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ORIGINAL ARTICLE

Three-dimensional high-resolution anorectal manometry in functional anorectal disorders: results from a large observational cohort study

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Abstract

Background The aim of the study was to describe the results of 3D high-resolution anorectal manometry (3DHRAM) in a large cohort of patients with functional anorectal disorders.

Methods In this single-center retrospective study, all consecutive patients referred for investigation of fecal incontinence (FI) or dyssynergic defecation (DD) underwent 3DHRAM. The parameters analyzed were usual manometric data, repartition of dyssynergic patterns, and the prevalence of a new "muscular subtype classification" underlying dyssynergia, anal sphincter defects, and pelvic floor disorders.

Results Final analyses were performed in 1477 patients with a mean age 54 ± 16 years; 825 patients suffered from DD, and 652 patients suffered from FI. Among these patients, 86% met the diagnostic criteria for dyssynergia. Type II dyssynergia was the most frequently observed (56%) in women and men suffering from FI and in women with DD. Type I was the most frequently observed in men with DD (49%). Regarding the muscle type subgroups, combined puborectalis muscle involvement with an external anal sphincter profile was the most frequently observed. The global prevalence of rectal intussusception and excessive perineal descent were 12% and 21%, respectively. Type III dyssynergia was more frequently associated with pelvic floor disorders than were other types of dyssynergia ($p < 0.001$).

Conclusion This large cohort study provides reference values for 3DHRAM in patients with functional anorectal disorders. Further studies are necessary to assess the prevalence of pelvic floor disorders in healthy volunteers and to develop new scores and classifications including all of these new parameters.

Keywords 3D high-resolution anorectal manometry · Functional anorectal disorders · Constipation · Fecal incontinence

Introduction

Anorectal manometry (ARM) is a physiological test routinely used for the study of functional anorectal disorders [1, 2]. The test's main indication in adults is the assessment of the pathophysiological mechanisms of fecal incontinence (FI) and dyssynergic defecation (DD). For many years, two different conventional techniques of ARM have been used: water-perfused catheter and balloon systems. However, many criticisms have regularly been made about these techniques, particularly regarding the lack of standardization and normative data from a large number of healthy individuals and patients [3–6]. Recently, a new ARM system using a high-resolution technique has been developed. The system features two probes, a 2D probe and a 3D solid-state probe with 256 pressure sensors, known as 3D high-resolution anorectal manometry (3DHRAM). A particularly interesting feature of these probes is their ability to provide physiological and morphological data simultaneously [7, 8]. Since the first publication in 2007 [9], various published studies have assessed three factors: (1) normal values obtained with these new tools [10–18]; (2) values observed in patients suffering from FI or DD [1, 8, 16, 19]; and (3) new data that can be offered, such as those pertaining to the diagnosis of anal sphincter defects and pelvic floor disorders (rectal intussusception and perineal descent)

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[20–22]. Unfortunately, despite the growing interest in these techniques, the common weakness of these studies is an insufficient number of patients, with no study exceeding 357 patients [23]. Thus, data obtained with high-resolution ARM must be validated in larger populations, with an assessment of the prevalences of the main values and anomalies.

Taking advantage of our expert referral center, we aimed to describe the results of 3DHRAM in a large cohort of patients with functional anorectal disorders.

Methods

Patients

In this single-center retrospective study, all consecutive patients referred to our center from 1 January 2015 to 30 June 2017, for investigation of FI or DD, were eligible. Our center (Physiological Unit of the Gastroenterological Department, North Hospital, Assistance Publique–Hôpitaux de Marseille) is a tertiary center in which two experimented operators regularly perform the investigations.

The inclusion criteria were as follows: age ≥ 18 years and FI or DD.

The exclusion criteria were as follows: age < 18 years; pregnancy; organic pathology of the colon or rectum detected by clinical examination; colonoscopy or CT scan; previous surgery for pelvic floor disorders, inflammatory bowel disease, diabetes mellitus, systemic sclerosis, or chronic neurological diseases; and missing 3DHRAM data.

For all the patients included, a detailed clinical history was recorded, including age, gender, body mass index (BMI), duration of symptoms, and obstetrical history. The severity of the predominant symptom, namely, DD or FI, was systematically evaluated using the Knowles-Eccersley-Scott-Symptom (KESS) score or the Wexner score, respectively [24, 25].

Balloon expulsion testing was not performed, reflecting our local practice.

Anorectal manometry

All patients underwent 3DHRAM. Patients were positioned in the left lateral supine position. The 3DHRAM probe (ManoScan 3D; Sierra Scientific Instruments, Los Angeles, CA, USA) was a rigid probe with a diameter of 10 mm, with 16 × 16 pressure sensors distributed over a height of 64 mm and spaced 2 mm apart in the axial plane and along the probe; this configuration allowed for simultaneous pressure recordings to be made over the entire anal canal. For each procedure, the probe was covered with a disposable sheath containing an expandable balloon, calibrated to between 0 and 300 mmHg and then inserted into the anal canal and rectum.

After a pressure stabilization period of 3 min, the pressure of the anal canal corresponding to the resting anal pressure was recorded. The patient was then asked to perform three successive voluntary contractions. The maximum squeezing pressure corresponded to the highest-pressure value in the anal canal, and the amplitude of the squeeze corresponded to the maximum pressure of the squeeze from which the resting pressure was subtracted. Then, the patient performed three bear-down attempts to strain, and the straining rectal pressure and residual anal canal pressure were measured. The relaxation percentage was calculated between the residual anal pressure and resting anal pressure. The recto-anal gradient was assessed by the difference between the rectal pressure during straining and the residual anal pressure during straining [26]. The recto-anal inhibitory reflex was measured after insufflation of air into the balloon in 10-mL increments, and the distension threshold that caused a drop in the anal canal pressure was measured, with the balloon deflated between each bearing [27].

Table 1 Baseline characteristics: overall population

Outcomes	Overall	FI	Dyschezia	*p*
n (%)	1477	652 (44)	825 (56)	N/A
Female sex *n* (%)	1255 (85)	549 (84)	706 (86)	N/A
Male sex *n* (%)	222 (15)	103 (16)	119 (14)	N/A
Mean age (years (SD))	54 (16)	56 (15)	52 (15)	*< 0.001*
BMI (kg/m^2 (SD))	24 (5)	25 (6)	23 (4)	*< 0.001*
Symptom duration (years (SD))	8 (11)	5 (7)	11 (13)	*< 0.001*
Mean Wexner score (SD)	11 (5)	11 (5)	N/A	N/A
Mean KESS score (SD)	23 (8)	N/A	23 (8)	N/A
Vaginal delivery *n* (%)	949 (76)	460 (84)	489 (69)	*< 0.001*
Cesarean delivery *n* (%)	165 (16)	69 (13)	96 (14)	0.24

FI, fecal incontinence; *BMI*, body mass index; *SD*, standard deviation

Table 2 Baseline characteristics: patients with fecal incontinence

Outcomes	FI											
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
n (%)	549 (84)	103 (16)	N/A	44 (8)	485 (92)	N/A	163 (30)	384 (70)	N/A	23 (22)	80 (78)	N/A
Mean age (years (SD))	57 (15)	62 (15)	*0.001*	50.84 (17)	58 (14)	*0.002*	37 (7)	65 (8)	*< 0.001*	39 (7)	69 (8)	*< 0.001*
BMI (kg/m^2 (SD))	25 (6)	30 (0)	0.38	22 (5)	25 (6)	*0.02*	24 (6)	25 (6)	*0.03*	–	30 (0)	N/A
Symptom duration (years (SD))	5 (8)	3 (4)	*0.03*	4 (6)	5 (8)	0.37	5 (7)	5 (8)	0.61	4 (5)	3 (4)	0.61
Mean Wexner score (SD)	11 (5)	11 (5)	0.33	13 (5)	11 (5)	*0.04*	10 (5)	12 (5)	*0.003*	10 (6)	11 (5)	0.80
Vaginal delivery *n* (%)	460 (84)	N/A	N/A	N/A	N/A	N/A	118 (77)	337 (89)	*< 0.001*	N/A	N/A	N/A
Cesarean delivery *n* (%)	69 (13)	N/A	N/A	N/A	N/A	N/A	28 (21)	40 (13)	*0.02*	N/A	N/A	N/A

FI, fecal incontinence; *BMI*, body mass index; *SD*, standard deviation

Table 3 Baseline characteristics: patients with dyschezia

Outcomes	Dyschezia											
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
N (%)	706 (86)	119 (14)	N/A	97 (15)	531 (85)	N/A	326 (46)	378 (53)	N/A	45 (38)	74 (62)	N/A
Mean age (years (SD))	51 (15)	56 (16)	*0.005*	38 (16)	54 (13)	*< 0.001*	37 (8)	63 (8)	*< 0.001*	36 (9)	64 (9)	*< 0.001*
BMI (kg/m^2 (SD))	23 (4)	21 (1)	0.48	21 (4)	24 (4)	*0.03*	22 (4)	24 (4)	*0.01*	–	21 (1)	N/A
Symptom duration (years (SD))	12 (13)	8 (10)	*0.003*	9 (9)	12 (14)	*0.006*	10 (10)	13 (16)	*0.01*	9 (11)	7 (10)	0.45
Mean KESS score (SD)	24 (8)	22 (9)	0.33	23 (6)	23 (8)	0.96	26 (7)	22 (8)	*< 0.001*	26 (9)	20 (8)	0.16
Vaginal delivery *n* (%)	489 (69)	N/A	N/A	N/A		N/A	181 (63)	307 (89)	*< 0.001*	N/A	N/A	N/A
Cesarean delivery *n* (%)	96 (14)	N/A	N/A	N/A	96 (14)	N/A	48 (20)	47 (17)	0.40	N/A	N/A	N/A

FI, fecal incontinence; *BMI*, body mass index; *SD*, standard deviation

Table 4 Manometric values: overall population

Outcomes	Overall	FI	Dyschezia	*p*
n (%)	1477	652 (44)	825 (56)	N/A
Mean resting pressure (mmHg (SD))	76.6 (30.3)	65.8 (29.2)	85.2 (28.3)	*< 0.001*
Maximal squeezing pressure (mmHg (SD))	171.8 (76.7)	148.8 (76.9)	190.1 (71.5)	*< 0.001*
Mean anal canal length (cm (SD))	3.6 (4.2)	3.5 (1.8)	3.7 (5.3)	0.23
Mean residual anal canal pressure during straining (mmHg (SD))	92.6 (39)	81.7 (37.3)	101.2 (38.2)	*< 0.001*
Mean anal relaxation during straining (% (SD))	− 30.6 (77.7)	− 37.3 (98.7)	− 25.4 (55.4)	*0.01*
Mean rectal pressure during straining (mmHg (SD))	32.5 (29.4)	30.7 (22.1)	34 (33.9)	*0.02*
Mean recto-anal gradient	− 59.9 (45.7)	− 50.8 (39.6)	− 67.1 (48.8)	*< 0.001*
Recto-anal inhibitor reflex (RAIR) (%)	1477 (100)	652 (100)	825 (100)	1
Mean threshold RAIR (mL (SD))	14.9 (10.4)	15.1 (9.8)	14.8 (10.8)	0.6
Dyssynergia *n* (%)	1267 (86)	573 (89)	694 (86)	*0.05*
Dyssynergic pattern				0.12
I *n* (%)	317 (25)	145 (26)	172 (25)	
II *n* (%)	690 (55)	321 (57)	369 (54)	
III *n* (%)	42 (3)	12 (2)	30 (4)	
IV *n* (%)	195 (16)	83 (15)	112 (16)	
Muscle subtypes				0.94
(PB) *n* (%)	132 (11)	58 (11)	74 (11)	
(EAS) *n* (%)	0	0	0	
(PBS) *n* (%)	1068 (89)	473 (89)	595 (89)	

FI, fecal incontinence; *BMI*, body mass index; *SD*, standard deviation

Dyssynergia was defined in 3DHRAM by the absence of pressure reduction or an increase in the residual anal pressure during straining [28]. Patients were classified according to the classification of defecation disorders described by Rao et al.: rectal pressure > 40 mmHg and paradoxical anal contraction (type I); rectal pressure < 40 mmHg and paradoxical anal contraction (type II); rectal pressure > 40 mmHg and incomplete anal relaxation (type III); and rectal pressure < 40 mmHg and incomplete anal relaxation (type IV) [29].

Moreover, the manometric data obtained with 3DHRAM enabled the identification of muscles that prevent decreases in pressure in the anal canal. Indeed, the absence of pressure reduction could be due to external anal sphincter (EAS) contraction and/or puborectalis muscle contraction. Raja et al. previously showed that the puborectalis muscle is easily identifiable on 3D manometric images [30]. Thus, during straining, an area of posterior and superior high pressure was linked to contraction of the puborectalis muscle, and an anterior and inferior high pressure was linked to contraction of the EAS. Considering this additional criterion, three muscle subtypes were defined: patients with only puborectalis muscle contraction ("PB"); patients with only EAS contraction ("EAS"); and patients with both muscle contractions ("PBS"). However, because this is the first description of these patterns, an assessment of intra- and inter-reader agreement was designed. Thus, one participating physician analyzed the tracks with dyssynergia twice and classified patients into different muscular subtypes. Each manometry dataset was interpreted twice by this physician with a period of 2 weeks in between each assessment to correctly evaluate the intra-reader agreement. Then, a second junior physician analyzed 10% of the entire sample to assess the inter-reader agreement.

An assessment of sphincter anal defects (EAS, IAS, or both) was also performed according to the method described by Vitton et al. [20]

Finally, pelvic floor disorders that could be visualized with this technique (rectal intussusception and perineal descent) were also systematically investigated. According to previously published data, rectal intussusception was defined on 3DHRAM as the appearance of an anterior high-pressure zone during straining combined with excessive perineal descent [22]. As described by Vitton et al., excessive perineal descent was defined as the downward movement of the high-pressure zone during straining. At the end of the straining effort, the high-pressure zone should return to its initial position, thereby indicating that the position of the probe within the rectum has not moved [31].

Regulatory aspects

As this was a retrospective study that was performed in accordance with French clinical trial legislation, consent was not

Table 5 Manometric values: patients with fecal incontinence

Outcomes	FI											
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
n (%)	549 (84)	103 (16)	N/A	44 (8)	485 (92)	N/A	163 (30)	384 (70)	N/A	23 (22)	80 (78)	N/A
Mean resting pressure (mmHg (SD))	63.4 (27.6)	78.8 (33.8)	*< 0.001*	69.8 (31.6)	62.4 (27.1)	0.09	77.2 (24.8)	57.4 (26.7)	*< 0.001*	98.1(37.3)	73.31 (30.8)	*0.002*
Maximal squeezing pressure (mmHg (SD))	134.6 (63.5)	224.8 (95.7)	*< 0.001*	150.1 (70.0)	132.6 (62.7)	0.09	153.4 (63.7)	126.3 (61.0)	*< 0.001*	271.5 (88.7)	211.2 (93.9)	*0.007*
Mean anal canal length (cm (SD))	3.4 (1.9)	3.6 (0.8)	0.33	3.3 (0.8)	3.5 (2.0)	0.62	3.4 (0.7)	3.4 (2.3)	*0.74*	3.6 (0.9)	3.6 (0.8)	0.81
Mean residual anal canal pressure during straining (mmHg (SD))	76.4 (31.5)	110.2 (50.7)	*< 0.001*	87.3 (34.8)	74.9 (30.8)	*0.01*	87.4 (33.8)	71.6 (29.4)	*< 0.001*	124.8 (50.4)	106.1 (50.3)	0.12
Mean anal relaxation during straining (%)	− 34.4 (102.4)	− 52.3 (75.0)	0.10	− 38.8 (60.0)	− 34.4 (107.1)	0.79	− 15.1 (37.3)	− 42.8 (119.0)	*< 0.001*	− 49.3 (101.4)	− 53.1 (66.7)	0.83
Mean rectal pressure during straining (mmHg (SD))	29.0 (22.3)	39.7 (19.2)	*< 0.001*	26.2 (19.9)	29.3 (22.6)	0.38	23.9 (31.2)	16.2 (24.1)	*< 0.001*	39.4 (20.9)	39.7 (18.8)	0.95
Mean recto-anal gradient	− 47.2 (36.9)	− 69.9 (47.9)	*< 0.001*	− 61.9 (34.2)	− 45.4 (36.7)	*0.004*	− 63.5 (34.0)	− 40.1 (35.9)	*< 0.001*	− 81.7 (45.9)	− 66.5 (48.2)	0.18
Recto-anal inhibitor reflex (RAIR) (%)	549 (100)	103 (100)	1	44 (8.3)	485 (91.7)	1	163 (29.8)	384 (70.2)	1	23 (22.3)	80 (77.7)	1
Mean threshold RAIR (mL (SD))	14.2 (8.4)	19.7 (14.5)	*0.002*	16.4 (11.3)	14.0 (8.1)	0.20	12.1 (5.2)	15.0 (9.3)	*< 0.001*	16.5 (16.3)	20.7 (13.8)	0.25
Dyssynergia *n* (%)	482 (89)	91 (89)	0.95	40 (91)	428 (89)	0.78	138 (86.8)	342 (90)	0.21	16 (73)	75 (94)	*0.01*
Dyssynergic pattern			*0.006*			0.35			*< 0.001*			0.77
I *n* (%)	109 (23)	36 (40)		11 (28)	96 (23)		18 (13)	90 (27)		8 (50)	28 (38)	
II *n* (%)	278 (59)	43 (48)		25 (64)	244 (58)		75 (56)	203 (60)		7 (44)	36 (49)	
III *n* (%)	10 (2)	2 (2)		0	9 (2)		5 (4)	5 (1)		0	2 (3)	
IV *n* (%)	17 (16)	8 (9)		3 (8)	70 (17)		36 (27)	38 (11)		1 (6)	7 (10)	
Muscle subtypes			*< 0.001*			0.25			0.15			*0.03*
(PB) *n* (%)	34 (8)	24 (28)		1 (3)	31 (8)		6 (5)	28 (9)		1 (6)	23 (33)	
(EAS) *n* (%)	0	0		0	0		0	0		0	0	
(PBS) *n* (%)	411 (92)	62 (7)		36 (97)	365 (92)		119 (95)	290 (91)		15 (94)	47 (67)	

FI, fecal incontinence; *SD*, standard deviation; *(PB)*, puborectalis muscle; *(EAS)*, external anal sphincter; *(PBS)*, puborectalis muscle and external anal sphincter

Table 6 Manometric values: patients with dyschezia

Outcomes	Dyschezia											
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
n (%)	706 (85.6)	119 (14.4)	N/A	97 (15.4)	531 (84.6)	N/A	326 (46.2)	378 (52.5)	N/A	45 (37.8)	74 (62.2)	N/A
Mean resting pressure (mmHg (SD))	84.8 (28.1)	87.5 (29.4)	0.34	89.8 (25.5)	83.1 (28.3)	0.03	92.6 (26.1)	78.0 (28.1)	*< 0.001*	94.6 (30.7)	83.2 (27.9)	*0.04*
Maximal squeezing pressure (mmHg (SD))	180.5 (63.5)	246.3 (88.8)	*< 0.001*	201.5 (66.3)	175.6 (61.7)	*< 0.001*	196.8 (61.6)	166.3 (61.8)	*< 0.001*	227.9 (84.5)	257.7 (90.0)	0.08
Mean anal canal length (cm (SD))	3.6 (4.6)	4.4 (8.4)	0.14	4.0 (4.7)	3.6 (4.9)	0.47	3.5 (2.7)	3.8 (5.8)	0.44	3.5 (0.9)	4.9 (10.7)	0.36
Mean residual anal canal pressure during straining (mmHg (SD))	96.8 (34.9)	126.9 (46.2)	*< 0.001*	105.9 (40.2)	94.4 (33.9)	*0.009*	101.4 (35.1)	92.9 (34.4)	*0.001*	118.4 (44.4)	132.1 (46.8)	0.12
Mean anal relaxation during straining (% (SD))	− 20.2 (50.4)	− 56.0 (71.6)	*< 0.001*	− 23.1 (52.1)	− 20.1 (51.9)	0.60	− 13.2 (40.8)	− 26.5 (56.9)	*< 0.001*	− 34.8 (65.5)	− 69.1 (72.4)	*0.01*
Mean rectal pressure during straining (mmHg (SD))	32.2 (34.1)	44.8 (31.0)	*< 0.001*	32.9 (50.0)	32.2 (31.0)	0.84	28.9 (29.5)	35.0 (37.5)	*0.02*	40.2 (37.3)	47.5 (26.6)	0.22
Mean recto-anal gradient	− 64.5 (47.1)	− 82.5 (55.8)	0.001	− 73.0 (65.5)	− 62.2 (42.9)	*0.04*	− 72.6 (44.5)	− 57.6 (48.3)	*< 0.001*	− 79.1 (67.9)	− 84.6 (47.3)	0.60
Recto-anal inhibitor reflex (RAIR) *n* (%)	706 (85.6)	119 (14.4)	N/A	97 (15.4)	531 (84.6)	N/A	326 (46.2)	378 (52.5)	N/A	45 (37.8)	74 (62.2)	N/A
Mean threshold RAIR (mL (SD))	14.9 (11.2)	13.66 (7.8)	0.32	16.4 (15.6)	14.7 (10.3)	0.26	13.9 (10.8)	15.9 (11.6)	*0.04*	11.92 (4.0)	14.5 (8.9)	0.08
Dyssynergia *n* (%)	585 (83)	109 (92)	0.05	81 (83)	447 (85)	0.71	262 (83)	322 (88)	*0.02*	39 (86.7%)	70(94.6%)	0.18
Dyssynergic pattern			*< 0.001*			0.46			*0.002*			*0.003*
I *n* (%)	120 (21)	52 (49)		16 (20)	97 (22)		37 (14)	83 (26)		10 (26)	42 (61)	
II *n* (%)	323 (56)	46 (43)		47 (59)	240 (55)		148 (58)	175 (55)		22 (58)	24 (35)	
III *n* (%)	25 (4)	5 (5)		1 (1)	22 (5)		13 (5)	12 (4)		4 (1)	1 (1)	
IV *n* (%)	108 (18.8%)	4 (4)		16 (20)	80 (18)		59 (23)	48 (15)		2 (5)	2 (3)	
Muscle subtype			*< 0.001*			0.31			0.14			*0.01*
(PB)	44 (8)	30 (28)		4 (5)	37 (9)		15 (6)	29 (9)		5 (13)	25 (36)	
(EAS)	0	0		0	0		0	0		0	0	
(PBS)	519 (92)	76 (72)		73 (95)	392 (91)		236 (94)	282 (91)		32 (86)	44 (64)	

FI, fecal incontinence; *SD*, standard deviation; *(PB)*, puborectalis muscle; *(EAS)*, external anal sphincter; *(PBS)*, puborectalis muscle and external anal sphincter

Table 7 Pelvic floor disorders: overall population

Outcomes	Overall	FI	Dyschezia	*p*
n (%)	1477	652 (44)	825 (56)	N/A
Rectal intussusception *n* (%)	180 (12)	84 (13)	96 (12)	0.49
Excessive perineal descent *n* (%)	297 (21)	109 (17)	188 (23)	*0.003*

FI, fecal incontinence

required. Data were anonymized and collected from the APHM computerized file, which was declared to the "Commission Nationale Informatique et Liberté."

Statistical analysis

Descriptive data were summarized for the whole sample (excluding incomplete cases): sociodemographics, clinical data, and manometric values. Within the FI and DD groups, subgroup comparisons with respect to the following were performed: gender (women vs. men), parous (nulli- vs. multiparous), age classes (< 50 vs. ≥ 50 years). Comparisons were performed using chi-squared tests or Fisher's exact tests for qualitative variables and Student's *t*/Mann-Whitney tests for continuous variables. The intra- and inter-reproducibility of muscular classification were tested using kappa coefficients.

Results

One thousand five hundred patients were eligible for the current study. Among those patients, 23 were excluded from the analysis after revision of individual data because of missing data. A final analysis was performed in 1477 patients (mean age, 54 ± 16 years; 80% women), with 825 (56%) suffering from DD and 652 (44%) suffering from FI. Demographic data are presented in Tables 1, 2, and 3.

The mean pressure values obtained with 3DHRAM are presented in Tables 4, 5, and 6. Among all patients, 86% met the diagnostic criteria for dyssynergia, with a significantly higher frequency in the FI group (89.4%) than in the DD group (85.9%).

The prevalence of pelvic floor disorders in the overall population and according to gender, age, and parturient status is presented in Tables 7, 8, and 9.

The inter-observer reproducibility for muscular subtype is presented in Table 10 and the correlation of the dyssynergic pattern and muscular subtype with the mean KESS and Wexner scores and pelvic floor disorders is presented in Table 11.

The prevalence of anal sphincter defects is presented in Table 12.

Discussion

To our knowledge, this study represents the largest monocentric series of 3DHRAM data from 1477 patients that aimed to describe the prevalence of the main manometric anomalies. Data were collected over a period of 2.5 years in a tertiary center, and procedures were performed by two experimental operators thus limiting measurement bias [32]. The main interest in obtaining data from such a series is to validate observed values with a technique that is currently used to investigate functional anorectal disorders.

The demographic features observed in our study were comparable to those typically reported in the literature in

Table 8 Pelvic floor disorders: patients with fecal incontinence

Outcomes	FI												
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
n (%)	549 (84)	103 (16)	N/A	44 (8)	485 (92)	N/A	163 (30)	384 (70)	N/A	23 (22)	80 (78)	N/A
Rectal intussusception *n* (%)	71 (13)	13 (13)	0.90	6 (14)	63 (13)	0.94	18 (11)	53 (14)	0.41	2 (9)	11 (14)	0.72
Excessive perineal descent *n* (%)	95 (18)	14 (14)	0.33	6 (14)	87 (18)	0.44	34 (21)	61 (16)	0.14	5 (23)	9 (11)	0.18

FI, fecal incontinence

Table 9 Pelvic floor disorders: patients with dyschezia

Outcomes	Dyschezia											
	Women	Men	*p*	Women						Men		
				Nulliparous	Parous	*p*	Age < 50 years	Age ≥ 50 years	*p*	Age < 50 years	Age ≥ 50 years	*p*
n (%)	706 (86)	119 (14)	N/A	97 (15)	531 (85)	N/A	326 (46)	378 (52)	N/A	45 (38)	74 (62)	N/A
Rectal intussusception *n* (%)	91 (13)	5 (4)	*0.005*	10 (10)	75 (14)	0.31	35 (11)	56 (15)	*0.09*	1 (2)	4 (5)	0.41
Excessive perineal descent *n* (%)	172 (25)	16 (14)	*0.006*	21 (22)	131 (25)	0.52	81 (25)	91 (25)	0.91	6 (14)	10 (13)	0.99

Table 10 Reproducibility of muscular subtype

Reproducibility of muscular subtype	Kappa
Junior 1/senior	0.445 $p < 0.001$
Junior 1/junior 2	0.472 $p < 0.001$

terms of age, sex, and parturient status in both subgroups (FI and DD) [19, 33, 34]. The mean manometric values were comparable to those reported in the literature using a 3D high-resolution probe [17, 20]. As expected, the mean resting pressure and maximal squeezing pressure were significantly lower in the FI group than in the DD group, although some differences were observed according to gender and symptoms [12, 15]. In our study, the mean prevalence of dyssynergia was 85.8%, with a higher global prevalence in FI than in DD patients, which was not expected. In previous studies with high-resolution probes, the prevalence of dyssynergia in FI patients was 23% and 54.9–71.4% with 2D and 3D probes, respectively [13, 19]. However, the global prevalence of dyssynergia was in accordance with data reported in the literature using a high-resolution probe [28]. Moreover, in our study, as in the study by Raja et al., dyssynergia was present not only in the DD group but also in the FI group [30]. However, although Raja et al. demonstrated that 3D analysis was superior to 2D analysis for identifying dyssynergia, the clinical relevance of dyssynergia observed with ARM has been discussed for several years. Using high-resolution ARM, Grossi et al. recently demonstrated that the accuracy of this technique remains limited for discriminating between healthy subjects and patients because dyssynergia can be observed in nearly 90% of healthy subjects [28, 35, 36]. However, the identification of a dyssynergic pattern may be of clinical relevance. Rao et al. first described a classification system with conventional manometry and then with high-resolution manometry, with good reproducibility and a high inter-reader agreement rate, as performed in the current study [28, 37, 38]. In our study, regardless of symptoms, the most frequent dyssynergic pattern was type II, followed by type I. Although little data are currently available, the data that are available are quite contradictory. Indeed, while in the study by Grossi et al., patients in the constipation group more frequently had type IV dyssynergia than healthy volunteers, in the study by Mion et al., type I was more frequently observed in the constipation, FI, and healthy volunteer groups; by contrast, Ratuapli et al. reported that type III was the least frequently observed type [17, 23, 28]. Moreover, in a study including only women with FI conducted by James-Stevenson et al., the authors identified that among the 134 included patients, 21 had normal anal pressures, higher rectal defecation pressures, and more often had type I and III patterns [19]. However, while Mion et al. used

Table 11 Correlation of the dyssynergic pattern/muscular subtype with the mean KESS and Wexner scores and pelvic floor disorders

	Dyssynergic pattern					Muscular subtype		
	Type I	Type II	Type III	Type IV	p value	(PB)	(S)	p value
Muscular subtype *n* (%)					*p* < 0.001	NA	NA	NA
(PB)	63 (20)	59 (9)	4 (10)	10 (5)		NA	NA	NA
(S)	255 (80)	617 (91)	36 (90)	173 (94)		NA	NA	NA
Mean KESS score (SD)	21 (8)	25 (7)	21 (6)	24 (8)	*p* = 0.005	25 (9)	24 (8)	*p* = 0.53
Mean Wexner score (SD)	11 (5)	11 (5)	11 (8)	11 (5)	*p* = 0.72	10 (5)	11 (5)	*p* = 0.26
Perineal descent					*p* < 0.001			*p* = 0.60
Present *n* (%)	71 (22)	113 (16)	18 (43)	48 (24)		221 (20)	25 (18)	
Absent *n* (%)	252 (78)	583 (84)	24 (57)	148 (75)		860 (80)	110 (81)	
Rectal intussusception					*p* = 0.04			*p* = 0.37
Present *n* (%)	50 (15)	74 (11)	9 (21)	22 (11)		131 (12)	20 (15)	
Absent *n* (%)	272 (84)	623 (89)	33 (79)	174 (89)		949 (88)	115 (85)	

The mean KESS score was presented only for constipated patients, and the mean Wexner score was presented only for incontinent patients

FI, fecal incontinence; *SD*, standard deviation; *(PB)*, puborectalis muscle; *(EAS)*, external anal sphincter; *(PBS)*, puborectalis muscle and external anal sphincter

3DHRAM, the other assessments were made with 2D probes. In our study, the frequency distributions of the four patterns were the same in the FI and DD groups (in order of frequency: type II, I, IV, and III). However, in both groups, there was a significant difference in the distribution of dyssynergic patterns between women and men, with a nearly equivalent distribution between types I and II in men, whereas type II remained the most common in women. The high frequency of type I in men may be at least partially explained by the significantly higher mean rectal pressure measured in both groups in our study; however, other unidentified parameters may be involved. To our knowledge, no other data are currently available concerning the distribution of dyssynergic patterns according to gender. In addition, we observed that in patients with DD, the KESS score was significantly higher in patients with types II and I dyssynergia, whereas in patients with FI, there was no significant difference in the Wexner score according to dyssynergic pattern. Although additional data are needed, the distribution of dyssynergic patterns in our study can be validated by the large number of subjects included. The interest in identifying a dyssynergic pattern lies not only in discriminating healthy patients from those with anorectal functional disorders but also in guiding therapeutic strategies. In particular, although further studies are necessary, adapting biofeedback therapy to each patient's underlying symptom mechanisms and gender could be helpful.

A second new classification system for dyssynergia was described in our study—the three muscular subtypes. In our population, only two subtypes were observed: single puborectalis muscle injury (PB) and combined puborectalis muscle injury with EAS (PBS). None of the pressure profiles showed an EAS anomaly alone. Although this new morphological criterion is easily identifiable with 3DHRAM, the intra- and inter-reader agreement rates were moderate. In their study describing another method for identifying puborectalis function with 3DHRAM, Raja et al. obtained agreement rates similar to ours [30]. However, the clinical relevance of the proposed morphological criterion remains to be demonstrated.

The diagnosis rate of anal sphincter defects with 3DHRAM was very low in our study [20, 30]. However, to date, regardless of the method used (ours or the one described by Rezaie et al.),

Table 12 Anal sphincter defect

Outcomes	Overall	FI	Dyschezia	*p*
n (%)	1477	652	825	N/A
IAS defect *n* (%)	75 (5)	29 (4)	46 (6)	0.30
EAS defect *n* (%)	42 (3)	12 (2)	30 (4)	*0.04*
Mean extension of the IAS defect (degrees (SD))	105 (88)	111 (71)	101 (97)	0.84
Mean extension of the EAS defect (degrees (SD))	94 (66)	112 (49)	87 (72)	0.43

3DHRAM, 3D high-resolution anorectal manometry; *EUS*, endoanal ultrasound; *IAS*, internal anal sphincter; *EAS*, external anal sphincter

3DHRAM is not currently sufficiently effective to diagnose sphincter defects [39].

Previous studies have demonstrated that 3DHRAM could be helpful in to diagnose pelvic floor disorders, such as rectal intussusception and excessive perineal descent, with good inter-reader reproducibility [21, 22, 31]. Our study is the first to describe the prevalence of pelvic floor disorders assessed with 3DHRAM in a large population. Conventional defecography (CD) remains, to date, the gold standard for the diagnosis of pelvic floor disorders [40, 41]. The literature data show that rectal intussusception may be diagnosed on CD in 40% of patients referred for DD and in 10% of patients referred for FI [29]. In our study, the prevalences of rectal intussusception and excessive perineal descent observed with 3DHRAM were lower than those usually observed with CD or MRI defecography: 12.5% vs. 57.1% and 37.9%, respectively, for rectal intussusception and 20.6% vs. 74.5% and 52.3%, respectively, for excessive perineal descent [42]. The main reason for this difference is the absence of adequate propulsive forces during attempted defecation on 3DHRAM, probably due to the supine position. This difference in position and its consequences have been well analyzed by CD, MRI defecography, and dynamic endoanal ultrasonography and could explain the decreased detection of pelvic floor disorders [43, 44]. However, although it is necessary to compare a new technique with the gold standard (i.e., CD), it is useful to develop new scores and classification systems for new methods, such as 3DHRAM. The main limitation of our study is that we did not include any healthy volunteers. Indeed, as the clinical role of certain pelvic floor disorders can be discussed based on CD data, assessing the prevalence of these disorders observed with 3DHRAM in healthy volunteers will be interesting.

In conclusion, this study reported all the data that can currently be measured with 3DHRAM. Its strength was the size of the population, which allowed us to reliably validate the prevalences of anomalies observed in patients with functional anorectal disorders to obtain reference values. Further studies will be necessary to (1) assess the prevalence of pelvic floor disorders in healthy volunteers and (2) develop new scores and classification systems including all of the new 3DHRAM parameters to reliably identify patients and choose the most appropriate therapeutic strategy.

Author contributions CA performed the research, collected data, and wrote the paper.

LL performed the research and collected data.

CB performed the research and collected data.

KB conducted all statistical analyses.

MB performed the research, collected data, and wrote the paper.

VV designed the research study, performed the research, and wrote the paper.

Compliance with ethical standards

Ethical statement VV, MB, and CA have been consultants for Medtronic.

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