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SPECIAL SECTION: PELVIC FLOOR

MR defecography review

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Abstract
Pelvic floor dysfunction is a relatively common but often complex condition, presenting with a variety of clinical symptoms, especially when it involves multiple compartments. Clinical exam alone is often inadequate and requires a complementary imaging study. Magnetic resonance defecography (MRD) is an excellent noninvasive diagnostic study with its multiplanar capability, lack of ionizing radiation and excellent soft tissue resolution. It can identify both anatomic and functional abnormalities in the pelvic floor and specifically excels in its ability to simultaneously detect multicompartmental pathology and help with vital pre-operative assessment. This manuscript reviews the relevant anatomical landmarks, describes the optimal technique, highlights an approach to the interpretation of MRD, and provides an overview of the various pelvic floor disorders in the different anatomical compartments.

Keywords MR defecography · Dynamic pelvic floor MRI · Pelvic floor dysfunction · Pelvic organ prolapse · MRD

Introduction

Pelvic floor dysfunction is a debilitating disorder seen frequently in older women and often presents with a wide range of symptoms. In the United States, the prevalence of pelvic floor disorders is approximately 25% and doubles in women older than 80 years [1, 2]. The annual cost of ambulatory care in this patient population was about 412 million US dollars in 2006, and it is expected to grow as the population ages, increasing by 48% by 2050 [3, 4]. The etiology is multifactorial including advanced age, multiparity, obesity, connective tissue diseases, pelvic surgery, and disorders resulting in increased intra-abdominal pressure [5]. Patients with pelvic floor dysfunction present with nonspecific symptoms of pelvic pain, sense of pressure or bulge, constipation, and incontinence, and the abnormalities often involve more than one compartment [6]. Pelvic floor dysfunction may involve pelvic organ prolapse and/or pelvic floor relaxation. In patients with prolapse, there is abnormal decent of the pelvic organs, which include the urinary bladder, uterus, vagina, or bowel through the hiatus [5]. In pelvic floor relaxation, there is weakening of the pelvic floor support structures, which become ineffective. This results in descent of one or more compartments during rest and/or defecation, irrespective of organ prolapse [5].

Clinical utility of MRD

Diagnosing pelvic floor dysfunction can be challenging solely with physical examination, which may underestimate or misdiagnose the site of pelvic organ prolapse in 45–90% of patients and result in incorrect treatment and recurrence of symptoms in 10–30% of patients after surgery [7–9]. Maglinte et al. showed that although 95% of patients in his study had concomitant multicompartment defects, the majority of patients did not present with similar multicompartment symptoms on clinical exam [7]. He attributed this to a variety of reasons with some of these defects being asymptomatic, to patients being

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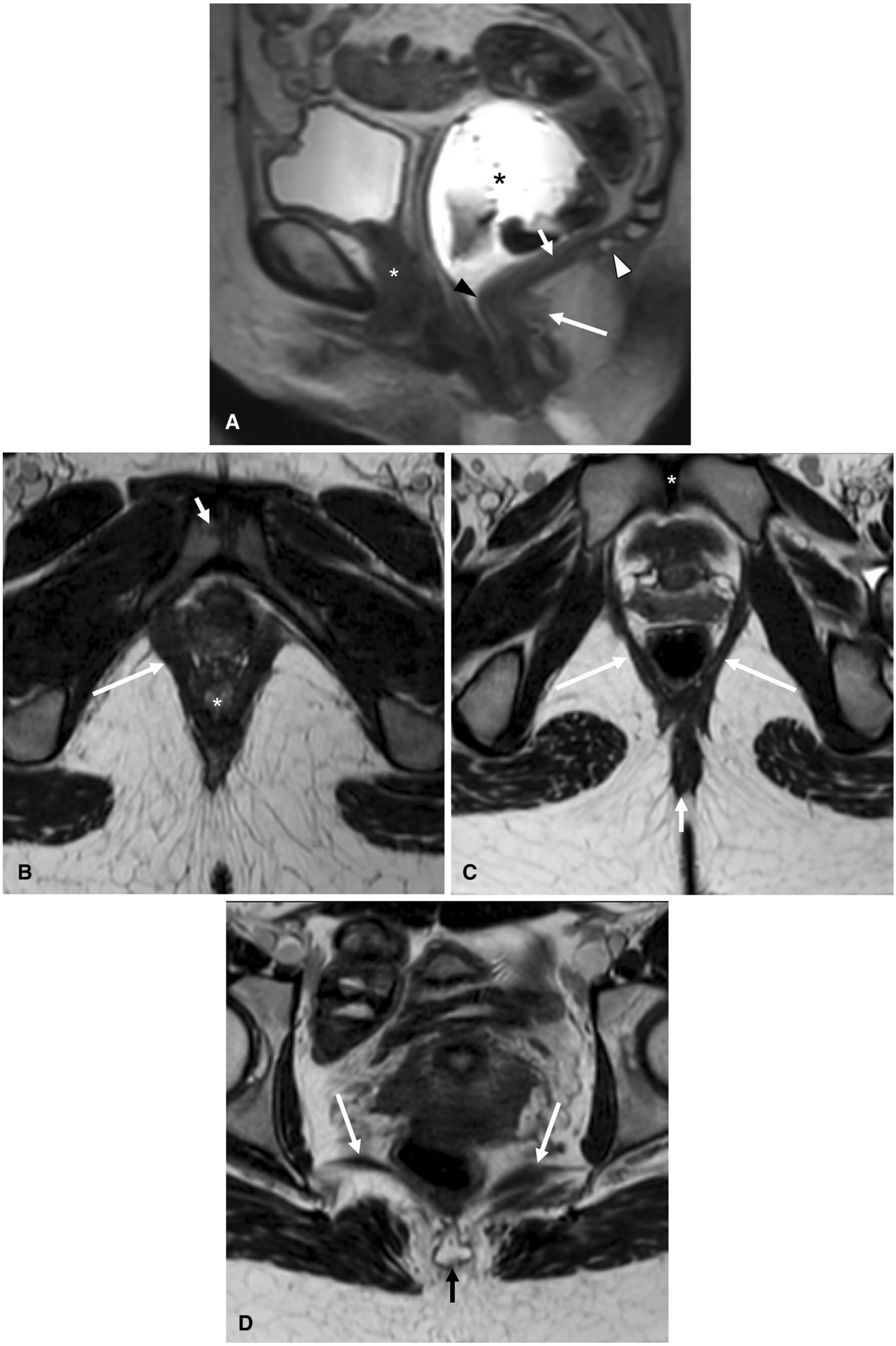
A
B
C
D

◂**Fig. 1** Normal pelvic support structures. **a** Sagittal T2-weighted image demonstrates posterior aspect of puborectalis (long arrow) seen at the level of anorectal junction (black arrowhead). Levator plate (short arrow) extends from the coccyx (white arrowhead) to the anorectal junction. Note normal vertical location of the urethra (white asterisk) and hyperintense gel distending the rectum (black asterisk). **b** Axial T2-weighted image demonstrates the sling of puborectalis (long arrow) attaching to the pubis (short arrow) and wrapping around the anorectal junction (*). **c** Axial T2-weighted image superior to (**b**) demonstrates pubococcygeus (long arrow) coursing from the pubis (*) to the levator plate (short arrow). **d** Axial T2-weighted image superior to (**c**) demonstrates iliococcygeus fibers (arrows) extending from the obturator fascia to the coccyx (short arrow)

embarrassed to report some of the symptoms [7]. Additional studies have demonstrated that radiology studies performed in a position of gravity, resulted in greater pelvic floor relaxation and increased intra-abdominal pressure compared to physical examination [7, 10–12].

Accurate diagnosis of pelvic floor dysfunction requires a multidisciplinary approach, often necessitating a complimentary imaging study. MRD plays a pivotal role because of its multiplanar capability, superior soft tissue contrast resolution, and ability to simultaneously identify multicompartment pathology [13]. It is excellent to evaluate for anatomic abnormalities, as it allows for direct visualization of both the pelvic organs and its support structures and can be correlated with the functional abnormalities. MRD has shown to unmask additional abnormalities compared to physical exam and may change surgical management in 67% of patients [5, 14–16]. While abnormalities in the anterior and middle compartment can be diagnosed by physical exam, posterior compartment pathology such as enteroceles, peritoneoceles, and rectorectal intussusceptions are not accurately differentiated on physical exam, but can be precisely evaluated by MRD [17–19]. Additionally, in patients presenting with defecatory dysfunction, MRD can help differentiate anatomic and mechanical causes of defecatory dysfunction (rectocele/rectal intussusception) from functional causes like dyssynergia. For patients with clinically suspected pelvic organ prolapse, or defecatory dysfunction, the American College of Radiology Appropriateness Criteria has assigned MR defecography with rectal contrast a rating of 9, and a rating of 7 in patients with urinary dysfunction, where scores of 7–9 are regarded as "usually appropriate" [20, 21].

Magnetic resonance defecography (MRD) is a reliable test that involves multiple dynamic sequences with excellent soft tissue resolution. It can simultaneously evaluate both anatomy and function of all pelvic compartments and their associated muscles and fascia in multiple planes, and the technique benefits from lack of ionizing radiation [5].

Anatomy of the pelvic floor

The pelvic floor is divided anatomically into the anterior, middle, and posterior compartments [22]. The anterior compartment contains the urinary bladder and urethra, the middle compartment contains the uterus and vagina, and the posterior compartment contains the rectum and anal canal. The pelvic floor is also a 3-dimensional complex network of support structures composed of fascia, ligaments, and muscle to from three interconnected layers, which help maintain the integrity of the pelvic support [5, 23]. The endopelvic fascia forms the superior most layer, which is a network of connective tissues comprising of various ligaments and fascia. It covers the pelvic organs and levator ani, providing support to the pelvic organs [22, 24]. The middle layer of the pelvic floor is formed by the pelvic diaphragm, which includes the levator ani and coccygeus muscle, which are well seen on MRI (Fig. 1). The levator ani is composed of the puborectalis, iliococcygeus, and pubococcygeus muscle. The levator plate is formed by the posterior fibers of the pubococcygeus muscle, which fuse to form a median raphe [5, 25]. The puborectalis is best seen on the axial T2 weighted images and the iliococcygeus and pubococcygeus are better evaluated on the coronal T2 plane [5, 25]. The inferior layer of the pelvic floor is formed by the urogenital diaphragm (perineal membrane), and is composed of connective tissues and the deep transverse muscle, which attaches posteriorly to the perineal body [5, 25].

The anorectal junction is identified at the angle formed by the distal rectum and anal canal with the puborectalis muscle seen posteriorly (Fig. 1). The apex of the anorectal junction forms the anorectal angle, which changes with the contraction of the puborectalis muscle, with normal values ranging from 108° to 127° at rest [5, 13]. The anal sphincter complex comprises of the internal anal sphincter (IAS), the longitudinal muscle layer within the fat containing intersphincteric space and the external anal sphincter (EAS), which is contiguous with the puborectalis muscle superiorly [26]. Detailed MRI anatomy of the pelvic floor will be discussed in this same issue by Flusberg et al.

Technique

MRI scanner configuration

MRI defecography exams are commonly performed on clinically available systems, which use an enclosed magnet with 1.5T or 3.0T field strengths. A recent consensus survey by the Society of Abdominal Radiology's

Disease-focused panel (SAR-DFP) for pelvic floor dysfunction found nearly 47% of the respondents had no preferred magnet strength, while 38% preferred imaging on a 1.5T to a 3T magnet [27]. Balanced sequences provide a higher signal-to-noise ratio per unit acquisition time on 3T magnets, but are also more susceptible to off-resonance effects which result in more banding artifacts [28]. MRD can be performed in a sitting position within an open configuration gantry or in a supine position in a closed magnet system. Several studies comparing patient positioning have resulted in contradictory findings. While some studies have shown supine MRD to underestimate the degree of pelvic organ prolapse in patients with posterior compartment symptoms, compared to sitting MRD which better simulates the physiology of defecation [15, 29], other studies have shown no significant difference in the diagnosis of most clinically relevant pelvic floor abnormalities and the underestimation on supine MRD may not impact clinical management [30]. In general, active defecation images with adequate rectal emptying and repetitive valsalva maneuvers are key regardless of the patient position and help reduce the number of false negatives [21, 31–34]. However, since upright MRI systems have limited availability, MR defecography exams are usually performed in supine position.

Patient instructions

Patient education is key to obtaining diagnostic quality MR defecography. Detailed instructions about the preparation and operational steps of the examination (rest and defecography phase) should be explained to the patient before beginning of the examination, to improve compliance during the examination and to improve the chances of successful evacuation of the rectal gel at the time of dynamic imaging.

Patient preparation and positioning

With patient in left lateral position on the scanner table, ultrasound gel is inserted into the rectum (120 cc) via a flexible tube [35]. Alternatively, potato starch mixed with gadolinium-based contrast agent has been used for distension by some researchers [36]. The use of vaginal gel (20–50 cc) is optional and the decision is often made on a case-by-case basis following discussion with referring physician [5, 13]. Bladder contrast is not indicated, but patients may need to empty the bladder prior to the start of the study to allow for physiologic filling and adequate distention by the time the dynamic images are obtained. Patients are offered adult diapers, towels, or enema ring (fluid collection device) to avoid spillage of rectal and vaginal gel on the scanner table. Following the preparation, patient is positioned supine with knees slightly bent with support behind the knees [37–39]. The images are acquired without intravenous or oral contrast.

MR image acquisition

A multichannel torso phased array anterior coil and a multichannel table-integrated posterior coil are applied around the patient once they are lying in supine position. The coils are centered on the low pelvis, with the patient pelvis positioned within the central magnet bore.

Static Imaging Static images are necessary for evaluation of the anatomy of pelvic organs and support structures, with special attention given to the muscles (puborectalis and iliococcygeus). The anatomic images are also helpful in determining anal sphincter anatomy, indirect signs of endopelvic fascial defects, and sequela of any prior surgical interventions. T2-weighted fast spin-echo (FSE) or fast recovery FSE sequences in the axial, coronal, and sagittal plane without fat saturation are usually obtained. High resolution 3D T2-weighted images with isotropic voxel acquisition (SPACE, Siemens Medical Solutions scanners, VISTA Phillips scanners, or CUBE on GE Healthcare scanners, respectively) can also be acquired in a single plane, and then reconstructed to any necessary projection.

Dynamic Imaging Dynamic imaging usually follows the resting static images. This involves the use of a sequence that has the property of fast image update to be able to acquire images while the patient strains, squeezes and defecates [5]. During straining, patients are asked to exert pressure across a closed sphincter, similar to a Valsalva maneuver to assess the internal and external anal sphincters. The squeezing phase (Kegel maneuver) is helpful to assess the puborectalis muscle and the defecation phase (expulsion of gel) helps assess the interplay of all support structures [5, 40]. It should be noted, however, that in some patient populations, particularly where language and communication barriers are prevalent, instructions for Kegel and strain phases may lead to confusion and inconsistent patient performance. In such cases, Kegel maneuvers may be omitted. In general, the MRD protocol should be customized to result in consistently diagnostic studies. However, multiple (at least two) attempts at straining and defecation should be routinely acquired to ensure depiction of maximal degree of pathology. In a healthy patient, the anorectal angle decreases during squeezing and the anorectal junction rises by 1–2 cm from its resting state [5, 41]. In contrast, during straining and defecation, the anorectal angle increases with shortening and opening of the anal canal, evacuating the rectum.

The optimal location for dynamic evaluation is selected from a static sagittal series through the pelvis. Large-field-of-view acquisition in mid-sagittal position is chosen as the anatomy of urinary bladder, urethra, vagina, rectum, and anal canal are well demonstrated in this plane. T2-weighted sequences such as half-Fourier acquisition turbo spin-echo (HASTE, Siemens Medical Solutions scanners) or single-shot fast spin-echo (SSFSE, GE Healthcare scanners) have similar capability to demonstrate pelvic floor mobility [42]. Dynamic acquisition using balanced steady state free precision sequences (SSFP) can also be obtained in the mid-sagittal plane, and cine acquisitions are acquired over a 30 s interval during the expulsion of gel. The protocol is summarized in Table 1.

The defecation sequence should be repeated at least three times to ensure adequate expulsion of the gel. If the patient is unable to evacuate the rectal gel, they are encouraged to empty the rectum in the bathroom and return for post evacuation valsalva images to help unmask cul-de-sac hernia and other anterior and middle compartment hernias that may have been masked by rectal distention. Expulsion of gel during the defecation phase provides the most accurate information about the severity of prolapse. Employment of the straining phase is variable across institutions and there is increasing evidence that defecography phase is more useful to identify and unmask clinical abnormalities [39, 42]. The Society of Abdominal Radiology's Disease-focused panel (SAR-DFP) for pelvic floor dysfunction strongly recommends evaluation of pelvic organ prolapse during the defecography phase.

Pitfalls in technique

True severity of pelvic organ prolapse is unmasked in the defecography phase [39]. It is imperative for the patient to expel out the rectal gel completely. Inadequate effort may result in failure of emptying of rectum and result in the under detection of enterocele and rectal intussusception. Inadequate effort may also result in the nonrelaxation of anorectal angle which should become progressive obtuse with defecation; this should be differentiated from pelvic floor dyssynergia which demonstrates paradoxical narrowing of the anorectal angle and hypertrophy of the puborectalis muscle from its persistent contraction [43, 44]. Over distention of the urinary bladder should also be avoided as it may obscure additional findings in other compartments and result in underestimation of pelvic organ prolapse [45].

Interpretation of MR defecography

A standardized approach to image review and use of a structured report are essential steps in providing accurate and comprehensive interpretation of MR defecography. The Society of Abdominal Radiology Pelvic Floor Dysfunction Disease Focused Panel recommends a structured reporting template, which can be accessed from its weblink below.

http://www.abdominalradiology.org/resource/resmgr/education_dfp/PelvicFloor/MRdeftemplate7.2017(P).pdf.

The report can be modified as needed after discussion and feedback from referring physicians to ensure that all clinically relevant information is included. Grading schemas can be kept on hand in the reading room or built into dictation pick lists to allow for quick analysis of acquired measurements. This can be especially beneficial to ensuring consistent high-quality reports from less experienced readers and trainees.

Image interpretation begins with assessment of anatomic coverage on static imaging and defecatory effort on dynamic sagittal series. The dynamic defecation cine sequence should be reviewed to select the image with maximal strain. This is then displayed next to a comparable rest image.

Reference lines and distances are then placed and calculated on both rest and maximal strain images. The pubococcygeal line (PCL) is drawn first from the posterior-inferior pubis to the last visible coccygeal joint (Fig. 2) [5]. An alternative reference line is the midpubic line (MPL), which extends across the long axis of the pubic symphysis and denotes the level of the vaginal hymen, a landmark for clinical staging [5, 46, 47]. The H-line and M-line are then drawn and used to assess for pelvic floor dilatation and descent, respectively. The H-line is drawn on the mid-sagittal T2 weighted image, from the inferior margin of the pubic symphysis to the posterior rectal wall at the anorectal junction and the M-line is drawn perpendicularly from the

Table 1 Dynamic pelvic MRI protocol

Pulse sequence	TR/TE (ms)	Section thickness (mm)	Field of view (mm)	Flip angle (°)	Matrix (pixels)
Axial HASTE	1500/85	7	200–240	170	256×210
Coronal HASTE	1500/85	7	200–240	170	256×216
Sagittal HASTE	1500/84	6	200–240	170	256×240
Steady state free precession sequence—mid-sagittal (acquired over 30 s)	3.25/1.63	8	200	70	256×140

These parameters are established on a 3T scanner. SSFP cine images should be obtained during Kegel, straining and defecation

TR repetition time, *TE* echo time

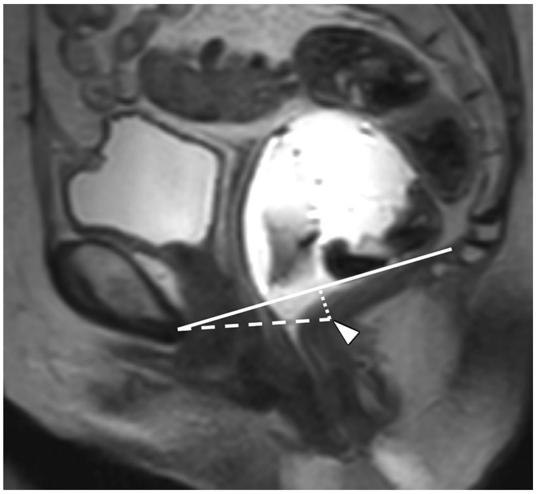

Fig. 2 Reference lines. Sagittal T2-weighted image demonstrates placement of reference lines. Pubococcygeal line (PCL, solid line) extends from the inferior pubis to the last coccygeal joint. H-line (long-dashed line) extends from the inferior pubis to the posterior rectal wall at the anorectal junction (arrowhead). M-line (short-dashed line) is perpendicular to the PCL from the posterior aspect of the H-line

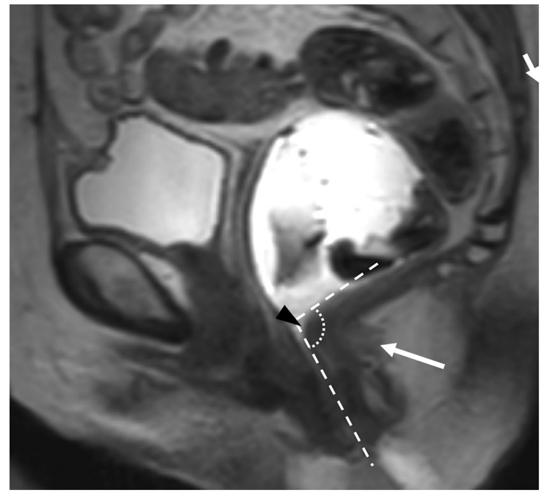

Fig. 3 Anorectal angle. The apex of the anorectal junction (black arrowhead) is the anorectal angle with normal values ranging from 108° to 127° at rest. Note the puborectalis muscle (long arrow) posteriorly

posterior aspect of the H-line to the PCL (Fig. 2). The H-line measures the anterior–posterior distance of the levator hiatus, while the M-line measures the descent of the muscular pelvic floor and should normally measure ≤ 6 cm and ≤ 2 cm respectively [5, 20]. A perpendicular line from the PCL to the bladder base and another line from the PCL to the anterior cervical lip or superior vaginal cuff are placed to estimate the degree of anterior and middle compartment descent, respectively. Urethral angle relative to the long axis of the patient is another measure of anterior descent. A line is also drawn from the most anterior position of the rectal wall to its expected location to determine presence and grade of anterior rectocele.

The anorectal angle is measured to evaluate for pelvic floor dyssynergia. The anorectal junction measured at rest is ≤ 2 cm below the PCL, with normal values ranging from 108° to 127° at rest (Fig. 3) [5, 13]. At maximum squeeze, the anorectal angle decreases by 15–35% as a result of contraction of the puborectalis, moving the anorectal junction anteriorly and superiorly. During straining and defecation, the converse occurs secondary to relaxation of the puborectalis muscle, which moves anorectal junction posteriorly and inferiorly, making the anorectal angle obtuse by 15–20%. Urethral angle is measured between the axis of the urethra and the patients body axis. Laxity or disruption of the urethral ligaments leads to urethral hypermobility, diagnosed when there is > 30% horizontal angulation of the urethra away from the normal vertical axis with strain [48, 49].

After these measurements are obtained, dynamic images are reviewed again for presence of any cul-de-sac abnormality. The rectum is evaluated for intussusception, often most apparent near the completion of evacuation. Static images must also be examined to evaluate the pelvic ligaments, anal sphincter complex, and additional included pelvic structures. Puborectalis is often thinned in patients with stress and mixed urinary incontinence, and is thickened in patents with dyssynergia [50, 51]. Any areas of asymmetry should raise concern for structural defects in the support system. Although no validated normal references values for puborectalis thickness are available, an anecdotal rule of thumb is that the puborectalis is thickened when it is greater than three times the thickness of the pubococcygeus, a finding that supports diagnosis of pelvic floor dyssynergia.

Pelvic floor dysfunction

Pelvic floor dysfunction may involve pelvic organ prolapse and/or pelvic floor relaxation. In pelvic floor relaxation, there is weakening of the pelvic floor support structures, which become ineffective. This results in descent of one or more compartments during rest and/or defecation, irrespective of organ prolapse [5]. During pelvic floor relaxation, there is descent of the pelvic floor and widening of the levator hiatus, which are assessed by the H and M lines [20]. The grading system is summarized in Table 2.

In patients with prolapse, there is abnormal decent of the pelvic organs, which include the urinary bladder, uterus, vagina, or bowel through the hiatus [5]. Pelvic organ prolapse is measured by using the PCL or MPL as a reference. The PCL is more frequently used due to its simplicity and higher inter-observer variability, but does not offer a clear

Table 2 Grading of pelvic floor relaxation using H and M lines [5, 20]

Grade	H-line Hiatal enlargement	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

H-line and M-line measurements are performed on a mid-sagittal balanced gradient echo sequence at maximal strain during defecation

Table 3 Grading of pelvic organ prolapse using PCL as Ref. [5, 20, 23]

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

*Distance is measured from the PCL to the inferior bladder base (cystocele), anterior cervical lip (uterine prolapse) and superior vaginal cuff (vaginal prolapse)

Table 4 Grading of pelvic organ prolapse using MPL as Ref. [5, 20, 23]

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

*Distance is measured from the MPL to the inferior bladder base (cystocele), anterior cervical lip (uterine prolapse) and superior vaginal cuff (vaginal prolapse)

advantage over the MPL [46, 52, 53]. When the PCL is used as reference, it is graded by the "rule of three", described in Table 3 [5, 20, 23]. When the MPL is used as reference, there are 5 stages as described in Table 4 [5, 20, 23].

Anterior compartment pathology: cystocele and urethral hypermobility

The structures supporting the urethra and bladder include the urethral ligaments (pubo-, peri-, para-, and sub-urethral ligaments) and paravaginal fascia (Fig. 4). At rest, normal orientation and position of the urethra are vertical and retropubic, respectively [54, 55]. Laxity or disruption of the urethral ligaments leads to urethral hypermobility, defined as excessive posterior rotation of the urethral axis with strain. This is best seen on sagittal MRI sequences where the urethra has

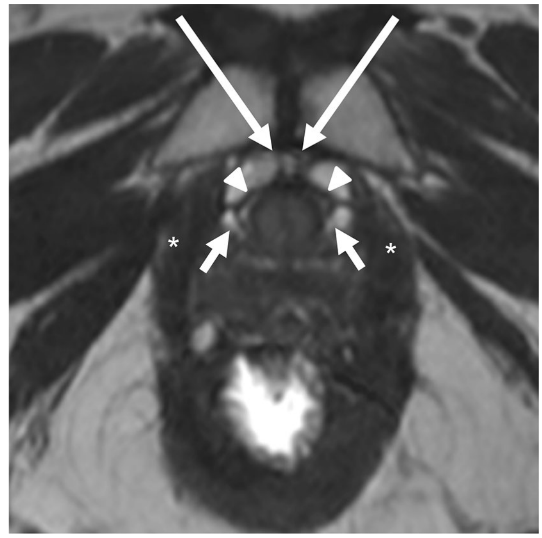

Fig. 4 Urethral ligaments. Axial T2-weighted image demonstrates pubourethral ligaments (long arrows) coursing from the pubis to the anterior urethra. Periurethral ligaments (arrowheads) course from the urethral origin of the pubourethral ligaments to the medial aspects of the puborectalis muscle (*). Paraurethral ligaments (arrowheads) connect the lateral wall of the urethra to the periurethral ligaments

a posterior oblique orientation at rest and rotational descent with strain. Urethral hypermobility is frequently associated with descent of the urethra below the pubis symphysis and descent of the bladder below the pubococcygeal line (PCL), which represents the level of the pelvic floor (Fig. 5) [5]. Summers et al. showed that 2/3rd of urethral displacement are related to bladder displacement [56]. Diagnosing urethral hypermobility has surgical implications as they are often repaired with a sling procedure [57].

A cystocele results from suboptimal anterior abdominal wall bladder support and/or from defects of the pubocervical fascia, and is identified on physical examination as abnormal bladder descent with bulging of the anterior vaginal wall, with or without anterior vaginal wall prolapse. On MRI, the normal position of the bladder base is above the PCL at rest, and at or just below the PCL with strain. If there is abnormal descent, the bladder moves in an arc-like, posterior and inferior trajectory, descending well below the PCL, causing mass effect on the anterior wall of the vagina (Fig. 5).

Middle compartment pathology: uterine and vaginal prolapse

The structures supporting the uterus and vagina include the pubocervical fascia, cardinal, and uterosacral ligaments. At rest, the normal position of the uterus is well above the PCL, the lower vagina orientation is vertical, and the upper vagina orientation (above the levator plate) is posterior oblique (Fig. 6). Abnormal descent of the uterus and

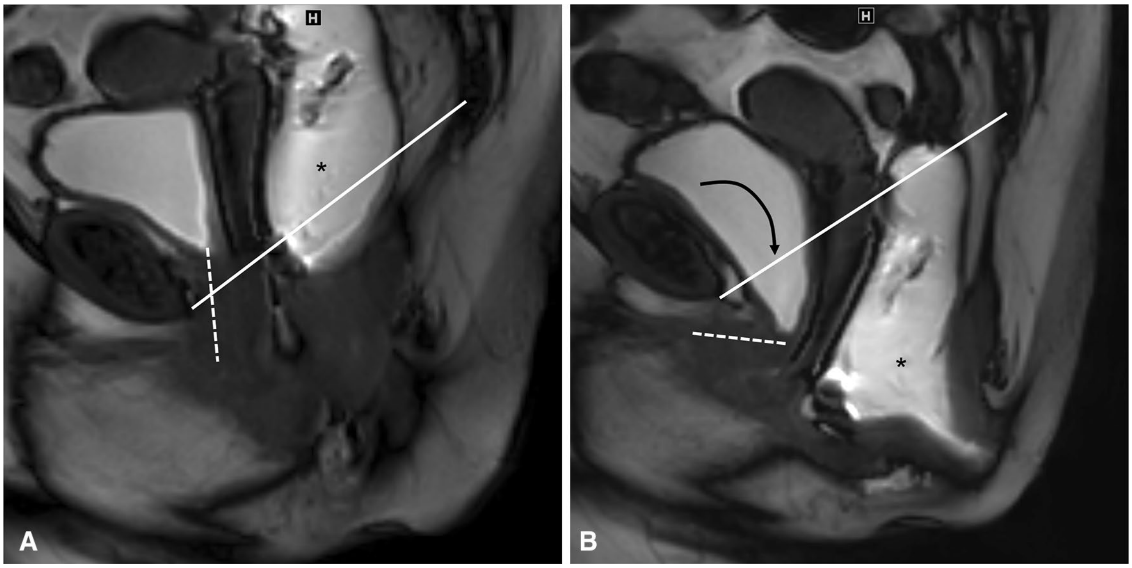

Fig. 5 Urethral hypermotility and cystocele. Sagittal balanced gradient echo image at rest (**a**) demonstrates minimal posterior angulation of the urethra (dashed line) of approximately 26° to the axis of pubis. On the sagittal balanced gradient echo image with defecation (**b**), the urethra axis rotates posteriorly (to 133°), and descends below the pubis symphysis, consistent with urethral hypermobility. This is associated with posterior and inferior descent of the bladder (black curve), 2.6 cm below the level of the pubococcygeal line (solid white line), consistent with mild cystocele. Note gel distending the rectum (*)

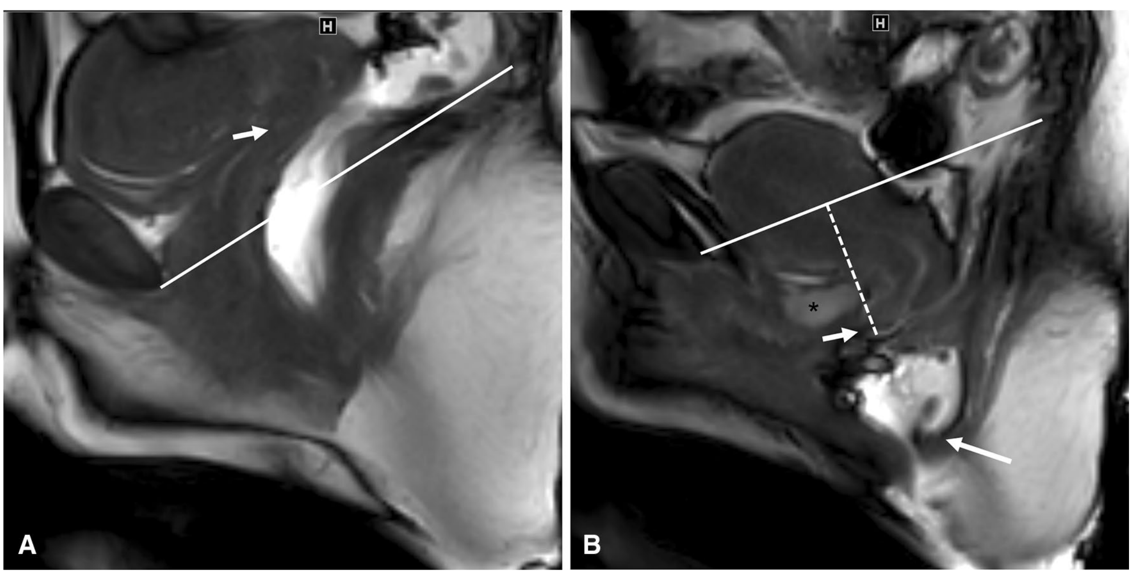

Fig. 6 Uterine prolapse. Sagittal T2 balanced gradient echo at rest (**a**) and with defecation (**b**) demonstrate descent of the anterior cervical lip (short arrow) with maximal stress (dashed line, **b**) to approximately 4 cm below the pubococcygeal line (white line), consistent with moderate uterine prolapse. Note concomitant moderate cystocele (*) and severe descent of the anorectal junction (long arrow)

vagina indicates loss of normal supporting structures, allowing the uterus to descend between the pubovesical fascia anteriorly and rectovaginal fascia posteriorly. On MRI, it is abnormal to see any part of the uterus or vaginal apex below the PCL (Fig. 6). The vagina may appear shortened and the lower vagina displaced inferiorly and anteriorly. Due to the shared fascial supports, uterine prolapse is associated with cystocele and anterior vaginal wall eversion (Fig. 6) [7]. After hysterectomy, vaginal prolapse is commonly associated with multicompartmental defects including cystocele, enterocele, or rectocele [7].

The severity of bladder and uterine prolapse can be graded using the PCL or MPL as reference and is summarized in Tables 3, 4 [5, 20, 23].

Posterior compartment pathology: rectocele, rectal intussusception, atrophic external anal sphincter, and pelvic dyssynergia

MRD, performed either with a closed or open configuration, is considered an accurate imaging technique to assess the posterior compartment for pelvic floor dysfunction. In contrast to fluoroscopic colpocystodefecography, MR defecography does not require exposure of the patient to ionizing radiation, and allows excellent anatomic depiction of surrounding soft tissue structures [6]. The posterior compartment consists of the rectum and anus, as well as the anorectal junction (defined as the point where the distal rectum joins the proximal anal canal). Adequate evaluation of the posterior compartment requires assessment during defecation and imaging during strain alone is inadequate [34].

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 [5]. Rectoceles can be located anteriorly or posteriorly to the rectum. Anterior rectoceles are much more common, seen on clinical examination as a bulge impressing upon the posterior vaginal wall. Clinical examination is not very sensitive in detection of anterior rectocele, with a sensitivity of between 30 and 80% [24, 58]. On physical exam, it is often difficult to distinguish an anterior rectocele from a cul-de-sac hernia and at times an enterocele. A cul-de-sac hernia, also known as peritoneocele, is defined as a herniation of peritoneal folds into the rectovaginal septum, below the cul-de-sac, passing the proximal one-third of the vagina (Fig. 7) [59]. These hernias are the most difficult to diagnose with physical exam alone. When a cul-de-sac hernia contains small bowel loops, it is named enterocele (Fig. 8). When it contains sigmoid colon, it is named sigmoidocele [59]. Patients with prior history of hysterectomy or urethropexy are at increased risk for cul-de-sac hernia due to damage of the rectovaginal fascia [59].

Patients with rectocele can experience vaginal symptoms (bulging or dyspareunia) or rectal abnormalities (sensation of incomplete evacuation, constipation, and defecatory dysfunction) [20]. To diagnose anterior rectocele on MRI, protrusion of the rectal wall should be measured in the anterior–posterior dimension with respect to its expected location, which can be approximated by the location of the anterior aspect of the anal canal (Fig. 9) [6]. A bulge of <2 cm can be seen in asymptomatic patients and is considered mild, 2–4 cm is considered moderate, and >4 cm considered large anterior rectocele [60, 61]. Posterior rectoceles are rare and are seen when there is damage of the levator plate [62]. Lateral rectoceles also occur when there is compromise of the rectovaginal fascia, which are diagnosed when there is a lateral defect in the rectovaginal septum from the iliococcygeus fascia [63]. In addition to lateral defects, defects may occur midline or through high transverse fascial defects. A rectocele can develop at or below the levator plate, along the vertical vagina. Trauma from vaginal childbirth can lead to

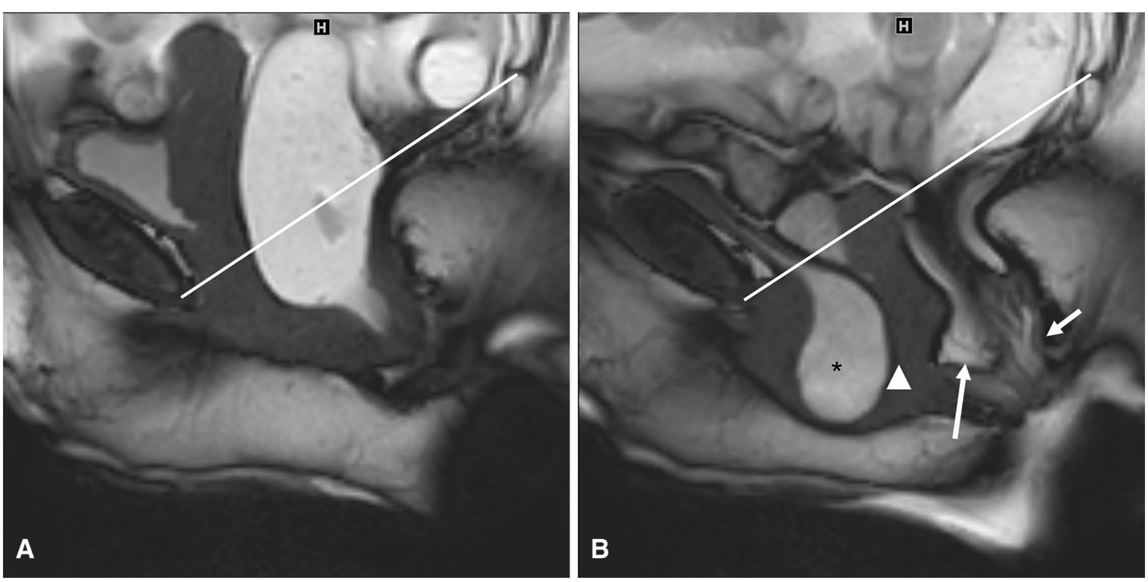

Fig. 7 Peritonocele. Sagittal balanced gradient echo image at rest (**a**) and end defecation (**b**) shows descent of the mesenteric fat (long arrow) inferiorly in relation to the pubococcygeal line (straight line), extending into the rectovaginal space. Note a concomitant moderate cystocele (*), moderate uterine prolapse (arrowhead), and moderate descent of the anorectal junction (short arrow)

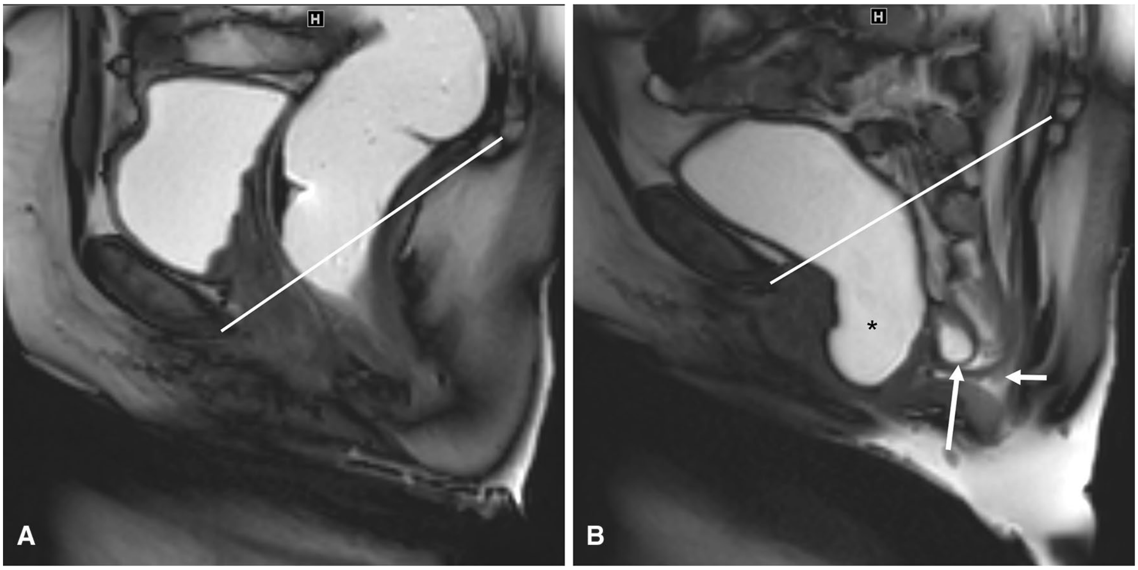

Fig. 8 Enterocele. Sagittal balanced gradient echo images at rest (**a**) and end defecation (**b**) demonstrate descent of the small bowel (long arrow) inferiorly in relation to the pubococcygeal line (straight line). Decompressed rectum (short arrow) at end defecation allows for most accurate depiction of the enterocele. Note a concomitant moderate cystocele (*)

perineal lacerations, and weakening of the bulbocavernous and transverse perineal muscles, which can create additional sites of potential rectocele development [64]. The pelvic peritoneal sac can herniate into the rectovaginal space and may contain mesenteric fat (peritoneocele), small bowel (enterocele), or sigmoid colon (sigmoidocele) (Figs. 7, 8) [5].

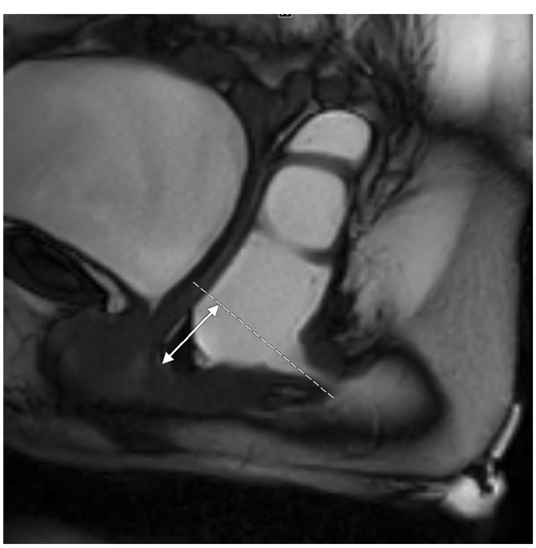

Fig. 9 Anterior rectocele. Sagittal balanced gradient echo image demonstrates anterior bulge of the rectal wall > 2 cm, measured from a line drawn from the level anterior aspect of the anal canal (dotted line)

Rectal intussusception

Rectal intussusception and prolapse occur with chronic straining and damage to the surrounding fascia. Rectal intussusception is defined as invagination of the rectal wall, and can be defined as intrarectal (confined to the rectum), intra-anal (extending to the anal canal) or extra-anal (passing beyond the anal orifice) [6, 65]. Extra-anal intussusception is also known as rectal prolapse. Rectal intussusceptions may only contain mucosa (mucosal—also known as partial thickness intussusception) or contain all layers of the rectum (Fig. 10) [66]. They may involve only the anterior wall of the rectum or more commonly be circumferential in nature. Pudendal neuropathy secondary to chronic straining in the setting of rectal prolapse may result in external anal sphincter atrophy and fecal incontinence [20]. Although MRD is less sensitive for evaluation of rectal intussusception compared to fluoroscopic defecography, with a reported relative sensitivity of 70%, MRD can differentiate mucosal from full-thickness intussusception, a differentiation that may alter management [65]. Management differs depending on whether the intussusception is partial or full thickness. For example, partial thickness intussusception may be treated non-surgically or by transanal resection of prolapsed mucosa; whereas, full-thickness intussusception often requires rectopexy [24, 67]. While mucosal intussusceptions are seen as thin dark curvilinear structures that bunch along the rectal wall during defecation, full-thickness intussusceptions appear as invagination of the entire rectal wall upon itself. The clinical relevance of missed findings at MR defecography has been reported as of little importance.

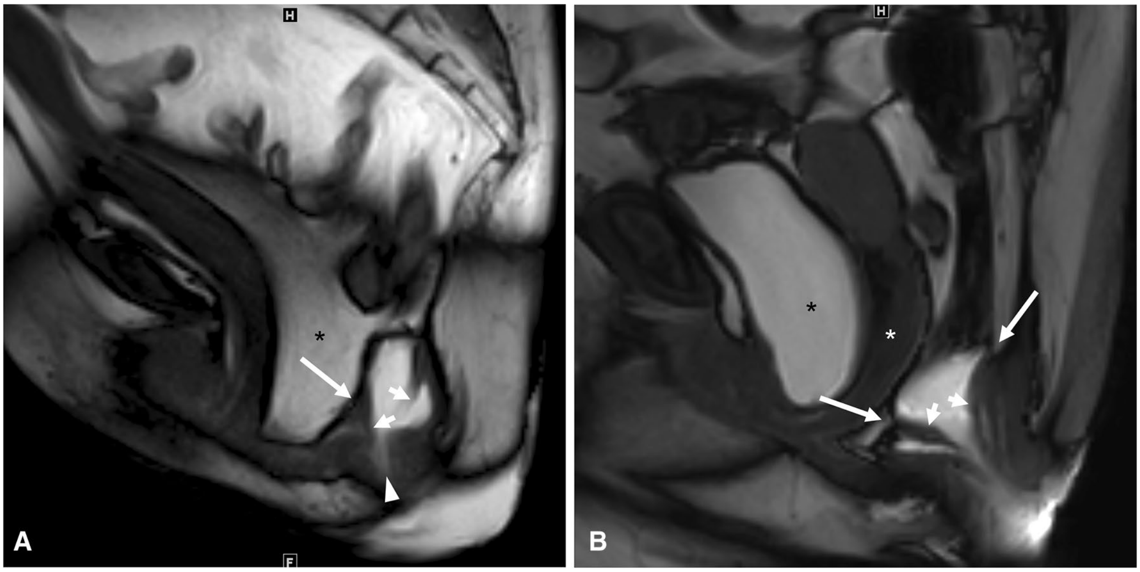

Fig. 10 Rectal intussusception. **a** Sagittal balanced gradient echo image during the defecation phase demonstrates a mucosal rectal intussusception. Note thin invaginated flaps of the rectal mucosa (short arrows) without an associated deformity of the outer rectal wall (long arrow). Anteriorly, the mucosal intussusception extends into proximal anal canal (arrowhead). Note a concomitant large peritoneocele (*). **b** Sagittal balanced gradient echo image during the defecation phase demonstrates a full-thickness rectal intussusception. Note that the invaginated flaps are thick (short arrows) as they involve the full thickness of the wall, with associated deformity of the outer wall (long arrows). The intussusception remains intrarectal. Note a concomitant cystocele (black asterisk) and uterine prolapse (white asterisk)

The presence of low-grade intussusception is high, even in the asymptomatic population. The difference between these modalities is also likely related to the difficulty in standardizing procedures, and to the fact that the mobility of the rectum and degree of straining during defecation are likely to affect the formation and degree of any intussusception [13].

In describing rectal intussusception, it is important to use a grading system, as this helps the colorectal surgeons in planning the surgical repair. Many institutions refer to the Oxford radiologic grading system of rectal intussusception. This grades the rectal intussusception according to the lowest extent reached by the apex of the intussusceptum, in relation to the associated rectocele and anal canal. Grade 1 is the high rectal intussusception, which descends no lower than the proximal limit of the rectocele. Grade 2 is the low rectal intussusception, which descends into the level of the rectocele, but not onto the sphincter/anal canal. Grade 3 is the high anal intussusception, which descends into the sphincter/anal canal. Grade 4 is the low anal intussusception, which descends into the sphincter/anal canal. Grade 5 is the external or overt rectal prolapse, with protrusion from the anus [68].

Atrophic external anal sphincter

Defecation involves a series of events that are under both involuntary and voluntary control, requiring adequate sensory perception and coordinated anorectal movement of stool [69]. The diagnostic criteria for fecal incontinence are delineated in the Rome IV criteria for functional anorectal disorders and include the recurrent uncontrolled passage of fecal contents in individuals with a developmental age >4 years and a duration of symptoms >3 months [70]. This condition is reported to affect up to 9% of the population, and has a greater predilection for middle-aged women and residents of nursing homes [9, 71]. Other risk factors for fecal incontinence include older age, diarrhea, vaginal birth, multiparity, and urinary incontinence [69]. The etiology of fecal incontinence is generally multifactorial; however, damage to the pelvic floor structures that maintain continence is a major underlying etiology [20, 72].

MR defecography can provide valuable information in patients with fecal incontinence, particularly for assessment of rectal descent, the presence of rectoceles, and the integrity of the internal and external anal sphincter (EAS) complex [14, 21]. MR imaging findings in patients with fecal incontinence can include atrophy, thinning, and defects of the EAS (Fig. 11) [20, 40, 73]. EAS atrophy is graded as mild when there is $<50\%$ thinning or fatty replacement and severe when there is $>50\%$ thinning or fatty replacement [73, 74]. Adequate evaluation of EAS atrophy is vital, as it is associated with poor surgical outcomes following anal sphincter repair [75]. In a retrospective study of 50 patients with fecal incontinence, MR

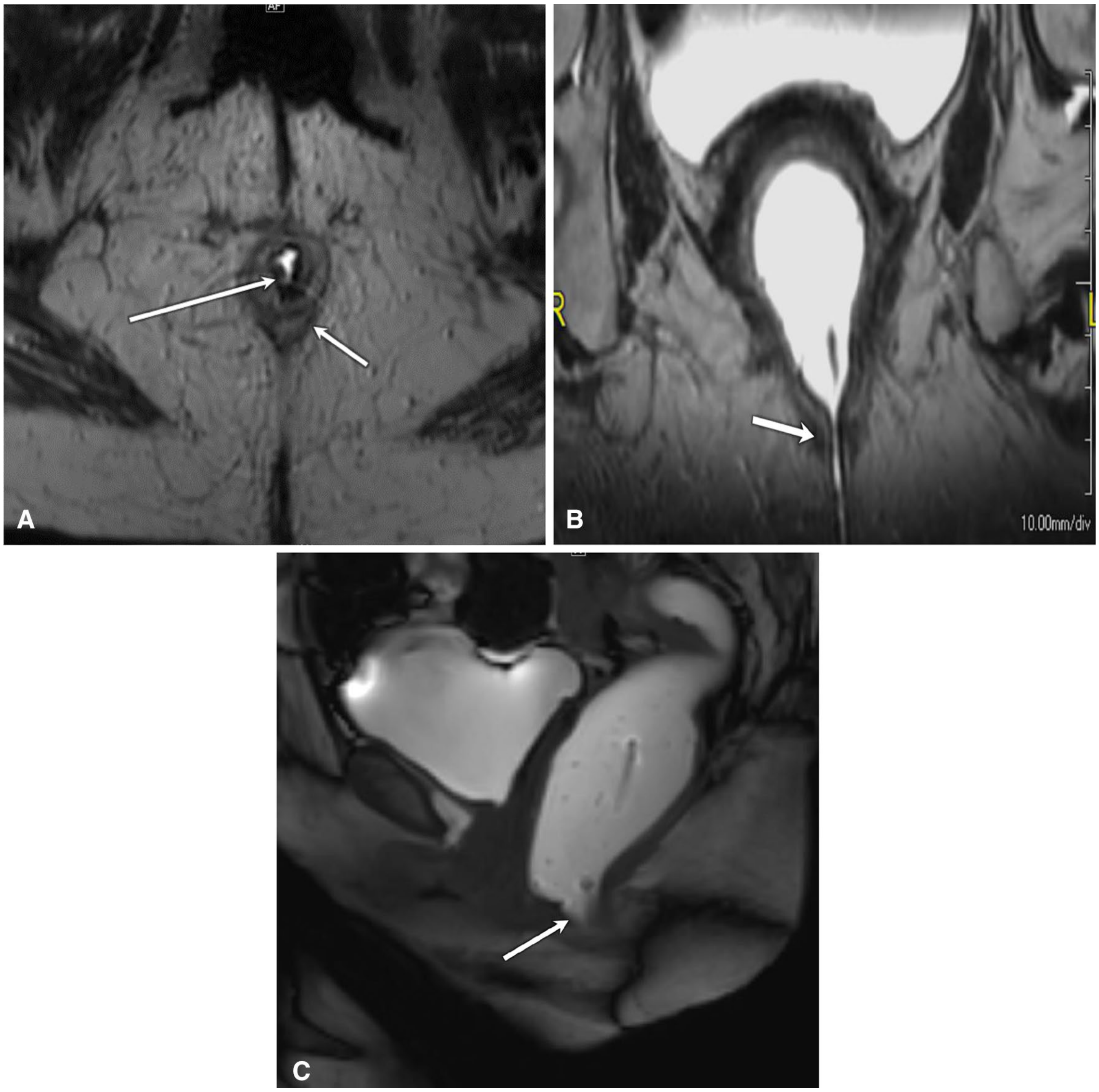

Fig. 11 Fecal Incontinence. Axial-oblique through the axis of the anal canal high resolution T2-weighted image. **a** Shows atrophied internal anal (long arrow) and external anal sphincter (short arrow). Coronal-oblique through the axis of anal canal T2 weighted image. **b** Shows a foreshortened canal (short thick arrow), measuring approximately 1 cm. Sagittal T2 weighted image. **c** Demonstrates a patulous canal (arrow)

defecography revealed descent of the rectum > 6 cm relative to the PCL in 94%, anterior rectoceles in 34%, and rectal prolapse in 20% of patients [14]. In this same study, results of MR defecography led to changes in the surgical approach in 67% of patients who ultimately underwent surgery, underscoring the potential value of this test for assessment of fecal incontinence [14]. Patients with anorectal disorder often have a patulous anal canal, which maybe a marker of injury to the anal sphincter, damage to anal cushions, or anal denervation [76].

Pelvic dyssynergia

Pelvic floor dyssynergia, also termed spastic pelvic floor or anismus, is the failure or inability to coordinate the abdominal and pelvic floor muscles involved in defecation and results in functional outlet obstruction [70]. The diagnostic criteria for dyssynergic defecation are delineated in the Rome IV criteria for functional anorectal disorders and include inappropriate contraction of the pelvic floor (typically measured with anal surface EMG or manometry) with adequate propulsive forces during attempted defecation. Criteria must be fulfilled for the last 3 months with symptom onset at least 6 months before diagnosis [70]. Presenting manifestations may include constipation, prolonged and incomplete defecation, and delay between opening of the anal canal and initiation of defecation [6].

MR defecography can be highly useful for patients who have equivocal clinical testing for dyssynergic defecation; in order to identify structural lesions, visualize paradoxical contraction of puborectalis and disordered defecation, and to assess superimposed pelvic floor relaxation. The persistent contraction of the puborectalis results in muscle hypertrophy and a prominent impression on the anorectal junction, with a paradoxical narrowing in the anorectal angle (ARA) during defecation (Figs. 12, 13) [43]. Dynamic MRI can demonstrate prolonged and incomplete evacuation and increase of the time interval between opening of the anal canal and defecation [5]. Prolonged and incomplete evacuation is defined

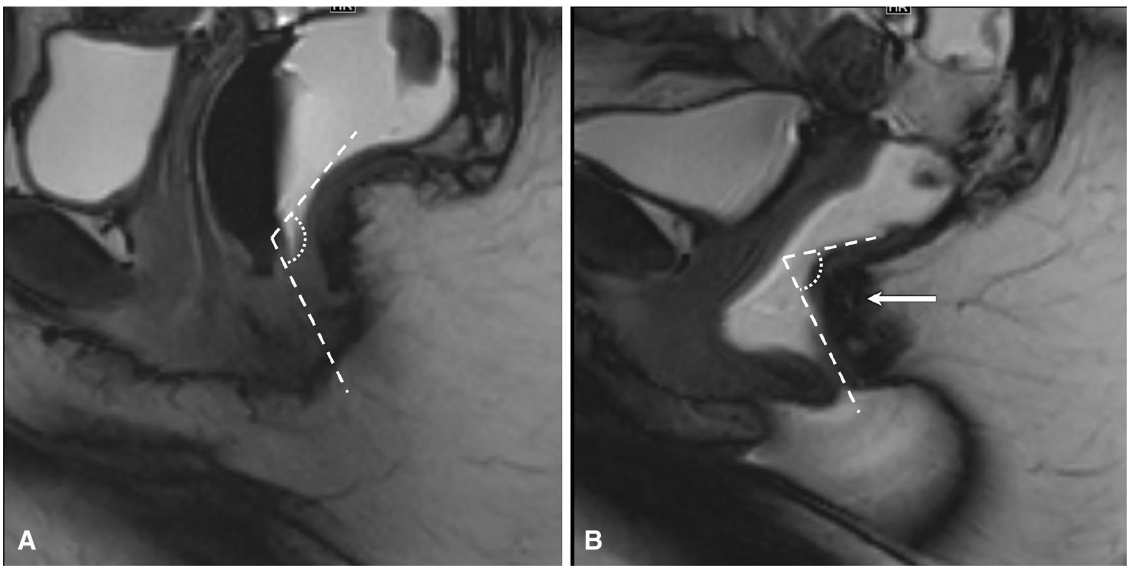

Fig. 12 Pelvic floor dyssynergia. Sagittal balanced gradient echo images at rest (**a**) and with defecation (**b**) demonstrates paradoxical narrowing of the anorectal angle during defecation. Notice contraction of the puborectalis (**b**, arrow) with straining. Passage of gel through the anal canal and descent of the anorectal junction confirm adequate straining effort

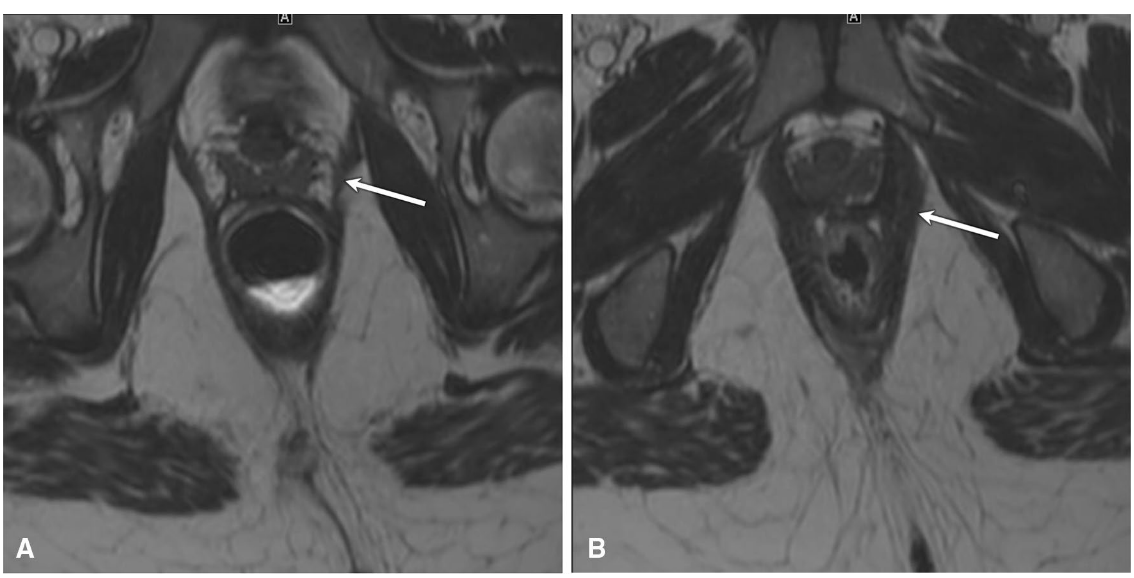

Fig. 13 Pelvic floor dyssynergia. Axial high resolution T2-weighted images through the level of pubococcygeus (**a**) and puborectalis (**b**) demonstrate diffuse thickening of puborectalis (**b**, arrow), greater than three times the thickness of pubococcygeus (**a**, arrow)

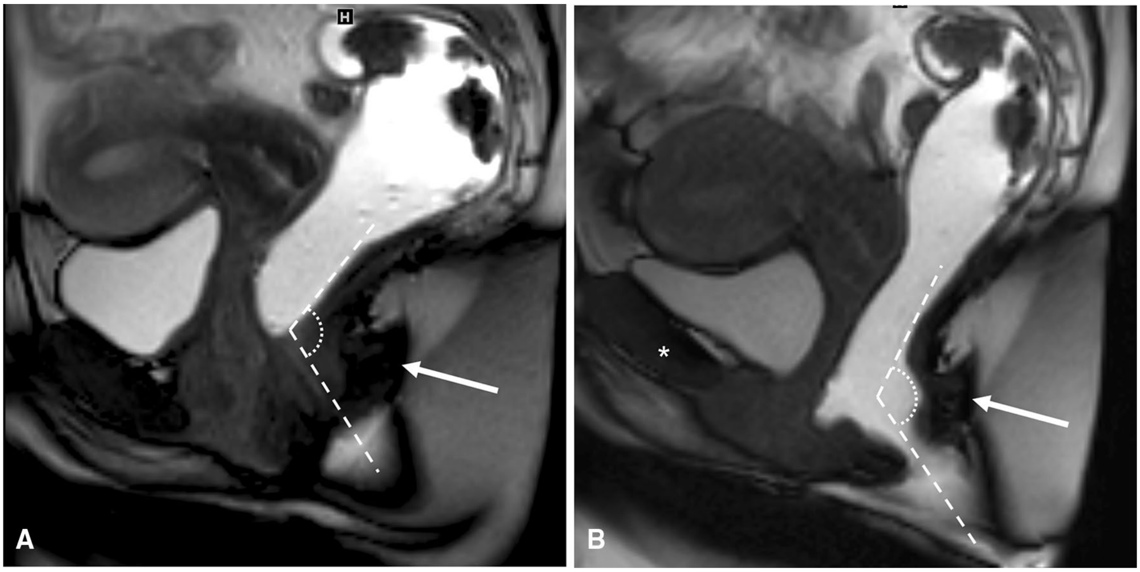

Fig. 14 Pelvic floor dyssynergia. Sagittal balanced gradient echo images at rest (**a**) and with defecation (**b**) in a different patient *without* dyssynergia demonstrates expected widening of the anorectal angle with defecation (**b**). With defecation, puborectalis (long arrow) relaxes and moves inferiorly and posteriorly with respect to pubis (*, **b**)

as the inability to expel rectal gel within the whole examination or two-thirds of the rectal gel within 60 s. The 60-s cut-off value for a normal evacuation time at MR defecography is taken from published data in the literature where conventional defecography was performed in patients with dyssynergic defecation [44].

Additional MR findings can include anterior rectocele and lack of normal pelvic descent [20]. A prior study of 48 patients with suspected dyssynergic defecation demonstrated high sensitivity for the finding of impaired evacuation (100%) and paradoxical contraction of the sphincter (83%) [44]. The finding of abnormal change in the ARA alone yielded lower sensitivity (50%) with high specificity (97%) for the detection of dyssynergic defecation; although, detection rates improved to 94% when changes in ARA were combined with paradoxical sphincter contraction [13]. Treatment of dyssynergic defecation includes multi-component, comprehensive biofeedback therapy, including patient education, enhancing the push effort, training to relax the pelvic floor muscles and practicing simulated defecation [70, 77]. Abnormal change of the ARA, (the angle between the central axis of the anal canal and the posterior wall of the distal part of the rectum) is defined as a decrease in the ARA between rest and straining, and was found more often in patients with pelvic dyssynergy than in control patients. Normally, the ARA increases between rest and straining given the normal pelvic floor descent at straining (Fig. 14). Paradoxical contraction of the anal sphincter during evacuation is diagnosed when there is a marked impression of the puborectalis muscle or anal sphincter in the posterior anorectal wall and a poorly relaxing puborectalis muscle or anal sphincter, which does not cause normal pelvic floor descent during straining and defecation [44].

Conclusion

Pelvic floor dysfunction is a common and often complex disorder presenting with a wide range of nonspecific clinical symptoms. This poses a significant diagnostic challenge to clinicians often remaining under diagnosed and affecting the quality of life in a number of patients. MRD is a comprehensive imaging test that can provide detailed anatomy of the pelvic floor, use its dynamic capability to help diagnose multicompartmental pathology and assist with the appropriate surgical approach, playing an integral part in both the diagnosis and management of pelvic floor dysfunction [13, 14, 78].

References

1. Hallock JL and Handa VL. The epidemiology of pelvic floor disorders and childbirth: an update. Obstet Gynecol Clin North Am. 2016 March; 1-13.
2. Wu JM, Vaughan CP, Goode PS, Redden DT, Burgio KL, Richter HE, Markland AD. Prevelance and trends of symptomatic pelvic floor disorders in U.S. women. Obstet Gynecol. 2014 January; 123(1): 141-148.
3. Sung VW, Washington B, Raker CA. Costs of ambulatory care related to female pelvic floor disorders in the United States.

American Journal of Obstetrics and Gynecology. 2010; 202(5): 483.e1–483.e4.
4. Wu JM, Kawasaki A, Hundley AF, Dieter AA, Myers ER, Sung VW. Predicting the number of women who will undergo incontinence and prolapse surgery, 2010 to 2050. American journal of Obstetrics and gynecology. 2011; 205(3):230.el-330.e5.
5. García del Salto L, de Miguel Criado J, Aguilera del Hoyo LF, Gutiérrez Velasco L, Fraga Rivas P, Manzano Paradela M, Díez Pérez de las Vacas MI, Marco Sanz AG, Fraile Moreno E. MR imaging–based assessment of the female pelvic floor. Radiographics. 2014;34(5);1417-39.
6. Mortele KJ and Fairhurst J. Dynamic MR defecography of the posterior compartment: indications, techniques and MRI features. Clinical Imaging, 2007;31(5): p.371.
7. Maglinte DD, Kelvin FM, Fitzgerald K, Hale DS, Benson JT. Association of compartment defects in pelvic floor dysfunction. AJR Am J Roentgenol. 1999 Feb;172(2):439-444.
8. Kelvin FM, Hale DS, Maglinte DD, Patten BJ, Benson JT. Female pelvic organ prolapse: diagnostic contribution of dynamic cystoproctography and comparison with physical examination. AJR Am J Roentgenol. 1999 Jul;173(1):31-37.
9. Nygaard I, Barber MD, Burgio KL, Kenton K, Meikle S, Schaffer J, Spino C, Whitehead WE, Wu J, Brody DJ; Pelvic Floor Disorders Network. Prevalence of symptomatic pelvic floor disorders in US women. JAMA, 2008; 300(11): p.1311-1316.
10. Halligan S, Spence-Jones C, Kamm MA, Bartram CI. Dynamic cystoproctography and physiological testing in women with urinary stress incontinence and urogenital prolapse. Clin Radiol, 1996;51:785-790.
11. Altringer WE, Saclarides TJ, Dominguez JM, Brubaker LT, Smith CS Four-contrast defecography: pelvic "floor-oscopy". Dis Colon Rectum 1995; 38:695-699.
12. Kelvin FM, Maglinte D, Hornback JA, Benson JT. Pelvic prolopase: assessment with evacuation proctography (defecography). Radiology 1992; 184:547-551.
13. Colaiacomo MC, Masselli G, Polettini E, Lanciotti S, Casciani E, Bertini L, Gualdi G. Dynamic MR imaging of the pelvic floor: a pictorial review. Radiographics 2009; 10:1148/rg.e.35.
14. Hetzer FH, Andreisek G, Tsagari C, Sahrbacher U, Weishaupt D. MR defecography in patients with fecal incontinence: imaging findings and their effect on surgical management. Radiology, 2006; 240(2): p. 449-457.
15. Kelvin FM, Maglinte DD, hale DS, Benson JT. Female pelvic organ prolapse: a comparison of triphasic dynamic MR imaging and triphasic fluoroscopic cystocolpoproctography. AJR Am J Roentgenol. 2000 Jan; 174(1):81-88.
16. Lienemann A, Anthuber C, Baron A, Kohz P, Reiser M. Dynamic MR colpocystorectography assessing pelvic floor descent. Eur Radiol 1997;7:1309-1317.
17. Pizzoferrato AC, Nyangoh Timoh K, Fritel X, Zareski E, Bader G, Fauconnier A. Dynamic Magnetic Resonance Imaging and pelvic floor disorders: how and when? Eur J Obstet Gynecol Reprod Biol. 2014;181;259-266.
18. Gupta S, Sharma JB, Hari S, Kumar S, Roy KK, Singh N. Study of dynamic magnetic resonance imagining in diagnosis of pelvic organ prolapse. Arch Gynecol Obstet. 2012;286(4);953-958.
19. Van Iersel JJ, Formijne Jonkers HA, Verheijen PM, Broeders IA, Heggelman BG, Sreetharan V, Fütterer JJ, Somers I, van der Leest M, Consten EC. Comparison of dynamic magnetic resonance defecography with rectal contrast and conventional defecography for posterior pelvic floor compartment prolapse. Colorectal Dis. 2017;19(1):O46-O53.
20. Kobi M, Flusberg M, Paroder V, Chernyak V. Practical guide to dynamic pelvic floor MRI. Journal of magnetic resonance imaging: JMRI 2018;47(5): p.1155-1170.
21. Pannu HK, Javitt MC, Glanc P, Bhosale PR, Harisinghani MG, Khati NJ, Mitchell DG, Nyberg DA, Pandharipande PV, Shipp TD, Siegel CL, Simpson L, Wall DJ, Wong-You-Cheong JJ. ACR Appropriateness Criteria pelvic floor dysfunction. J Am Coll Radiol, 2015;12(2): p.134-142.
22. Bitti GT, Argiolas GM, Ballicu N, Caddeo E, Cecconi M, Demurtas G, Matta G, Peltz MT, Secci S, Siotto P. Pelvic floor failure: MR Imaging evaluation of anatomic and functional abnormalities. Radiographics 2014; 34:429-448.
23. Woodfield CA, Krishnamoorthy S, Hampton BS, Brody JM. Imaging pelvic floor disorders: Trend toward comprehensive MRI. AJR Am J Roentgenol. 2010 June;194:1640-1649.
24. Felt-Bersma RJ, Tiersma ES, Cuesta MA. Rectal prolapse, rectal intussusception, rectocele, solitary rectal ulcer syndrome and enterocele. Gastroenterol Clin North Am. 2008. 37(3): p. 645-668, ix.
25. Strohbehn K. Normal pelvic floor anatomy. Obstet Gynecol Clin North Am. 1998;25(4):683-705.
26. Dobben AC, Felt-Bersma RJ, ten Kate FJ, Stoker J. Cross-sectional imaging of the anal sphincter in fecal incontinence. AJR Am J Roentgenol. 2008 Mar;190(3):671-682.
27. Lalwani N, Khatri G, El Sayed RF, Ram R, Jambhekar K, Chernyak V, Kamath A, Lewis S, Flusberg M, Scholz F, Arif-Tiwari H, Palmer SL, Lockhart ME, Fielding JR. MR defecography technique: recommendations of the society of abdominal radiology's disease-focused panel on pelvic floor imaging. Abdom Radiol (NY). 2019 Aug 5. https://doi.org/10.1007/s00261-019-02160-7. [Epub ahead of print]
28. Bernstein MA, Huston III J, Ward HA. Imaging artifacts at 3.0T. J Magn Reson Imaging 2006;24(4):735-746.
29. Grob ATM, Olde Heuvel J, Futterer JJ, Massop D, Veenstra van Nieuwenhoven AL, Simonis FFJ, van der Vaart CH. Underestimation of pelvic organ prolapse in the supine straining position, based on magnetic resonance imaging findings. Int Urogynecol J. 2019 Jan 17. https://doi.org/10.1007/s00192-018-03862-0. [Epub ahead of print]
30. Bertschinger KM, Hetzer FH, Roos JE, Treiber K, Marincek B, Hilfiker PR. Dynamic MR imaging of the pelvic floor performed with patient sitting in an open-magnet unit versus with patient supine in a closed-magnet unit. Radiology. 2002;223:501–508.
31. Pannu HK, Scatarige JC, Eng J. Comparison of supine MRI with and without rectal contrast to fluoroscopic cystocolpoproctography for the diagnosis of pelvic organ prolapse. J Comput Assit Tomogr 2009;33:125-130.
32. Gufler H, Ohde A, Grau G, Grossmann A. Colpocystoproctography in the upright and supine positions correlated with dynamic MRI of the pelvic floor. Eur J Radiol 2004;51:41-47.
33. Tumbarello JA, Hsu Y, Leicky-Gaupp C, Rohrer S, deLancey JO. Do repetitive valsalva maneuvers change maximum prolapse on dynamic MRI? Int urogynecol J 2010;21:1247-1251
34. Flusberg M, Sahni VA, Erturk SM, Mortele KJ. Dynamic MR defecography: assessment of the usefulness of the defecation phase. AJR Am J Roentgenol. 2011 Apr;196(4):W394-399.
35. Khatri G, Bailey AA, Bacsu C, Christie AL, Kumar N, Pedrosa I, Zimmern P. Influence of rectal gel volume on defecation during dynamic pelvic floor magnetic resonance imaging. Clin Imaging. 2015 Nov-Dec;39(6):1027-1031.
36. Solopova AE, Hetzer FH, Marincek B, Weishaupt D. MR defecography: prospective comparison of two rectal enema compositions. AJR Am J Roentgenol. 2008 Feb;190(2):W118-124.
37. Law MY, Fielding JR. MRI of Pelvic Floor Dysfunction: Review. AJR Am J Roentgenol. 2008;191: S45-53.
38. CS Reiner, D Weishaupt. Dynamic pelvic floor imaging: MRI techniques and imaging parameters. Abdom Imaging, 38 (2013), pp.903-911.

39. Arif-Tiwari H, Twiss CO, Lin FC, Funk JT, Vedantham S, Martin DR, Kalb BT. Improved detection of pelvic organ prolapse: Comparative utility of defecography phase sequence to nondefecography valsalva maneuvers in dynamic pelvic floor magnetic resonance imaging. Curr Probl Diagn Radiol. 2019 Jul - Aug;48(4):342-347.
40. Bharucha AE, Fletcher JG, Harper CM, Hough D, Daube JR, Stevens C, Seide B, Riederer SJ, Zinsmeister AR. Relationship between symptoms and disordered continence mechanisms in women with idiopathic faecal incontinence. Gut, 2005. 54(4): p.546-555.
41. Fielding JR. Practical MR imaging of female pelvic floor weakness. Radiographics 2002;22:295-304.
42. Bhan SN, Mnatzakanian GN, Nisenbaum R. MRI for pelvic floor dysfunction: can the strain phase be eliminated? Abdom Radiol (NY). 2016;41:215-220.
43. Halligan S, Bartram CI, Park HJ, Kamm MA. Proctographic features of anismus. Radiology, 1995. 197(3): p.679-682.
44. Reiner CS, Tutuian R, Solopova AE, Pohl D, Marincek B, Weishaupt D. MR defecography in patients with dyssynergic defecation: spectrum of imaging findings and diagnostic value. Br J Radiol, 2011. 84(998): p.136-144.
45. Haya N, Segev E, Younes G, Glodschmidt E, AuslendeR, Abramov Y. The effect of bladder fullness on evaluation of pelvic organ prolapse. Int J Gynaecol Obstet 2012;118:24-26.
46. Broekhuis SR, Fütterer JJ, Barentsz JO, Vierhout ME, Kluivers KB. A systematic review of clinical studies on dynamic magnetic resonance imaging of pelvic organ prolapse: the use of reference lines and anatomical landmarks. Int Urogynecol J pelvic floor dysfunct 2009;(6):721-729.
47. Singh K, Reid Wm, berger LA. Assessment and grading of pelvic organ prolapse by use of dynamic pelvic floor in women: quantification of muscle mass. American Journal of Roentgenology. 2000;174(3):657-660.
48. Bergman A, McCarthy TA, Ballard CA, Yanai J. Role of the Q-tip test in evaluating stress urinary incontinence. J reprod Med 1987;32:273-275.
49. Bennett GL, Hecht EM, Tanpitukpongse TP, Babb JS, Taouli B, Wong S, Rosenblum N, Kanofsky JA, Lee VS. MRI of the urethra in women with lower urinary tract symptoms: Spectrum of findings at static and dynamic imaging. AJR Am J Roentgenol. 2009:193:1708-1715.
50. Yaşar L, Telci SO, Doğan K, Kaya E, Ekin M. Predictive role of measurement of pelvic floor muscle thickness with static MRI in stress and mixed urinary incontinence. Int Urogynecol J. 2019 Feb;30(2):271-277.
51. Dierick F, Galtsova E, Lauer C, Buisseret F, Bouché AF, Martin L. Clinical and MRI changes of puborectalis and iliococcygeus after a short period of intensive pelvic floor muscles training with or without instrumentation: A prospective randomized controlled trial. Eur J Appl Physiol. 2018 Aug;118(8):1661-1671.
52. Woodfield CA, Hampton BS, Sung V, Brody JM. Magnetic resonance imaging of pelvic organ prolapse: comparing pubococcygeal and midpubic lines with clinical staging. Int Urogynecol J pelvic floor dysfunct 2009;20:695-701.
53. Novellas S, Mondot L, Bafghi A, Fournol M, Baudin G, Coco L, Bongain A, Chevallier P. Evaluation of two classifications systems for pelvic prolapse on dynamic MRI. J Radiol 2009; 90(11 pt 1):1717-1724.
54. Kim JK1, Kim YJ, Choo MS, Cho KS. The urethra and its supporting structures in women with stress urinary incontinence: MR imaging using an endovaginal coil. AJR Am J Roentgenol. 2003 Apr;180(4):1037-1044.
55. Macura KF, Genadry RR, Bluemke DA. MR imaging of the female urethra and supporting ligaments in assessment of urinary incontinence: spectrum of abnormalities. RadioGraphics 2006;26:1135-1149.
56. Summers A, Winkel LA, Hussain HK, DeLancey JOL. The relationship between anterior and apical compartment support. Am J obstet Gynecol. 2006 May; 194(5):1438-1443.
57. Funk MJ, Levin PJ, Wu JM. Trends in the surgical management of stress urinary incontinence. Obstet Gynecol. 2012 Apr; 119(4): 845-851.
58. Olsen AL, Smith VJ, Bergstrom JO, Colling JC, Clark AL. Epidemiology of surgically managed pelvic organ prolapse and urinary incontinence. Obstet Gynecol, 1997. 89(4): p. 501-506.
59. Salvador JC, Coutinho MP, Venâncio JM, Viamonte B. Dynamic magnetic resonance imaging of the female pelvic floor-a pictorial review. Insights Imaging. 2019 Jan 28;10(1):4.
60. Bartram, C.I., G.K. Turnbull, and J.E. Lennard-Jones, Evacuation proctography: an investigation of rectal expulsion in 20 subjects without defecatory disturbance. Gastrointest Radiol, 1988.13(1): p.72-80.
61. Bernier, P., G.W. Stevenson, and P. Shorvon, Defecography commode. Radiology, 1988. 166(3): p. 891-2.
62. Maglinte DD, Kelvin FM, Hale DS, Benson JT. Dynamic cystoproctography: a unifying diagnostic approach to pelvic floor and anorectal dysfunction. AJR Am J Roentgenol. 1997 Sep;169(3):759-767.
63. Mustain WC. Functional Disorders: Rectocele. Clin Colon Rectal Surg. 2017 Feb;30(1):63-75.
64. Lefevre R, Davila GW. Functional disorders: rectocele. Clin Colon Rectal Surg. 2008 May;21(2):129-137.
65. Dvorkin LS, Hetzer F, Scott SM, Williams NS, Gedroyc W, Lunniss PJ. Open-magnet MR defaecography compared with evacuation proctography in the diagnosis and management of patients with rectal intussusception. Colorectal Dis. 2004 Jan;6(1):45-53.
66. Elshazly WG, El Nekady Ael A, Hassan H. Role of dynamic magnetic resonance imaging in management of obstructed defecation case series. Int J Surg. 2010;8(4):274-282.
67. Tsiaoussis J, Chrysos E, Glynos M, Vassilakis JS, Xynos E. Pathophysiology and treatment of anterior rectal mucosal prolapse syndrome. Br J Surg. 1998 Dec;85(12):1699-1702.
68. Collinson R, Cunningham C, D'Costa H, Lindsey I. Rectal intussusception and unexplained faecal incontinence: findings of a proctographic study. Colorectal Dis. 2009 Jan;11(1):77-83.
69. Rao SS. Advances in diagnostic assessment of fecal incontinence and dyssynergic defecation. Clin Gastroenterol Hepatol. 2010 Nov;8(11):910-919.
70. Rao SS, Bharucha AE, Chiarioni G, Felt-Bersma R, Knowles C, Malcolm A, Wald A. Functional Anorectal Disorders. Gastroenterology. 2016 Mar 25. pii: S0016-5085(16)00175-X.
71. Whitehead WE, Borrud L, Goode PS, Meikle S, Mueller ER, Tuteja A, Weidner A, Weinstein M, Ye W; Pelvic Floor Disorders Network. Fecal incontinence in US adults: epidemiology and risk factors. Gastroenterology. 2009 Aug;137(2):512-7, 517.e1-2
72. Lunniss PJ, Gladman MA, Hetzer FH, Williams NS, Scott SM. Risk factors in acquired faecal incontinence. J R Soc Med. 2004 Mar;97(3):111-6.
73. Erlichman DB, Kanmaniraja D, Kobi M, Chernyak V. MRI anatomy and pathology of the anal canal. J Magn Reson Imaging. 2019 May 22.
74. Terra MP, Beets-Tan RG, van der Hulst VP, Deutekom M, Dijkgraaf MG, Bossuyt PM, Dobben AC, Baeten CG, Stoker J. MRI in evaluating atrophy of the external anal sphincter in patients with fecal incontinence. AJR Am J Roentgenol. 2006 Oct;187(4):991-999.
75. Gilliland R, Altomare DF, Moreira H Jr, Oliveira L, Gilliland JE, Wexner SD. Pudendal neuropathy is predictive of failure following anterior overlapping sphincteroplasty. Dis Colon Rectum. 1998 Dec;41(12):1516-1522.

76. Prichard D, Harvey DM, Fletcher JG, Zinsmeister AR, Bharucha AE. Relationship Among Anal Sphincter Injury, Patulous Anal Canal, and Anal Pressures in Patients With Anorectal Disorders. Clin Gastroenterol Hepatol. 2015 Oct;13(10):1793-1800.
77. Chiarioni G, Whitehead WE. Biofeedback therapy for constipation. GI Motility Testing: A Laboratory and Office Handbook, ed. M.R. Parkman HP, Rao SSC. 2011, Thorofare, NJ:: Slack Inc.
78. Attenberger UI, Morelli JN, Budjan J, Herold A, Kienle P, Kleine W, Häcker A, Baumann C, Heinzelbecker J, Schoenberg SO, Michaely HJ. The value of dynamic magnetic resonance imaging in interdisciplinary treatment of pelvic floor dysfunction. Abdom Imaging. 2015 Oct;40(7):2242-2247.