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Dynamic pelvic floor imaging: MRI techniques and imaging parameters

Caecilia S. Reiner,[1] Dominik Weishaupt[2]

[1]Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, Raemistrasse 100, 8091 Zurich, Switzerland
[2]Division of Radiology, Triemli Hospital, Zurich, Switzerland

Abstract

Magnetic resonance imaging (MRI) is an excellent tool to understand the complex anatomy of the pelvic floor and to assess pelvic floor disorders. MRI enables static and dynamic imaging of the pelvic floor. Using static T2-weighted sequences the morphology of the pelvic floor can be visualized in great detail. A rapid half-Fourier T2-weighted, balanced steady state free precession, or gradient-recalled echo sequence are used to obtain sagittal images while the patient is at rest, during pelvic squeeze, during pelvic strain and to document the evacuation process. On these images the radiologist identifies the pubococcygeal line (PCL) (which represents the level of the pelvic floor). In normal findings, the base of the anterior and the middle compartment are above the PCL at rest, and the pelvic floor elevates during contraction. During straining the pelvic floor muscles should relax and the pelvic floor descends normally less than 3 cm below the PCL. Pelvic floor MRI based on the static and dynamic MRI sequences allows for the detection and characterization of a vast array of morphologic and functional pelvic floor disorders. In this review, we focus on technical aspects of static and dynamic pelvic floor MRI.

Key words: Dynamic MRI—Pelvic organ prolapse—Pelvic floor

Pelvic floor anatomy

The pelvic floor is a complex anatomic and functional unit and provides support for the pelvic organs. The main support structures of the pelvic floor are the endopelvic fascia and ligaments, the pelvic diaphragm and the urogenital diaphragm. Intact structures of the pelvic floor are a prerequisite for maintaining fecal and urinary continence and for normal coordination of relaxation during defecation and urination.

Visualization of the endopelvic fascia and ligaments is still challenging with magnetic resonance imaging (MRI). Histologically the endopelvic fascia is better described as endopelvic connective tissue, which covers the levator ani muscles and pelvic organs, and attaches to the pelvic bones. In recent literature three different ligaments of the pelvic floor named periurethral, paraurethral, and pubourethral ligaments supporting the urethra and the bladder neck have been described in MRI studies [1–3].

The pelvic diaphragm is the part of the pelvic floor best visualized on MRI. It consists of four muscle groups: the levator ani muscle formed by the puborectalis, the pubococcygeus and the iliococcygeus muscle, and the ischiococcygeus muscle (Fig. 1). The pelvic floor muscles play an integral role in pelvic floor support.

The urogenital diaphragm is the most caudal structure of the pelvic floor and stretches horizontally between the ischial rami extending to the external sphincter of the anal canal (Fig. 2). The urogenital diaphragm consists of connective and muscular tissue.

Three-compartment model

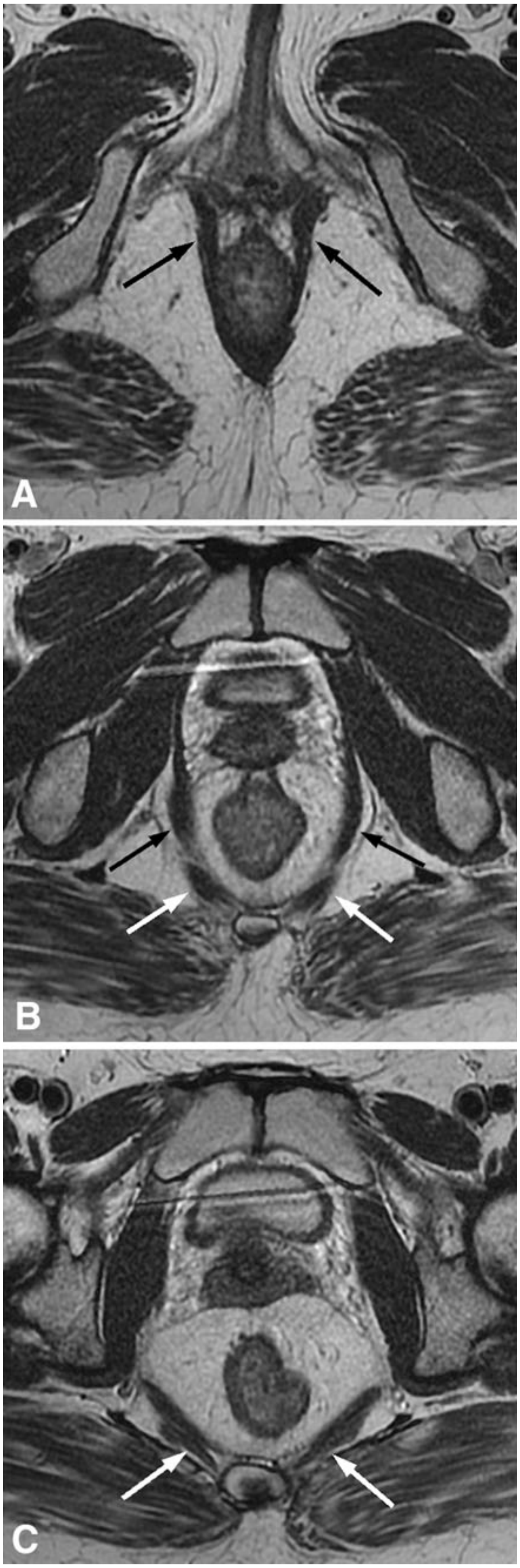
In clinical routine a simple anatomic concept of the pelvic floor has gained acceptance. Especially for treatment planning, the female pelvic floor may be separated into three functional compartments: the anterior compartment (bladder and urethra), the middle compartment (vagina, cervix, uterus, and adnexa), and the posterior compartment (anus and rectum). Pelvic floor pathologies are usually complex conditions involving one or more compartments [4].

Technical aspects

Patient positioning

Dynamic pelvic floor imaging is usually performed in the supine position in a clinical closed-configuration MR

Correspondence to: Caecilia S. Reiner; *email:* caecilia.reiner@gmx.at



◀ **Fig. 1.** Axial T2-weighted fast spin-echo images show a normal pelvic diaphragm of a 29-year-old female patient. The pelvic diaphragm is formed by the puborectalis muscle (*black arrows* in **A**), the pubococcygeus (*black arrows* in **B**), the iliococcygeus (*white arrows* in **B**), and the ischiococcygeus muscle (*white arrows* in **C**).

system. MRI may be performed in the physiologic seated position if an open-configuration MR system is available.

Only few studies investigated the influence of the body position on pelvic floor pathologies and defecation. The only study comparing MRI in sitting and supine position found that they were equally effective in identifying most clinically relevant abnormalities of the pelvic floor. According to the study of Bertschinger et al. [5], imaging patients in supine position affects the diagnosis of intussusceptions, as all intussusceptions found in seated position were missed in supine position. However, these results should be interpreted with caution, knowing that most pelvic floor pathologies show their full extent only during evacuation [6], which was not performed during supine imaging in the aforementioned study. One study comparing supine MRI and sitting conventional defecography found no differences for the position of the anorectal junction (ARJ) and the anorectal angle (ARA) [7]. In contrast, a study using conventional defecography showed significant differences for ARA and pelvic floor descent between left lateral decubitus and seated position [8]. In another study performing clinical examinations with the balloon expulsion test, differences in the defecation maneuver were found for different body positions [9]. For adequate image interpretation it is important to keep these possible differences in mind and to perform imaging in a standardized fashion using always the same body position. In order to maximize straining efforts and to facilitate evacuation in the supine position, a wedge can be placed underneath the patient's knees.

Patient preparation

There is no uniform approach to patient preparation in the literature. The use of contrast agent for opacification of pelvic organs in MRI varies among different studies, from the use of no contrast agent to filling of the bladder, vagina, small bowel, and rectum with contrast agent or the placement of markers [10–12]. In accordance with a study by Pannu et al. [13] authorities agree that the evaluation of the posterior compartment of the pelvic floor should be performed with opacification of the rectum. The study showed that MRI with rectal contrast material revealed significantly more pelvic floor abnormalities than MRI without rectal contrast material [13]. The contrast material in the rectum not only helps with the delineation of the rectum, but also allows studying the actual act of defecation.

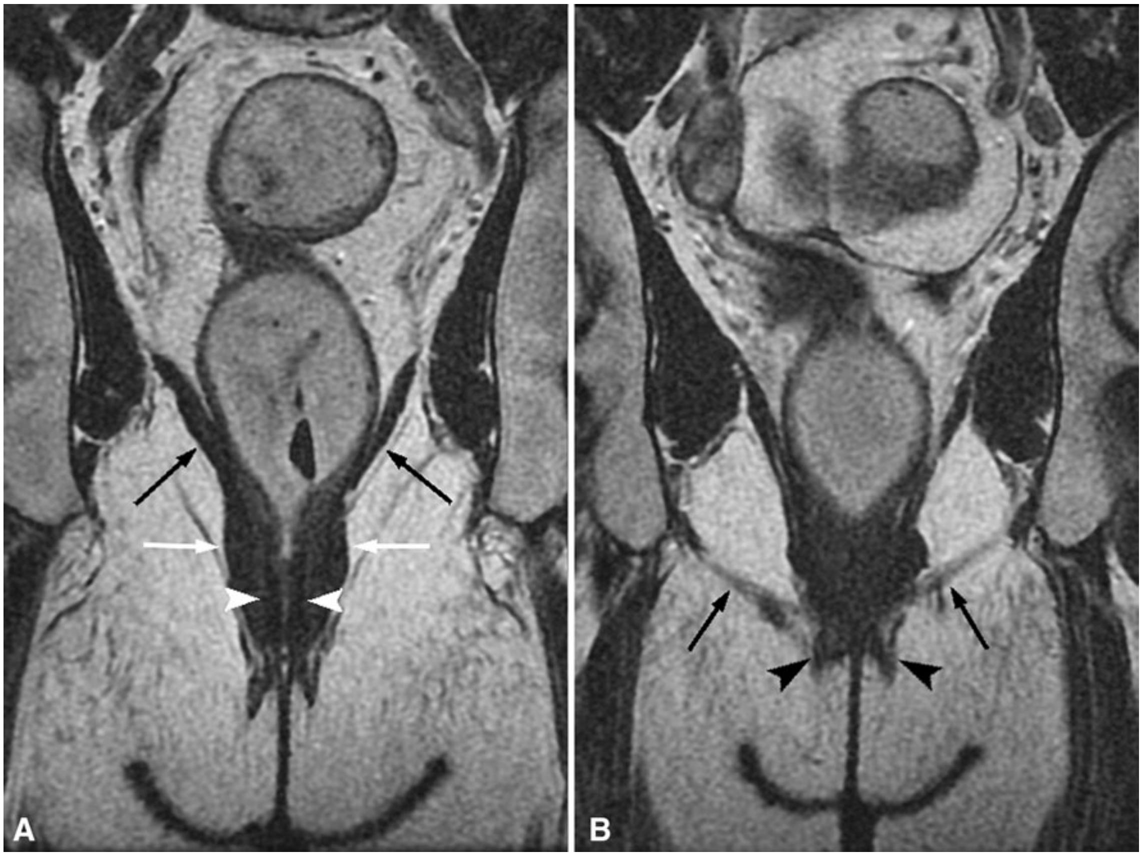


Fig. 2. Coronal T2-weighted fast spin-echo images of the pelvis of a 29-year-old female patient. (**A**) Normal levator ani muscles (*black arrows*), puborectalis muscle (*white arrows*), and internal sphincter of the anal canal (*white arrowheads*) at the level of the rectum. (**B**) Urogenital diaphragm (*black arrows*) extending to the external sphincter of the anal canal (*black arrowheads*).

In our standard imaging protocol, we do not perform opacification of the bladder or vagina with contrast material. For delineation of the bladder we examine patients with a moderately filled bladder. In order to ensure adequate filling, we ask patients not to void the bladder 1 h before the examination. Care has to be taken, that the bladder is not markedly distended, which otherwise might mask pelvic organ prolapse. In the middle compartment the soft-tissue contrast is usually sufficient to identify the anatomical landmarks without extra opacification.

The contrast agent used for the rectal enema should have a stool-like viscosity to imitate the evacuation phase. Studies have shown that the manifestations of pelvic floor pathologies vary with different fecal consistency [14, 15]. Authors recommend ultrasound gel [6, 16, 17] or potato starch [5, 18, 19]. The advantages of ultrasound gel as a rectal enema are that it is widely available, no special preparation is necessary, and it is easy to administer. The major disadvantage is that ultrasound gel is less viscous than potato starch. This limitation can be overcome by adding methylcellulose making the rectal enema more viscous. If potato starch is used as rectal enema it needs to be mixed with gadolinium-based MR contrast agent.

Immediately before the examination, the rectum is filled with contrast agent with the patient in left lateral decubitus position on the MR scanner. The contrast agent is instilled via a rectal catheter. The amount of contrast agent is variable and ranges between 120 and 300 mL [6, 18, 20]. Investigators either use a standardized amount of contrast agent or administer contrast agent until the patient feels a sustained desire to defecate. Until now it is not known whether the amount of contrast agent administered affects the extent of pelvic floor pathologies. However, the time needed to evacuate the contrast agent, and thus the assessment of the evacuation ability considerably depends on the amount of contrast agent. Therefore, a standardized volume of contrast agent should be used.

Beside the administration of contrast agent, a clear instruction of the patient about the procedure of the examination is essential. Patient cooperation is critical to obtain useful MR images. Patients need to be instructed about the different steps of the examination with imaging at different pelvic floor positions, including imaging at rest, at squeezing, at straining, and during defecation. In order to protect the scanner from soiling the table is covered with plastic and a stoma bag is fixed to the patient's anus.

MRI protocol

MR imaging is performed with a pelvic phased-array coil covering the pelvis. MRI protocols for dynamic pelvic floor imaging vary between different institutions. A dedicated protocol should include at least one sequence for imaging the patient during straining and evacuation. Usually the MRI protocol includes static and dynamic sequences. Imaging parameters for a standard MRI protocol for dynamic pelvic floor imaging are given in Table 1.

Static imaging. For static imaging non-fat-suppressed T2-weighted fast spin-echo (FSE) or fast recovery FSE sequences in the axial and coronal plane are used. These sequences are used to evaluate the pelvic floor support structures such as the pelvic floor muscles and endopelvic ligaments. Differences in the thickness and position of the levator ani muscles influencing continence can be evaluated. The puborectalis muscle is best visualized in the axial plane and can show some asymmetry as a normal variation (Fig. 1) [21].The iliococcygeus muscle is best visualized in the coronal plane and normally shows convex shape towards cranial. In case of muscle atrophy the iliococcygeus muscle as a part of the levator plate may show a convex shape towards caudal. The endopelvic ligaments are only variably seen when using a pelvic phased-array coil. Because the endopelvic fascia is not directly visualized using a pelvic phased-array coil, attempts have been made to describe secondary signs of fascial defects such as the posterior protrusion of the bladder [22].

Dynamic imaging. The central part of pelvic floor MRI is imaging at the different pelvic floor positions (Fig. 3). The position and eventual prolapse of pelvic organs is best visualized in the midsagittal plane. First, the position of the pelvic organs is evaluated at rest. To view the contractility and thus the strength of the pelvic floor muscles images are recorded during squeezing (contraction of the pelvic floor). In a third phase, including straining and evacuation, pelvic floor pathologies are evaluated. In order to view the full extent of pelvic floor pathologies imaging needs to be performed during evacuation of the contrast agent as shown in a recent study, where a substantial number of pathologic conditions would have been missed if defecation phase images had not been obtained [6]. In the study of Flusberg et al. [6], significantly more rectoceles, enteroceles, and intussusceptions were identified, and also the degree of bladder, uterovaginal, and anorectal descent was significantly more marked on defecation images than on straining images [6].

Different MR sequences can be used for dynamic imaging with the basic prerequisite being a fast image update [23]. T2-weighted single-shot fast spin-echo sequences (SSFSE) or alternatively balanced steady state free precession (bSSFP) sequences may be used for imaging at rest, at squeezing, and at straining. For imaging of the evacuation phase either a bSSFP sequence or a T1-weighted multiphase gradient-recalled echo (GRE) sequence can be used. If the T1-weighted sequence is used, the rectal enema needs to be tagged with a small amount of gadolinium-based MR contrast agent. For imaging the evacuation phase it is important to use a sequence, which offers the possibility to acquire images over a long time period without the necessity to reload the sequence.

Image interpretation

Reference lines

Image interpretation is performed according to the three-compartment model of the pelvic floor [4]. The three compartments are assessed for morphologic changes such as pelvic organ prolapse at different pelvic floor positions. To determine the presence and extent of pelvic organ prolapse, the use of a point of reference is helpful. Several points and lines of reference for measuring pelvic organ prolapse have been proposed [24]. The most commonly used lines are the pubococcygeal line (PCL) and the midpubic line (MPL) both defined on midsagittal images. The PCL is defined as the line drawn from the inferior border of the symphysis pubis to the last coccygeal joint (Fig. 3). The MPL is defined as a line

Table 1. Protocol for MR imaging of the pelvic floor with a 1.5 T MR scanner (Signa HDx, GE Healthcare)

Pulse sequence	TR/TE (ms)	Section thickness/gap (mm)	Matrix (mm)	Field of view (cm)	Flip angle (°)	NEX
T2 FSE axial	2,260/92	3/1	256 × 160	23 × 23	90	3
T2 FSE coronal	5,400/95	3/1	256 × 160	26 × 26	90	2
bSSFP midsagittal[a]	3.6/1.6	10/0	224 × 160	31 × 31	45	2
Multiphase FSPGR midsagittal[b]	7.3/1.7	10/0	256 × 160	31 × 31	80	2

FSE fast spin echo, *bSSFP* balanced steady state free precession (FIESTA), *FSPGR* fast spoiled gradient echo, *TR*/*TE* repetition time/echo time, *NEX* number of excitations

[a] Acquired at rest, at sphincter contraction, and at straining

[b] Acquired during defecation

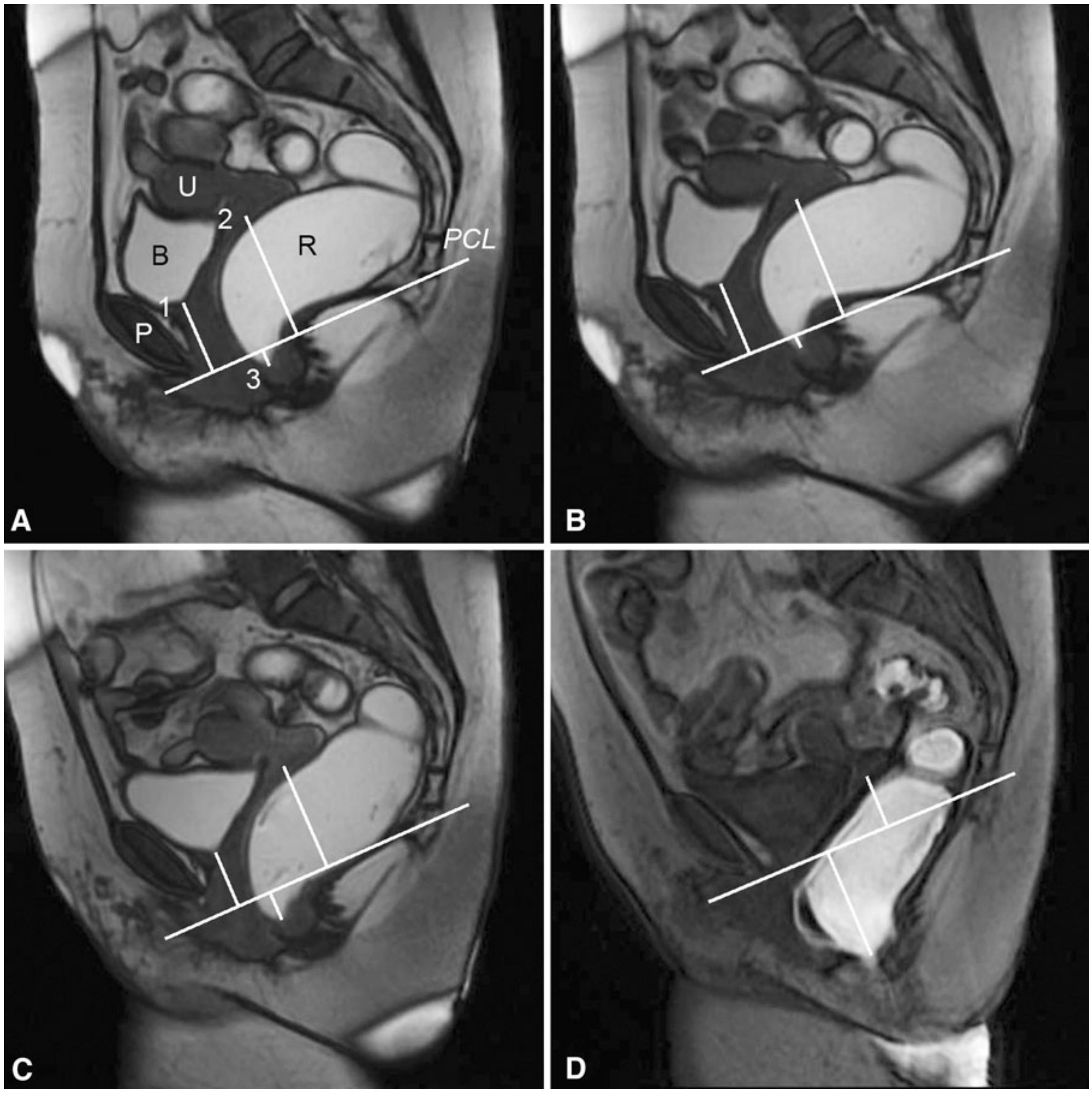


Fig. 3. A 61-year-old patient with chronic outlet obstruction. On midsagittal MR images (**A**–**C** T2-weighted steady state free precession sequence; **D** T1-weighted gradient-recalled echo sequence) obtained at rest (**A**), at squeezing (**B**), at straining (**C**), and during evacuation (**D**) the position of the base of the bladder (*1*, anterior compartment), the vaginal vault (*2*, middle compartment), and the anorectal junction (*3*, posterior compartment) is measured at a 90° angle to the PCL. *P* symphysis pubis, *B* bladder, *U* uterus, *R* rectum, *PCL* pubococcygeal line.

extending caudally along the long axis of the symphysis pubis (Fig. 4). The PCL represents the levator plate, whereas the MPL corresponds to the level of the hymen, which is the landmark used for clinical staging [25]. For measuring pelvic organ prolapse a perpendicular line is drawn from the reference line (PCL or MPL) to the bladder base (anterior compartment), the cervix or vaginal vault (middle compartment), and the ARJ (posterior compartment) (Figs. 3, 4). The ARJ is defined as the cross point between a line along the posterior wall of the distal part of the rectum and a line along the central axis of the anal canal. To determine the stage of pelvic organ prolapse the measurements are made on the images, which show maximal organ descent, usually during maximal straining or during evacuation (Figs. 3, 4). Staging systems for both the PCL and MPL exist (Tables 2, 3).

The choice of the reference line mainly depends on the radiologist and the referring clinician, as none of the two lines have shown clear superiority [24]. The PCL, however, has the advantage of being the most widely used reference line, mainly used by surgeons and gastroenterologists. The MPL is better known among urogynecologists as it is similar to their clinical staging system. Both reference lines show only moderate to poor agreement with clinical staging of pelvic organ prolapse [26], which

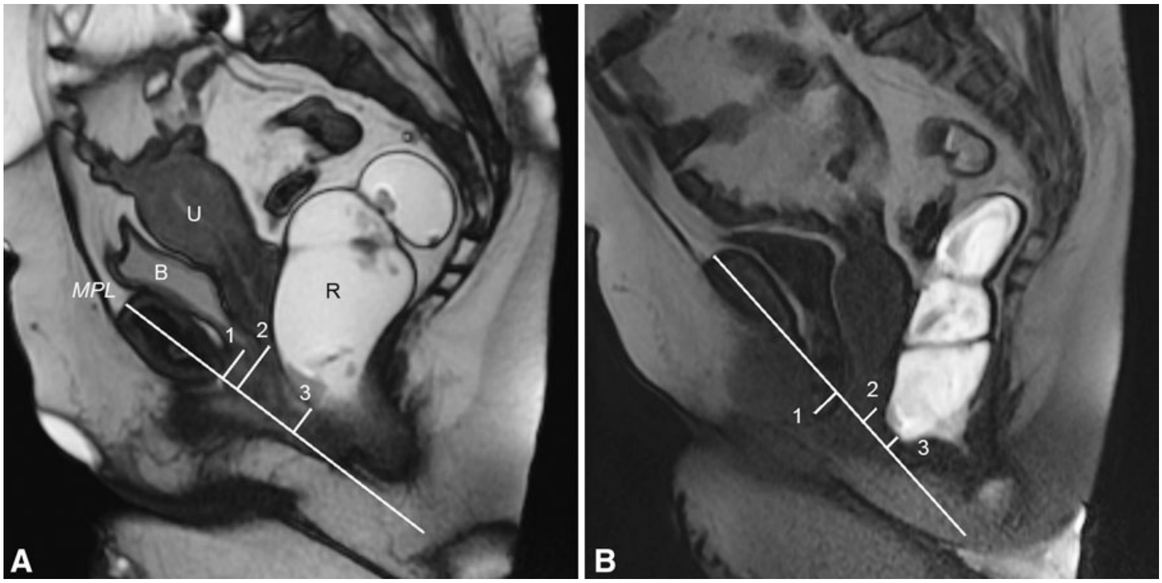


Fig. 4. A 57-year-old female patient with descending perineum syndrome. Midsagittal T2-weighted steady state free precession image obtained at rest (**A**) and T1-weighted gradient-recalled echo image at maximal pelvic floor descent during evacuation (**B**) show measurements of the three pelvic floor compartments (*1*, anterior; *2*, middle; *3*, posterior compartment) with the midpubic line (MPL) used as reference line. *B* bladder, *U* uterus, *R* rectum.

Table 2. Staging of pelvic organ prolapse with the pubococcygeal line (PCL)

Stage	Measurements[a]
Small organ prolapse	<3 cm caudal to PCL
Moderate organ prolapse	3–6 cm caudal to PCL
Large organ prolapse	>6 cm caudal to PCL

[a] As measured for anterior, middle, and posterior compartment during maximal straining or evacuation

Table 3. Staging of pelvic organ prolapse with the midpubic line (MPL)

Stage	Measurements[a]
Stage 0	>3 cm cranial to MPL
Stage 1	1–3 cm cranial to MPL
Stage 2	<1 cm cranial or caudal to MPL
Stage 3	>1 cm caudal to MPL
Stage 4	Complete organ eversion

[a] As measured for anterior, middle, and posterior compartment during maximal straining or evacuation

might be partly due to the fact that anatomical landmarks used for MR measurements and for clinical examination differed in most of the studies. One study using similar anatomical landmarks found good correlations between MR images and clinical staging for the anterior and middle compartment [27].

HMO-system

Beside the measurements in relation to the MPL, another grading system for pelvic floor abnormalities used by urogynecologists is the HMO-system [28]. The HMO-system not only grades pelvic organ prolapse, but also measures pelvic floor relaxation, which are two separate, but often coexisting pathologic entities.

In pelvic floor relaxation, the pelvic floor with its active and passive support structures becomes weakened leading to hiatal descent and hiatal widening. The degree of pelvic floor relaxation is measured using two lines: the H-line, which represents hiatal widening and extends from the inferior aspect of the symphysis pubis to the posterior wall of the rectum at the level of the ARJ and the M-line, which represents hiatal descent and extends perpendicularly from the PCL to the posterior end of the H-line (Fig. 5).

Pelvic organ prolapse is defined as any organ descent beyond the H-line. The organ descent constitutes the O-component of the HMO-system and is measured as the shortest distance between the most caudal aspect of a given organ during maximal straining (bladder, vaginal vault or any part of the remaining cervix in cases with a hysterectomy, small bowel, sigmoid colon) and the H-line (Fig. 5) [28, 29]

The staging system for pelvic floor relaxation and pelvic organ prolapse is given in Table 4. Also HMO-measurements are performed when pathologic findings show maximal extension, usually during maximal straining or evacuation.

Anorectal angle

In addition to the measurements of pelvic floor descent in the three compartments, the ARA can be measured. It is defined as the angle between the posterior wall of the

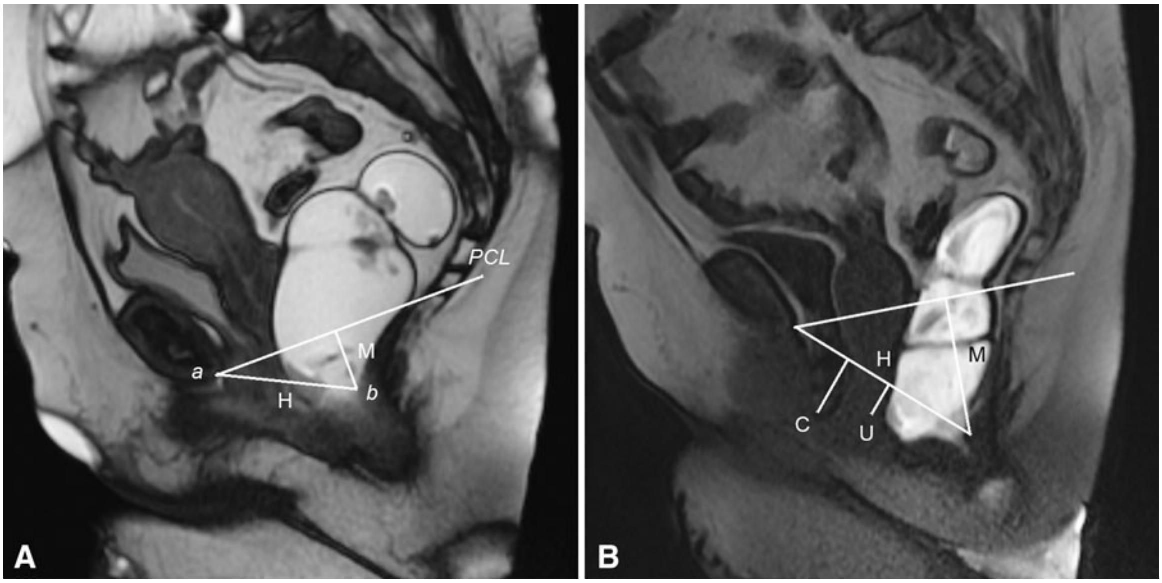


Fig. 5. A 57-year-old female patient with descending perineum syndrome. (**A**) Midsagittal T2-weighted steady state free precession image obtained at rest shows landmarks used in the HMO-system. The landmarks are the inferior aspect of the symphysis pubis (*a*) and the posterior wall of the rectum at the level of the anorectal junction (*b*). The H-line (*H*) represents the anteroposterior hiatal width and extends from *a* to *b*. The M-line (*M*) represents hiatal descent and extends perpendicularly from the pubococcygeal line (*PCL*) to the posterior end of the H-line. (**B**) Midsagittal T1-weighted multiphase gradient-recalled echo image during evacuation shows measurements of organ prolapse according to the HMO-system (*C* cystocele, *U* uterusprolapse).

Table 4. Staging of pelvic floor relaxation and pelvic organ prolapse according to the HMO-system[a]

Stage	H-line	M-line	O-line
0 (normal)	<6 cm	0–2 cm	Cranial to H-line
1 (small)	6–8 cm	2–4 cm	0–2 cm caudal to H-line
2 (moderate)	8–10 cm	4–6 cm	2–4 cm caudal to H-line
3 (large)	≥10 cm	≥6 cm	≥4 cm caudal to H-line

[a] As measured during maximal straining or evacuation

distal part of the rectum and the central axis of the anal canal and can be measured at rest, squeezing, and straining (Fig. 6).

Normal values vary between 95° and 109° for the ARA at rest [7, 30, 31]. During maximum pelvic floor contraction the pelvic floor is elevated and the ARA is decreased by about 10°–20°. During straining and evacuation the pelvic floor descends and the ARA is widened to about 103° to 138° [7, 30, 31]. It has to be noted that the reproducibility of ARA measurements has been debated and questioned in several studies [32, 33], whereas other studies found the ARA a consistent and reliable parameter [34].

Because of the wide range of normal and abnormal ARA measurements it is more important to study the changes of the ARA between the different positions. The angle should decrease from rest to squeezing and should widen during straining and evacuation.

Evacuation ability

In the last phase of dynamic pelvic floor MRI the process of evacuation is evaluated. The time needed for evacuation and the completeness of evacuation can be recorded, as well as the relaxation of the pelvic floor muscles.

The evacuation time depends on the amount of rectal enema. When the rectum is filled with 120 to 200 mL two-thirds of the contrast material should be evacuated within 30 s [20]. For a larger amount of contrast agent of 400 mL the evacuation time is prolonged to 60 s [35].

The assessment of the evacuation time and completeness of evacuation is especially useful in patients with obstructed defecation. The evacuation phase in MRI can reveal reasons for abnormal defecation including rectoceles and intussusceptions.

Normal findings

At rest, the base of the bladder and the cervix or vaginal vault lie at or above the level of the PCL. The ARJ typically projects at or within 3 cm below the level of the PCL. The rectum is filled with contrast medium and should be smooth in outline; the anal canal is closed. During maximum pelvic floor contraction (squeezing) the pelvic floor is elevated in relationship to the PCL and the ARA is decreased. Recording pelvic floor movement when the patient contracts the pelvic floor demonstrates pelvic floor muscle strength. Impaired movement may reflect weakness of the pelvic floor muscles [36]. During

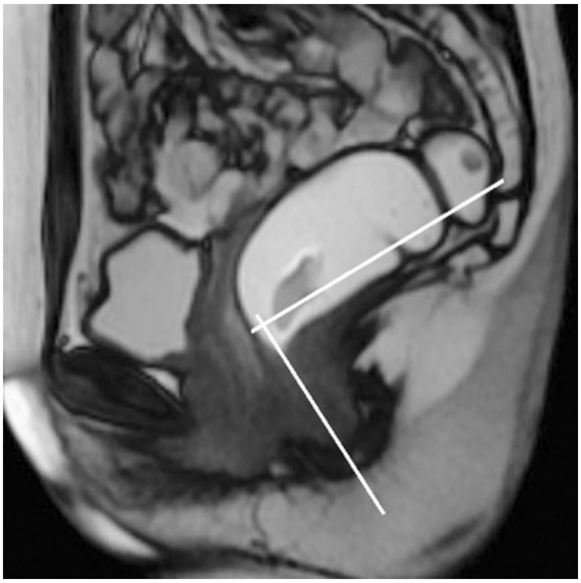


Fig. 6. Midsagittal T2-weighted steady state free precession image of a 47-year-old female patient with measurement of the anorectal angle at rest. The anorectal angle is measured between a line drawn along the posterior border of the distal part of the rectum and a line drawn through the central axis of the anal canal.

straining, the pelvic floor muscles relax and the pelvic floor descends normally less than 3 cm below the PCL. With the descent of the ARJ, the ARA increases. Finally the anal canal opens and the contrast material is evacuated.

Conclusion

Dynamic pelvic floor MRI is a relatively new method, which combines morphologic information of the pelvic floor along with function. Dynamic pelvic floor MRI provides a global examination of the pelvic floor, which is recommended as adjunct to clinical examinations and functional tests for the evaluation of different pelvic floor pathologies in patients presenting with symptoms such as constipation or incontinence.

In order to obtain a diagnostic examination of high quality, certain technical aspects such as the choice of the contrast agent for the rectal enema and imaging of the evacuation phase, need to be considered. Straightforward MR image interpretation is possible using the three-compartment model as a simple anatomical concept of the pelvic floor.

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