Practical Guide to Dynamic Pelvic Floor MRI

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CME

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Educational Objectives

Upon completion of this educational activity, participants will be better able to:

- Identify normal anatomy of anterior, middle and posterior compartments
- Apply reference lines and angles used in assessment of pelvic floor dysfunction
- Identify and grade the severity of pelvic floor relaxation and pelvic organ prolapse

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Pelvic floor dysfunction encompasses a spectrum of functional disorders that result from impairment of the ligaments, fasciae, and muscles supporting the pelvic organs. It is a prevalent disorder that carries a lifetime risk over 10% for undergoing a surgical repair. Pelvic floor weakness presents as a wide range of symptoms, including pain, pelvic pressure or bulging, urinary and fecal incontinence, constipation, and sexual dysfunction. A correct diagnosis by clinical examination alone can be challenging, particularly in cases involving multiple compartments. Magnetic resonance imaging (MRI) allows noninvasive, radiation-free, high soft-tissue resolution evaluation of all three pelvic compartments, and has proved a reliable technique for accurate diagnosis of pelvic floor dysfunction. MR defecography with steady-state sequences allows detailed anatomic and functional evaluation of the pelvic floor. This article provides an overview of normal anatomy and function of the pelvic floor and discusses a practical approach to the evaluation of imaging findings of pelvic floor relaxation, pelvic organ prolapse, fecal incontinence, and obstructed defecation.
Level of Evidence: 5
Technical Efficacy: Stage 2

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Pelvic floor dysfunction is a broad term that encompasses multiple clinical conditions involving the urinary bladder (urinary incontinence and disorders of urinary emptying), rectum (fecal incontinence and disorders of defecation), uterus and vagina (sexual dysfunction, vulvodynia, dyspareunia), and frank pelvic organ prolapse. The symptoms vary in severity and include pelvic pressure and pain, dyspareunia, incontinence, incomplete emptying, and organ protrusion. The prevalence of pelvic floor dysfunction is ~24%, with 16% of women experiencing urinary incontinence, 9% experiencing fecal incontinence, and 3% experiencing pelvic organ prolapse.[1] The proportion of women with pelvic floor dysfunction increases with increasing age, parity, and weight.[1] This group of conditions poses a major healthcare concern, since the lifetime risk of undergoing a single operation for prolapse or incontinence by age 80 is 11%, with 17–29% of patients requiring reoperation.[2–4]

Proper diagnosis of the pelvic floor dysfunction mechanism for an individual patient requires a multidisciplinary approach, which may include evaluation by a urologist, gynecologist, proctologist, and colorectal surgeon. A correct and complete diagnosis by clinical examination alone can be challenging, particularly in cases of posterior vaginal wall prolapse and/or a multicompartment problem.[5,6] Underestimation of pelvic organ prolapse may lead to an incorrect choice of treatment, contributing to high recurrence rates.[7,8] Imaging has become an important complementary tool in the assessment of pelvic floor disorders, and dynamic pelvic floor magnetic resonance imaging (MRI), or MR defecography, has evolved as one of the essential imaging techniques.[9–11] MRI can simultaneously noninvasively evaluate all pelvic floor compartments, and provide information about muscles and ligaments with great contrast resolution, without the use of ionizing radiation and with minimal patient discomfort.[12] While anterior and middle compartment causes of pelvic floor dysfunction can often be detected by physical exam, posterior compartment pathology such as enteroceles, peritoneoceles, and rectorectal intussusceptions are commonly not detected by physical exam but are well visualized by MRI.[13–15] As a result, the American College of Radiology Appropriateness Committee assigned MR defecography with rectal contrast a rating of 9 in patients with clinically suspected pelvic organ prolapse or defecatory dysfunction, and a rating of 7 in patients with urinary dysfunction, where scores 7–9 are interpreted as "usually appropriate."[16]

Anatomy of the Female Pelvic Floor

The pelvic floor serves two major functions; one, to provide structural support for the abdominal viscera, and the other to allow urinary and fecal emptying and continence. The female pelvic floor is divided into three compartments: the anterior compartment contains the bladder and urethra, the middle compartment contains the uterus and vagina, and the posterior compartment contains the rectum and anus. The posterior compartment also contains the anorectal junction, the point where the distal rectum joins the proximal anal canal (Fig. 1).

The three interconnected layers that compose the pelvic floor are the superior endopelvic fascia, the pelvic diaphragm, and the inferior perineal membrane or urogenital diaphragm.

Endopelvic Fascia

The endopelvic fascia is the superior-most and the thinnest layer of the pelvic floor comprised of a network of connective tissues superficial to the peritoneum that covers the pelvic organs and levator ani. The subdivisions of the endopelvic fascia are named based on the organs they cover.

In the anterior compartment, the pubocervical fascia extends from the pubic symphysis to the anterior vaginal wall. Three urethral ligaments that provide support for the female urethra are formed: the ventral transversely oriented periurethral ligament originating from the puborectalis, paraurethreal ligament originating laterally along the urethra and inserting into the periurethral ligaments, and pubourethral ligaments extending from the pubic bone and coursing ventrally to the urethra (Fig. 1).[17,18] Both the anterior vaginal wall and urethral ligaments provide support to the urethra.[19] Damage to these structures may result in a cystocele, urethrocele, and stress incontinence.

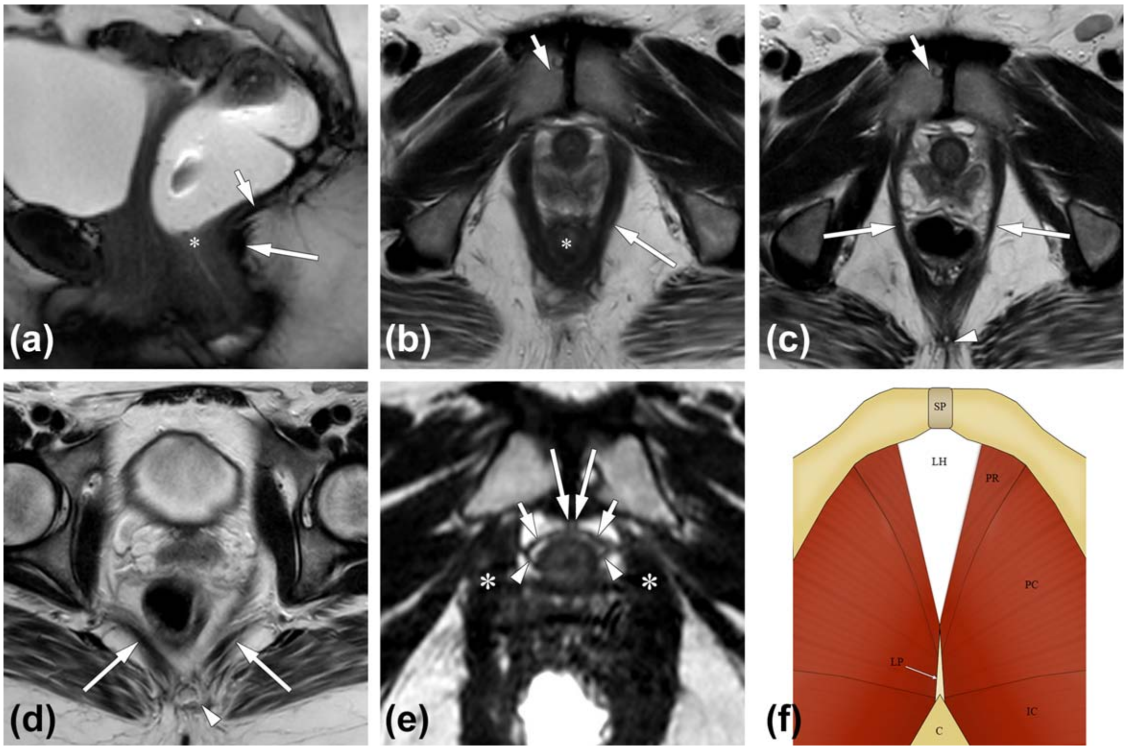


FIGURE 1: Normal pelvic floor anatomy. (a–d) Normal levator ani anatomy, 63-year old female. (a) Sagittal balanced gradient echo sequence demonstrates levator plate (short arrow). Posterior aspect of puborectalis (long arrow) is seen at the level of anorectal junction (*). (b) Axial T_2-weighted image demonstrates the sling of puborectalis (long arrow) originating at the pubis (short arrow) and wrapping around the anorectal junction (*). (c) Axial T_2-weighted image superior to (b) demonstrates the course of pubococcygeous (long arrow) extending from the pubis (short arrow) to the coccyx (arrowhead). (d) Axial T_2-weighted image superior to (c) demonstrates ilicoccygeous fibers (arrows) extending from the obturator fascia to the coccyx (arrowhead). (e) Normal urethral supporting ligaments in a 60-year-old female. Axial T_2-weighted image demonstrates pubourethral ligaments (long arrow) extending from the anterior urethra to the pubis. Periurethral ligaments (short arrow) extend from the point of urethral attachment of the pubourethral ligaments laterally to the medial aspects of the puborectalis muscles (*). Paraurethral ligaments (arrowhead) connect the lateral wall of the urethra to the periurethral ligaments. (f) Schematics illustrating axial view of the pelvic floor muscles. LH = levator hiatus; PR = puborectalis; PC = pubococcygeus; IC = ileococcygeus; LP = levator plate; C = coccyx; SP = symphysis pubis.

The parametrium and paracolpium are the components of the endovaginal fascial condensation in the middle compartment. These surround the vagina, cervix, and uterus and prevent prolapse.

In the posterior compartment, the perineal body, also known as the central tendon of the perineum, lies in the anovaginal septum. It is an anchoring structure for muscles and ligaments. The rectovaginal fascia extends along the posterior aspect of the vagina and anterior wall of the rectum, and attaches to perineal body. A tear in the rectovaginal fascia leads to rectocele formation.[20]

Pelvic Diaphragm

The pelvic diaphragm is the middle layer of pelvic floor support and is comprised of the levator ani and ischiococcygeus muscles. The levator ani is a group of striated muscles made up of the iliococcygeus, pubococcygeus, and puborectalis muscles. These muscles are well seen on pelvic MRI, and are constantly contracting to maintain the tone of the pelvic floor. The puborectalis muscle is a U-shaped muscle that arises from the superior pubic symphysis and forms the levator hiatus around the bladder, urethra, vagina, and rectum (Fig. 1). The puborectalis wraps around the posterior margin of the anorectal junction, forming the impression seen on the sagittal view (Fig. 1). Anteriorly, the pubococcygeus arises from the superior ramus of the os pubis, where it attaches to the fascia of the obturator internus. The iliococcygeus originates from the junction of the fascia of the obturator internus and the tendinous arch of the pelvic fascia.[21] Posteriorly, the iliococcygeus and pubococcygeus insert into the lateral aspects of the coccyx (Fig. 1). Medially, the iliococcygeus and pubococcygeus on either side unite and intertwine with each other, forming a levator plate, a structure posterior to the rectum that provides considerable support to the pelvic viscera (Fig. 1).[21] The ischiococcygeus muscle extends from the coccyx to the ischial spines bilaterally and is a relatively unimportant player of the pelvic diaphragm.[22]

The levator ani muscles are well visualized on MRI (Fig. 1). The pubococcygeus and iliococcygeus muscles may be best evaluated on coronal projection due to the horizontal position of these muscles and their upward convexity.

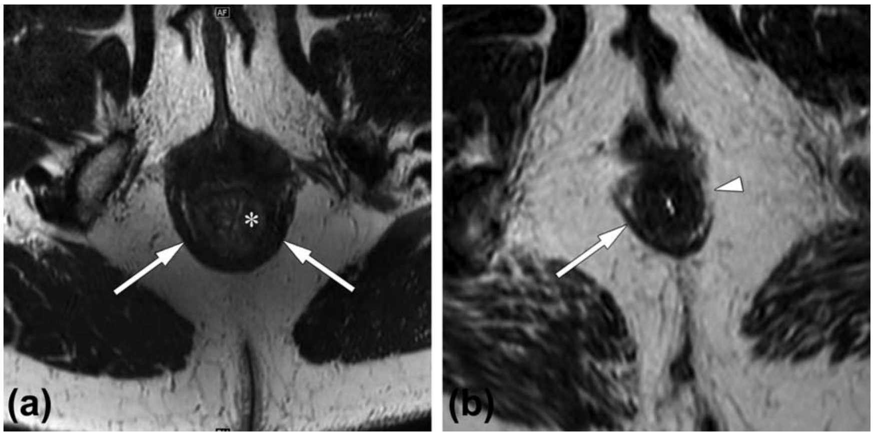


FIGURE 2: Normal anatomy of the anal sphincter in a 57-year-old woman. (a) On axial T_2-weighted image, the external anal sphincter (EAS) is normal in thickness and has diffusely low signal intensity (arrows); note the normal internal anal sphincter (*) demonstrating intermediate signal intensity. In contrast, axial T_2-weighted image in a 71-year-old woman with fecal incontinence (b) demonstrates diffuse thinning of the EAS (arrow) with an area of discontinuity (arrowhead).

Axial T_2-weighted images are best to evaluate the puborectalis. Radiologists should look for symmetry in both thickness and signal of these muscles. Mild apparent asymmetry in thickness (<50%) of the levator ani may be artifactual.

The normal internal anal sphincter (IAS) is formed by smooth muscle in direct continuation with the circular muscle of the distal rectum. The IAS demonstrates intermediate signal intensity on T_1- and T_2-weighted images (Fig. 2). The external anal sphincter (EAS) is comprised of skeletal muscle and demonstrates low signal on T_2-weighted images (Fig. 2). It should be noted that the inferior edge of the EAS may be open posteriorly and anteriorly, which should not be confused for a tear.[23]

Perineal Membrane/Urogenital Diaphragm

The perineal membrane, also known as the urogenital diaphragm, is a triangular-shaped membrane forming the inferior pelvic floor. It is composed of the deep transverse muscle of the perineum and connective tissue. Posteriorly it attaches to the perineal body. Laterally, it attaches to the ischial rami, and anteriorly to the pubic symphysis.

MR Defecography Technique

The protocols for dynamic pelvic floor MRI vary by institutions, but most commonly these studies are performed in the supine position in a standard 1.5T or 3T scanner. Upright open-bore scanners provide assessment in a physiologic sitting position with high accuracy; however, such scanners are not widely available and therefore infrequently utilized.[24] While a supine position is not physiologic, dynamic MRI in the supine position has been shown to perform similarly to dynamic MRI in the sitting position for detection of clinically significant pelvic floor abnormalities.[25]

Prior to scanning, ultrasound gel is instilled into the rectum via a small rubber catheter or a syringe. The amount of gel varies across institutions, but is usually in the range of 100–180 mL. The gel is well tolerated by patients, allows easier defecation, and improves detection of pelvic organ prolapse and rectal intussusception.[26] Smaller volume of rectal gel (120 mL) yields defecatory effort similar to that with a larger volume (180 mL).[27] In our institution, ~100 mL of gel is inserted when the patient is on the table via a catheter-tip syringe. It should be noted, however, that one recent prospective study in patients with obstructed defecation reported that up to 46% of anterior compartment abnormalities may only be depicted without rectal contrast.[28]

The cornerstone of pelvic floor assessment with MRI is the dynamic portion of the study, consisting of a cycle of rest, squeeze, strain, and defecation. The rest images are used as a reference to assess pelvic floor relaxation and descent on subsequent phases. During squeeze, the patient is asked to perform a Kegel maneuver in order to assess pelvic floor responsiveness, in particular puborectalis contraction. Patients may find the squeezing instruction to be confusing, however, especially when there are language and communication barriers; this should be kept in mind when evaluating and interpreting the images. Traditionally, both strain and defecation images are acquired to assess for pelvic floor relaxation and organ prolapse. However, the defecation phase may reveal a significantly larger number and higher grade of abnormalities, and the strain phase does not reveal findings that were not seen on the defecation phase.[29,30] Therefore, elimination of the strain phase and use of defecation phase only has been recently proposed.

Patient preparation and cooperation is essential for optimal imaging and detection of pathology, since lack of compliance with the required maneuvers invariably results in a nondiagnostic study. However, dynamic MRI can be a challenging exam from the perspective of the patient. As part of the examination, the patient is asked to Valsalva and

TABLE 1. Sample Protocol for MRI Evaluation of Pelvic Floor Weakness

Pulse sequence	Imaging plane	TR/TE (msec)	FOV (cm)	Slice thickness (mm)	Matrix
SSFSE	Axial, coronal and sagittal	888.4/80	20-24	5	128x128
Steady state free precession sequence*	Mid-sagittal	3.16/1.58	20	10	148x146
3D T2-weighted	Axial	2,000/120	16	1	320x320

These parameters were established on a 1.5T scanner (Ingenia; Philips, Best Netherlands). TR = repetition time; TE = echo time; FOV = field of view. Steady-state free precession sequence: acquired over 30 sec. VISTA = volume isotropic turbo spin echo acquisition.

defecate in a claustrophobia-inducing magnet, with a stranger watching and recording their effort. This is understandably a fearsome and frequently awkward experience. Furthermore, defecating in the nonphysiologic supine position may be difficult, and patients may be embarrassed at the thought of soiling the table. All these factors can contribute to a suboptimal Valsalva effort and inability to defecate during the study, and as a result yield a study which is either nondiagnostic or considerably underestimates the degree of pathology. However, the patients referred for pelvic floor assessment are usually highly motivated, as their symptoms are bothersome enough for them to seek subspecialized consult. Therefore, several steps can be taken to greatly improve patient compliance and achieve an optimized exam. Before the patient is brought into the scanner, the technologist should explain the study and reassure the patient that expulsion of the gel is the goal of the examination. Squeeze and Valsalva maneuvers can be practiced before entering the scanner, as well as on the table prior to scanning. During the defecation phase, patients should receive continuous feedback and encouragement. The instruction for defecation that is favored by the technologists in our institution and yields a high degree of compliance is: "Push as much of the gel out, as fast as you can."

The MRI protocol utilized for pelvic floor evaluation at our institution is summarized in Table 1. The patient is scanned in the supine position with the legs slightly bent, with an absorbent pad under the buttocks. The examination begins with static single shot fast spin echo T_2-weighted images in the sagittal, axial, and coronal planes. Coverage includes the pubic symphysis, bladder neck, vagina, rectum, and coccyx. An axial, high-resolution, isometric T_2-weighted sequence through the anal sphincter is also obtained. The dynamic sequences are then acquired using a steady-state free precession sequence (BTFE/FIESTA/trueFISP) after selection of an appropriate mid-sagittal slice demonstrating the anorectal junction. This sequence offers near real-time continuous imaging and depicts a greater degree of abnormalities compared with a sequential single-shot fast spin echo sequence.[31] Each dynamic sequence is obtained over a 30-second period as follows: 5–10 seconds rest, 15–20 seconds defecation, 5 seconds rest. In our patient population, the squeeze phase has proven to be a considerable source of confusion and therefore is excluded from the protocol. However, the squeeze phase can be helpful in assessing the responsiveness of puborectalis, and therefore should be included as part of the dynamic sequence, if possible.[32] The dynamic sequence is repeated at least twice to ensure generation of adequate strain pressures and successful defecation.[33] If the technologist assesses Valsalva effort as suboptimal, they reiterate the instructions to the patient and then repeat the dynamic sequences.

Consequently, the technologist plays an instrumental role in obtaining a diagnostic study. Technologists should be trained to put patients at ease prior and during the study, to coach and encourage patients during the dynamic portion, to recognize appropriate anatomic coverage, and to assess whether the straining/defecation effort was sufficient. When developing an MR defecography program de novo, it is advisable for the radiologist to monitor every exam until they are consistently well-performed.

Assessment of Pelvic Floor Function

Reference Lines

There are several reference lines used to assess the presence and degree of pelvic floor dysfunction. Appropriate placement of these lines is the first and one of the most crucial steps in interpreting dynamic pelvic floor MRI. The most commonly used reference line is the pubococcygeal line (PCL), which represents the level of the pelvic floor.[11,12,34–36] The PCL is drawn from the most inferior aspect of the pubic symphysis to the last coccygeal joint (Fig. 3).[11,34–38] An alternative, less commonly used reference line for evaluation of the pelvic floor is called the midpubic line (MPL). The MPL is drawn along the long axis of the

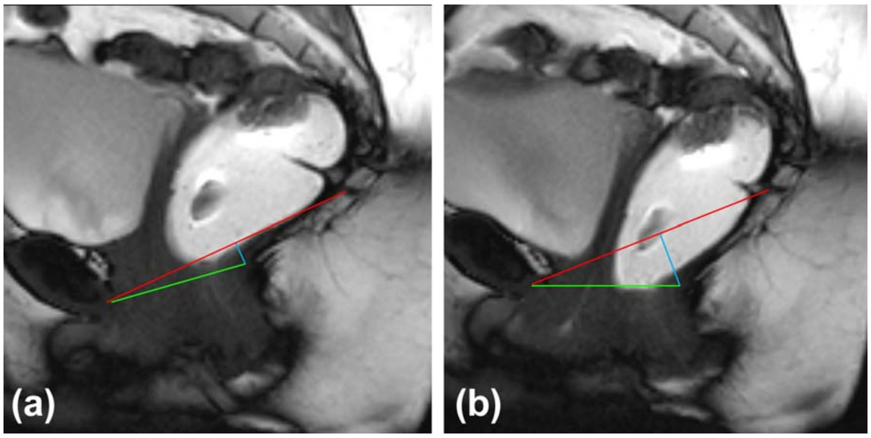


FIGURE 3: Placement of the reference lines. Mid-sagittal balanced gradient echo sequences at rest (a) and stress (b) in a 63-year-old woman with mild stress incontinence. The pubococcygeal line (PCL) (red) is drawn from the inferior pubis to the last coccygeal joint. The H line (green) is drawn from the inferior pubis to the posterior aspect of the rectal wall at the level of the anorectal junction. The M line (blue) is drawn as a perpendicular from the posterior H line to the PCL.

pubic symphysis and marks the level of the vaginal hymen.[39]

The H line is then drawn from the most inferior aspect of the pubic symphysis to the posterior rectal wall at the level of the anorectal junction (Fig. 3). The H line reflects the anteroposterior length of the levator hiatus and should measure $\leq$6 cm. The M line is subsequently drawn perpendicular from the PCL to the posteriormost aspect of the H line (Fig. 3). The M line measures the degree of muscular pelvic floor descent and should be $\leq$2 cm.

The anorectal angle is measured by drawing lines along the posterior border of the rectum and long axis of the anal canal, with the anorectal junction being the apex of anorectal angle (Fig. 4). The normal angle at rest varies between 104° to 127°.[32,40]

Normal Function of the Pelvic Floor

At rest and Valsalva, the bladder base, upper third of the vagina, sigmoid, small bowel, and peritoneal reflection should all be above the level of the PCL. The anorectal junction should remain within 2 cm below the PCL. At maximal squeezing, the puborectalis contracts; as a result, the anorectal junction is drawn anteriorly and superiorly, and the anorectal angle decreases by 15–35° (Figs. (4 and 5); Supplemental Video 1).[32,41] During straining/defecation as the puborectalis relaxes, the anorectal junction moves posterior and inferior away from the pubis, and as a result the anorectal angle becomes more obtuse by 15–20° (Figs. (4 and 5), Supplemental Video 2).[32,41]

Pelvic Floor Dysfunction

Pelvic floor dysfunction or weakness encompasses a spectrum of functional disorders that result from impairment of the ligaments, fasciae, and muscles supporting the pelvic organs. The underlying cause is multifactorial, with conditions such as multiparity, pudendal nerve injury, advanced age, obesity, menopause, connective tissue disorders, smoking, chronic obstructive pulmonary disease, and a chronic increase in intraabdominal pressure contributing to the development of the pelvic floor dysfunction.[42] There are two components to pelvic floor dysfunction: pelvic floor relaxation and pelvic organ prolapse. Although these two

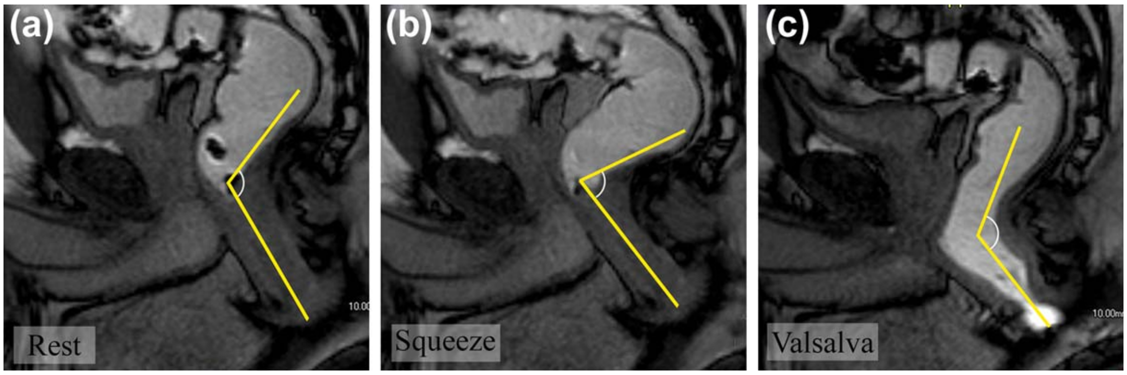


FIGURE 4: Normal function of the pelvic floor. Schematic at various phases of the dynamic cycle. At rest (a), the location of the anorectal junction serves as a reference. During squeeze (Kegel maneuver) the puborectalis contracts and draws the anorectal junction superior and anterior toward the pubis (b). During defecation the puborectalis relaxes and allows the anorectal junction to move inferior and posterior away from the pubis (c).

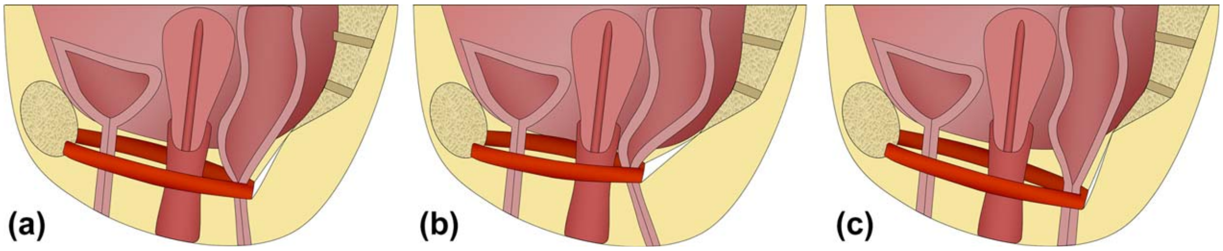


FIGURE 5: Normal function of the pelvic floor. Mid-sagittal balanced gradient echo image in a 46-year-old man at various phases of the dynamic cycle. At rest (a), the measurement of the anorectal angle (yellow lines) serve as a reference. During squeeze (Kegel maneuver) the puborectalis contracts and draws the anorectal junction superior and anterior toward the pubis, decreasing the anorectal angle by 15–20° (b). During defecation the puborectalis relaxes and allows the anorectal junction to move inferior and posterior away from the pubis, increasing the anorectal angle by 15–20° (c).

components are related and often coexistent, they may not be present simultaneously and should be differentiated.

Pelvic Floor Relaxation

In pelvic floor relaxation the pelvic floor muscles become weakened and unresponsive.[34,43,44] The pelvic floor musculature can be thought of as a hammock supporting the pelvic organs, with the levator hiatus representing an opening in this hammock (Fig. 6). In the setting of pelvic floor relaxation, the hammock of the pelvic floor sags (descent), and its opening becomes stretched out (widening) (Fig. 6). Similar to this analogy, pelvic floor relaxation is graded by two components: pelvic floor descent (assessed by the M line) and hiatal widening (assessed by the H line) (Fig. 6; Supplemental Video 3).[45] Table 2 summarizes the criteria for grading pelvic floor relaxation.[46]

Pelvic Organ Prolapse

Pelvic organ prolapse refers to abnormal protrusion of any pelvic organ below the level of the pelvic floor. Prolapse can be isolated or multicompartmental, and may include any combination of organs including the urethra, bladder, vagina, uterus, rectum, sigmoid, or small bowel. Dysfunction of all three compartments is common due to shared structural support.[47] Loss of levator ani muscle bulk greater than 50% is seven times more likely to be present in patients with pelvic organ prolapse.[48–50]

Clinically, pelvic organ prolapse is assessed by the pelvic organ prolapse quantification (POP-Q) system, where the level of the vaginal hymen is used as a reference line for the patient in the lithotomy position performing the Valsalva maneuver.[39] In the POP-Q system, the plane of hymen is defined as "zero"; organ location above the plane is denoted by negative numbers and below the plane is denoted by positive numbers.[51] Locations of six defined points in the POP-Q system with respect to the plane of hymen are assessed on physical examination, and a standardized grid is then used to arrive at the final stage of prolapse.[51] Stage 0 denotes no prolapse; in Stage 1, the most distal portion of the prolapse is more than 1 cm above the level of the hymen; in Stage 2, the most distal portion of the prolapse is 1 cm or less proximal or distal to the plane of hymen; in Stage 3, the most distal portion of the prolapse protrudes more than 1 cm below the hymen but no farther than 2 cm less than the total vaginal length; Stage 4 denotes complete vaginal eversion.[51] The POP-Q terminology avoids assigning a specific label (eg, cystocele or rectocele) to the prolapsing part of the vagina, acknowledging that the actual organ(s) above the prolapse cannot be accurately determined by a physical examination.[51]

On dynamic MRI, both the PCL and MPL can be used as a reference. If the PCL is used as the reference, the severity of pelvic prolapse is graded by the "rule of three": descent of an organ below the PCL by ≤ 3 cm is considered

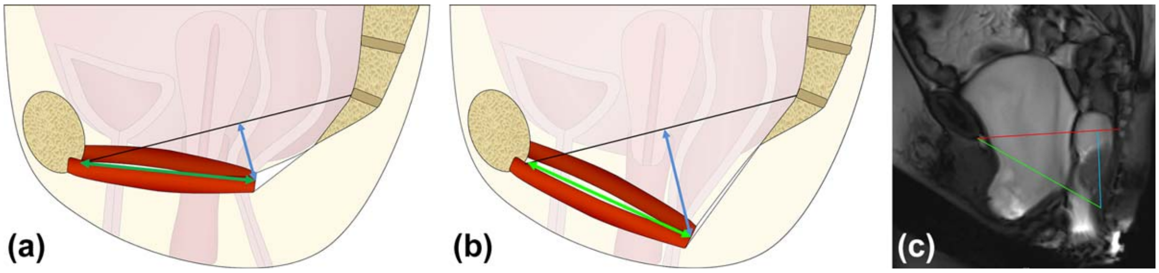


FIGURE 6: Pelvic floor relaxation. (a) Schematic representation of a normal pelvic floor demonstrates normal anteroposterior length of the levator hiatus (green arrow) and normal location of the posterior edge of the puborectalis with respect to PCL (blue arrow). (b) Schematic representation of the pelvic floor relaxation demonstrates sagging of the pelvic floor, resulting in the hiatal widening (green arrow) and muscular descent (blue arrow). (c) Mid-sagittal balanced gradient echo MR image at defecation in a 58-year-old woman demonstrates H line (green) measuring 11 cm, constituting severe widening. M line (blue) measures 6.5 cm, constituting severe descent. Overall, the findings represent severe pelvic floor relaxation (see Table 2).

TABLE 2. Grading of Pelvic Floor Relaxation Using H and M Lines[34,43]

Grade	H line (hiatal widening)	M line (pelvic floor descent)
Normal	<6 cm	<2 cm
Mild	6-8 cm	2-4 cm
Moderate	8-10 cm	4-6 cm
Severe	>10 cm	>6 cm

mild, descent by 3–6 cm is considered moderate, and descent by >6 cm is considered severe (Table 3).[36,38,52] If the MPL is used, the organ prolapse is graded in five stages, from Stage 0 to Stage 4 (Table 4). Since the MPL approximates the level of the hymen, it theoretically closely approximates assessment by POP-Q.[53] However, both the PCL and MPL have demonstrated only fair agreement with the clinical staging of pelvic organ prolapse, and neither was shown to offer a clear advantage over the other.[12,39,54] The use of the PCL offers greater simplicity and higher interobserver agreement over the MPL.[55] Therefore, the PCL is the reference line most frequently used for measuring organ prolapse, including at our institution.[12,34] However, the decision to use the MPL or PCL as the reference line should be tailored to the individual clinical practice, taking into account the preferences of the referring physicians.

Anterior Compartment

Cystocele

Cystocele is defined as abnormal descent of the urinary bladder at rest or with straining as a result of tears in the endocervical fascia. In cases where symptoms primarily include stress urinary incontinence, MRI is typically not necessary. In more severe cases, bladder descent is accompanied by a clockwise bladder rotation and urethral prolapse.[43] Therefore, in patients with high-grade cystoceles the transverse orientation of the urethra results in kinking at the bladder neck, masking the symptoms of stress incontinence, which may become apparent after bladder prolapse is repaired.[43] Higher-grade cystoceles may present as a bulge along the anterior vaginal wall, and thus result in difficult intercourse or dyspareunia.[11]

TABLE 3. Grading Pelvic Organ Prolapse Using the Pubococcygeal Line as the Reference[34,39,44,73]

Grade	Distance from the PCL
Mild	1–3 cm below
Moderate	3–6 cm below
Severe	>6 cm below

PCL = pubococcygeal line. The distance is measured from the inferior bladder (cystocele), anterior inferior cervical lip (uterine prolapse) and superior vaginal cuff (vaginal prolapse).

TABLE 4. Grading Pelvic Organ Prolapse Using the Midpubic Line as the Reference[34,39,44]

Stage	Distance from the MPL
0	>3 cm above
1	1–3 cm above
2	Within 1 cm of the MPL (above or below)
3	>1 cm below
4	Complete organ eversion

MPL = midpubic line. The distance is measured from the inferior bladder (cystocele), anterior inferior cervical lip (uterine prolapse) and superior vaginal cuff (vaginal prolapse).

On dynamic MRI, a cystocele is diagnosed when the inferior bladder descends >1 cm below the PCL (Fig. 7; Supplemental Video 3). Supine dynamic MRI is significantly better at evaluating cystoceles compared with intraoperative findings, with a reported sensitivity of 100%, positive predictive value of 97%, and negative predictive value of 100%.[56] Overdistension of the urinary bladder should be avoided since a distended bladder is associated with underestimation of pelvic organ prolapse severity and an overdistended cystocele may obscure findings in other compartments.[57,58]

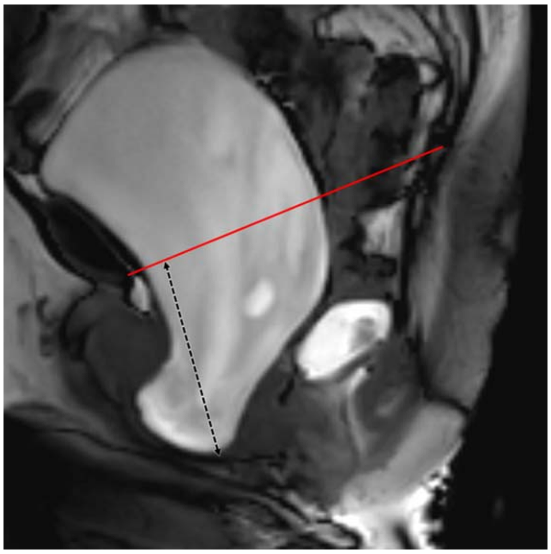


FIGURE 7: Severe cystocele in a 46-year-old woman with vaginal bulging and stress incontinence. Mid-sagittal balanced gradient echo MR image at defecation demonstrates extension of the inferior bladder 6.5 cm (dotted line) below the level of the PCL (red line) (see Table 3).

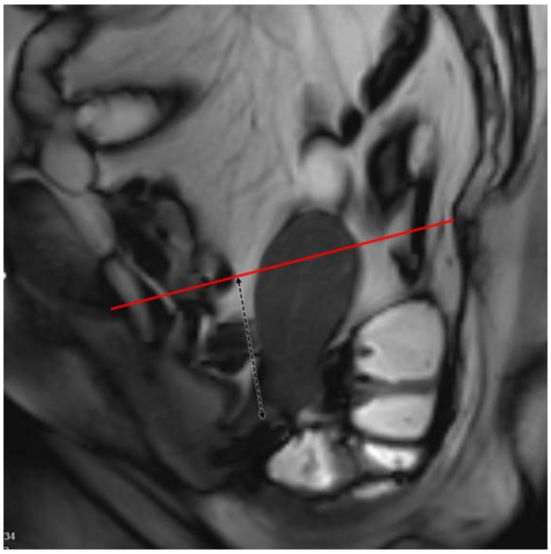


FIGURE 8: Moderate uterine prolapse in a 49-year-old woman with chronic pelvic pressure. Mid-sagittal balanced gradient echo MR image at defecation demonstrates descent of the uterus, with the anterior cervical lip located 5.1 cm (dotted line) below the level of the PCL (red line) (see Table 3).

Urethral Hypermobility

As mentioned previously, the axis of the urethra in a normal patient should always maintain a vertical position with respect to the pelvic floor, and be nearly parallel to the axis of the symphysis pubis. Anterior angulation of the urethra by more than 30° from its resting axis indicates urethral hypermobility.[59] There are multiple causes of urethral hypermobility, including prior surgery, defects in the pelvic floor muscles and endopelvic fascia, birth trauma, prior pregnancy, obesity, and advanced age.[23] As discussed above, distinction of urethral hypermobility from a large cystocele is important, as large cystoceles may mask the stress incontinence attributable to urethral hypermobility.[60]

Middle Compartment

Uterine and Vaginal Vault Prolapse

The uterosacral ligaments provide major support to the uterus and upper vagina. Complete tear of the supporting ligaments results in uterine descent into the vaginal introitus; resultant pulling and tearing of the vaginal supporting ligaments can cause complete vaginal eversion and uterine prolapse outside the vaginal introitus.[57] Defects in the pubocervical fascia, rectovaginal fascia, parametrium, and paracolpium contribute to the uterine and vaginal prolapse. Damage to the fascial support associated with uterine and vaginal prolapse commonly leads to prolapse of other organs, making comprehensive assessment of the entire pelvis with MRI particularly important.[61] Patients with uterine prolapse may present with a vaginal mass, dyspareunia, or urinary retention.[11] Grade 4 uterine prolapse (roughly corresponding to severe prolapse if the PCL is used as the reference) can result in progressive ureteral obstruction.[62] Radiologists should be aware that large fibroids may prevent or underestimate uterine prolapse.[40]

Uterine prolapse is measured by drawing a line from the anterior inferior cervical lip to the PCL or MPL (Fig. 8). In patients with prior hysterectomy, the measurement is drawn from the posterosuperior vaginal apex.

Cul-De-Sac Hernia

Damage to the supporting structures in the middle compartment may result not only in uterine prolapse but also prolapse of the cul-de-sac contents. This can include peritoneal fat (peritoneocele), small bowel (enterocele), and/or sigmoid colon (sigmoidocele) (Fig. 9). Compared with all other forms of organ prolapse, cul-de-sac hernias present the biggest diagnostic challenge on physical examination, especially when multiple organs are involved.[43] Specifically, differentiation between a high rectocele and cul-de-sac hernias is limited based on physical examination, yet such differentiation is quite clinically relevant, as it affects the surgical approach.[11,14,63] Patients status posthysterectomy are at a greater risk of cul-de-sac hernia due to damage of the rectovaginal septum.[64] Because the distended rectum protrudes and occupies the space anteriorly during defecation, the cul-de-sac hernia may become evident only at the end of evacuation (Fig. 9).[45]

Posterior Compartment

Rectocele

A rectocele is an outpouching of the rectal wall during defecation secondary to weakening of the support structures of the pelvic floor, particularly of the rectovaginal fascia.[34] Risk factors for development of rectoceles include surgery, birth trauma, advanced age, and conditions leading to chronically increased intra-abdominal pressure.[35] Anterior rectoceles are much more common than posterior rectoceles, and can be seen on clinical exam as a bulge along the posterior vaginal wall. However, sensitivity of clinical examination for detection of an anterior rectocele varies from 30% to 80%.[2,65] Furthermore, as discussed above, differentiation between anterior rectocele and cul-de-sac hernia can be difficult by physical exam alone. Symptoms related to rectoceles may be vaginal (bulging or dyspareunia) or rectal (sensation of incomplete evacuation, constipation, and defecatory dysfunction).

On MRI, an anterior rectocele is measured in anterior posterior dimension in relationship to the expected location of the anterior anorectal wall, which can be approximated by the location of the anterior anal canal (Fig. 10).[41] A bulge of <2 cm can be seen in asymptomatic population and is considered mild, 2–4 cm is considered moderate, and >4 cm large.[66,67] Posterior rectoceles are rare, and when seen are due to damage of the levator plate.[68]

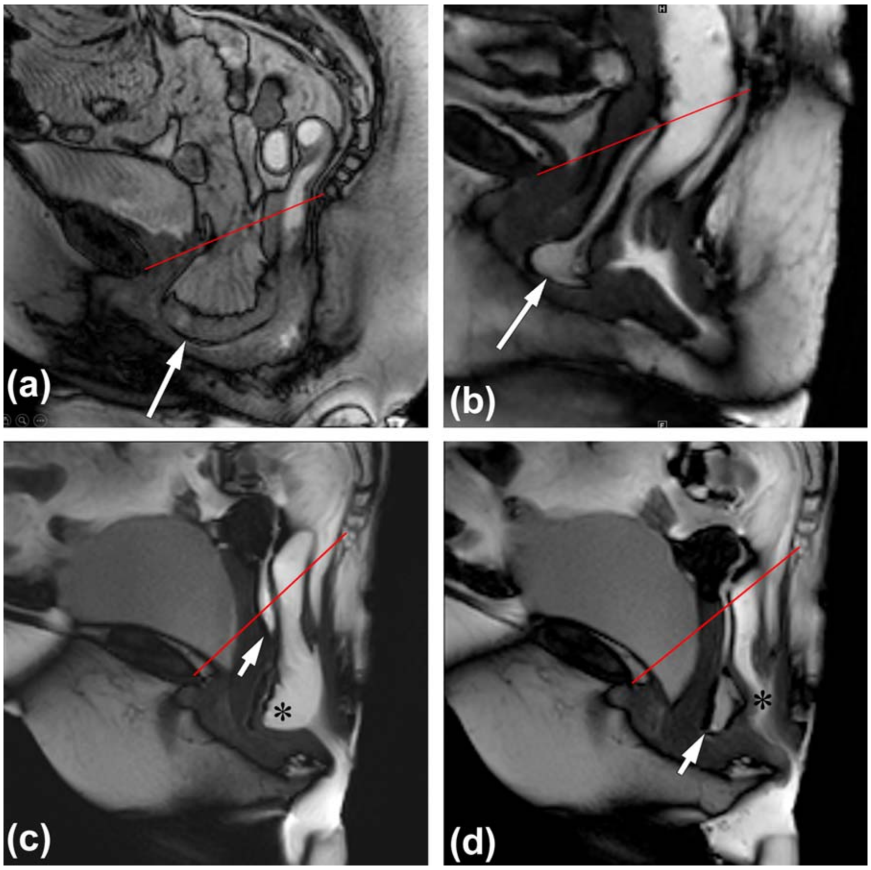


FIGURE 9: Cul-de-sac hernias. (a) Enterocele: Mid-sagittal balanced gradient echo MR image at defecation in a 51-year-old woman with chronic constipation and pelvic pressure demonstrates extension of multiple small bowel loops (arrow) into the cul-de-sac, 5.4 cm below the level of the PCL (red line). (b) Peritoneocele: Mid-sagittal balanced gradient echo MR image at defecation in a 49-year-old woman with symptoms of obstructive defecation demonstrates extension of peritoneal fat (arrow) into the cul-de-sac, 5.5 cm below the level of the PCL (red line). (c,d) Unmasking peritoneocele at end defecation: Mid-sagittal balanced gradient echo MR images at defecation in a 46-year-old woman with symptoms of fecal incontinence before (c) and after (d) decompression of the rectum. Peritoneal fat remains above the rectovaginal space (arrow, c) with rectal filling (*). After the rectum (*) is decompressed (d), descent of peritoneal fat into the rectovaginal space (peritoneocele, arrow) is evident.

Rectal Intussusception and Prolapse

Rectal intussusception and prolapse result from chronic straining and damage to the surrounding fascia. Rectal intussusception is defined as invaginations of the rectal wall, and can be defined as intrarectal (ie, confined to the rectum), intra-anal (ie, extend to the anal canal), or extra-anal (ie, pass beyond the anal orifice).[41,69] Extra-anal intussusception is also known as rectal prolapse (Fig. 11). Internal intussusceptions may involve the entire wall (full-thickness intussusception) or only the mucosa (mucosal intussusception). Circumferential intussusception is more common, but intussusceptions involving the anterior wall only may also be seen. Chronic straining in the setting of rectal prolapse may eventually lead to pudendal neuropathy resulting in external anal sphincter atrophy and fecal incontinence.

Dynamic MRI is less sensitive for evaluating rectal intussusception compared to fluoroscopic defecography, with a reported relative sensitivity of 70%.[69] However, dynamic MRI is able to differentiate mucosal from full thickness intussusception, which may alter management. Partial thickness intussusception may be treated nonsurgically or require transanal resection of prolapsed mucosa, while full-thickness may require rectopexy.[65,70] On MRI, mucosal intussusceptions can be identified as thin dark curvilinear structures that bunch along the rectal wall during defecation (Fig. 11). The curvilinear configuration is necessary to differentiate mucosa from air or stool in the rectum. Full-thickness intussusceptions appear as invagination of the entire rectal wall upon itself (Fig. 11).

Fecal Incontinence

Fecal incontinence is defined as the involuntary loss of fecal material at an inappropriate time or place.[71] In patients who are considered candidates for surgical therapy for fecal incontinence, MR defecography may reveal multiple overlapping conditions, including pelvic floor descent, intussusceptions, rectoceles, and enteroceles.[72,73] As with other manifestations of pelvic floor dysfunction, the cause of fecal incontinence is often multifactorial, but occult damage to the continence mechanism through vaginal delivery and anal

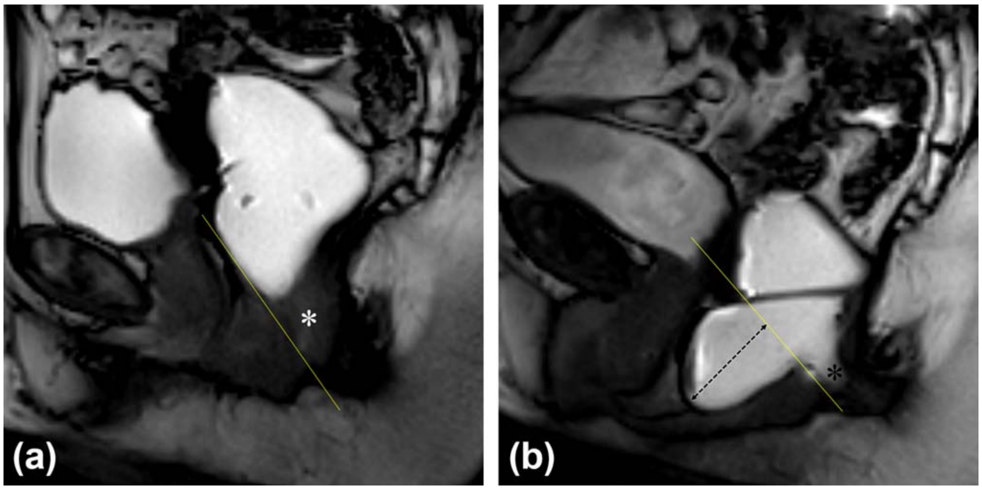


FIGURE 10: Large anterior rectocele in a 63-year-old female with history of incomplete evacuation. (**a**) Mid-sagittal balanced gradient echo images at rest (a) and defecation (**b**) demonstrate protrusion of the rectum at defecation 4.2 cm (dotted line, b) anterior to the expected location (yellow line). Note that the expected position of the anterior rectum is in line with the anterior border of the anal canal (*).

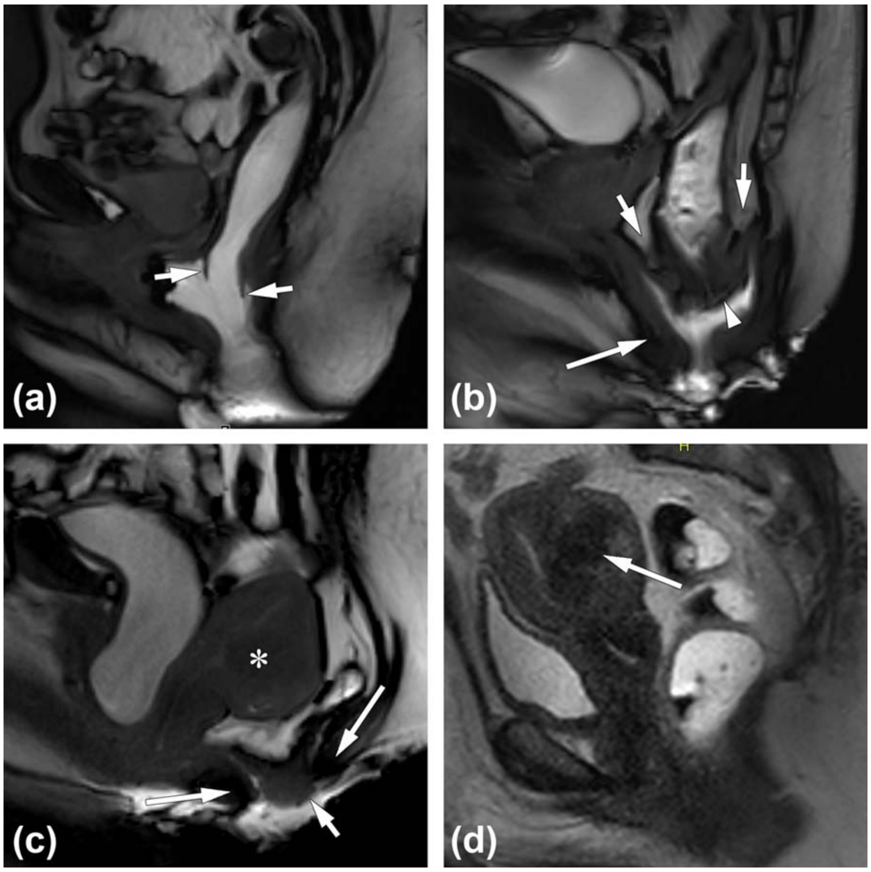


FIGURE 11: Rectal intussusception and prolapse. (**a**) Mucosal intrarectal intussusception in a 41-year-old woman with obstructive defecation. Mid-sagittal balanced gradient echo MR image at defecation demonstrates telescoping of the mucosa, which manifests as curvilinear thin low signal intensity projections from anterior and posterior rectal wall (arrows). The intussuscepted mucosa remains within the rectal lumen. (**b**) Full-thickness intra-anal intussusception in a 38-year-old man with chronic constipation. Mid-sagittal balanced gradient echo MR image at defecation demonstrates infolding of the entire rectal wall upon itself (arrowhead), protruding into the anal canal (long arrow). Note the deformity of the outer contour of the rectal wall (short arrows), confirming that full thickness of the wall is involved in the intussusception. (**c**) Rectal prolapse in a 43-year-old woman with multicompartmental organ prolapse on the physical examination. Mid-sagittal balanced gradient echo MR image at defecation demonstrates protrusion of the intussuscepted rectal wall (short arrow) beyond the anal canal (long arrows). Note an incidental finding of a posterior intramural leiomyoma (*), confirmed on sagittal SSFSE image (**d**).

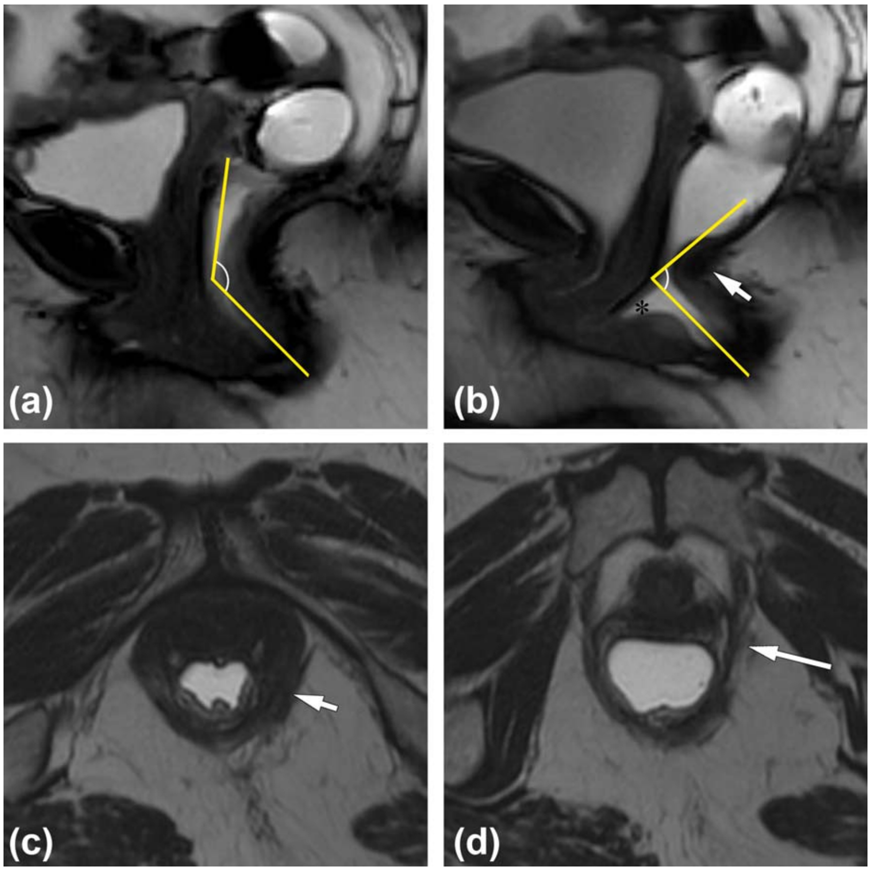


FIGURE 12: Pelvic floor dyssynergia in a 39-year-old woman with chronic constipation and symptoms of obstructive defecation. Mid-sagittal balanced gradient echo MR images at rest (a) and defecation (b) demonstrate paradoxical contraction of the puborectalis (arrow) with the resultant narrowing of the anorectal angle from 127° at rest (a) to 80° with maximal stress (b). Axial T_2-weighted images (c,d) demonstrate diffuse thickening of the puborectalis (long arrow, c), which is at least twice the thickness of the pubococcygeus (short arrow, d). Note a coexistent small anterior rectocele with maximal stress (*, b).

surgery are major contributing factors.[71] MR assessment of the anal sphincter is therefore particularly important in patients with fecal incontinence.[16]

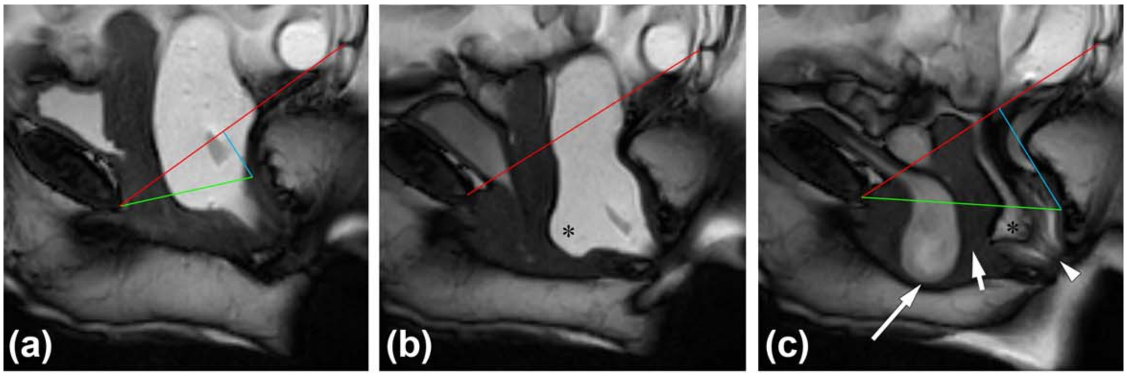
Abnormalities of the EAS include thinning, fatty atrophy, and frank defects (Fig. 2).[32] Patients with EAS atrophy report more symptomatic fecal incontinence than patients without EAS atrophy.[74] Higher age and body mass index (BMI) are associated with the presence of more severe EAS atrophy.[74]

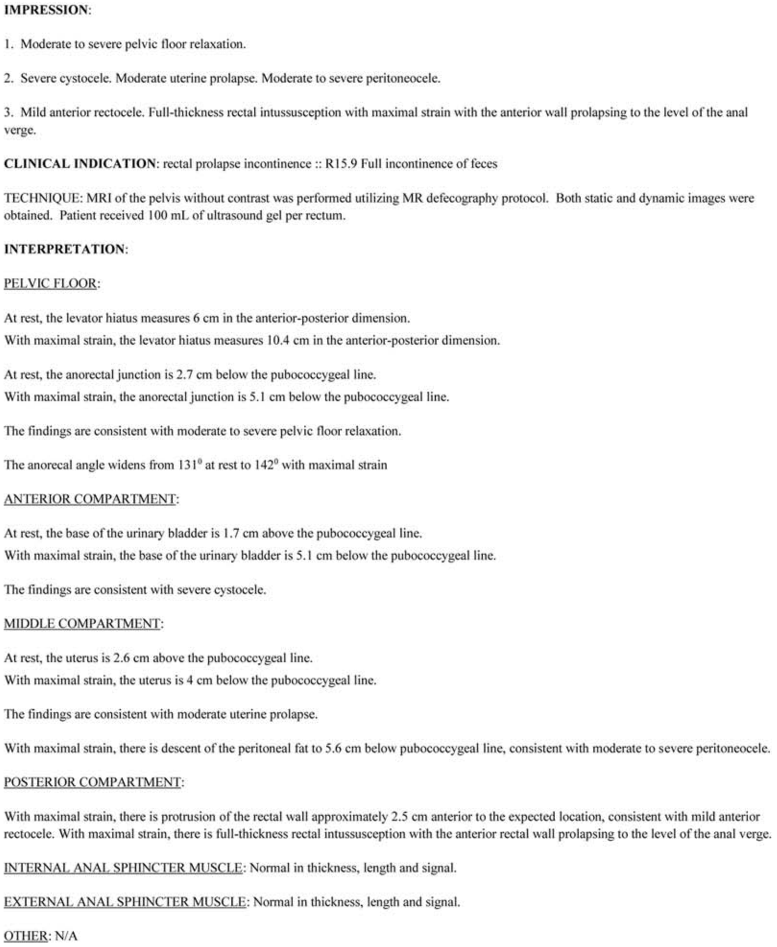
Pelvic Floor Dyssynergia

Pelvic floor dyssynergia is also known as anismus or spastic pelvic floor syndrome. This entity results from failure of relaxation or paradoxical contraction of the puborectalis muscle during defecation. Symptoms include constipation, prolonged and incomplete defecation, as well as delay between opening of the anal canal and initiation of defecation.[75] This condition is often associated with anterior rectocele, and results in obstructed defecation.[41,75] In this condition, findings on MR defecography during defecation include lack of normal pelvic descent, inability to evacuate, paradoxical decrease in the anorectal angle due to puborectalis muscle contraction with anterior and superior displacement of the anorectal junction, and hypertrophy of the puborectalis resulting in a prominent impression on the anorectal junction (Fig. 12; Supplemental Video 4). Since patients with pelvic floor dyssynergia often experience chronic constipation, MRI may reveal superimposed pelvic floor relaxation and varying degrees of pelvic organ prolapse. Therefore, measurement of the anorectal angle and careful attention to puborectalis motion on the dynamic portion of the exam may be necessary for proper diagnosis of pelvic floor dyssynergia. In addition to diagnosing pelvic floor dyssynergia, MR defecography can assess changes in dynamic indices of the pelvic floor after biofeedback therapy.[76]

Practical Summary of Interpretation of Dynamic Pelvic Floor MRI

Interpreting MR defecography starts with reviewing all the dynamic sequences and assessing for appropriate anatomic coverage and adequate defecatory effort. The images with greatest strain effort are selected and are displayed side-by-side with the rest images (Fig. 13; Supplemental Video 5). Reference lines, including the PCL, H line, and M line are then placed on both rest and maximal strain images to assess the presence and degree of pelvic floor relaxation. The distances




IMPRESSION:

1. Moderate to severe pelvic floor relaxation.

2. Severe cystocele. Moderate uterine prolapse. Moderate to severe peritoneocele.

3. Mild anterior rectocele. Full-thickness rectal intussusception with maximal strain with the anterior wall prolapsing to the level of the anal verge.

CLINICAL INDICATION: rectal prolapse incontinence :: R15.9 Full incontinence of feces

TECHNIQUE: MRI of the pelvis without contrast was performed utilizing MR defecography protocol. Both static and dynamic images were obtained. Patient received 100 mL of ultrasound gel per rectum.

INTERPRETATION:

PELVIC FLOOR:

At rest, the levator hiatus measures 6 cm in the anterior-posterior dimension.
With maximal strain, the levator hiatus measures 10.4 cm in the anterior-posterior dimension.

At rest, the anorectal junction is 2.7 cm below the pubococcygeal line.
With maximal strain, the anorectal junction is 5.1 cm below the pubococcygeal line.

The findings are consistent with moderate to severe pelvic floor relaxation.

The anorecal angle widens from 131^0 at rest to 142^0 with maximal strain

ANTERIOR COMPARTMENT:

At rest, the base of the urinary bladder is 1.7 cm above the pubococcygeal line.
With maximal strain, the base of the urinary bladder is 5.1 cm below the pubococcygeal line.

The findings are consistent with severe cystocele.

MIDDLE COMPARTMENT:

At rest, the uterus is 2.6 cm above the pubococcygeal line.
With maximal strain, the uterus is 4 cm below the pubococcygeal line.

The findings are consistent with moderate uterine prolapse.

With maximal strain, there is descent of the peritoneal fat to 5.6 cm below pubococcygeal line, consistent with moderate to severe peritoneocele.

POSTERIOR COMPARTMENT:

With maximal strain, there is protrusion of the rectal wall approximately 2.5 cm anterior to the expected location, consistent with mild anterior rectocele. With maximal strain, there is full-thickness rectal intussusception with the anterior rectal wall prolapsing to the level of the anal verge.

INTERNAL ANAL SPHINCTER MUSCLE: Normal in thickness, length and signal.

EXTERNAL ANAL SPHINCTER MUSCLE: Normal in thickness, length and signal.

OTHER: N/A

(d)

FIGURE 13: Interpretation of the pelvic floor MRI in a 74-year-old woman with rectal prolapse and fecal incontinence. Mid-sagittal balanced gradient echo images at rest (a), maximal defecation of the first strain cycle (b), and the second strain cycle (c) are displayed side-by-side. The reference lines (the PCL, red; H line, green; M line, blue) are placed on all three images. Mild anterior rectocele (*, b) is seen at the first strain cycle. In the second strain cycle (c) the rectum is decompressed, and severe cystocele (long arrow), moderate uterine prolapse (short arrow), peritoneocele (*), and full thickness rectal intussusception (arrowhead) become evident. (d) Structured report of the findings.

from the PCL to the bladder base and anterior cervical lip or superior vaginal cuff are drawn to evaluate for anterior and middle compartment abnormalities. To assess for anterior rectocele, a line is drawn from the anterior rectal wall to its expected location. The anorectal angle is measured on both rest and strain images to evaluate for pelvic floor dyssynergia.

Dynamic sequences are then re-reviewed for additional findings. The cul-de-sac should be inspected for peritoneocele, enterocele, or sigmoidocele. The rectum and anal canal should be scrutinized for mucosal or full thickness intussusception. Finally, the nondynamic sequences are reviewed for pelvic ligament integrity, appearance of the anal sphincter, and incidental findings.

Having a structured report greatly aids as a checklist for interpretation of dynamic pelvic floor MRI, and should include the clinically relevant information needed by the

TABLE 5. Summary of Surgical Approaches to Pelvic Organ Prolapse Repair[77]

Surgical Technique	Indication
Abdominal sacral colpopexy	Recurrent cystocele, vault prolapse, or enterocele
Uterosacral ligament suspension	Post-hysterectomy vaginal vault prolapse
Sacrospinous fixation	Post-hysterectomy vaginal vault prolapse
Anterior vaginal repair (anterior colporrhaphy)	Cystocele and/or urethrocele
Posterior vaginal repair (posterior colporrhaphy) and perineorrhaphy	Rectocele and/or defects in perineum
Vaginal repair with synthetic mesh or biologic graft augmentation	Complex defects involving combination of anterior compartment and middle compartment

referring physician. The structured report used in our institution is shown in Fig. 13.

Management

Management of pelvic floor dysfunction is complex and is dictated by patient's symptoms, location and severity of abnormality, and patient's wishes. Nonsurgical techniques may be effective for many patients; for instance, increased fiber intake and biofeedback therapy for defecatory dysfunction and vaginal pessary for symptoms of pelvic organ prolapse.[77,78] Surgery is indicated for the treatment of pelvic organ prolapse in patients who have symptoms affecting quality of life, and who have either failed or declined nonsurgical treatments.[77] Various vaginal and abdominal surgical approaches for the treatment of pelvic organ prolapse exist, and the choice of surgical approach is dictated by the location and severity of prolapse, the nature of the symptoms (eg, presence of urinary, bowel, or sexual dysfunction), the patient's general health and preference, and the surgeon's expertise.[77] Table 5 summarizes the main surgical approaches as detailed in American College of Obstetrics and Gynecology Practice Bulletin Number 185: Pelvic Organ Prolapse.[77] As described previously, MRI is a valuable tool for the accurate assessment of the involved compartments, and is superior to physical examination in cases with multicompartmental involvement. As such, MRI can assist in selection of the appropriate surgical approach. For example, in one study MRI changed management or the surgical approach relative to the clinical evaluation by an interdisciplinary team in nearly half of patients.[9] In patients with fecal incontinence, the results of MRI lead to changes in the surgical approach 67% of surgical candidates.[73]

Conclusion

Dynamic MRI is an integral part of assessment and surgical planning for pelvic floor dysfunction. Familiarization with the reference lines and angles as well as knowledge of the normal anatomy and function of the pelvic floor allows radiologists to confidently interpret these studies and accurately assess for pelvic floor relaxation, pelvic organ prolapse, fecal incontinence, and obstructed defecation.

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