19). Increased rectal sensitivity is associated with urgency incontinence, proctitis, or irritable bowel syndrome when using conventional manometry. In contrast, decreased sensitivity is associated with passive incontinence and chronic constipation.

NORMAL VALUES

Normal values have been reported for the aforementioned systems and catheters, and significant differences according to type, in addition to those dependent on factors such as age, gender, parity, BMI (31), etc.

Normal values reported for anal canal pressures, rectal sensitivity, and defecatory maneuvers with HR-ARM in both men and women are listed in Table 1. Normal values for HD-ARM are listed in table 2.

No normal values are available for the Spanish population, hence a multicenter study might be considered to provide reference values at a national level, both for solid-state and perfusion high-resolution systems.

The Grupo Español de Motilidad Digestiva (GEMD) is now launching a multicenter study with the Medtronic® system to obtain reference values on a national scale. The challenge we are taking on is to ultimately establish normal values in a group of healthy, asymptomatic volunteers – using an adequate sample size estimation (larger than heretofore reported) – both for solid-state and perfusion high-resolution systems, considering subject-related factors, and relying on a consensus methodology to promote technical standardization, so that results may be transferred between institutions on an international scale as is already the case with high-resolution esophageal manometry, which would facilitate reliability in multicenter studies, research advancement, and then higher diagnostic efficiency.

NEW HR-ARM AND HD-ARM PARAMETERS AND INTERPRETATION

A criticism of conventional manometry was lack of standardization. HR-ARM and HD-ARM allow a more standardized, reproducible use of the technique (32).

Indisputably, these technologies allow to better research and understand the functional anatomy of the sphincter complex, providing a detailed distribution of pressures in the anal canal, and both their axial and circumferential asymmetries (33,34). While appropriate parameters for these systems are now under development and evaluation by various research teams, many cannot be used in clinical practice yet; however, they do provide highly relevant information allowing a redefinition of anorectal anatomy and physiology.

Temporo-spatial topographic analysis provides a qualitative description, including visualization of two pressure zones in the anal canal during voluntary contraction, representing EAS (distal) and puborectalis muscle (proximal) contractions, which allows an assessment of paradoxical puborectalis contraction (20,35). It also permits to observe different voluntary contraction morphologies in healthy individuals, and spontaneous anal canal activity as in transient relaxations (20) (Figs 3A and 3B). The latter have a mean duration of 23 seconds in healthy individuals, are more common in the postprandial period, and produce symptoms in up to 76% of cases (urge to break wind). Changes in transient relaxation characteristics or perception are likely relevant in fecal incontinence (36). In patients with proctalgia fugax HR-ARM has been shown to facilitate the identification of ultra-slow anal waves (37) (Fig. 3F).

Furthermore, these techniques may play a role in the assessment of anatomical changes; in this respect, HD-ARM has been shown to be useful for the diagnosis of sphincter disorders when compared to endoanal ultrasound (38,39). Similarly, HR-ARM and HD-ARM may be useful for the diagnosis of pelvic floor disorders including descending perineum syndrome (40,41), rectal prolapse and intussusception (Fig. 3D) when compared to fluoroscopy or MRI defecography (42-44). However, no correlation has been found between resting pressure and voluntary contraction pressure, and internal or external anal sphincter thickness, respectively, using HD-ARM and 3D ultrasound (45). HD-ARM has shown that anal canal relaxation with rectal ampulla distension varies along the canal's length, with maximum changes proximal to the internal anal sphincter (46).

However, no additional benefits over the standard technique have been found for the study of fecal incontinence, and its role in discriminating healthy individuals from dyssynergic defecation patients has been questioned (21,25,47) to the point of doubting the actual contribution of this technology (48). This may be due, at least partly, to our using conventional metrics in HR-ARM, as newer parameters should be assessed with this approach (49). For instance, a phenotype classification has been suggested, which is difficult to apply in clinical practice (50).

In an attempt to discriminate healthy individuals from fecal incontinence patients a voluntary contraction profile has been described for HR-ARM; this parameter integrates the product of mean pressure increase, sphincter length, and voluntary contraction duration (mmHg.cm.5s), and increases sensitivity to fecal incontinence by 59% as compared to conventional metrics (51).

Newer HR-ARM- and HD-ARM-specific parameters have also been reported to better discriminate between dyssynergic defecation patients and healthy individuals, including the anal contractile integrated, post-contraction pressure, anal integrated relaxation pressure, and sliding velocity in the anal canal. In a study in 40 healthy volunteers (28 women, mean age 35 years) and 20 patients with dyssynergic defecation (12 women, mean age 46 years), the latter exhibited significantly different values as compared to the former in each of the above parameters, suggesting that said parameters are able to tell normalcy from pathology (52). Integrated pressurized volume (IPV) has been recently posited – it is measured in the anal canal and rectum to calculate the IPV ratio, a parameter already used in high-resolution esophageal manometry, and its correlation with balloon expulsion testing. This measurement may better predict delays in the balloon expulsion test in comparison with conventional parameters (53,54).

While the newly-posed measurements are promising, and will likely help us advance in the recognition of functional anorectal disorders, as was the case with high-resolution esophageal manometry, further studies including higher numbers of healthy individuals and patients are required for their validation. Similarly, these promising “anatomic data” require a review, possibly a classification, of pelvic disorders as defined with HR-ARM.

To conclude, HR-ARM and HD-ARM are more intuitive and easier to perform than the standard technique, and represent an aid to better understand anorectal physiology by allowing correlation between anatomy and function, as well as the pathophysiology of functional anorectal conditions. These technologies permit the assessment of spontaneous activity in the anal canal, which is difficult to evaluate using the conventional technique, and are highly promising for the assessment of anatomic changes in the anal canal and pelvic floor. Their development is slower as compared to high-resolution esophageal manometry, and here a control arm is required with larger numbers of well-selected healthy individuals, including a variety of age, gender, parity status, and probably ethnics groups. Furthermore, it is key that properly standardized reference values be available, both for solid-state and perfusion systems. Consensus and validation are also important for novel measurement parameters specific of high-resolution manometry in order to enhance its diagnostic yield in the study of both motor and functional anorectal disorders.

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Table 1. Normal values reported for anal canal, defecatory maneuver, and rectal sensitivity pressures in healthy women and men using 9-23-sensor HR-ARM catheters

Normal anal canal pressures in women using 9-23-sensor catheters						
Author (n)	Year	Equipment	Maximum resting pressure (mmHg)	Maximum voluntary contraction pressure (mmHg)	Voluntary contraction duration (sec)	Anal canal length (cm)
Noelting <i>et al.</i> (19) (n = 62)	2012	Medtronic (solid state: circumferential)	< 50 years: 88 ± 3 > 50 years: 63 ± 5*	< 50 years: 167 ± 6 > 50 years: 162 ± 12	< 50 years: 12 ± 1 ≥ 50 years: 14 ± 3	< 50 years: 3,6 ± 0.1 > 50 years: 3.5 ± 0.2
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	32 (24-42) [†] Nulliparae: 30	75 (61-89) [†] Nulliparae: 71 (56-	ND	ND

			(15-37) With births: 33 (26-46)	82 With births: 83 (63-107)		
Carrington <i>et al.</i> (20) (n = 96)	2015	MMS (UniTip Unisensor AG)	65 ± 19 [†] Nulliparae: 69 ± 17 With births: 62 ± 19	225 ± 89 Nulliparae: 259 ± 90 With births: 207 ± 84 [‡]	11 ± 9 Nulliparae: 12 ± 10 With births: 10 ± 9	3.5 ± 0.8 Nulliparae: 3.6 ± 0.9 With births: 3.4 ± 0.8
Rasijeff <i>et al.</i> (14) (n = 40)	2017	MMS (UniTip Unisensor AG)	57 (26-94) Nulliparae: 55 (20-111) With births: 58 (26-86)	172 (35-329) Nulliparae: 182 (36-381) With births: 149 (35-254)	ND	ND
Normal anal canal pressures in men using 9-23-sensor catheters						
Author (n)	Year	Equipment	Maximum resting pressure (mmHg)	Maximum voluntary contraction pressure	Voluntary contraction duration (sec)	Anal canal length (cm)

				(mmHg)		
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	46 (39-56) [†]	178 (140-212) [†]	ND	ND
Carrington <i>et al.</i> (20) (n = 19)	2015	MMS (UniTip Unisensor AG)	73 ± 23 [†]	290 ± 155	16 ± 11	3.9 ± 0.8
Rasijeff <i>et al.</i> (14) (n = 20)	2017	MMS (UniTip Unisensor AG)	71 (49-117)	322 (63-538)	ND	ND
Author (n)	Year	Equipment	Residual anal pressure (mmHg)	Percent anal relaxation	Intrarectal pressure (mmHg)	Rectoanal gradient (mmHg)
Normal defecatory maneuver parameters in women						
Noelting <i>et al.</i> (19) (n = 62)	2012	Medtronic (solid state: circumferential)	< 50 years: 63 ± 5 > 50 years: 47 ± 6	< 50 years: 32 ± 5 > 50 years: 25 ± 10	< 50 years: 20 ± 3* > 50 years:	< 50 years: -41 ± 6* > 50 years: -12 ± 6

					32 ± 5	
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	19 (10-35) Nulliparae: 13 (4-25) With births: 22 (11-53)	30 (0-75) Nulliparae: 34 (0-87) With births: 22 (0-67)	37 (27-51) [†] Nulliparae: 30 (25-38) With births: 44 (31-55)	16 (5-30) Nulliparae: 16 (9-30) With births: 16 (0-30)
Carrington <i>et al.</i> (20) (n = 96)	2015	MMS (UniTip Unisensor AG)	43 ± 21 Nulliparae: 47 ± 19 With births: 45 ± 22	24 ± 22 Nulliparae: 27 ± 25 With births: 16 ± 33	64 ± 31 Nulliparae: 66 ± 38 With births: 62 ± 27	ND
Normal defecatory maneuver parameters in men						
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	30 (12-48)	ND	55 (31-77) [†]	-29 (1-46)
Carrington <i>et al.</i> (20) (n = 96)	2015	MMS (UniTip Unisensor AG)	43 ± 21	24 ± 22	64 ± 31	ND

Author (n)	Year	Equipment	First sensation (cc)	Desire to defecate (cc)	Urgency (cc)	Pain (cc)
Rectal sensitivity in women						
Noelting <i>et al.</i> (19) (n = 62)	2012	Medtronic (solid state: circumferential)	< 50 years: 33 ± 2 > 50 years: 32 ± 2	< 50 years: 56 ± 3 > 50 years: 59 ± 4	< 50 years: 86 ± 5 > 50 years: 96 ± 5	ND
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	10 (10-20) Nulliparae: 10 (10-20) With births: 20 (10-20)	60 (50-70) [†] Nulliparae: 60 (50-80) With births: 60 (50-68)	115 (98-153) Nulliparae: 100 (90-150) With births: 120 (100-160)	ND
Rectal sensitivity in men						
Lee <i>et al.</i> (22) (n = 27)	2014	Sandhill (solid state)	10 (10-20)	80 (60-120)	130 (110-178)	ND

() 95% CI; *p < 0.05 vs. < 50 years; †p < 0.05 *versus* men; ‡p < 0.05 *versus* nulliparae; ND: no data.

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Author	Year	Maximum resting pressure	Maximum voluntary contraction pressure	Voluntary contraction duration	Anal canal
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Table 2. Normal anal canal pressures and defecatory maneuver parameters as measured with a 256-sensor HD-ARM catheter (Medtronic)

(n)		(mmHg)	(mmHg)	(sec)	(cm)
Normal anal canal pressures in women					
Li <i>et al.</i> (17) (n = 46)	2013	68.5 (63.6-73.4)	167.4 (150.5-184.3)*	14.7 (13.2-16.3)*	3.5 (3.3-3.7)
Coss-Adame <i>et al.</i> (21) (n = 42)	2015	76 (71-81)*	205 (186-224)*	28 (27-36)	4 (3.8-4.2)
Wickramesinghe <i>et al.</i> (45) (n = 101)	2015	87.02 ± 18.43	179.21 ± 52.96 (SD: 53)	ND	3.67 ± 0.52 (SD: 0.5)
Mion (31) (n = 36)	2017	83 (75-90)	180 (163-198)*	ND	ND
Normal anal canal pressures in men					

Li <i>et al.</i> (17) (n = 64)	2013	69.5 (65.2-73.8)	194.8 (180.9-208.6)	12.3 (10.8-13.8)	3.6 (3.4-3.8)
Coss-Adame <i>et al.</i> (21) (n = 36)	2015	90 (83-96)	266 (245-287)	30 (28-30)	4.3 (4.1-4.5)
Mion <i>et al.</i> (31) (n = 10)	2017	89 (74-103)	273 (239-308)	ND	ND
Author (n)	Year	Residual anal pressure (mmHg)	% of anal relaxation	Intrarectal pressure (mmHg)	Rectoanal gradient (mmHg)
Normal defecatory maneuver parameters in women					
Li <i>et al.</i> (17) (n = 46)	2013	62.2 (51.8-78.7)	27.2 (21.2-33)	45.8 (31.2-60.4)	-12.8 (-29.8-4.1)
Sauter <i>et al.</i> (12) (n = 15)	2014	ND	ND	28 (12-58)	-46 (-61, -32)

Xu <i>et al.</i> (35) (n=37)	2014	77 (66.2-87.4)	25.7 (20.1-31.4)	51.5 (44.4-58.6)	-21.3 (-32.2, -10.3)
Coss-Adame <i>et al.</i> (21) (n = 18)	2015	36 (28-43)	ND	39 (34-45)	ND
Normal defecatory maneuver parameters in men					
Li <i>et al.</i> (17) (n = 46)	2013	81.2 (72.6-89.7)	22.5 (16.6-28.3)	72.3 (53.5-91.2)	-13.4 (-28.5, -4.1)
Coss-Adame <i>et al.</i> (21) (n = 18)	2015	40 (28-52)	ND	43 (35-51)	ND

() 95% confidence interval; *p < 0.05 *versus* males; ND: no data.

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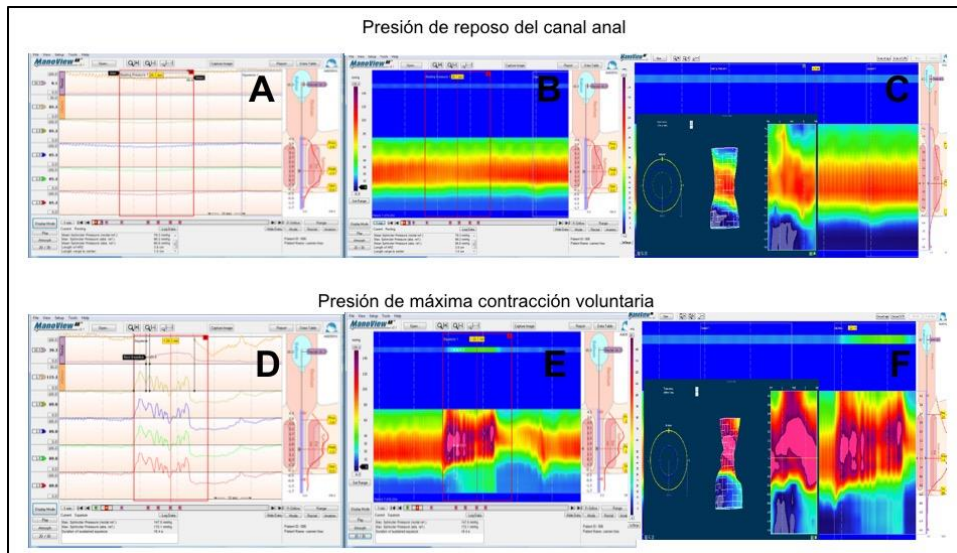


Fig. 1. Resting anal canal pressure and maximum voluntary contraction pressure using conventional, high-resolution, and high-definition manometry. (A) and (D) conventional tracings for anal canal resting pressure and maximum voluntary contraction pressure. (B) and (E) A space-time topography of high-resolution manometry, where anal canal length and pressure at rest (B) and during contraction (E) are better visualized in color. High-definition manometry provides a 3-plane (3D) reconstruction of the anal canal, and images C and F show the morphology of the anal sphincter at rest and during maximum voluntary contraction (original image).

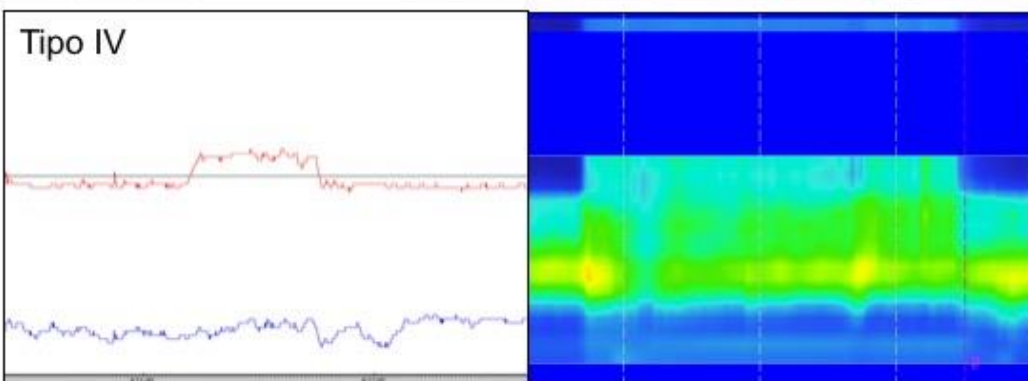
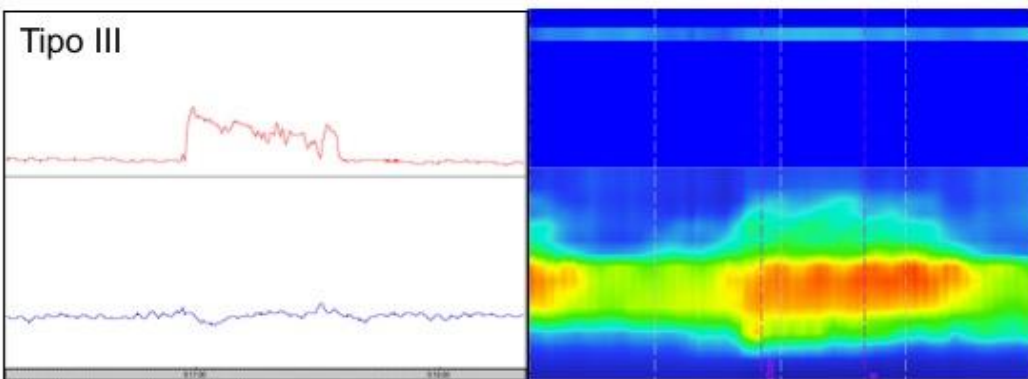
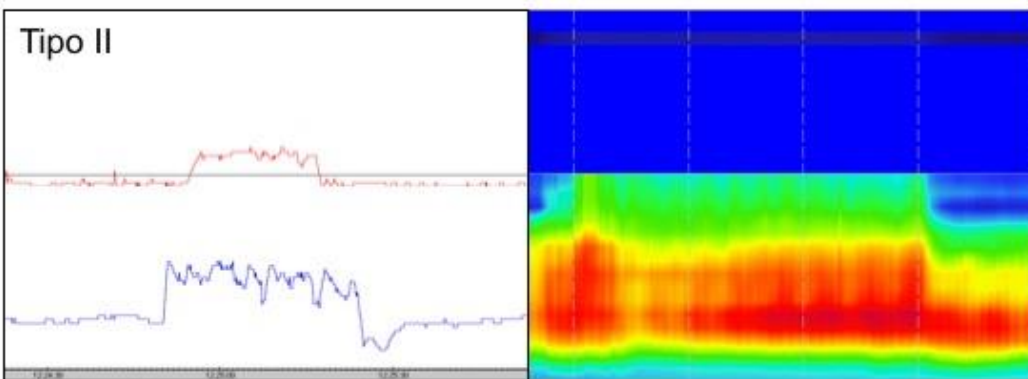
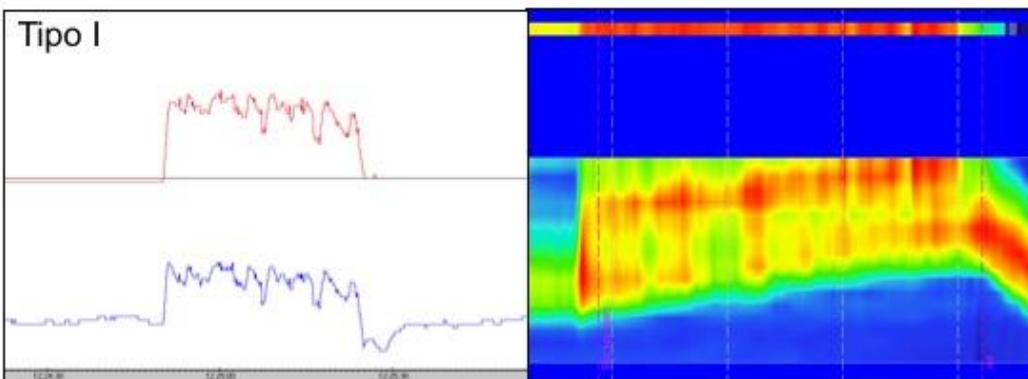
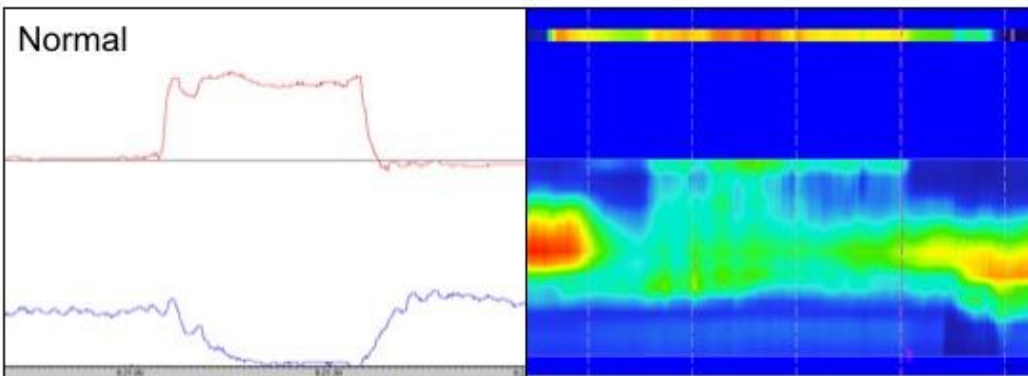


Fig. 2. Dyssynergic defecation classification according to manometric pattern using high-resolution manometry. Conventional anorectal manometry tracings are seen on the left side, and those of high-resolution manometry on the right side. The red line in conventional manometry represents intrarectal pressure, and the blue line represents anal pressure during defecatory maneuver. As may be seen, types I and III are characterized by paradoxical contraction or absent anal sphincter relaxation, whereas types II and IV are characterized by weak or absent rectal propulsion. High-resolution manometry tracings show two colored bands, a thin one above (rectal) and a thick one below (anal), where brighter colors represent higher pressures and paler colors represent lower pressures. Reproduced with permission from: Remes-Troche JM, Coss-Adame E, Lopéz-Colombo A, et al. The Mexican consensus on chronic constipation. *Rev Gastroenterol Mex* 2018;pii S0375-0906(18)30047-8. DOI: 10.1016/j.rgmx.2017.12.005

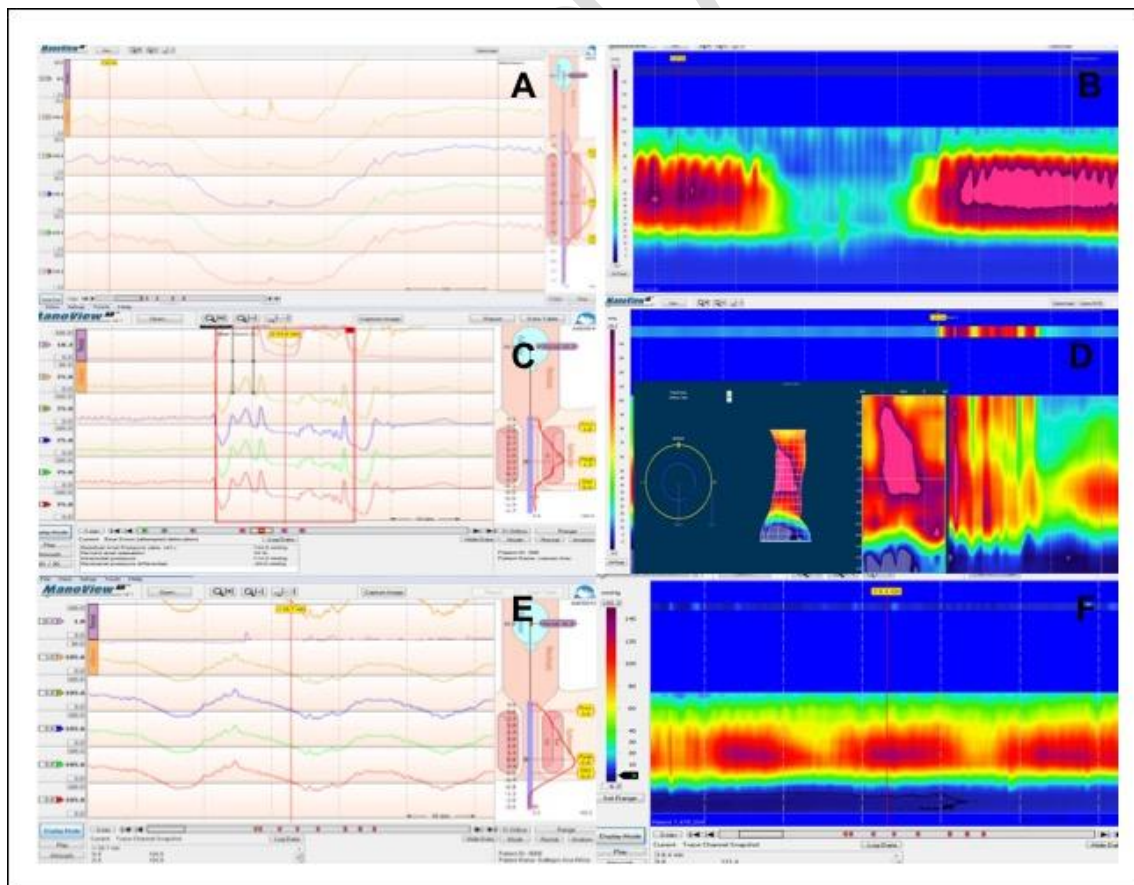


Fig. 3. Transient anal sphincter relaxations, anal ultra-slow waves, and rectal intussusception identified by high-resolution and high-definition manometry. Transient anal sphincter relaxations identified with conventional line tracings (A) and high-resolution topography (B) in a patient with fecal incontinence. During the defecatory maneuver line tracings (C) fail to identify the presence of rectal intussusception, whereas the 3D reconstruction of high-definition manometry clearly reveals its presence (D). Presence of ultra-slow anal waves at rest, detected by pressure line tracings (E) and topography (F) in a patient with proctalgia fugax (original images).

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