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INVITED REVIEW

Pelvic floor dysfunctions: how to image patients?

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Abstract

Pelvic floor dysfunctions embrace a large series of different conditions in which functional abnormalities of the pelvic floor lead to impairment in urinary and sexual functions and in rectal voiding. A multidisciplinary approach is needed in the evaluation of these patients, as well as the adoption of imaging studies adequate to explore the complex anatomy of the region and its dynamic functionality. Available imaging studies include: endoanal and transperineal ultrasound, X-ray defecography and MR defecography. The purpose of this review article is to illustrate the technique, indications, the current role, and diagnostic value of each one of these. The recent availability of new imaging techniques and related advantages will also be discussed.

Keywords Pelvic floor · MR defecography · Obstructed defecation syndrome · Cystocele · Pelvic floor disorders · Pelvic floor dysfunction

Abbreviations

PFD	Pelvic floor disorders
MR	Magnetic resonance
US	Ultrasound
EAUS	Endoanal ultrasound
TPUS	Transperineal ultrasound
W	Weighted
PCL	Pubococcygeal line
MPL	Midpubic line
ARJ	Anorectal junction
PCP	Pubococcygeal plane
POP Q	Pelvic organ prolapse-quantification
HMO	H-line M-line organ prolapse
VCUG	Voiding cystourethrogram
UHM	Urethral hypermobility

Introduction

Pelvic floor dysfunctions have a great impact on the quality of life representing a common clinical problem, especially in female patients [1–7]. Imaging of the female pelvic floor is of rising interest due to an ageing population, harboring an increasing incidence of pelvic floor disorders (PFD) and

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the rising need for comprehensive diagnosis and treatment. Women that are affected by PFD, often complain most about the impairment of their quality of life and ask for sufficient therapy, which is commonly surgical repair. Thus, imaging techniques have been constantly developed in recent years to support therapy planning and management.

Pelvic floor, classically divided in three compartments, anterior, middle and posterior, has to be intended as a single functional unit: when a defect in one of the three compartments occurs, it may influence in different manner the other compartments [6, 8–10]. For this reason, a multidisciplinary approach is needed in the evaluation of these patients, as well as imaging studies adequate to explore the complex anatomy of the region and its dynamic functionality [5, 11–13]. The choice of the most appropriate imaging technique depends on the specific clinical indication so a detailed clinical assessment always represents the first step in the evaluation of these patients [14, 15].

The available imaging studies are endoanal and transperineal ultrasound, X-ray defecography and magnetic resonance (MR) of the pelvic floor. MR of the female pelvic floor, particularly, combines high-resolution images with an excellent soft tissue contrast and provides the possibility to assess non-invasively and more objectively a spectrum of possible disorders affecting the pelvic floor in one examination.

The purpose of this review article is to illustrate the technique, indications, the current role and diagnostic value of each one of these. The recent availability of new imaging studies and related advantages will also be discussed.

Ultrasound

Ultrasound (US) offers different techniques in the assessment of patients with pelvic floor disorders such as 3D and 2D endoanal ultrasound (EAUS) and dynamic transperineal ultrasound (Table 1).

It can be a useful tool to detect perianal diseases impairing the voiding functionality and in the postsurgical follow-up to ensure that surgical devices are correctly placed [16].

Tridimensional and bidimensional endoanal ultrasound

3D-EAUS is performed by an endocavitary 3D-probe rotating at 360°, placed in the anal canal-lower rectum, for about 6 cm from the anal verge. It allows the acquisition of parallel 2D images, as the transducer moves in the cranio-caudal direction inside its case, taking a transaxial image of the anal canal each 0.2 mm. The acquired data are then post-processed, obtaining a 3D volume allowing, therefore, multiplanar imaging of the anal canal.

The role of endoanal ultrasound in pelvic floor functional diseases is focused on the detection of sphincter defects (Fig. 1), infectious process (Fig. 2), or neoplastic processes of the anal canal [17–20] (Tables 1, 2). Some authors adopted 2D and 3D anal ultrasonography to measure the surface of levator ani muscle at rest, during contraction, and in course of Valsalva's maneuver [21] and in the detection of rectocele, perineal descent and enterocele [22] with good diagnostic performance.

Furthermore anal endosonography is the gold standard for the assessment of anal sphincter integrity [22, 23] and may detect occult sphincter defects [24, 25]. Romano et al. quantified the accuracy of EAUS in detecting internal and external sphincter injuries, in comparison with intraoperative results, resulting respectively in 95.5% and 100% [26]. West et al. [27] found a good correlation between 3D-EAUS and endoanal MR in detecting external anal sphincter defects and Malouf et al. [28] demonstrated that EAUS has better performances than endoanal MR in evaluating internal sphincter damages [29].

3D-EAUS is the first-line imaging method in the evaluation of perianal infectious diseases (Fig. 2) in whom it plays, together with MR, a pivotal role in the initial diagnostic approach [24]. Brillantino et al. [30], in a series of 212 patients estimated the overall sensitivity and specificity of 3D-EAUS in comparison with intraoperative results in the diagnosis of perianal sepsis of 98.3 and 91.3%, respectively [31]. Emile et al. [24] and Almeida et al. [25] performed similar studies comparing the findings of EAUS with the intraoperative findings. Emile SH et al. found an overall accuracy for 3D-EAUS of 87, 88.5, and 89.5% in detection of internal opening (IO), primary tract (PT), and AS defects respectively, with a very good concordance between the findings of EAUS and intraoperative findings [24], whereas Almeida et al. found an accuracy of 3D-EAUS in relation to the surgical findings of 70.9% in the detection of the primary tract and of 56.3% in the detection of fluid collections [25]. Kolodziejczak et al. [32], evaluated retrospectively the accuracy of 3D-EAUS in the assessment of height and type of anal fistulas, compared to the intraoperative findings and found an overall accuracy of 3D-EAUS of 91% for fistula type and 92% for fistula height with a very good agreement with surgery considered as gold standard. In comparison with 2D-EAUS, 3D-EAUS showed a higher diagnostic accuracy in the diagnosis of intersphincteric, high transsphincteric, and suprasphincteric fistulas [17, 33]. 3D-EAUS is effective also in postsurgical evaluations (Fig. 1) and in assessing correct implants' location [34].

3D-EAUS is rapidly available, less expensive than MR, radiation-free, easy to perform, and highly reproducible [31, 35–38]. As drawback, 3D-EAUS allows a less-defined visualization of external anal sphincter and it seems to be

Table 1 Imaging studies to assess patients with pelvic floor disorders

Technique	Clinical indications	Advantages	Drawbacks	Protocol adopted	Radiation dose
Endoanal ultrasound	Perianal infectious/inflammatory process Evaluation of sphincteral morphology and detection of sphincter defects Post-surgical evaluation Detection and T staging of neoplastic masses of the anal canal	3D imaging Optimal visualization of sphincter anatomy Lack of ionizing radiations Patient preparation unnecessary Highly reproducible	Minimally invasive Lack of panoramicity Difficult in patients with anal stenosis or tenderness	Endocavitary 3D-probe Patient in left side decubitus No rectal cleaning enema H_2O_2 injection to obtain better depiction of fistula tract with external orifice	0
TPUS	Pelvic organs prolapse Enterocele Urinary dysfunction Postoperative assessment	Real-time functional and 2D or 3D anatomic information Lack of ionizing radiations Not invasive Easy available	Lack of panoramicity Not standardized procedure Unphysiological position Lack of evacuation phase	Standard convex US probe Supine position No rectal cleaning enema Rest, contraction and Valsalva maneuver	0
X-ray fluoroscopic defecography/X-ray fluoroscopic cysto-colpo-proctography	Test of choice in defecatory dysfunction Rectal intussusception Rectocele Enterocele and sigmoidocele Pelvic organ prolapse	Physiological defecatory position Test of choice to detect defecatory dysfunctions Optimal visualization of rectal intussusception	Ionizing radiations Lack of soft tissue contrast	Rectal ampulla:150–200 mL of high-density barium paste Per os: 200 mL of barium sulfate 60% 1 h before the examination Bladder: 400 cc of iodine contrast medium Vagina: 25 mL of barium paste No rectal cleaning enema Acquisitions during rest, contraction, squeezing and evacuation phases	1–10 mSv With a mean value of 4.9 mSv
MR defecography	Evaluation of the pelvic floor muscles, pelvic organs and supporting ligaments Pre-operative planning Post-surgical complications Urinary dysfunctions Hysterocele or vaginal vault prolapse Elytrocele and edrocele Pudendal nerve imaging Perianal fistulas and abscesses	Panoramicity Multiparametricity Lack of ionizing radiation High soft tissue contrast resolution Optimal visualization of external anal sphincter Possibility to add specific sequences for further evaluation of incidental findings	Unphysiological defecatory position in standard scanners Higher cost	Drink 500–700 mL of water 10–15 min before Supine position/sitting position on dedicated magnet Rectal ampulla: 200 mL gel Vagina: 25–30 mL gel Dynamic sagittal sequences acquired during rest, contraction, squeezing, and evacuation	0

less accurate than MR with endoanal coil in detecting external sphincter atrophy [28, 39]. Furthermore, the endoanal evaluation can be difficult in patients with anal stenosis or tenderness [40].

Transperineal ultrasound

Dynamic transperineal ultrasound (TPUS) is performed with standard 'convex' US probe or with dedicated 3D and 4D probes (Table 1) [18, 41].

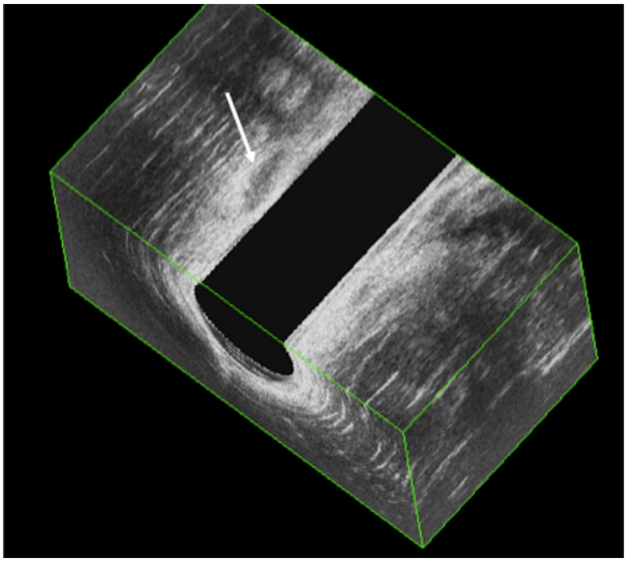

Fig. 1 Tridimensional endoanal ultrasound of a female patient complaining for both anal incontinence and dyskinetic evacuation showing the loss of integrity of the internal sphincters related to the previous surgery. Note the asymmetry of the internal sphincter, with residual portions on the right side (straight arrow) and the inhomogeneity of the external sphincter

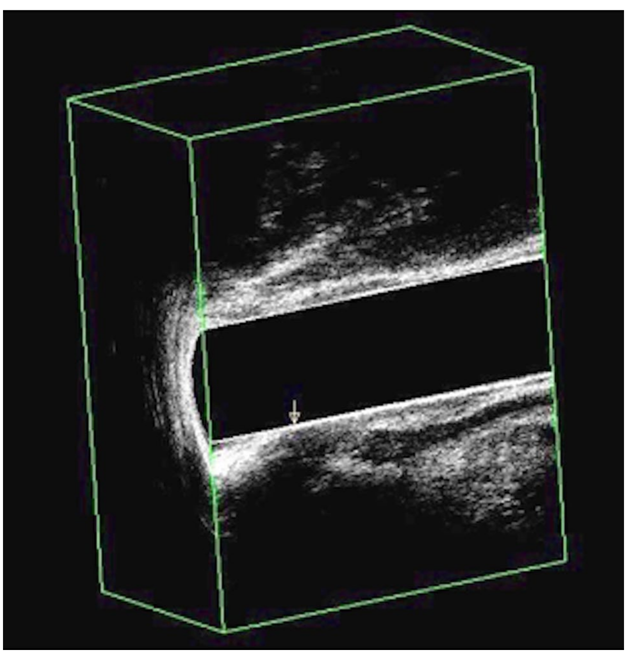

Fig. 2 Tridimensional endoanal ultrasound in sagittal view of a female patient complaining for obstructed and painful defecation related to anal hypertonia, showing a posterior anal fissure evolving in a superficial abscess (arrow)

The patient is supine positioned with the probe placed on the perineum close to the symphysis pubis. Images are acquired at rest, during contraction, and throughout the Valsalva maneuver [40].

TPUS allows also a dynamic evaluation of pelvic floor (dynamic TPUS). This is made after fulfilling rectum with 50 mL and, in female patients, the vagina, with 10 mL of US gel. With the probe in the sagittal view, it is possible to dynamically evaluate pelvic structures at rest, during squeeze, and straining (Tables 1, 3) [18].

In a comparative study, Steensma et al. [40] detected a good agreement between 3D-TPUS and evacuation proctography in detecting enterocele, moderate agreement in diagnosing rectocele, and a fair agreement in detecting intussusception [42].

A recently published work compared dynamic 3D-TPUS to conventional X-ray defecography, served as gold standard for the evaluation of pelvic floor disease. 3D-TPUS showed a high specificity in diagnosing rectoceles, enteroceles, rectal prolapses, and intussusception. This study demonstrated a good agreement between 3D-TPUS and conventional defecography in detecting posterior pelvic floor dysfunctions [18].

Concerning anterior compartment, TPUS could also be a good method to evaluate bladder neck position and mobility and in detecting cystoceles, showing a good reproducibility and a good correlation with X-ray procedures [42–45]

Furthermore, TPUS can detect excessive hiatal distensibility allowing us to measure the superior hiatus area (an area wider than 25 cm^2 is significantly associated with urogenital prolapse) [46].

In the middle compartment, it could be effective in detecting uterovaginal prolapse.

The main limit of 3D-TPUS is the non-physiological position of patient during examination and the impossibility in studying the defecation phase that is crucial to detect pathologies that may not be evident during submaximal strain [18]. Furthermore, it is not a standardized procedure with high variability in execution protocols [16].

TPUS may be also useful to evaluate anal sphincter defect, especially in patients refusing the transanal approach due to pain or stenosis [24, 47].

X-ray defecography

X-ray defecography represents the "gold standard" in the assessment of the pelvic floor disease, being a cost effective procedure with an easy execution protocol, more available than MR, and allowing the evaluation of the defecation process in the physiological sitting position. However, it is an invasive procedure due to ionizing radiations, with a mean effective dose of up to 4.9 mSv [40, 41] and the

Table 2 3D-EAUS sensitivity and specificity for the different clinical indications

References	Indications	EAUS			Standard of reference
		Se		Sp	
Romano et al. [26]	External anal sphincter defects	95.5%		100%	Surgery
Orsoni et al. (1999)	Peranal abscesses	100%		77%	Surgery
	Fistula in ano	89%		66%	
Gustafsson et al. [37]	Perianal fistula	90%		33%	Surgery
Maier et al. [36]	Perianal sepsis: fistulas and abscesses	60%		21%	Surgery
Buchanan et al. [35]	Fistula in ano	94%		50%	Outcome-derived reference standard
Brillantino et al. [30]	Perianal sepsis: fistulas and abscesses	98.3%		91.3%	Surgery
Alabiso et al. [41]	Perianal fistulas	98%		100%	MRI
Emile et al. [24]	Perianal fistulas and sphincter defects	Internal opening	97.4%	–	Examination under anesthesia
		Primary tract	89.3%	–	
		Secondary tract	100%	–	
Kolodziejczak et al. [32]	Perianal fistulas	Accuracy 91% fistula type			Surgery
		92% for fistula height			
Almeida et al. [25]	Perianal fistulas	Accuracy 70.9%			Surgery

Table 3 DTPUS protocol, sensitivity and specificity for the different clinical indications

Reference	Indication	DTPUS		Protocol	Standard of reference
		Se (%)	Sp (%)		
Beer-Gabel et al. [94]	Rectocele	89	100	Trasducer: curvilinear 5–8 MHz Position: left lateral Contrast medium: endocavitary gel (rectum, vagina) and water-soluble iodinated contrast medium (50 mL) diluted 1:1 with tap water per os (1 h before the procedure) Dynamic phases: rest, squeeze and evacuation	Defecography
	Intussusception	90	100		
	Prolapse	100	100		
Grasso et al. [42]	Enterocele	69	83	Transducer: endocavitary 6.2-MHz Position: semi-recumbent (110° sitting angle) in a gynecological chair, with legs flexed and opened Contrast medium: gel Dynamic phases: rest, squeezing, and straining	Colpocystodefecography
	Intussusception	90	100		
Steensma et al. [40]	Enterocele	64	98	After voiding Transducer: curvilinear 4–8 MHz Position: supine Contrast medium: gel Dynamic phases: rest, contraction, and squeezing	Entero-colpo-defecography
	Rectocele	78	77		
	Intussusception	22	90		
Beer-Gabel et al. [95]	Rectocele 2–4 cm	59	82	Previous enema Transducer: curvilinear 5–8 MHz Position: left lateral Contrast medium: gel Dynamic phases: rest, squeezing, and evacuation	Enterodefecography
	Rectocele > 4 cm	50	98		
	Enterocele	74	92		
	Intussusception	84	82		
	Rectal prolapse	75	97		

administration of four contrasts and allows to evaluate only the opacified organs [48, 49] neither muscular structures nor soft tissues of the pelvic floor [50–53].

It is conducted fulfilling, previously, rectal ampulla with 150–200 mL of high-density barium paste. Barium injection should be slow, loading rectum until rectosigmoid junction. In our experience, it is not necessary for patient's preparation with rectal cleaning enema.

As the pelvic prolapse often involves all the pelvic organs to obtain a wide assessment, it may be more appropriate to evaluate all of them and their interactions, also administering 25 mL of barium paste into the vagina (in female patients), about 200 mL of barium sulfate 60% per os 1 h before the examination to opacify the intestinal loops and injection 400 cc of iodine contrast medium into the bladder (Figs. 3, 4), temporarily placing a bladder catheter, that will be removed before beginning the examination.

The patient is then seated on a radiolucent commode and radiographs are acquired at rest in anteroposterior and sagittal views and during different functional phases in sagittal views, each one explored under fluoroscopy. All phases of the examination are video recorded.

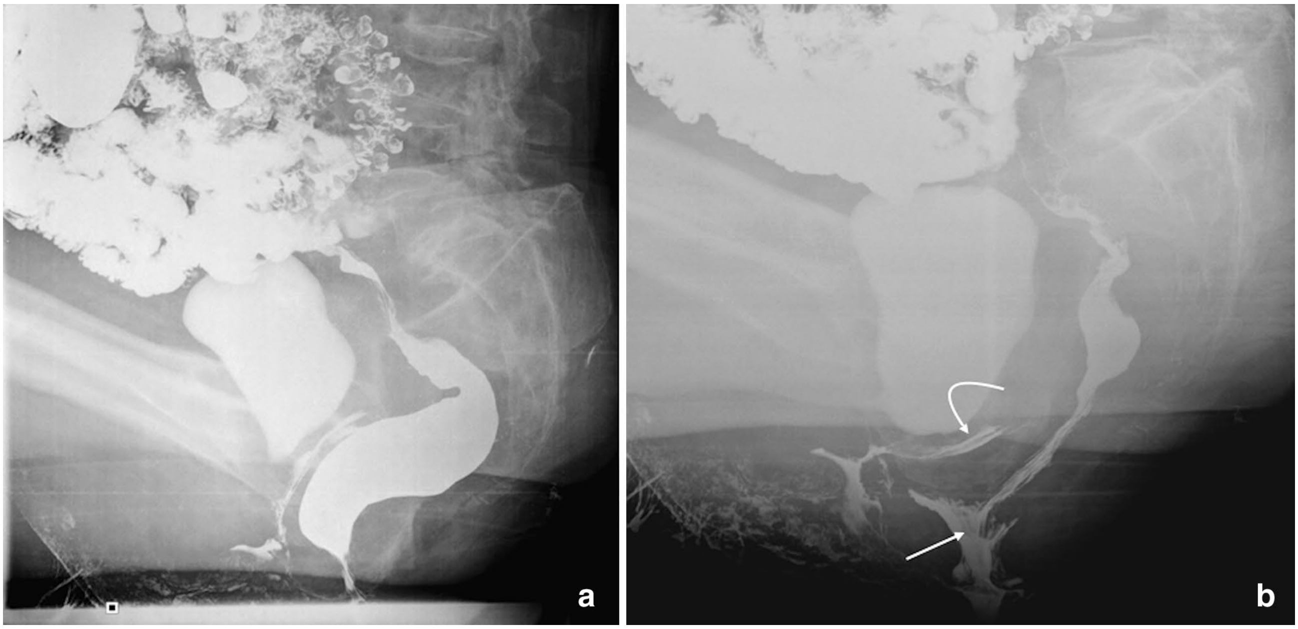

Fig. 3 Entero-colpo-cysto-defecography in latero-lateral views at rest (**a**) and evacuation (**b**). Note the perineal descent with multiple mucosal rectal prolapse and intussusception (straight arrow) and the horizontalization of the vaginal axis (curved arrow) during evacuation

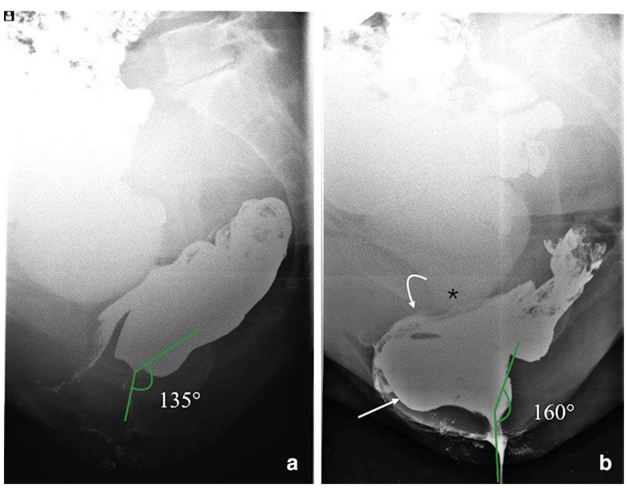

Fig. 4 Entero-colpo-cysto-defecography in latero-lateral views at rest (**a**) and during evacuation (**b**). Note the perineal descent with cystocele (asterisk), horizontalization of the vaginal axis (curved arrow) and rectocele (straight arrow) during evacuation. Green lines in a and b show the ano-rectal angle

For a correct and complete study, the following radiographs should be acquired (Figs. 4, 5, 6):

- Anteroposterior and sagittal views at rest
- Sagittal view during the maximum contraction of pelvic floor muscles
- Sagittal view during straining without defecation
- Sagittal view during evacuation
- Sagittal view during the rest, after evacuation is completed.

Images analysis includes the evaluation of the anorectal junction position, of the posterior vaginal fornix and of the bladder base, at rest and during strain and evacuation. The position of this anatomic structure is referred to the bis-ischiatic line.

Regarding the rectoanal compartment, the following points need to be evaluated:

- anorectal angle: the angle between the anal canal longitudinal axis and the posterior rectal line. Normal values range at rest between 65° and 100°;
- dyskinetic puborectalis muscle syndrome: lack of pelvic floor descent during straining and evacuation and paradoxical contraction of the levator ani;
- intussusception and rectal prolapse;
- rectocele: bulge of the anterior rectal wall, more than 2 cm from the longitudinal anal canal axis (Figs. 4, 5);
- descending perineum syndrome: perineum muscles hypotonia with impaired evacuation and incomplete emptying of the rectum. It is defined at imaging as a migration of the anorectal junction major of 3 cm during straining, and the anorectal angle of more than 130° at rest, increasing more than 155° during straining (Figs. 4, 5) [6, 54].

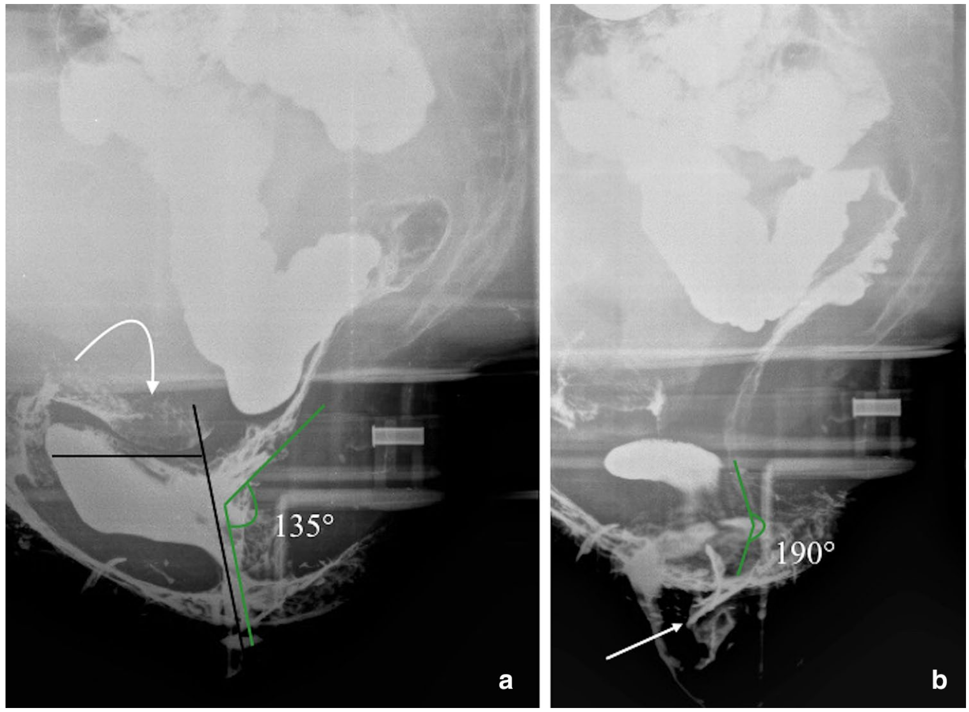

Fig. 5 Entero-colpo-defecography in anteroposterior and latero-lateral views in evacuation (**a**) and post-evacuation (**b**) phases. Note the perineal descent, the rectocele (**a** black lines), the horizontalization of the vaginal axis during evacuation (**a** curved arrow), and a complete mucosal external prolapse seen in the post-evacuation phase (**b** arrow). Green lines in **a**, **b** show the ano-rectal angle

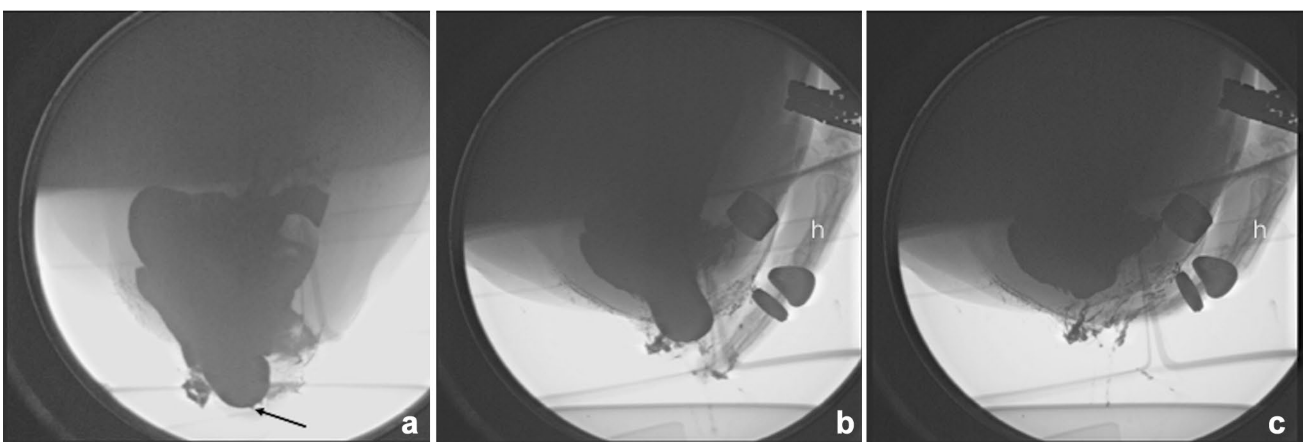

Fig. 6 Video entero-defecography in latero-lateral views during evacuation (**a**) and self-repositioning of the enterocele by hand (h) (**b**, **c**). In **a**, the arrow shows a small intestinal loop entering in the rectal ampulla and causing the eversion of the rectal wall (edrocele) (**a**)

Regarding the middle compartment, it is important to detect abnormal descent of the uterus (hysterocele) or vaginal vault prolapse. About the bladder, the presence of bladder neck hypermotility or funneling and the presence of cystocele need to be detected.

It is also important to evaluate if there is an abnormal descent of the peritoneal fat or intestinal loops in the Retzius', vesicovaginal space, or Douglas' space. These conditions: omentocele, enterocele, sigmoidocele, known as midline pelvic floor hernias, are identified when the peritoneal fat and/or the intestinal loops occupy more than a third of the space causing an increase of each space [5].

All these conditions can be adequately assessed only if the examination is conducted with four contrasts.

The mentioned disadvantages of the X-ray examination, progressively promoted the scientific interest in MR developments.

MR defecography

MR, due to its properties and to the high-contrast resolution, allows to obtain a detailed visualization of the pelvic floor structures and pelvic organs in a less invasive way, without using ionizing radiation, of intravenous contrast medium and without bladder catheterization (Table 1) [9, 55–62]. MR defecography was first described by Yang et al. in 1991 and now it represents the best imaging method to explore the pelvic floor disorders, allowing a wide view of the pelvis. The total examination time took about 25–30 min to be completed. Rectal cleaning is unnecessary, whereas the bladder has to be moderately distended so, if completely empty; the patient is invited to drink 400 mL of water about 15 min before the examination. Once the patient is on the table of the MR, in the left side position, rectum and vagina (in female patients) are filled with 200 mL and about 25–30 mL, respectively, of ultrasonographic gel [58, 63]. The patient is then supine positioned wearing a large pad.

After an initial localizer in the three different planes, the study protocol includes static and dynamic sequences (Tables 1, 4). Static MR images visualize pelvic floor anatomy and defects of the supporting structures, while dynamic MR images visualize pelvic organ mobility, pelvic floor weakness, pelvic organ prolapse and associated compartment defects [3, 5, 6, 64–66].

T2-weighted (W) sequences are the most useful in the evaluation of the pelvis, T1W sequences are added to evaluate signal changes of anatomical structures or abnormal findings, other sequences as T2W with fat suppression or

Table 4 Suggested protocol for MR defecography

	TSE T2W sag	TSE T2W ax	TSE T1W ax	TSE T2W axial and coronal to the urethral axis	TrueFISP T2W sag[a]
Matrix	181 × 256	181 × 256	181 × 256		181 × 256
Slices	25	25	25	30	1
Thickness	4 mm	5 mm	5 mm	3 mm	8 mm
TR/TE	5370/126	6430/114	611/11	5744/103	3.75/1.6
Flip angle	180°	180°	150°		80°

TSE turbo spin echo, *True-FISP* true fast imaging with steady-state precession, *W* weighted, *sag* sagittally oriented, *ax* axially oriented

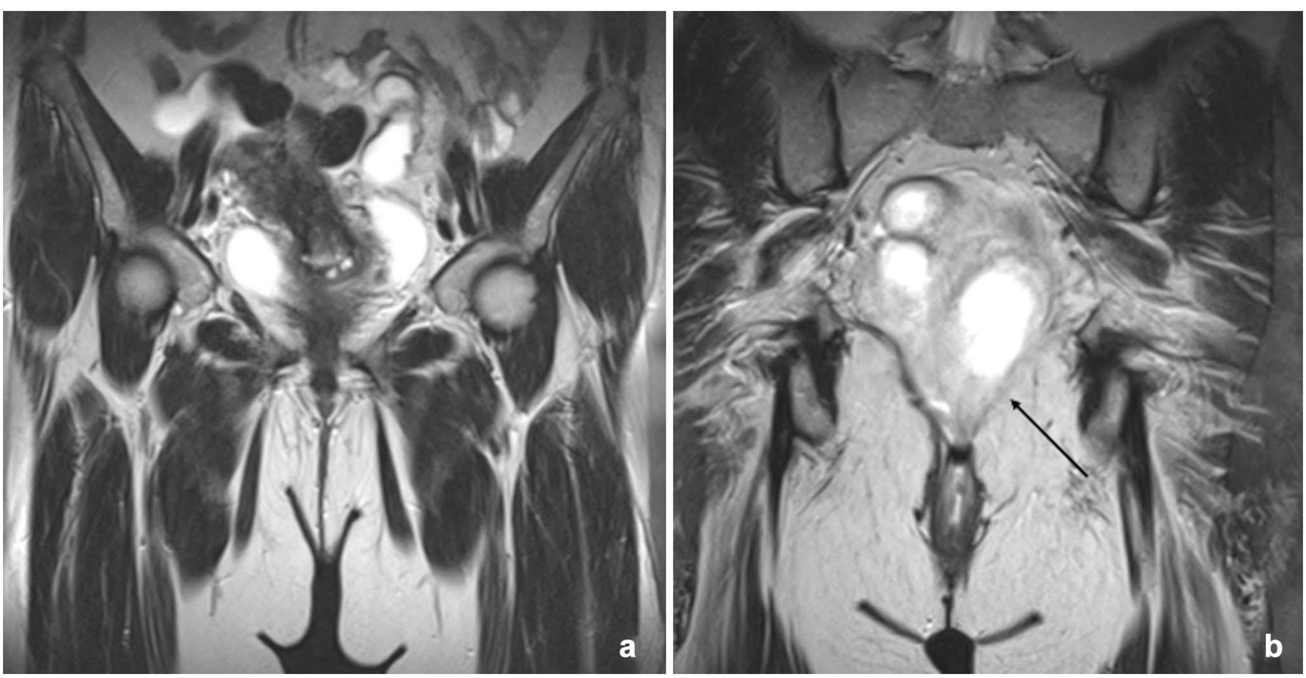

Fig. 7 MR defecography examination in supine position: T2W sequences at rest in the coronal plane (**a**). The coronal plane is oriented on the urethral (**a**) and anal canal axis (**b**) allowing us to evaluate the muscular structures and their symmetry. Note in **b** the asymmetry of the external sphincter and the levator plate with hypotrophy on the left side related to the previous surgery (arrow)

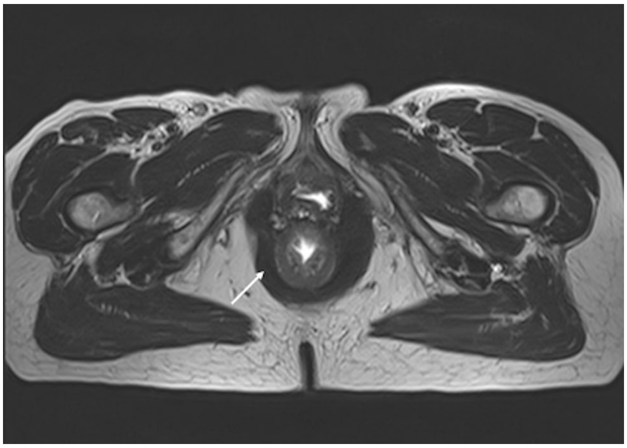

Fig. 8 MR defecography examination: T2W sequences at rest in the axial plane showing the hypertrophy and asimmetry of the external sphincter (arrow) due to a rectoanal mucosal prolapse

DWI can be used in specific cases, to characterize pathological processes [67].

In the T1W and T2W static sequences, it is possible to identify all the muscles and supporting ligaments, looking for muscular and fascial asymmetries, defects, pathological thickening or thinning, and irregularity of the contours (Figs. 7, 8), as well as the physiological thickness and integrity of the internal and external anal sphincters and of the puborectalis muscle [4]. These features are better evaluated in the axial and axial oblique planes, oriented perpendicularly to the anal canal axis.

So, MR examination begins with axial T1W and T2W sequences of the pelvis, including the anal canal, and is followed by T2W acquisition on sagittal plane allowing to define the position of the pelvic organs in the pelvis, detecting and measuring the perineal descent and the organ prolapse (Fig. 9). The position of the pelvic organs is assessed by measuring the perpendicular distance of the pelvic organs in respect to a reference line. There is no standardized method for evaluating pelvic floor descent on MR, and different reference lines, as the pubococcygeal line (PCL) or the midpubic line (MPL), may be used. There are several studies attempting to assess the relationship between clinical examination and MR using both the PCL and the MPL, with different results. Broekhuis et al. [68] found the PCL line most reliable to use in a cohort of 30 symptomatic patients. Pannu et al. [69] found no significant difference between the MPL and the PCL and the agreement with clinical exam for diagnosing pelvic organ prolapse. Rosenkrantz et al. [70] found that the MPL yields the greater frequency of prolapse than the PCL, even if findings of pelvic organ prolapse observed in asymptomatic patients are of uncertain significance and requires correlation with clinical and physical examination findings. A recent study evaluated the impact of the PCL position on hiatal descent grading, comparing different ways to draw the PCL and found that PCL with the posterior point located at the tip of the coccyx is a reliable and highly reproducible option to correctly grade the pelvic floor descent [71].

The position of the pelvic organs is then assessed measuring the perpendicular distance of the bladder base, the

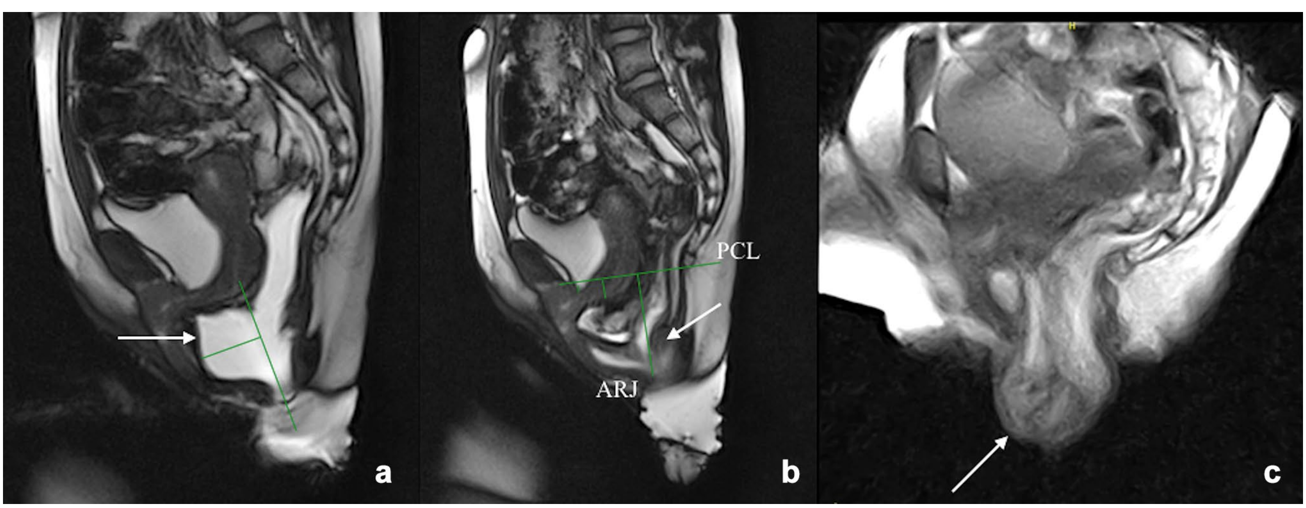

Fig. 9 MR defecography examination: T2W dynamic sequences in sagittal plane acquired in the supine position (**a**, **b**) and in the sitting position on a dedicated magnet during evacuation (**c**). The same patient showed in Fig. 5. Note the pathological perineal descent and the rectocele (**a** arrow) measured in straining phase (green lines) with rectal intussusception that can be appreciated only in the defecation phase (**b** arrow). Green lines in **b** indicate the measures of pelvic organs descent. The examination performed in the sitting position (**c**) allows us to detect the external rectal prolapse (arrow) that cannot be seen in the supine position (**b**)

vaginal fornix or vaginal vault (in female), and the anorectal junction (ARJ) in respect of the PCL line identifying the pubococcygeal plane (PCP) (Fig. 9). The PCP is the plane located from the inferior margin of the symphysis pubis to the last coccygeal joint. The ARJ is the point of reference for perineal descent and it is identified as the transition point between the end of the rectum and the anal canal.

A descent of more than 1 cm at rest of the bladder base and of the posterior vaginal fornix or vaginal vault in respect of the PCP is considered suggestive for prolapse, respectively, whereas a position lower than 3 cm of the ARJ in respect of PCP is indicative of perineal descent [6].

Regarding the organ prolapse, in the sagittal plane, it is possible to appreciate the presence of bladder neck funneling and cystocele, hysterocele or vaginal vault prolapse, and rectocele. Also, the attention should be paid to the peritoneal compartment, important for the surgical planning, detecting the presence of midline pelvic floor sagittal hernias, prolapse, and herniation of the peritoneum and/or peritoneal viscera in the Douglas', Retzius' and retrorectal spaces [5, 72]. Actually, these findings are seen at rest in the really serious condition, most commonly can be appreciated in the dynamic sequences of the study that allow us to explore the whole functionality of the pelvic floor with a real-time evaluation.

Sagittal static acquisitions are also important to specifically orient dedicated sequences to study the anal sphincters or the urethra. Indeed, especially in female patients complaining for urinary incontinence, it is suggested to evaluate the morphology of the pubourethral, periurethral, and paraurethral ligaments [73, 74] on dedicated thin thickness T2W sequences (3–3.5 mm) acquired in axial oblique planes (Fig. 10). In these patients, may be better to avoid the vaginal distension as it may anteriorly displace the urethra, impairing the visualization of peri and paraurethral ligaments. The coronal plane, oriented on the main axis of the urethra and of the anal sphincters, allows to determine the length of the sphincters and their symmetry.

Morphological static sequences are then followed by dynamic sequences. These are balanced steady-state gradient echo T2W sequences (TRUE FISP, FIESTA, Balanced-FFE) acquired in the midsagittal plane during squeezing and straining phases, with multiple attempts until rectal voiding is reached. The images so obtained are then assembled in cineview in postprocessing.

A descent of more than 1 cm of the bladder base and of the posterior vaginal fornix or vaginal vault in respect of

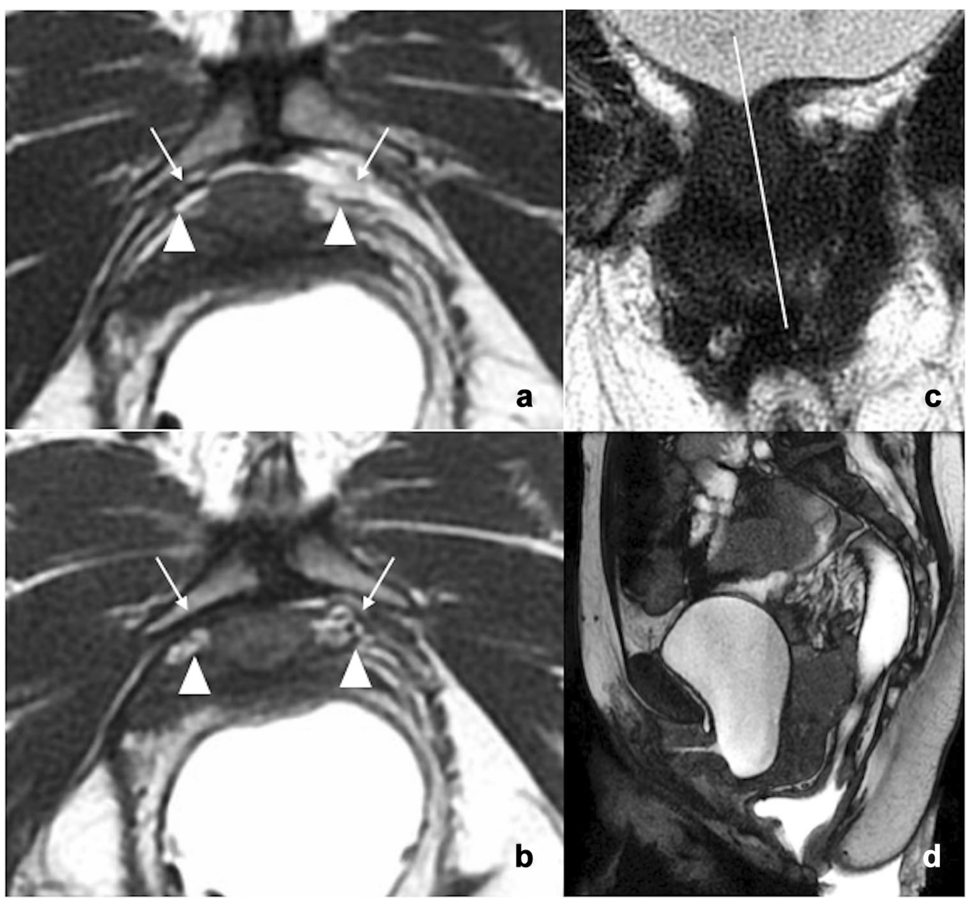

Fig. 10 T2W sequences acquired in axial (**a**, **b**) and coronal (**c**) planes for the dedicated study of the urethra: note the lesion of the left periurethral (**a**, **b** straight arrows) and paraurethral ligaments (**a**, **b** arrowheads) with right deviation of the urethral axis (**c** white line). In the T2W sagittal dynamic acquisition in the evacuation phase (**d**), there is a pelvic floor weakness with bladder neck funneling, cistocele, hysterocele, and anterior rectocele with rectal prolapse

the PCP and an excursion of more than 3 cm of the ARJ between rest and evacuation phases in respect of PCP is indicative of dynamic perineal descent [6].

The evacuation phase cannot be avoided, since it is crucial to detect perineal descent and organ prolapse that may not appear during submaximal strain (Figs. 9, 12, 13) [75–77].

In this phase the dyskinesia of the puborectal muscle, the pathological dynamic descent and the organ prolapse involving anterior, middle or posterior compartment in different combinations can be appreciated.

There are further different ways to quantify the pelvic organs prolapse: the H-line, M-line, organ prolapse (HMO) system [11, 78] mainly used by urologists and some gynecologists, the method proposed by Singh et al. [79] using the same landmark as the clinical grading system (the midpubic line) and the radiologic POP Q (pelvic organ prolapse-quantification) [11, 78] adopted as the reference plane to the plane of the hymen. The last method, using reference points similar to those used in the physical examination, may be better understood by the referring physicians [11]. Whatever the adopted system, it is important to underline that some of the findings detected at imaging have a clinical impact only if related with symptoms, so a detailed anamnestic and physical examination always represents the first step in the evaluation of these patients, as well as the cooperation with the referring clinician.

MR defecography has a pivotal role in the preoperative and postoperative evaluations, considering the availability of new surgical techniques for the correction of pathological perineal descent directed to adequately support the pelvic floor structures [80]. Indeed, MR is the only imaging technique allowing to accurately assess the soft tissues anatomy and the presence of lesions or postoperative complications outlining the entire course of muscles and ligaments in static and dynamic settings [81].

For the surgical planning, it is needed to define in the anterior compartment: the presence of urethral hypermobility and/or bladder neck funneling, usually associated with cystocele (Fig. 11, 12); in the middle compartment: the presence and grading of hysterocele or vaginal vault prolapse (Fig. 12); in the posterior compartment: the presence of rectocele, mucosal internal prolapse, rectal intussusception, sigmoidocele. Regarding the midline hernias, it is important to detect the presence of omentocele and enterocele and in which of the peritoneal spaces they develop. If a complete eversion of the posterior vaginal wall happens, this kind of hernia is called elytrocele (or posterior vaginal hernia) (Figs. 13, 14), if an eversion of the anterosuperior rectal wall occurs an edrocele is diagnosed [4, 5] (Fig. 12). The detection of midline hernias is difficult if the rectal ampulla is filled and so dynamic sagittal images acquired during straining need to be repeated until the evacuation of the endorectal gel [58, 80, 81].

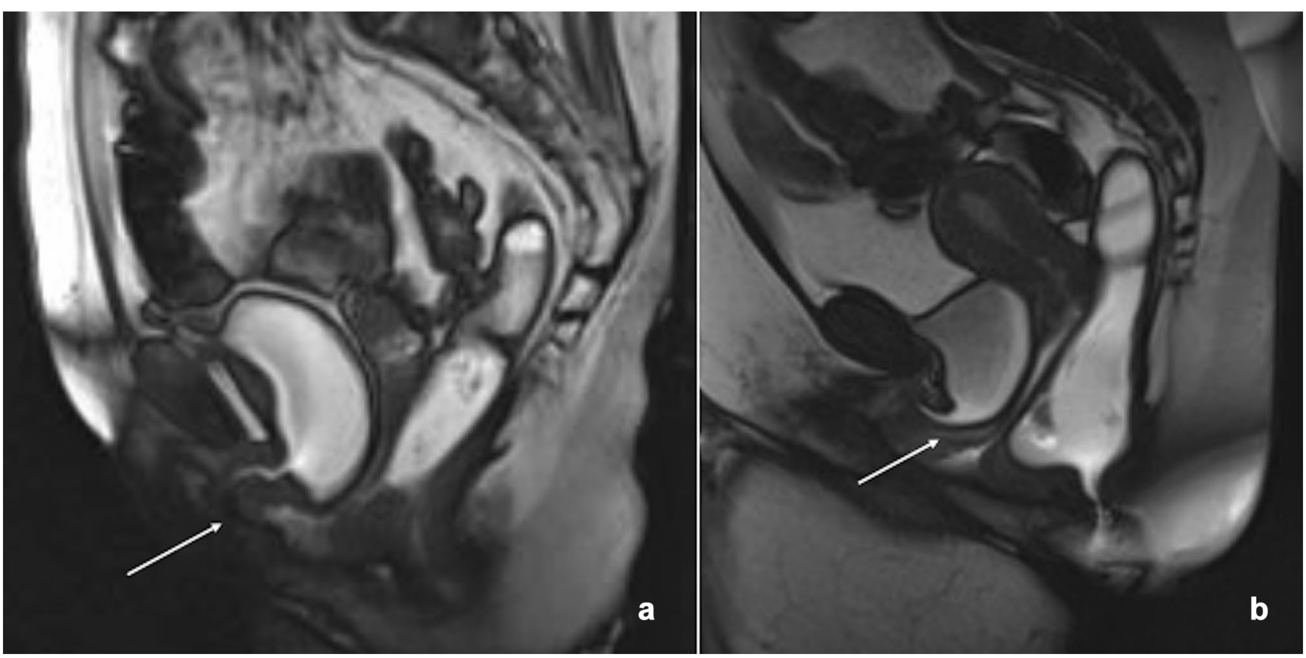

Fig. 11 MR defecography examination: T2W dynamic sequences in the sagittal plane acquired during straining (**a**, **b**) in two different patients. Note the difference between urethral hypermotility (**a** arrow) and bladder neck funnelling (**b** arrow), both of them associated with perineal descent and cystocele

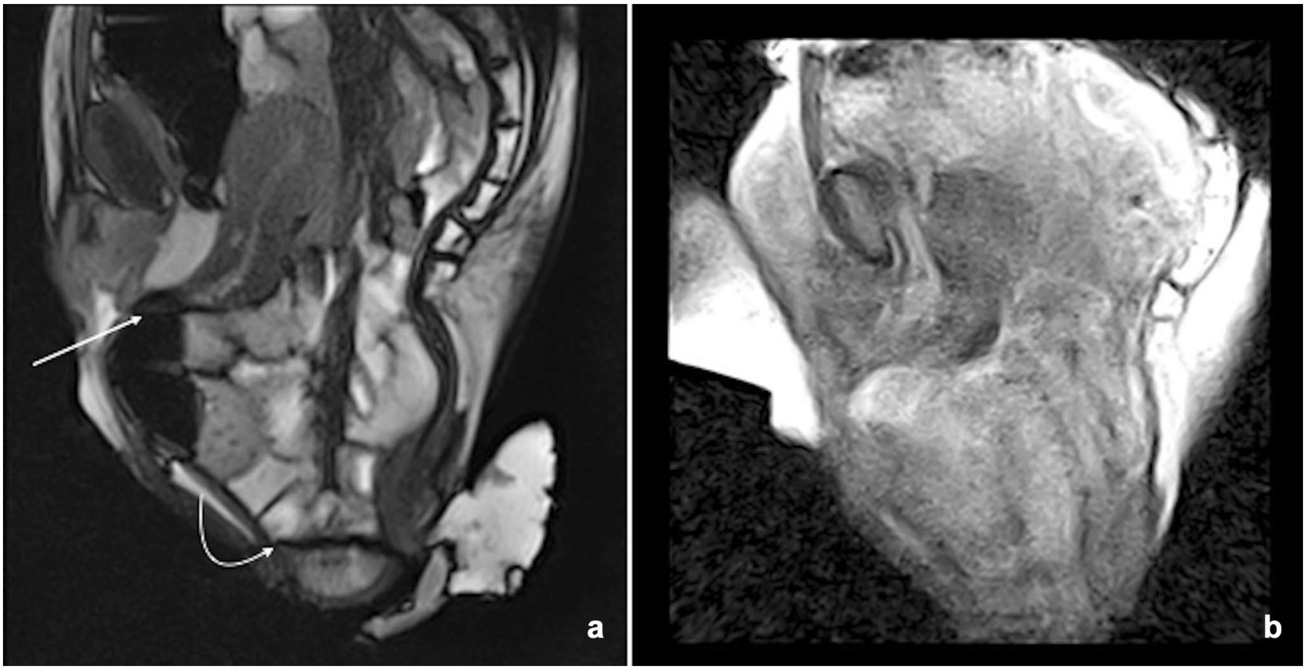

Fig. 12 MR defecography examination: T2W dynamic sequences in the sagittal plane acquired in the supine position (**a**) and in the sitting position on a dedicated magnet (**b**), during evacuation. The same patient showed in Fig. 5. Note the pathological perineal descent with the presence of cystocele, hysterocele (**a** straight arrow), and massive enterocele (**b** curved arrow) causing the eversion of the rectal wall (edrocele). The seriousness of this condition is better seen on the examination performed in the sitting position (**b**)

Fig. 13 MR defecography examination: T2W dynamic sequences in the sagittal plane acquired in the supine position (**a**) and in the sitting position on a dedicated magnet (**b**), during evacuation. Note the pathological perineal descent with the presence of median pelvic floor hernia (omentocele, white arrow) in Douglas' space causing an eversion of the vaginal wall (elytrocele), better seen in the sitting position (**b** arrow)

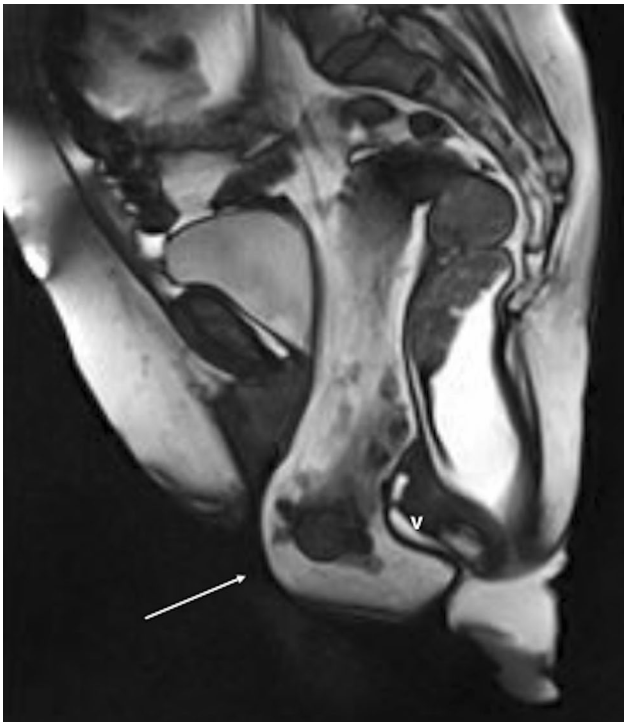

Fig. 14 MR defecography examination: T2W dynamic sequences in the sagittal plane acquired in the supine position in evacuation phase. Note the pathological perineal descent with the presence of a rare condition: omentocele and enterocele herniating anteriorly to the vagina (v), in the vesicovaginal space (arrows)

A limit in the detection of perineal descent and organ prolapse may be represented by the unphysiological supine position [6]. In this sense, several studies were conducted comparing X-ray defecography to the less invasive MR defecography.

The majority of the authors agree that MR defecography is superior to X-ray defecography in imaging all the pelvic floor structures in a non-invasive and more acceptable manner [9, 82], even if MR may show less accuracy than X-ray colpo-cysto-defecography especially, in the evaluation of anterior and middle compartment descents, probably due to imaging performed in the supine position [5, 50, 72, 82–84]. So, X-ray defecography may remain the first-line of investigation for the diagnosis of rectal intussusception, but MR defecography is suggested especially if surgery is planned [85]. No significant differences between X-ray defecography and MR defecography were detected in the evaluation limited to the the posterior compartment [86]. When adopting MR defecography, especially if it lacks the evacuation phase, clinicians need to be mindful about the risk of underdiagnosis particularly related to underestimation of rectoceles, intussusceptions, and descent of the anterior and middle compartment and so consider the use of additional imaging with X-ray defecography in case of suboptimal results [87]. In our opinion, this represents the advisable approach. In a recent study [88] comparing the utility of supine MR defecography with upright voiding cystourethrogram (VCUG) for the evaluation of cystocele and urethral hypermobility (UHM), the authors found that supine MR defecography demonstrates significantly higher prevalence and degree of cystocele and UHM than upright VCUG and alters the grade of bladder prolapse in a significant portion of the patient population. However, cystocele size on MR defecography correlates with clinical presence of prolapse symptoms. Actually, these results are in contrast with those of other studies and in our opinion, they may be influenced by the presence of the catheter during upright VCUG and with

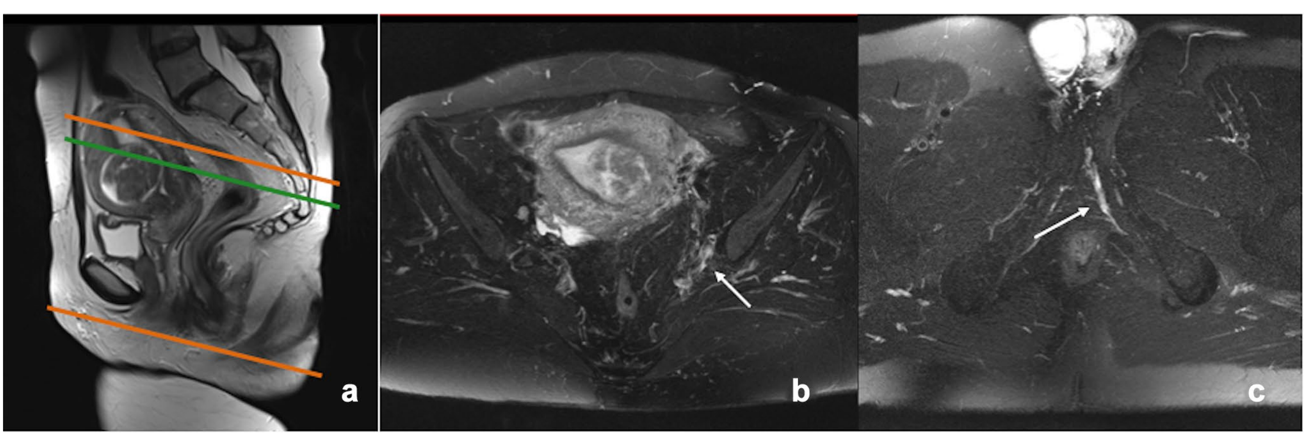

Fig. 15 MR examination performed for the evaluation of pudendal nerves in a female (**a**, **b**) and a male (**c**) patient complaining for pelvic, perianal pain. In **a** note the orientation of the T2 fat sat sequence showed in **b**. In **b**, obtained at the green line showed in a, there is a slight hyperintense signal surrounding the pudendal nerve in the Alcock canal (**b** arrow); in **c** an hyperintense signal surrounding the peripheral left branch of pudendal nerve is seen (arrow)

the differences in measuring the prolapse between the two examinations.

The presence of pelvic floor descent may be related with pelvic pain and pudendal neuropathy. The etiology of the pudendal neuropathy is still not well known. One of the hypotheses is that the progressive perineal descent causes stretching of the nerve increasing its inflammation [89]. If among the symptoms the patient complains for pelvic pain, T2W fat sat sequences expressly oriented to image the pudendal nerves can be added to the MR examination. If it is involved in the inflammatory process, an asymmetric hyperintensity in the T2W sequences affecting the nerve can be seen (Fig. 15) [89].

Advances in MR defecography

The main limitation of the standard MR defecography is related to the patient position during the examination that is not physiological and so the open magnets were studied to perform the examination in the physiological sitting position [6, 90–92]. These kinds of magnets, as well as the adopted sequences, are still not standardized and the role is currently debated in the literature.

In our Institution, a dedicated magnet was developed modifying an open tilting magnet system commonly used for the musculoskeletal examination: the magnet was positioned at 90° and a dedicated commode equipped with a flexible single-channel receiving coil, specifically designed, was inserted into the magnet. This allowed patients to be studied in the physiological position adopted during defecation [6]. The dynamic sequence was specifically designed for this new prototype: it is a balanced steady-state gradient echo sequence allowing us to repeatedly acquire images of the same layer previously selected.

Patient preparation and the examination time are the same described for the supine MR defecography.

In our series, were examined the results of static and dynamic pelvic MR performed in the supine position versus the sitting position in 31 patients with pelvic floor disorders [6]. In comparison with other published studies [90–93], this is the largest series of patients evaluated both in supine and in sitting positions, in a referral center with large experience, adopting an open system magnet.

At rest and in squeezing phases, the positions of the pelvic organs resulted significantly different when the patient was imaged in the two different positions (Figs. 9, 12), suggesting that the MR study in the supine position underestimates the fixed pelvic floor descent [6].

During the evacuation phase in the sitting position, the bladder and the vagina were located significantly lower than in the same examination phase in the supine position, whereas a significant difference for the perineal descent was not found suggesting that the maximal level of pelvic floor descent is more influenced by the muscles elasticity and by the pelvic floor muscle voluntary contractions than by the gravity force. Consequently, the MR in the supine position overestimates the grade of the dynamic descent of the pelvic floor [6].

The examination performed in the physiological position allows us to obtain the evacuation in almost all the patients and consequently, pathological conditions more evident in this phase as cystocele, hysterocele, rectocele and rectal intussusception and midline hernias can be assessed in detail (Figs. 9, 12).

MR defecography in the sitting position, allowing us to correctly diagnose and grade the pelvic organ descent and to obtain a detailed view of the pelvic ligaments and muscles without ionizing radiations, may be proposed as the all-in-one modality to explore the patients complaining for pelvic floor disorders.

Conclusion

Pelvic floor dysfunctions embrace a large series of different conditions in which functional abnormalities of the pelvic floor lead to impairment in urinary, rectal voiding, and sexual functions.

An integrated imaging approach is needed in the evaluation of these patients, adequate to explore the complex anatomy of the region and its dynamic functionality. Available imaging studies include: endoanal and transperineal ultrasound, X-ray defecography, and MR defecography.

The role of endoanal ultrasound in pelvic floor functional diseases is focused on the detection of sphincter defects, infectious process, or neoplastic diseases of the anal canal. Dynamic transperineal ultrasound may be helpful in exploring some functional diseases of the pelvic floor.

X-ray defecography represents 'gold standard' in the assessment of the pelvic floor functional disease allowing the evaluation of the defecation process in the physiological sitting position, however MR defecography has the advantage of a high resolution and detailed morphological and dynamic evaluation of the pelvic floor structures and pelvic organs in a non-invasive way. The main limitation is related to the supine position of the patient during the examination. New MR system allows to perform the examination in the physiological sitting position may be proposed as the all-in-one modality to explore the patients complaining for pelvic floor disorders.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement This manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

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