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SPECIAL SECTION: THE PELVIC FLOOR

Multimodality imaging of pelvic floor anatomy

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Abstract

The pelvic floor is composed of a network of muscles, ligaments, and fasciae, which provide active and passive support for the pelvic organs. Impairment of these pelvic floor elements can result in a variety of functional abnormalities and single or multicompartment organ prolapse. Knowledge of normal pelvic floor anatomy can aid the radiologist in understanding the complex nature of pelvic floor dysfunction and is important for comprehensive image interpretation. This article provides an overview of normal anatomy of the pelvic floor as seen on magnetic resonance imaging, ultrasound, and fluoroscopic studies performed in the evaluation of pelvic floor function.

Keywords Pelvic floor · Defecography · MR defecography · Anatomy

Introduction

The pelvic floor comprises three interconnected layers of muscle and connective tissue which provide structural support for the abdominopelvic viscera and help maintain bowel and urinary bladder continence. Anatomically, the female pelvis is divided into three compartments: the urinary bladder and urethra are in the anterior compartment, the uterus and vagina in the middle compartment, and the rectum and anus in the posterior compartment (Fig. 1). Impairment and disruption of the pelvic floor musculature, ligaments and fasciae may result in a spectrum of prolapse and functional abnormalities, often involving multiple compartments due to their shared structural support [1]. Knowledge of normal and abnormal pelvic floor anatomy is therefore imperative for comprehensive imaging assessment of pelvic floor dysfunction. This paper will review pelvic floor anatomy as seen on magnetic resonance imaging (MRI), ultrasound, and fluoroscopic imaging studies performed for the evaluation of pelvic floor function.

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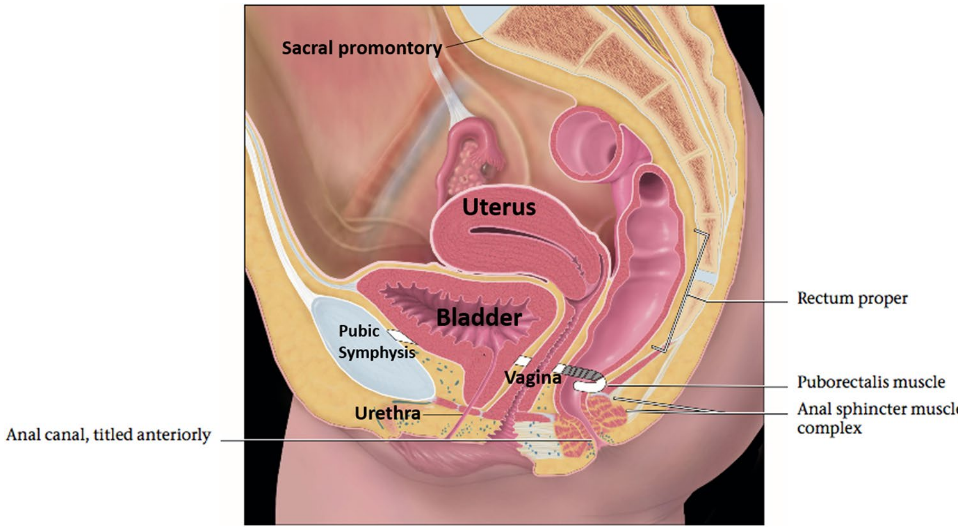

Fig. 1 Sagittal diagram of the female pelvis. The anterior compartment contains the bladder and urethra, the middle compartment contains the uterus and vagina, and the posterior compartment contains the rectum and anus. The anal sphincter is tilted anteriorly in the sagittal plane. The cranial part of the external anal sphincter is contiguous with the puborectalis With permission from: Elsayed [27]

Magnetic resonance imaging (MRI)

The inherent soft tissue resolution of MRI allows for accurate and detailed assessment of pelvic floor anatomy, as the integrity of the ligaments and muscles can often be directly visualized rather than being inferred by the presence and degree of pelvic organ prolapse. Anatomy is typically assessed on T2 weighted (T2W) images in the axial, coronal, and sagittal planes. High-resolution T2W images in the oblique-axial plane along the short axis of the anal canal are helpful for dedicated evaluation of the anal sphincter complex [2].

The pelvic floor is made up of three integrated layers: the endopelvic fascia, the pelvic diaphragm, and the perineal membrane. The pelvic bones and connective tissue layers of the endopelvic fascia and perineal membrane provide passive pelvic support, while the muscular pelvic diaphragm provides active support both at rest and during activity [3].

Endopelvic fascia

The endopelvic fascia is the thin superior layer of the pelvic floor. It is composed of a complex network of connective tissue which covers the pelvic organs and levator ani and attaches them to the pelvic wall via various condensations/ligaments and a fibrous band termed the arcus tendineus [4]. These attachments provide important structural support for the pelvic viscera. Different components of the endopelvic fascia are named based on their respective underlying organs. Areas of condensation, such as the urethral supports and perineal body, can be visualized on MRI.

In the anterior compartment, there has been no uniformity of opinion concerning the structures supporting the female urethra and specifically the urethral ligaments. There is disagreement in the literature as to whether the pubourethral ligament is a unique structure or whether it represents a terminal extension of the arcus tendineus [5]. For purposes of consistency with previous publications, we will refer to the connective tissue attachments of the urethra to the pelvic sidewall as “ligaments”. El Sayed et al. identified ventral and dorsal urethral ligaments based on cadaveric dissection and MR imaging of the cadavers and healthy female volunteers [6]. Ventral ligament groups were termed pubourethral, periurethral, and paraurethral. The pubourethral ligament was found to consist of three separate components which course in an anteroposterior direction from the bladder neck to the pubic bone; typically only the proximal component can be seen on MRI. The periurethral ligaments were transversely oriented, and the paraurethral ligaments were obliquely oriented from the periurethral ligament to the lateral aspect of the urethra. Dorsal to the urethra, a ligament separate from the anterior vaginal wall termed the “suburethral ligament” extends anterolaterally to the pelvic sidewall forming a sling behind the urethra. These ligaments were found to be moderately or easily visible on MRI in approximately half of healthy volunteers [6]. When visible, they are seen on T2W MRI as thin hypointense linear structures adjacent to the urethra (Fig. 2).

The anterior vaginal wall provides additional support to the urethra via the pubocervical fascia, which attaches to the pubic symphysis, arcus tendineus, and pubococcygeus; the pubocervical fascia is not discernable on MRI. In conditions of increased abdominal pressure, the urethra is compressed against the anterior vaginal wall which acts as a hammock for urethral support and helps maintain urinary continence [7]. Disruption of any of these

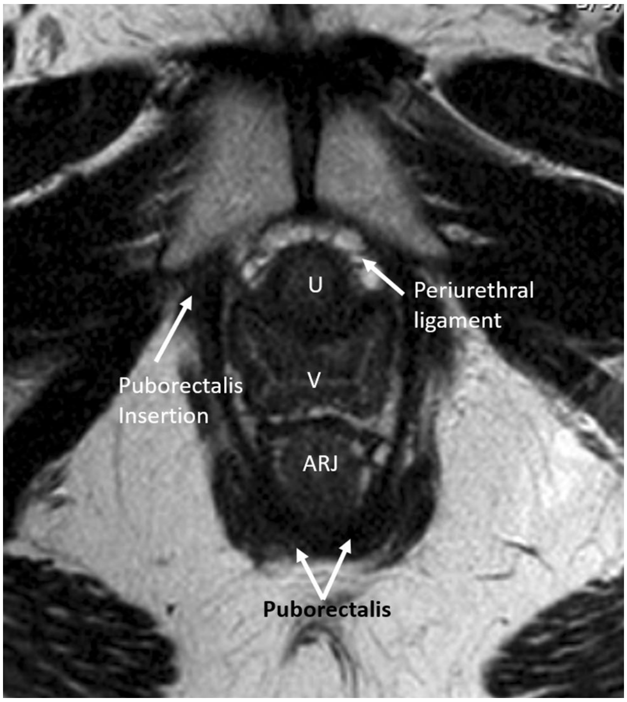

Fig. 2 Axial T2W MR image shows the ventral periurethral ligaments. The puborectalis is seen attaching to the pubic bone and coursing behind the anorectal junction (ARJ). Note the normal urethra (U) and "H" shaped vagina (V)

supporting fascial elements may contribute to the formation of cystocele or urethrocele, or development of stress incontinence.

In the middle compartment, the endopelvic fascia includes the parametrium and paracolpium. These attach to the bony pelvis via the transversely oriented cardinal ligaments, which run in the inferior broad ligament, and the sacrouterine (also called uterosacral) ligaments, which extend posteriorly to the sacrum (Fig. 3). Disruption of these supporting fasciae and ligaments may result in uterine or vaginal prolapse. The paracolpium provides support to the vagina at three levels (Fig. 3): the upper third (level I) suspends the upper vagina, the middle third (level II) attaches the vagina to the arcus tendinous at the lateral pelvic wall, and the lower third (level III) fuses the vagina to the levator ani and perineal body [3]. Defects of the endopelvic fascia result in secondary anatomic signs of pelvic floor deficiency as seen on axial images. With a level III fascial defect, there is a widening of the presacral space and sagging of the detached lower third of the anterior vaginal wall resembling a drooping "mustache" [8, 9]. With level II fascial defects, sagging of the fluid-filled posterior urinary bladder wall due to detachment of the vaginal supporting fascia from the lateral pelvis is termed the "saddlebags sign". The vagina may also lose its normal "H" shape and become flattened [10]. Level I fascial defects cause posterior drooping of the lateral upper vaginal walls known as the "chevron sign" [8, 10].

The rectovaginal fascia, also called the rectovaginal septum, extends from the posterior wall of the vagina to the anterior wall of the rectum, and attaches to the peritoneum superiorly and the perineal body inferiorly. The rectovaginal septum also merges into the sacrouterine ligaments, contributing to a continuous column of pelvic support from

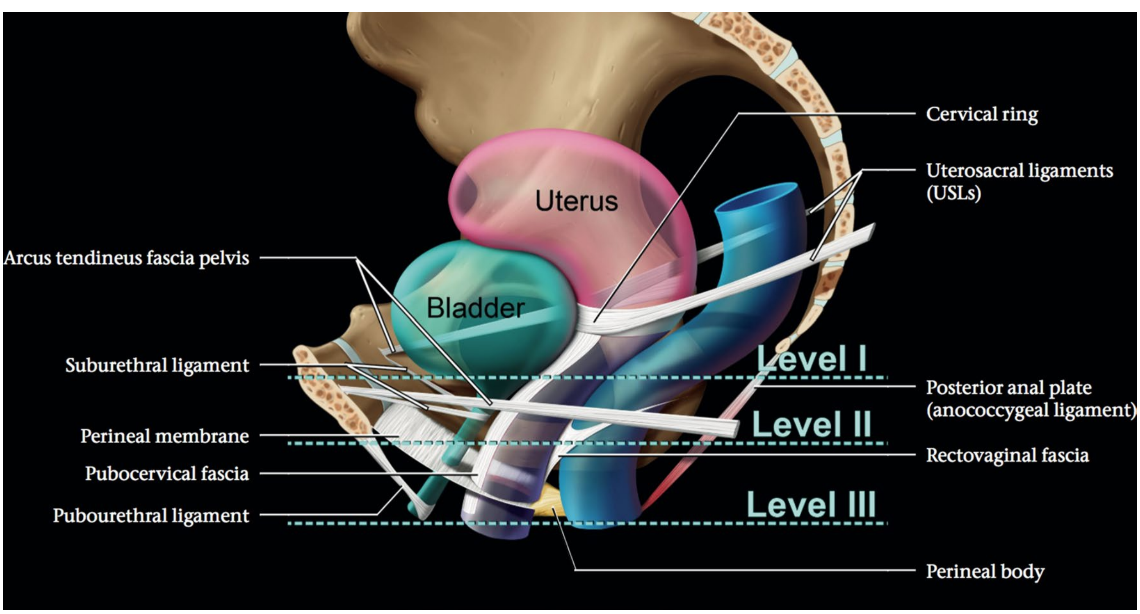

Fig. 3 Sagittal diagram of the female pelvis. The paracolpium supports the vagina at three levels, approximated by dividing the vagina into thirds. The perineal body sits in the anovaginal septum With permission from: Elsayed [28]

the sacrum to the perineum [11]. The perineal body, also referred to as the central tendon of the perineum, can be seen as a hypointense structure in the anovaginal septum on T2W images (Fig. 4b). It acts as an anchoring site for multiple muscles and fasciae. Weakness or defects in the rectovaginal septum or perineal body may result in rectocele or cul-de-sac hernia [12]. A break in this support mechanism also allows the perineal body to become hypermobile, resulting in an abnormal descent with increased intraabdominal pressure and contributing to prolapse [11].

Pelvic diaphragm (Levator Ani)

The pelvic diaphragm is the middle layer of the pelvic floor and includes the levator ani and coccygeus muscles. The levator ani constitute the active mechanism of pelvic support, continuously contracting in the resting state, preserving pelvic floor tone, and preventing pelvic organ prolapse [13]. The levator ani is composed of three muscle groups: puborectalis, pubococcygeus, and iliococcygeus (Fig. 4). The U-shaped puborectalis attaches to the inner aspect of the pubic symphysis, forming a sling around the urethra, vagina and anorectal junction and bounding the levator hiatus.

The puborectalis is well visualized on axial T2W sequences (Fig. 2) and can also be identified indenting the posterior anorectal junction on a midsagittal T2W image (Fig. 4b). A normally functioning puborectalis will contract during the Kegel maneuver, drawing the anorectal junction anteriorly and superiorly, narrowing the anorectal angle, and preventing defecation. With Valsalva, a normally functioning puborectalis will relax, widening the levator hiatus, allowing the anorectal junction to descend, and widening the anorectal angle to ease defecation. A weak puborectalis may appear thinned with lateral ballooning and widening of the levator hiatus. Muscle tears can be visualized as unilateral or bilateral defects, scars, or loss of the attachment site at the pubic bone. The vagina may flatten and protrude through the puborectalis defect

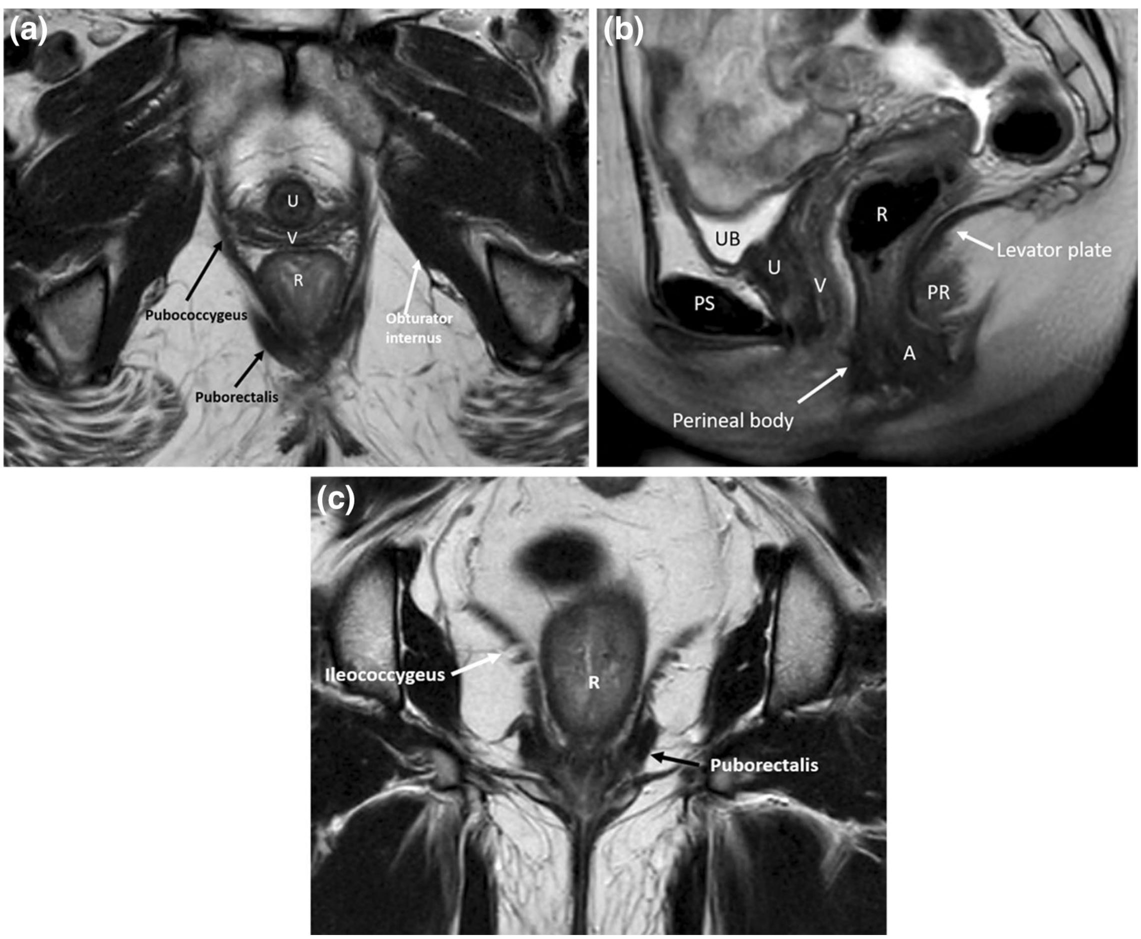

Fig. 4 Anatomy of the levator ani in three orthogonal planes. **a** Axial T2W MR shows the transition from the puborectalis muscle to the pubococcygeus. **b** Midline sagittal T2W MRI demonstrates the puborectalis (PR) and the levator plate posterior to the anorectal junction and lower rectum. **c** Coronal T2W MR shows the iliococcygeus muscle. Pubic symphysis (PS), urinary bladder (UB), urethra (U), vagina (V), rectum (R), and anus (A) are all visualized

[10]. Puborectalis hypertrophy can be seen in patients with defecatory dysfunction due to pelvic floor dyssynergia.

The pubococcygeus and iliococcygeus muscles have a more transverse orientation in the axial plane and are well visualized in the coronal plane (Fig. 4c). The pubococcygeus and iliococcygeus attach to the pelvic wall via the arcus tendineus levator ani, a site of linear fascial thickening covering the obturator internus muscle; the pubococcygeus attaches more anteromedially at the superior pubic ramus, and the iliococcygeus more laterally. Some fibers of the pubococcygeus attach to the vagina (pubovaginalis), perineal body (puboperinealis), and puborectalis. Posteriorly, the pubococcygeus and iliococcygeus attach to the coccyx and form the levator plate, the fused posterior condensations of the two muscle groups [14]. When a person is standing, the levator plate has a horizontal orientation, providing support for the rectum and upper vagina. Weakness or disruption of the levator ani may cause the levator plate to droop down, predisposing to pelvic organ prolapse [7]. Damage to the levator plate may also result in posterior rectoceles [4].

The coccygeus, also called the ischiococcygeus, is less integral to pelvic floor support; it is the most posterior pelvic diaphragm muscle seen on axial T2W images, extending from the ischium to the coccyx (Fig. 5). The coccygeus sits anterior to the sacrospinous ligament, which is an important anatomic landmark used as a fixation site in vaginal suspension surgery to treat prolapse.

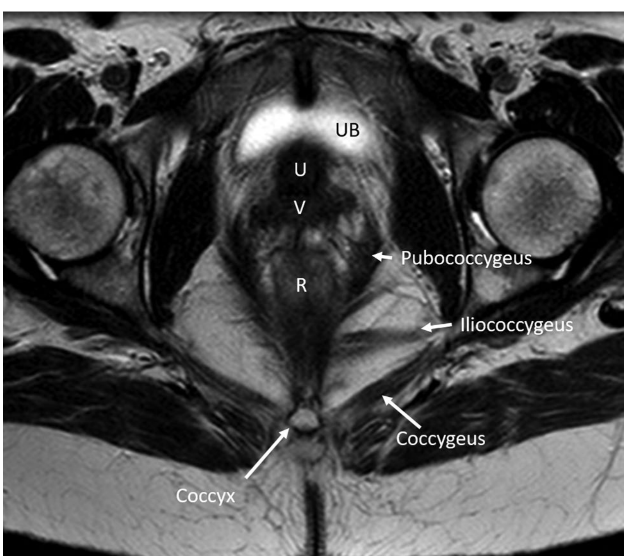

Fig. 5 Axial T2W MR demonstrates the paired coccygeus muscles extending from the ischia to the coccyx. Fibers of the pubococcygeus and iliococcygeus are also seen. Cross sections of the urinary bladder base (UB), urethra (U), vagina (V), and rectum (R) are seen in this plane

Perineal membrane

The perineal membrane, previously referred to as the urogenital diaphragm, represents the most inferior layer of the pelvic floor. The perineal membrane has attachments to the urethra, vagina, levator ani, arcus tendinous, and bulbocavernosus. The ventral component of the perineal membrane contains the compressor urethrae and urethrovaginal sphincter muscles, and the dorsal component attaches the vagina and perineal body to the bony pelvis via transverse fibrous bands of connective tissue [15].

Anal sphincter

The anal sphincter complex is well visualized on high resolution T2W images (Fig. 6). The internal anal sphincter (IAS) is the continuation of the circular smooth muscle of the distal rectum [16] and typically shows intermediate signal intensity on T2W images [2]. The intersphincteric space contains fat predominantly and will follow the signal of macroscopic fat on all sequences, appearing hyperintense on T2W sequences without fat saturation [2]. The external anal sphincter (EAS) is a group of skeletal muscles circumferentially surrounding the anus and contiguous superiorly with the puborectalis. The EAS has lower signal intensity than the IAS on T2W images and appears similar to other skeletal muscles [2]. Attention to the integrity of the anal sphincter complex is important in evaluating patients with fecal incontinence and defecatory dysfunction. Patients with fecal incontinence may have atrophy or defects of the sphincter complex. Conversely, muscular hypertrophy of the internal anal sphincter can be a rare cause of obstructed defecation [2]. Endoanal MRI can also be utilized to evaluate the anal sphincter complex, although detailed discussion is beyond the scope of this paper [17].

Reference lines for interpretation of MR defecography

Interpretation of MR Defecography relies on knowledge of several reference lines (Fig. 7). A line drawn from the inferior pubic symphysis to the last coccygeal joint is called the pubococcygeal line (PCL), which marks the level of the pelvic floor and is the most widely utilized reference line in interpretation of MR defecography [18]. Pelvic organ prolapse is graded by the position of the various pelvic viscera with respect to the PCL. An alternative reference line which approximates the level of the hymen is termed the mid-pubic line (MPL). The MPL is drawn along the midline long axis of the pubic symphysis [19]. The level of the hymen is found

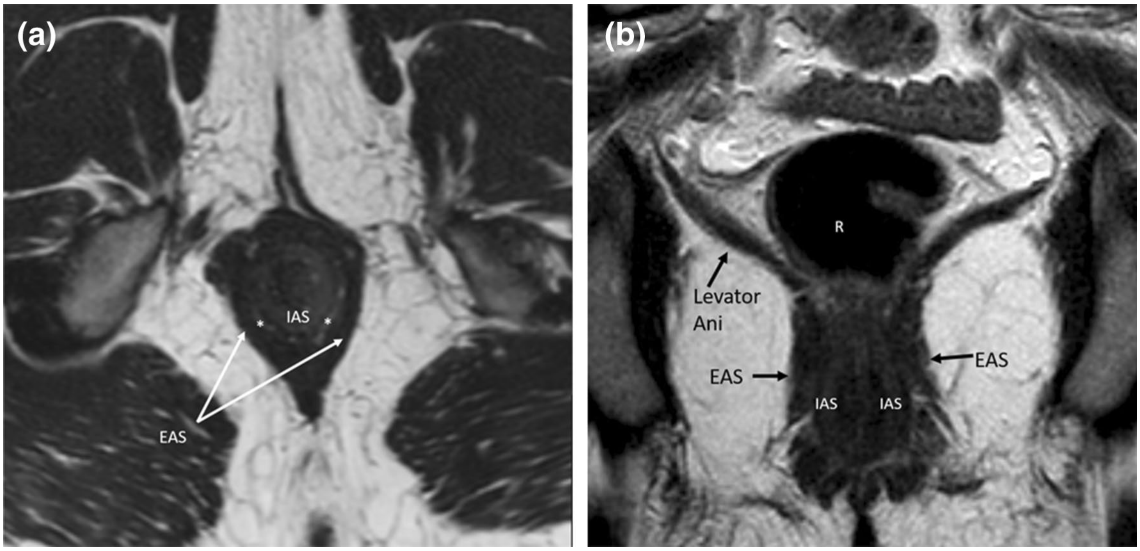

Fig. 6 Anal sphincter complex on **a** axial oblique and **b** coronal oblique high resolution T2W MRI. The internal anal sphincter (IAS) shows intermediate signal intensity, and the external anal sphincter (EAS) lower in signal intensity. Hyperintense gross fat is seen in the intersphincteric space (asterisks)

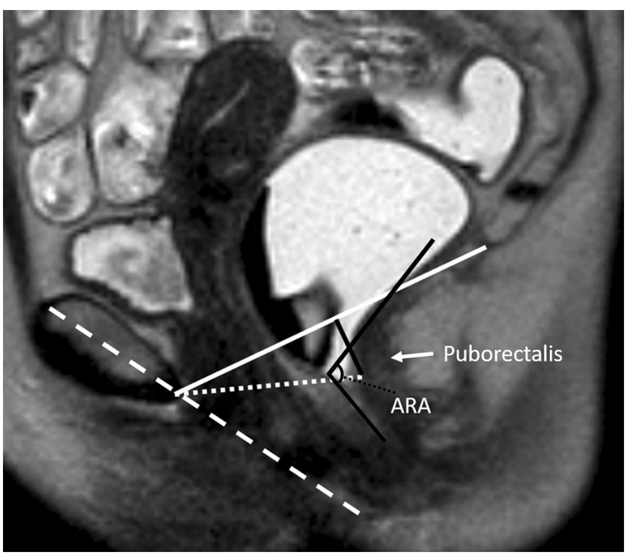

Fig. 7 Midline sagittal BFFE with rectal contrast demonstrating the reference lines used in interpretation of MRD: pubococcygeal line (solid white line), mid-pubic line (dashed line), H line (dotted line), and M line (solid black line). The anorectal angle (ARA) is formed by the junction of lines drawn along long axis of the anal canal and the posterior border of the rectum. The anorectal junction is at the apex of anorectal angle. The puborectalis can be seen at the posterior margin of the anorectal junction

at the intersection of the MPL and the center of the longitudinal axis of the vagina.

The levator hiatus is bound by the puborectalis. The anteroposterior length of the levator hiatus is measured by the H line, which is drawn on a midline sagittal image from the inferior pubic symphysis to the posterior anorectal junction at the puborectalis. The width of the levator hiatus can be measured between the right and left arms of the puborectalis on an axial image at roughly the level of the mid-urethra [20]. The M line approximates the degree of muscular pelvic floor descent, and extends perpendicularly from the PCL to the posterior-most aspect of the H line. The anorectal angle (ARA) represents the angle created by a line drawn parallel to the anal canal and a line parallel to the posterior rectal wall. The anorectal junction (ARJ) can be identified at the apex of the ARA, with the puborectalis at its posterior margin (Fig. 7). Many of these reference lines are also used for interpretation of fluoroscopic defecography.

MRI in the post-operative patient

MRI can be performed for evaluation after surgery to treat prolapse and urinary incontinence. Although detailed description is beyond the scope of this article, knowledge of relevant anatomy is needed for accurate interpretation of these studies. Urethral bulking agents may be used to treat urinary incontinence; this can result in a mass-like appearance of the urethra or periurethral tissues. Mesh and slings generally appear as linear hypointense structures on T2W images. Two common types of mid-urethral slings used to treat urinary incontinence are retropubic and transobturator slings. A retropubic sling has a "U" shape and can be seen in the retropubic space [21]. The arms of a transobturator sling take a more lateral course to the obturator foramen and are more difficult to visualize with MRI [21]. Mesh can be used for treatment of vaginal prolapse. Possible anchor sites for vaginal mesh include the arcus tendineus, sacrospinous ligament, obturator membrane, and ischiorectal fossae. In sacrocolpopexy for vaginal apex prolapse, the mesh is fixed to the sacral promontory.

Reporting anatomy

Knowledge of specific anatomic abnormalities may aid in determining appropriate management in pelvic floor dysfunction. Inclusion of a dedicated anatomy section in a dictation template can be helpful to ensure comprehensive reporting of findings. Pertinent anatomy pertaining to specific clinical presentations is included in Table 1.

Ultrasound

The pelvic floor can be examined with ultrasound via a translabial, introital, transvaginal, or endoanal approach. For the purpose of this discussion, we will focus on the anatomy demonstrated by the translabial approach. Translabial ultrasound (TLUS) allows simultaneous imaging of the three female pelvic floor compartments. With the addition of dynamic maneuvers such as Valsalva and Kegel, pelvic floor function and the presence of pelvic organ prolapse can be visualized in real-time. TLUS is particularly well-suited to evaluation of midurethral slings, and may also provide an assessment of vaginal mesh [22]. Multiplanar imaging, 3-D rendered axial images, and multi-slice imaging provide additional detail, which are of value in assessing the levator ani insertions, the levator hiatus, and midurethral slings. TLUS can evaluate the anal sphincter in a multiplanar fashion; endoanal sonography remains the gold standard for anatomic evaluation of the anal sphincter, but detailed discussion of this modality is beyond the scope of this article [23]. The limitations of TLUS primarily relate to the assessment of individual muscle groups and the supportive ligaments.

Table 1 Anatomy checklist for specific clinical indications

Pelvic organ prolapse
Levator hiatus width
Levator muscle integrity
Fecal incontinence
Anal sphincter
Urinary incontinence
Urethral morphology
Urethral ligaments
Defecatory dysfunction
Anal sphincter
Puborectalis
Post-operative mesh and slings
Retropubic space
Obturator foramen
Coccygeus-sacrospinous ligament complex
Ischiorectal fossa
Sacral promontory
Vaginal apex

Ultrasound pelvic floor evaluation

The midline sagittal image obtained at rest provides an overview of pelvic anatomy on TLUS. The field of view should include the pubic symphysis anteriorly and the anorectal junction posteriorly; the entire urethra, vagina, anorectal junction and rectal ampulla should be visualized (Fig. 8). The anterior compartment containing the urethra and urinary bladder is positioned immediately posterior to the pubic symphysis with the normal urethra oriented vertically. The urethral lumen is typically not seen, as it is below the resolution and grayscale of TLUS. The inner urethral longitudinal smooth muscle layer is well visualized and will appear hypoechoic. The outer urethral striated layer is more echogenic and not as well-defined [24]. The middle compartment containing the vagina is positioned in the mid pelvis. The appearance of the vagina depends on pre- or post-menopausal status and presence fluid or gas within the canal. The posterior compartment containing the anal canal to the rectal ampulla is visualized at the posterior aspect of the image. The levator plate can be seen as a hyperechoic structure posterior to the anorectal junction. A line drawn

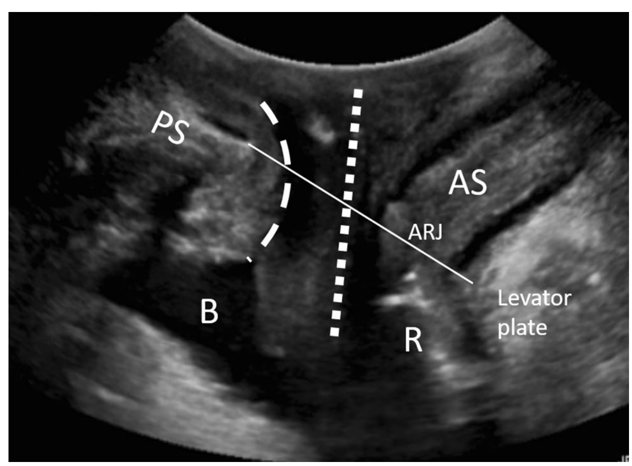

Fig. 8 Midline sagittal view of the pelvic floor includes the pubic symphysis (PS) at the anterior aspect of the image and extends to the posterior aspect of the anorectal junction (ARJ). The echogenic tissue posterior to the anorectal junction in the midline corresponds to the levator plate. The urethra (dashed line) and bladder (B) are in the anterior compartment. The vagina (dotted line) is in the middle compartment and the anal sphincter (AS) and rectal ampulla (R) are in the posterior compartment. Plane of minimum dimension (solid line) extends from the inferior aspect of the pubic symphysis to the posterior aspect of the anorectal junction

from the inferior aspect of the pubic symphysis to the levator plate defines the plane of minimum dimension of the levator hiatus (Fig. 8). Pelvic organ prolapse and pelvic floor function is assessed by the relative position of the pelvic organs with respect to the plane of minimum dimension during strain (Valsalva) maneuvers and pelvic floor contractions (Kegel). The inferior border of the pubic symphysis can also be used as a landmark for prolapse.

Volume imaging is utilized to measure the circumference of the levator hiatus and the integrity of the levator ani insertions [25, 26]. On an axial volume rendered image, the levator ani can be seen as an echogenic band surrounding the urethra, vagina, and anorectum (Fig. 9). The anterior insertion of the puborectalis/pubococcygeus on the pubic symphysis can be evaluated in this plane. Mid-urethral slings and vaginal mesh can also be visualized as echogenic linear material with a cross-hatch pattern (Fig. 9a).

The anal sphincter complex has a characteristic appearance on ultrasound (Fig. 10). Due to its tilted orientation, it is seen in long axis in the sagittal and axial planes, and in

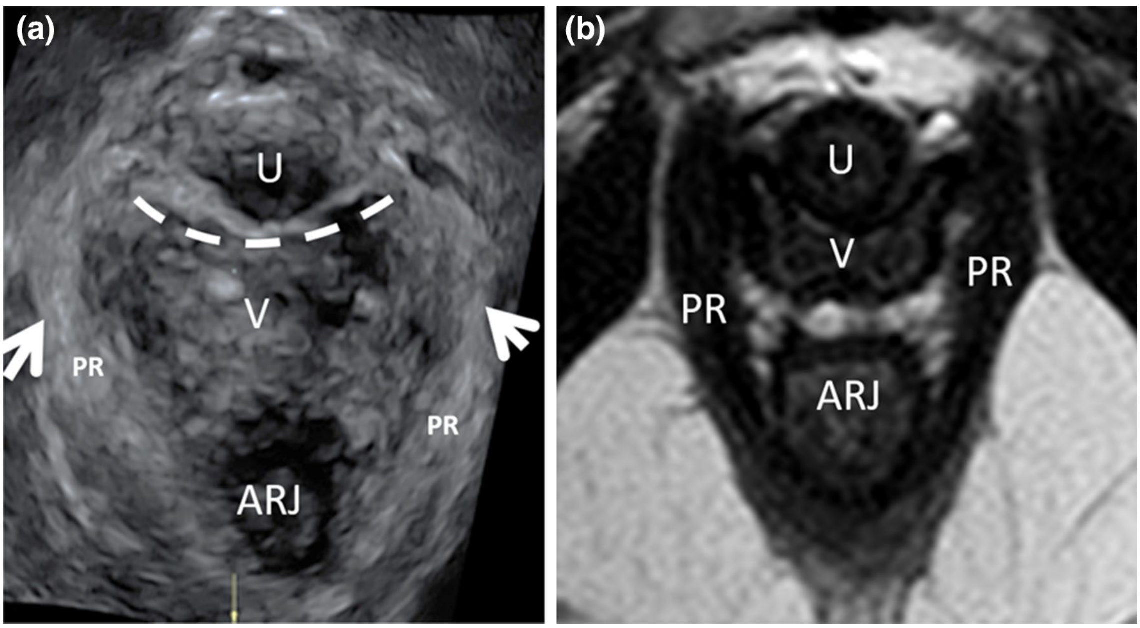

Fig. 9 **a** Volume rendered axial TLUS and **b** corresponding axial T2W MR image in a different patient demonstrate the urethra (U), vagina (V) and anorectal junction (ARJ) with surrounding puborectalis (PR). The levator ani insertions are intact on ultrasound (arrowheads). A retropubic midurethral sling on the ultrasound is represented by highly echogenic structure posterior to urethra (dotted line)

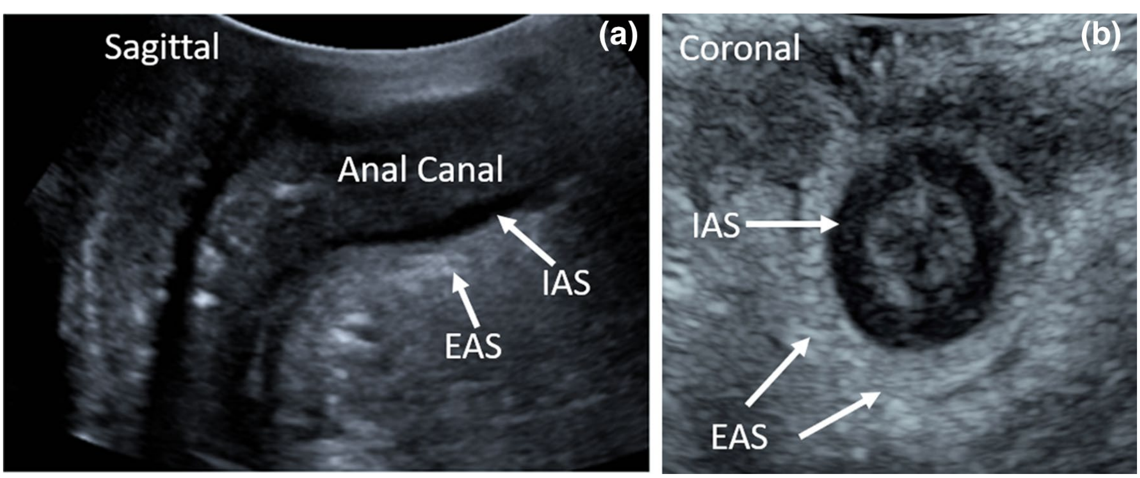

Fig. 10 Anal sphincter complex on TLUS. **a** Sagittal 2D and **b** coronal 2D images demonstrate the hypoechoic inner internal anal sphincter (IAS) and hyperechoic outer external anal sphincter (EAS)

Fig. 11 Lateral radiograph of the pelvis with rectal and small bowel contrast. The pubococcygeal line (dotted line) extends from the inferior aspect of the pubic symphysis (PS) to the coccyx and is used to define the pelvic floor. The ischiococcygeal line (white line) extends from the ischial tuberosity to the coccyx and may be used to demark the pelvic floor if the PCL is not seen. The line drawn from the pubic symphysis to the anorectal junction (dashed line) represents the puborectalis length/levator hiatus. The anorectal junction is at the apex of the anorectal angle (ARA)

short axis with its concentric rings in the coronal plane. The IAS is the inner hypoechoic component, and the EAS is the outer hyperechoic component [23]. The muscles should be relatively uniform in thickness. On TLUS, the IAS and EAS can be assessed for areas of thinning, contralateral thickening, and frank defects.

Fluoroscopy

Direct visualization of anatomy on fluoroscopic defecography (FD) is limited to the osseous structures and only the pelvic organs filled with intraluminal contrast. Supporting ligaments, fascia and muscles are essentially invisible. Anatomy is inferred by the location and motion of contrast filled structures with various maneuvers performed during FD. The landmarks most important in FD (Fig. 11) include the PCL, ARA, and ARJ. When the pubic symphysis is not well seen due to patient body habitus, the ischiococcygeal line (ICL) may be used to demark the pelvic floor. The ICL extends from the ischial tuberosity to the coccyx.

Because there is a wide range of normal on FD, quantification of pelvic floor motion with specific measurements is less useful than overall qualitative appearance. Interpretation relies on the direction and degree of change with respect to resting state rather than absolute measurement values. In general, during Kegel maneuvers, the ARA should decrease from baseline (rest), the ARJ should elevate and anal canal remain closed. During strain, the ARA should return to near baseline and anal canal remain closed. During evacuation, the ARA should become obtuse and anal canal open. Descent of the pelvic floor and organs is referenced relative to the PCL.

Conclusion

Dynamic imaging with MRI, ultrasound, and fluoroscopy is performed to evaluate a range of abnormalities in pelvic floor function. MRI provides detailed visualization of the pelvic floor support structures and may identify anatomic defects that correlate with functional abnormalities. Ultrasound can be used to evaluate the levator ani and anal sphincter complex, while fluoroscopy is more limited in direct anatomic assessment. The three imaging modalities share common anatomic landmarks that are used to evaluate pelvic floor function. Knowledge and identification of the relevant pelvic floor anatomy and reference lines is critical for accurate interpretation of these imaging studies.

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