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REVIEW ARTICLE

Imaging in urogynaecology

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Abstract The assessment of patients with pelvic floor dysfunction necessitates a combination of clinical skills and adjunct investigations, including detailed imaging. This article reviews a variety of static and dynamic imaging modalities available in the field of urogynaecology, with an emphasis on their clinical implication in identifying the structural and functional causes of pelvic floor disorders. A number of different modalities have been used including X-rays, ultrasound and magnetic resonance imaging. Their place and value are discussed with comments on the validity of the various techniques.

Keywords Pelvic floor · Imaging · Ultrasound · MRI · Prolapse · Incontinence

Introduction

Pelvic floor dysfunction is very common, and despite being associated with very low mortality, it can seriously affect a patient's quality of life. The wide range of pelvic floor disorders are often difficult to assess completely based on clinical examination alone. Understanding of the physiology of pelvic floor dysfunction integrated with multimodal imaging is the key to a holistic approach of such disorders. Due to the high complexity of pelvic floor functional anatomy, new imaging techniques have been introduced to enhance clinicians' understanding of incontinence and prolapse, which could provide useful information for better management of these disorders. This review article covers the static and functional imaging of the pelvic floor employed in the modern management of pelvic floor disorders. The current literature was reviewed by electronic search of PubMed between 1994 and 2011, as well as hand search of International Urogynecological Association and International Continence Society meeting abstracts (keywords used: pelvic floor, imaging, ultrasound, MRI, prolapse, incontinence).

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Static imaging

Endoanal ultrasound

Based on a meta-analysis of 717 vaginal deliveries, the incidence of anal sphincter defects following vaginal delivery detected by endoanal ultrasonography is 30% for primiparae and 9% in multiparae [1]. Evaluation of internal anal sphincter (IAS) and external anal sphincter (EAS) with endoanal ultrasound is the gold standard in investigating patients with obstetric anal sphincter injuries and anal incontinence.

High resolution scanning endoprobes are sensitive in detecting sphincter damage due to their enhanced spatial resolution and reduced diameter that limits patients' discomfort. The lubricated probe is inserted in the anus with the woman lying in a lateral position and images are taken in the axial plane; however, with the advent of three-dimensional technology, images can be also taken and analysed in the sagittal and coronal plane [2].

Endoanal ultrasound requires operator experience to facilitate the correct interpretation of the images. The sphincter complex produces different reflectivity of the various tissues, hence providing a typical image of the sub-epithelial tissue being exactly adjacent to the probe and the internal anal sphincter seen as an outer hypoechogenic (black) circle ring. On the outside of the internal anal sphincter, a longitudinal layer can be seen, which is formed by an extension of the longitudinal smooth muscle of the rectum and fibro-elastic tissue of the endopelvic fascia. The external anal sphincter is visualised as a hyperechogenic circular structure on the outermost aspect and its thickness varies according to the level of the anal canal [3]. More specifically, the upper anal canal is identified by a hyperechoic horseshoe sling of the puborectalis muscle posteriorly and the absence of the EAS in the midline anteriorly. The mid-anal canal level, which includes deep and superficial parts of the anal sphincter complex, is identified by the completion of the EAS ring anteriorly in combination with the maximum IAS thickness (Fig. 1). The lower canal level is defined as that immediately caudal to the termination of the IAS and comprises only the subcutaneous EAS [3, 4].

The IAS thickens with age and is abnormally thickened with rectal prolapse and intussusception [5]. A defective or thinned IAS is associated with passive faecal incontinence, while some studies have reported its association with systemic sclerosis [6]. EAS bulk and thickness is not as well delineated with endoanal ultrasound. Magnetic resonance imaging (MRI) has been found to be better in visualising the fat replacement of the muscle as a result of atrophy [7].

The most common clinical indication for endoanal ultrasound is the assessment of sphincter integrity following obstetric trauma. Sphincter damage may occur as a result of perineal trauma or extension of an episiotomy during childbirth and almost invariably involves the anterior part of the sphincter. Fibrotic tissue replaces the muscle fibres as part of the healing process following a repair, and this appears as a low echogenic band on ultrasound. Perineal tears may involve EAS and IAS and if clinically undetected will result in defects as shown in Figs. 2 and 3. Ultrasound is essentially the reference standard to detect sphincter damage following vaginal delivery, with up to 35% of women having ultrasonically detectable damage, often missed by clinical examination. When women with occult tears were studied, there was no association between those women with incontinence and those who did not experience incontinence. However, in the group of women with tears and an initial postpartum deterioration, incontinence continued to worsen over a decade of follow-up, more so than in the group of women without tears [8].

As clinical evaluation of the anal sphincter complex alone is proven to be unreliable, the use of well-established imaging modalities such as endoanal ultrasound have allowed a more consistent assessment of the integrity of anal sphincter complex and can change the management of anal incontinence [9–11].

Pelvic floor ultrasound

Pelvic floor ultrasound has recently revolutionised the imaging of pelvic floor functional anatomy. Standard requirements for two-dimensional translabial/transperineal ultrasound of the pelvic floor include a B-mode ultrasound machine with cine-loop function and a 3.5–6-MHz curved array transducer. Although currently used in specialist urogynaecology centres, this could be used in any outpatient clinical setting without causing discomfort to the patient. Pelvic floor ultrasound provides both static and

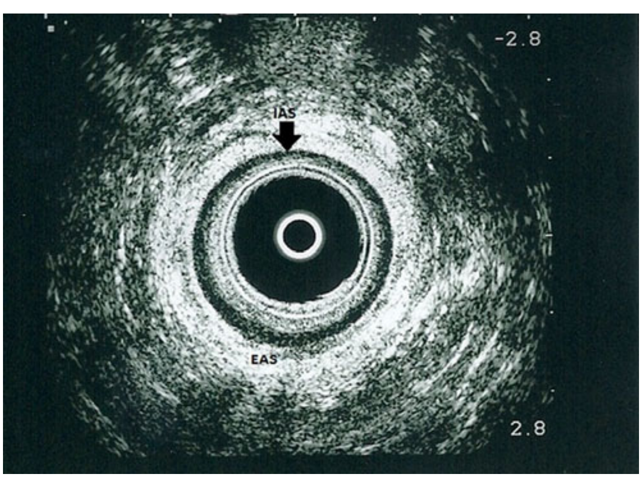

Fig. 1 Normal anatomy of anal sphincter complex at the deep external anal sphincter level. *IAS* internal anal sphincter, *EAS* external anal sphincter

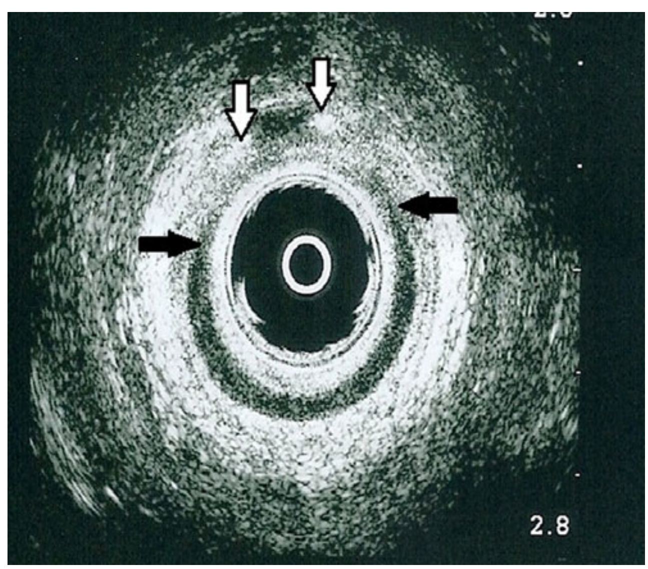

Fig. 2 A persistent defect of the anterior external (*white arrows*) and internal anal (*black arrows*) sphincter

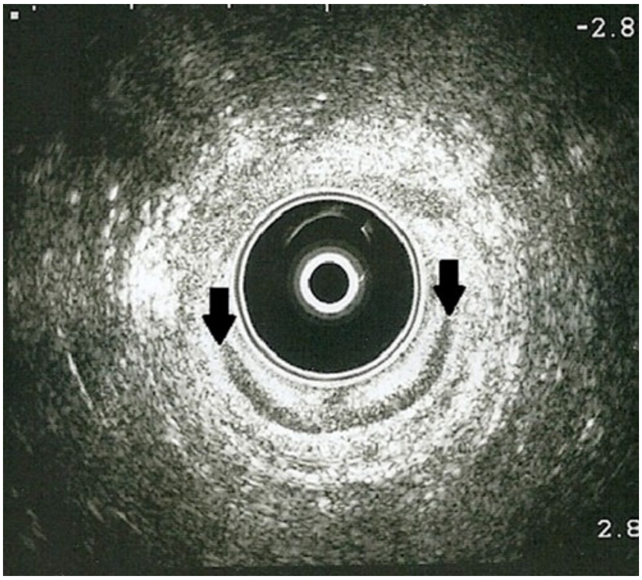

Fig. 3 Isolated anterior defect of the internal anal sphincter (*black arrows*)

dynamic imaging allowing assessment of the anatomy and function of the different compartments.

The curved array ultrasound probe is placed on the perineum after being covered with non-powdered glove or plastic wrap, with the patient lying in the dorsal lithotomy position with the hips flexed and slightly abducted [12]. Alternatively, the technique can be performed with the woman in the standing position. The patient must empty her bladder prior to voiding, leaving ideally a residual of no more than 30 ml. The quality of the image can also be enhanced by pulling the labia apart and with increased hydration of the tissue (images are of better quality in pregnancy and less clear in a postmenopausal status) [12].

The standard midsagittal view includes the symphysis pubis anteriorly with the urethra and bladder neck lying immediately dorsally, the vagina and cervix medially and the rectum and anal canal visualised posteriorly (Fig. 4). Further posteriorly to the anorectal junction, the central portion of the levator plate is seen as a hyperechoic structure. Parasagittal or transverse views often yield additional information, i.e. confirming urethral integrity, enabling assessment of the puborectalis muscle and depicting mesh implants. Problems with obtaining a good view of the pelvis can be secondary to vaginal prolapse casting shadows, the pubic bone making a shadow and a full rectum, particularly in association with a rectocele obscuring the posterior compartment. The vaginal apex can be difficult to visualise with these problems.

Static three-dimensional images of the pelvic floor can be obtained in three planes: sagittal, coronal and axial. By capturing images over time during manoeuvres such as Valsalva, a fourth dimension, time, can be added to the data collected with this modality. It is particularly valuable for assessing the dynamic function of the pelvic floor complex. Moreover, rendered volume images can provide an enhanced view of the soft tissues, especially the levator ani complex [12] (Fig. 4). Although MRI has been the standard investigation for detecting pelvic floor muscle injuries as a result of vaginal birth, high resolution three-dimensional ultrasound images can be equally accurate in demonstrating anatomical defects which can result to prolapse and incontinence. Such defects can easily be missed during clinical examination and could lead to a suboptimal surgical repair [13].

With regards to the anterior vaginal compartment, ultrasound can be very helpful in determining the position of the bladder neck as well as its movement during an increase in abdominal pressure. The position of the bladder neck is defined with reference to the inferio-posterior margin of the symphysis pubis or to a set of coordinates around the central axis of the symphysis pubis [14]. Measurements are taken at rest and during maximum Valsalva and the difference between the two values provides the distance of the bladder neck movement in millimetres. Previous studies have shown high reproducibility of ultrasound measurement of bladder neck descent [15]. Although there is no definition of normality regarding bladder neck descent, cut-offs between 15 and 40 mm have been proposed to define hypermobility. Various confounders such as bladder volume, patient's position and catheterisation have been shown to influence measurements. It has been noted that obtaining or standardising an effective Valsalva manoeuvre can often be difficult, especially in nulliparous women who frequently co-activate the levator muscle [16]. The aetiology of increased bladder neck descent has both a congenital and an environmental component, mainly linked with birth trauma and prolonged second stage of labour [17, 18]. The transperineal ultrasound imaging of the bladder neck with a standard Valsalva pressure of 40 cmH_2O has been used as a method of predicting the development of stress urinary incontinence postnatally. If a woman in the third trimester has a bladder neck movement of greater than 1 cm or 40°, then she has a 50% chance of persisting postnatal stress incontinence. If the bladder neck movement is less than this, then the risk of postnatal stress incontinence is 5% [19]. Antenatal pelvic floor exercises can halve the incidence of postnatal stress incontinence in the high risk group [20].

Another easily visualised feature of the urethrovesical junction is urethral funnelling, which can be seen in women with stress urinary incontinence, as well as in asymptomatic women [21]. Funnelling of the internal urethral meatus may be observed on Valsalva and sometimes even at rest and is often, but not always, associated with leakage.

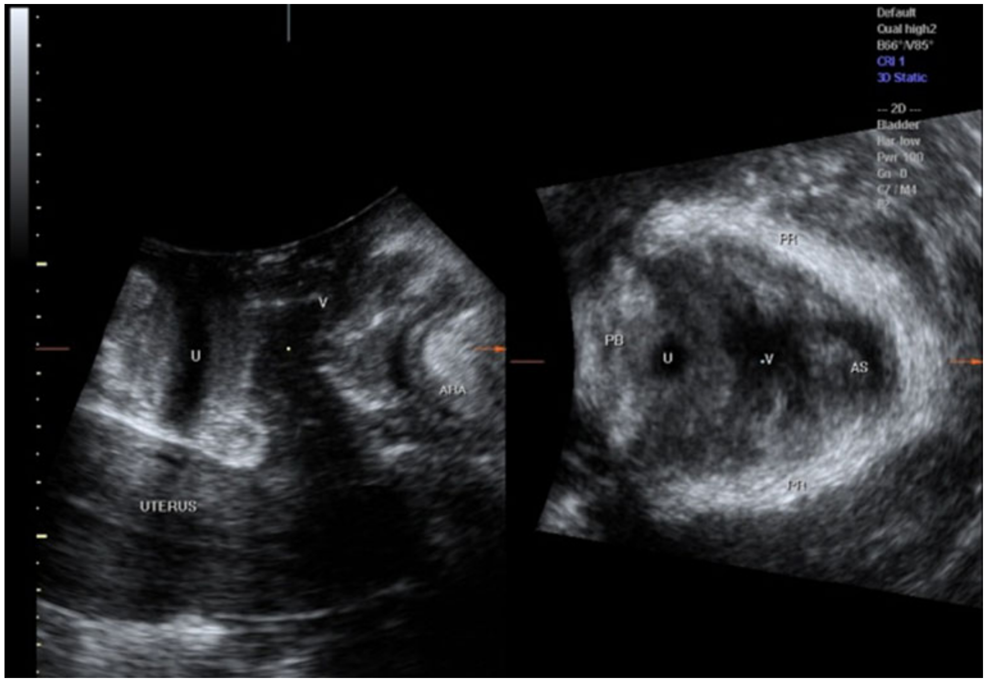

Fig. 4 Three-dimensional ultrasound image of an asymptomatic nulliparous woman at rest. Pubic bone (*PB*), urethra (*U*), vagina (*V*), puborectalis (*PR*), uterus and anorectal angle (*ARA*) are denoted in the sagittal (*left*) and axial (*right*) plane

Three-dimensional ultrasound scanning can clearly image the urethral sphincter, offering a useful tool to investigate urethral anatomy and function [22, 23]. This technique was validated by correlating urethral images from cadavers with histological findings [24]. Athanasiou et al. [25] have demonstrated smaller urethral sphincter volumes in women with stress urinary incontinence compared to normal controls, whereas Digesu et al. [26] showed that three-dimensional ultrasound assessment of the urethral sphincter predicts the outcome following colposuspension and may be useful in preoperative counselling.

Ultrasonographic measurement of bladder wall thickness (BWT), first described in 1994, is a well-established diagnostic tool in the assessment of overactive bladder symptoms [27] (Fig. 5). Increased bladder wall thickness (proposed cut-off is 5 mm) has been described in patients with overactive bladder (OAB) or detrusor overactivity and is hypothesised to be associated with detrusor hypertrophy secondary to isometric contractions [28–31]. The technique for measuring BWT has been the focus of numerous studies, with the transvaginal approach deemed as the most reliable technique [32]. Recent systematic reviews have looked at different techniques of BWT measurement and suggested that discrepancies between described techniques cannot allow for safe conclusions about diagnostic accuracy to be drawn [32–34]. Bladder wall thickness has been found to decrease in women with overactive bladder who take anticholinergic therapy. It was found that the symptoms continued to improve even though the bladder wall thickness had stopped decreasing [32].

Two-dimensional and three-dimensional ultrasound imaging can be used to define the type of anterior wall prolapse, which can sometimes be difficult by clinical examination only. Two different types of cystocoele with different clinical manifestations exist: a cystocoele with intact urethrovesical angle, which results in voiding dysfunction and women are less likely to suffer from stress urinary incontinence, and a cystourethrocele which is associated with normal flow rates and urodynamics stress incontinence [35].

Three-dimensional ultrasound technique can be valuable in detecting urethral diverticula, bladder tumours or foreign bodies (Fig. 6). Urethral diverticula, which can easily be

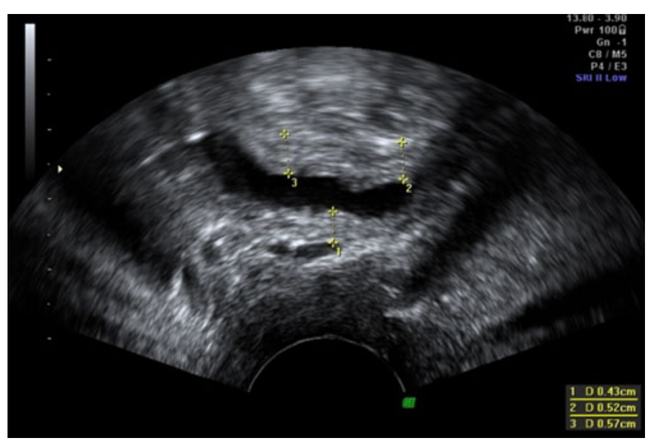

Fig. 5 Two-dimensional transvaginal ultrasound image of BWT measurement. Measurements are taken at the trigone (*1*), anterior wall (*2*) and dome (*3*) of the bladder

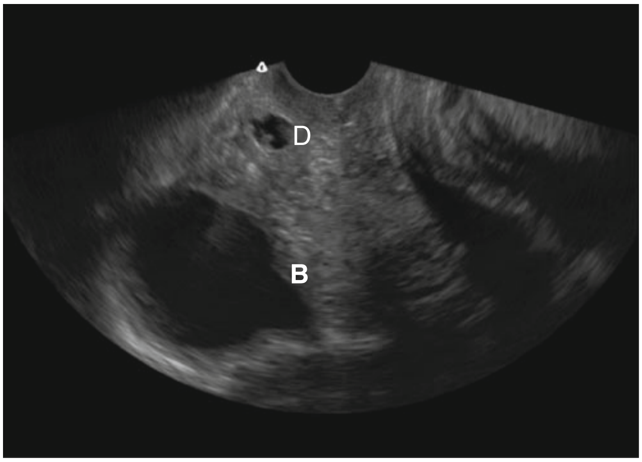

Fig. 6 Two-dimensional ultrasound sagittal view of a urethral diverticulum (*D*). The bladder (*B*) is shown cephalad to the diverticulum

overlooked in women unless imaging is undertaken, can produce a wide range of urinary symptoms from voiding dysfunction to dysuria and urgency. Translabial ultrasound can also be used to measure post-void residuals, using a formula originally designed for transvaginal scanning [36].

Vaginal wall thickness (VWT) is another imaging biomarker that has emerged in an attempt to further investigate the pathophysiology of pelvic floor dysfunction in a minimally invasive way. Two-dimensional transvaginal ultrasound in measuring VWT has recently been validated and found to correlate well with histological findings of cadaveric vaginal tissue [37]. Assessing vaginal wall thickness by using a widely available imaging modality may help clinicians in identifying congenital or physiological (menopause) structural causes for primary and recurrent prolapse.

Ultrasound estimation of bladder weight (UEBW) has also been advocated as an imaging biomarker in assessing women with lower urinary tract symptoms. Well-designed studies in men have established UEBW as a measure of bladder outlet obstruction which can result in detrusor hypertrophy and thus increase bladder weight [38]. In a recent study by Panayi et al. [39], UEBW was correlated with lower urinary tract symptoms and urodynamic diagnosis in women, showing that women with OAB symptoms or detrusor overactivity demonstrated significantly higher UEBW values than women with stress and mixed urinary incontinence symptoms or urodynamic stress incontinence.

In the posterior vaginal compartment, three-dimensional ultrasound offers a cheaper and more accessible alternative in detecting anatomical defects than other traditional modalities, such as barium or MRI proctography. Experienced operators can distinguish between a true rectocoele, where the defect lies within the rectovaginal septum, causing prolapse and defaecatory symptoms, and a rectocoele that results from an intact but abnormally distensible rectovaginal septum, associated mainly with a sensation of a bulge in the vagina [40]. Distinguishing between an intact and a defective rectovaginal septum could potentially lead to specific repair techniques of rectocoele; however, findings have yet to be confirmed in studies with large cohorts [41].

Three-dimension ultrasound of the pelvic floor has added much to the identification of the location and type of the increasingly used meshes and slings in urogynaecology (Fig. 7). Images reviewed in the axial plane can distinguish between transobturator and retropubic tapes by following the position of the arms. Moreover, three-dimensional imaging is helpful when assessing women with complications of suburethral slings, such as voiding dysfunction and de novo urgency, helping the surgeon to decide whether loosening or cutting of the sling is required. Polypropylene meshes are highly echogenic and thus easily identified in the coronal and axial plane, unless they are obscured by vaginal prolapse. If the mesh is not correctly positioned to support the vagina, a feature known as "mesh shrinkage" or "mesh retraction" may occur, increasing the likelihood of reoccurrence of the prolapse [42].

Periurethral injectables, used as a continence procedure, can also be depicted with three-dimensional pelvic floor ultrasound. Synthetic implants, like macroplastique, are hyperechogenic, whereas collagen injections are hypoechoic and can be seen as spherical structures surrounding the bladder neck.

One of the major advantages of the three-dimensional ultrasound imaging of the pelvic floor is the acquisition of static as well as dynamic images of the levator ani, levator hiatus and urethral rhabdosphincter. Despite the lower resolution when compared with the endovaginal probes, a three-dimensional curved array probe with a 70–85° acquisition angle will include the entire levator hiatus with symphysis pubis, urethra, paravaginal tissues, the vagina, anorectum and puborectalis muscle. By analysing the images either on or off-line, measurements of the urethral sphincter volume, levator hiatal diameters and area, as well as puborectalis and pubovaginalis volumes, can be obtained in order to diagnose birth trauma-related prolapse or stress urinary incontinence. There have been studies in the recent literature suggesting that levator ani morphological and functional abnormalities, commonly identified in vaginally parous women, can be attributed to either levator ani trauma (avulsion theory) or altered biomechanics of the levator ani complex [43–45].

Pelvic floor MRI

The advent of high resolution MRI techniques has offered considerable insight into the aetiology of the

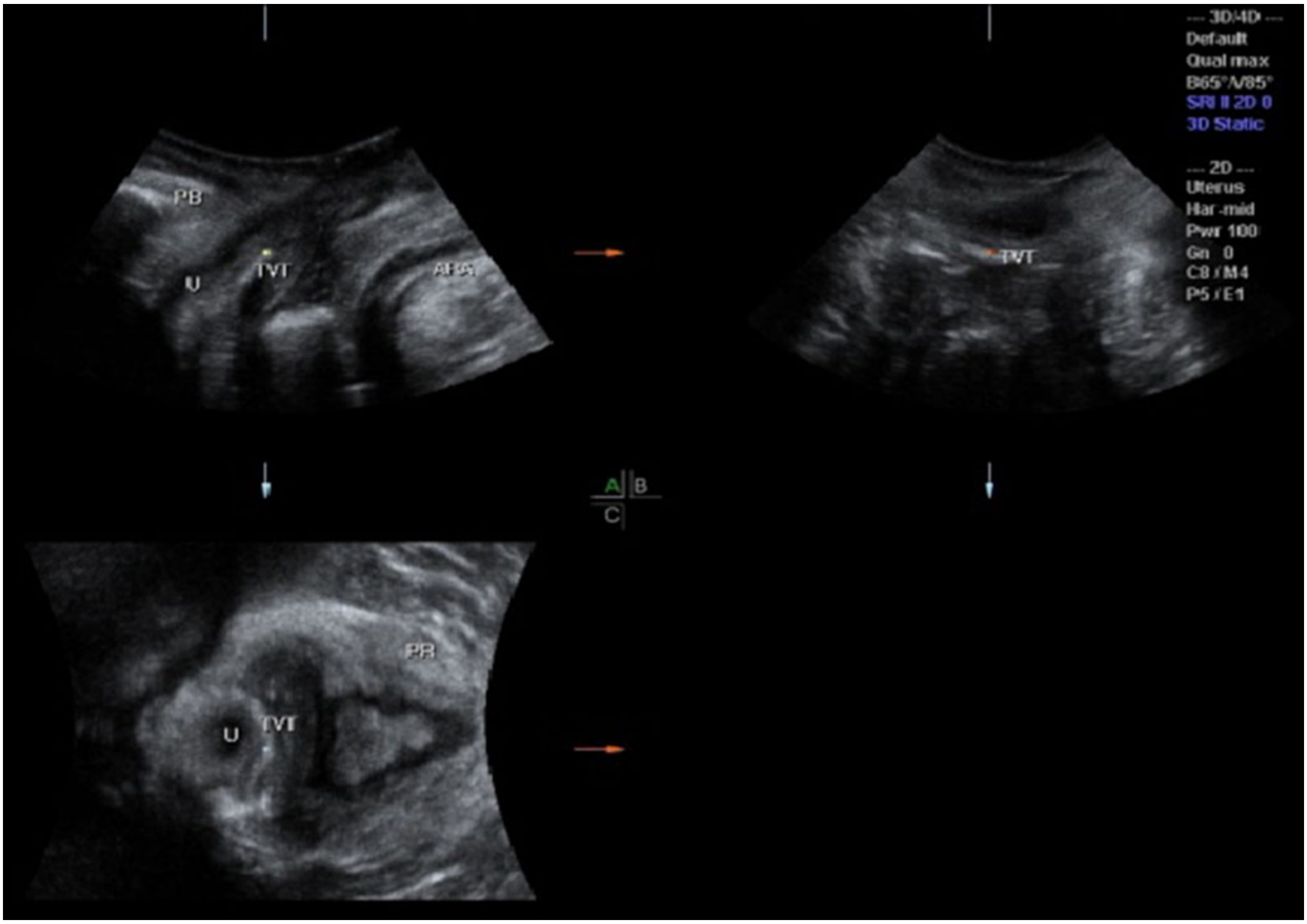

Fig. 7 Three-dimensional ultrasound pelvic floor image of a 56-year-old woman following TVT insertion. The tape is shown as a hyperechogenic structure underneath the mid-urethra in the sagittal (*top left*), coronal (*top right*) and axial (*bottom*) planes. *PB* pubic bone, *U* urethra, *PR* puborectalis, *ARA* anorectal angle

pelvic floor structural defects. MRI techniques are deemed superior to fluoroscopy, which has been considered the gold standard for more than 20 years in detecting pelvic floor abnormalities. Without using ionising radiation, MRI's high soft tissue and temporal resolution can capture ligamentous and muscular pelvic floor structures in fine detail; however, the considerable cost and the need for specialist radiological interpretation are the main disadvantages for its use.

No previous patient preparation is required for static pelvic floor MR imaging. Most commonly, images are acquired in axial, sagittal and coronal planes. The patient is placed in the supine position, unless an open magnet is available, where the images can be obtained with the patient seated.

Several studies have shown that MRI is a useful method for diagnosing and staging pelvic organ prolapse, with detection rates similar to fluoroscopic techniques, and that MRI is often able to reveal more extensive organ prolapse than physical examination alone [46, 47]. In order to determine the presence and extent of prolapse with MRI, several lines and levels of reference have been proposed. The most commonly used ones are either a line drawn from the inferior margin of the pubis symphysis to the last coccygeal joint (pubococcygeal line—PCL) or a line extending caudally along the longitudinal axis of the symphysis pubis in the sagittal plane, noted as midpubic line (MPL; Fig. 8) [44, 45, 48–50]. The choice of reference line is dependent on the radiologist performing the imaging and referring clinician, as none of the two have been shown to have better agreement with the clinical staging of the prolapse [51]. Notably, the MPL seems to correspond to the level of the hymen as shown by studies on cadaveric dissection [49]. The largest measurement from the leading point of the organ in study (bladder base, cervix/vault or anorectal junction) perpendicular to the reference line during straining or evacuation is used to stage the presence and degree of pelvic organ prolapse. Staging systems for both the PCL and MPL exist, as shown in Tables 1 and 2 [49, 51].

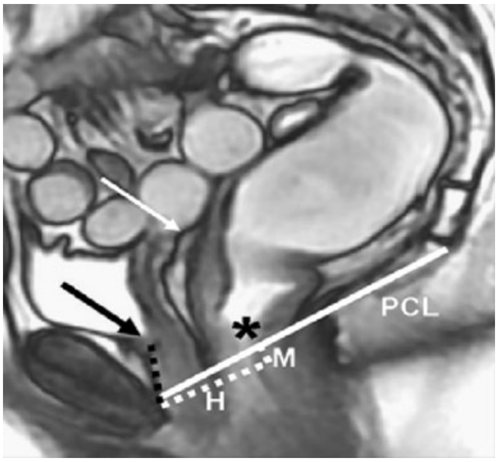

Fig. 8 Sagittal MRI image obtained at rest in a 50-year-old normal volunteer woman. The PCL is drawn from the inferior border of the pubic symphysis to the last coccygeal joint. The *H line* is drawn from the inferior border of the pubic symphysis to the posterior wall of the rectum at the level of the anorectal junction. The *M line* is drawn perpendicularly from the PCL to the most posterior aspect of the H line. Images show normal positions of the bladder base (*black arrow*), the vaginal vault (*white arrow*), and anorectal junction (*asterisk*) with respect to the PCL (with permission from Colaiacomo et al. [72])

The puborectalis muscle is seen as a separate structure on MRI lateral to the pubovisceralis. The pubovisceralis and puborectalis are best imaged in the axial and sagittal planes, whereas the iliococcygeus muscle is better visualised in the coronal plane. There is considerable variation in the levator ani size and thickness between individuals, which needs to be taken into account during interpretation of MRI findings [48].

The impact of vaginal delivery on the various components of the levator ani muscle has been well studied. It has been shown that during vaginal birth the strain forces to the pelvic floor can cause the levator ani to stretch as much as 320% [44]. Up to 20% of parous women may sustain injury to the levator ani, and this is associated with forceps delivery, anal sphincter tears and episiotomy [45]. Dietz and Steensma reported similar results by using three-dimensional ultrasound, with 15.4% of 338 parous women having unilateral or bilateral detachments of the puborectalis muscle (avulsion) [43].

Table 1 MRI staging of pelvic organ prolapse using midpubic line (MPL)

Stage	Criteria[a]
0	>3 cm to (TVL[b]−2 cm) above MPL
1	Does not meet stage 0, but >1 cm above MPL
2	≤1 cm above or below MPL
3	>1 cm below MPL
4	Complete organ eversion

[a] Distance of inferior bladder base, anterior cervical lip and anterior anorectal junction from MPL

[b] On physical examination and sagittal MR images, total vaginal length (TVL) is the greatest vertical vaginal measurement in centimetres from the posterior vaginal fornix to the level of the introitus in patients with a cervix. In patients without a cervix, the measurement is made from the most superior aspect of the vaginal cuff to the level of the introitus

Table 2 MRI staging of pelvic organ prolapse using pubococcygeal line (PCL)

Stage of prolapse	Criteria[a]
Small	1 to <3 cm below PCL
Moderate	3–6 cm below PCL
Large	>6 cm below PCL

[a] Distance of inferior bladder base, anterior cervical lip and anterior anorectal junction from PCL

The anal sphincter complex can be visualised in both the axial and coronal planes. The IAS is the innermost muscle and is uniformly intermediate in signal intensity on T2-weighted images. The EAS is the outermost muscle and is usually lower in signal intensity on T2-weighted images. The EAS may be open anteriorly or posteriorly as a normal variation and this should not been regarded as a defect [52]. Pelvic floor MRI is equally accurate (91%) to ultrasound in detecting anal sphincter defects and more accurate (93%) than ultrasound in demonstrating sphincter atrophy [53].

Static MRI imaging of the pelvic floor has been used to study the mechanism of urinary incontinence. Continent women have the levator plate nearly parallel to the pubococcygeal line and the bladder neck is above the pubococcygeal line and closer to the symphysis pubis, when compared with women with urodynamic stress incontinence [54, 55]. Digesu et al. studied sagittal and parasagittal MRI pelvic floor images in women who underwent Burch colposuspension. They showed that the procedure resulted in a shorter distance between the levator ani muscle and the bladder neck and was associated with continence [56].

Visualisation of the endopelvic fascia and the ligamentous structures providing support to the viscera is still challenging with the current modalities. Recent data, however, have provided an insight in the supportive structures of the urethra and the vagina. Macura et al. [57] described three different ligaments that provide support to the female urethra: the periurethral, paraurethral and pubourethral ligaments, which have so far been controversially reported in anatomy textbooks and imaging studies.

Endoanal MRI

Endoanal MRI, with the use of an endocoil, is admittedly more complex and time-consuming than endoanal ultrasound. However, it provides higher quality images of the anal sphincter complex. The examination is carried out with the use of a lubricated sheathed coil which is inserted into the anus with the woman in the left-lateral position. Subsequently, the woman is turned onto the supine position and the images are taken in the axial plane. The bladder should be emptied prior to the investigation, which normally does not last for more than 30 min. Alternatively, if the placement of the endocoil in the rectum is not well tolerated, an externally placed phased array coil can produce good images and facilitate sphincter depiction, depending on the operator's experience.

One of the major indications for endoanal MRI is the assessment of anal sphincter volume. MRI is superior to endoanal ultrasound in measuring the thickness of the external anal sphincter which is normally around 4 mm [53]. External anal sphincter atrophy is defined by thinning of the muscle and replacement by fat; less than 50% thinning of the muscle is considered as moderate atrophy, whereas >50% thinning and replacement by fat is deemed as severe atrophy [58, 59].

Endocoil MRI seems to be equally effective as endoanal ultrasound in depicting anal sphincter tears. In a study by Dobben et al. [60], the two modalities were found to have very similar positive predictive values in detecting patients with anal sphincter tears that subsequently required surgical repair. Overall, endoanal ultrasound remains the investigation of choice for assessing the anal sphincter integrity following obstetric injuries as it is quicker, less costly and often more readily available.

Dynamic imaging

Fluoroscopy

For 20 years, fluoroscopy of the pelvic floor has been the gold standard in detecting vaginal prolapse in women with urinary and defaecatory symptoms. Despite the advent of new dynamic imaging modalities such as dynamic MRI and four-dimensional ultrasound, fluoroscopic techniques such as voiding cystourethrography (VCUG), evacuation proctography, cystoproctography and cystocolpoproctography are still of great value mainly due to their wide availability and their ability to depict on pelvic floor abnormalities with the patient in a physiological position, either standing or seating. On the other hand, disadvantages include the more invasive nature of the investigation, the use of ionising radiation, the need for contrast, as well as the inability to simultaneously evaluate all three pelvic compartments. Hence, different techniques are used for each of the pelvic compartments.

VCUG is primarily used for detecting anterior vaginal wall prolapse in women with a history of urinary incontinence. The patient is imaged in the lateral standing position after the bladder has been filled with iodinated contrast. Images are taken during rest, coughing and voiding to assess for any bladder base descent. Evaluation and diagnosis of vesicourethral reflux, bladder and urethral diverticula and bladder wall trabeculation is then possible (Fig. 9) [61].

Evacuation proctography or defaecatory proctography is the fluoroscopic technique used for assessing rectal evacuation, prolapse and rectocoele in women with constipation and defaecatory dysfunction. The study is based on voluntary evacuation of paste enema (barium) administered into the rectum through a syringe. If an enterocoele is suspected, oral medium contrast can be administered 2 h prior to the study to assess the small bowel. The patient is then seated on a commode placed on the footrest of the X-ray table, and continuous imaging by videofluoroscopy is performed before, during and after evacuation. Five criteria need to be met for a defaecatory proctogram to be considered normal [62]: increased anorectal angulation, obliteration of the puborectal muscle impression, wide anal canal opening, total evacuation of contrast and normal pelvic floor resistance are features of a normal study that have been confirmed in a series of asymptomatic volunteers [63].

Pelvic floor descent can be measured with reference to fixed bony landmarks. The most commonly used reference points are the PCL, which is a line drawn from the inferior part of the symphysis pubis to the sacrococcygeal joint, and the MPL which is an extension of the long axis of the symphysis pubis [46, 64]. The PCL is the line that corresponds to the pelvic floor. The anorectal

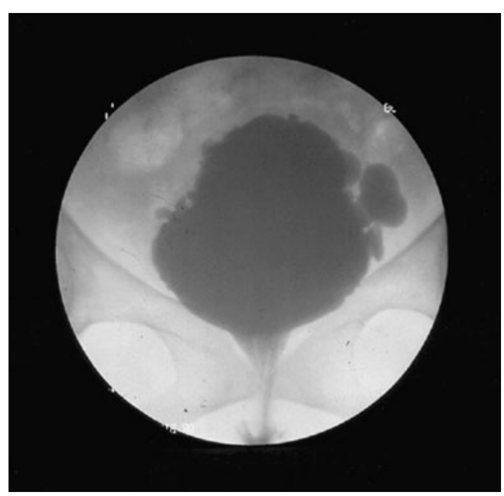

Fig. 9 VCUG image of a 46-year-old female presenting with neurogenic detrusor overactivity. The bladder has trabeculation and bladder diverticulae with a wide open bladder neck

angle (ARA), the angle between the anal canal axis and the posterior upper rectum, reflects the status of puborectalis muscle, which forms a sling around the posterior aspect of the anorectal junction. In general, ARA should be approximately 90° at rest; however, the clinical value of this measurement is questioned [65]. Normally, complete evacuation involves pelvic floor descent, relaxation of the puborectalis and sphincter muscles with decreased impression of the puborectalis on the posterior rectal wall (wider anorectal angle). Following evacuation, the reverse sequence of events takes place and so the anatomic structures return to their pre-evacuation position. Apart from assessing rectal evacuation, proctography can elucidate rectal prolapse, rectocoele and rectal intussusception which also result in dysfunctional defaecation. Rectal intussusception can be shown as invagination of the rectum on itself or into the anal canal. Rectocoele is defined as a protrusion of the anterior wall of the rectum wall more than 2 cm from a line drawn along the axis of the anal canal. Another cause of constipation which can be depicted by evacuation proctography is the absent or delayed rectal emptying due to the inability of the puborectalis muscle to relax during voluntary evacuation. The condition is known as “pelvic dyssynergy” or “paradoxical puborectalis contraction” or “annismus”, which can be diagnosed if more than 66% of rectal contrast material is not evacuated within 30 s [66].

A complete method of imaging pelvic floor disorders involves the use of multi-compartmental fluoroscopic techniques such as cystoproctography, cystocolpoproctography and functional MRI, as discussed previously in this text. Dynamic cystoproctography, as described by Kelvin et al. [67], involves opacification of the rectum, bladder, vagina and small bowel to facilitate imaging of dysfunction in all pelvic compartments at the same time. Despite the simplicity of an approach involving concurrent opacification of the pelvic organs, the argument against the validity of this technique is based on the presumption that prolapsed organs competing for space in the pelvis may obscure the true severity of different prolapse. A staged approach, which allows for assessment of the different compartments separately without the risk of masking a prolapsed organ, has been suggested as a preferable technique [46].

Dynamic MRI

Magnetic resonance imaging has been mentioned as a static imaging modality in detecting pelvic floor disorders such as prolapse, levator ani defects and anal sphincter tears. MRI can be equally considered as a dynamic imaging technique depending on the protocol used. Whether the patient lies in supine position or sits upright, if an open machine is available, studies have shown that dynamic MRI is equally effective in detecting multi-compartmental defects by studying defaecatory dynamics without the use of contrast medium [68]. Some protocols involve the administration of ultrasound gel or other media to opacify the rectum and facilitate imaging during defaecation, especially when intussusception is suspected. Dynamic MRI is performed in the midsagittal position with the slice positioning such that all the pelvic organs are visualised. Using a rapid image sequence such as fast imaging with steady state precession or single shot fast spin echo, images are obtained every second as the patient performs various manoeuvres (Kegel, maximum Valsalva, voluntary defaecation).

Depiction of pelvic organ prolapse via MRI has been previously mentioned in this article. Due to vey high soft tissue resolution, dynamic MRI can reveal complex pelvic floor weaknesses that are difficult, if possible, to be diagnosed clinically (Fig. 10). Sigmoidcoeles, enterocoeles and peritoneocoeles can be imaged without the use of contrast in the sagittal plane adding significant information about the patient’s symptomatology and offering guidance in choosing the best surgical approach.

Rectal intussusception may be diagnosed by the presence of rectal wall in-folding from the ampulla towards the anal canal. Intussusception is considered low grade if the in-folding wall is thin and is confined to the rectum. In high-grade intussusception, the in-folding is thicker and may enter the upper anal canal. The sensitivity of MRI in diagnosing rectal intussusceptions has been reported to be lower than that of evacuation proctography [69].

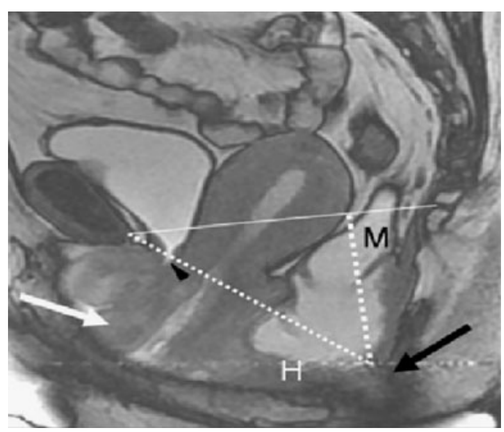

Fig. 10 Severe uterine prolapse in a 41-year-old woman. Sagittal function MRI image obtained during defaecation shows the uterus moving downward inside the vagina and the cervix exits the vaginal introitus (*white arrow*). *H* and *M lines* are abnormally elongated. The vagina appears shortened and everted; this finding is associated with the change in cervix-fundus angulation and flexion. Urethral funnelling without hypermobility (*arrowhead*) and severe (7 cm) posterior compartment descent (*black arrow*) are also seen (with permission from Colaiacomo et al. [72])

Pelvic floor descent is often seen on dynamic MRI during Valsalva manoeuvre. Such findings need to be analysed with reference to the patients' history and clinical symptoms. For example, pelvic floor descent can be attributed to pudendal neuropathy, if the patient is complaining about defaecatory dysfunction which leads to prolonged and excessive straining. On the other hand, prolapse symptoms and incontinence are more likely to be linked to pelvic floor muscle and fascial defects due to trauma during childbirth, resulting in pelvic floor descent through a different pathophysiological mechanism.

Four-dimensional pelvic floor ultrasound

Four-dimensional ultrasound imaging of the pelvic floor has enhanced the clinical approach to complex urogynaecology conditions. It is increasingly available in tertiary urogynaecology centres. Four-dimensional transperineal/translabial ultrasound offers the ability to record the dynamic functional anatomy of the pelvic floor without the restrictions of transferring the patient to a radiology suite for a fluoroscopic investigation or MRI, or the use of ionising radiation and contrast medium. The technique does not require input by a radiology specialist as it can be performed by the clinician to supplement the clinical examination and facilitate diagnosis. Depending on quality settings and acquisition angles, modern ultrasound scanners are capable of obtaining 0.5–20 volumes per second producing cine loops of volume data that can depict morphological changes of the pelvic floor structures during provocative manouevres (contraction, Valsalva).

The ability to acquire real-time volume data sets of the pelvic floor anatomy with ease makes four-dimensional transperineal ultrasound superior to MRI [55, 65]. Prolapse assessment by magnetic resonance requires ultrafast acquisition, which is not widely available and does not allow optimal resolutions [55]. Moreover, ultrasound real-time imaging allows identification and controlling for confounders, such as suboptimal performance of provocation manouevres, often seen during Kegel contraction or co-activation of levator ani muscles during Valsalva, which cannot be depicted on MRI [14, 70].

Discussion

Increasing awareness of the prevalence and complexity of pelvic floor dysfunction necessitates a combined approach by incorporating clinical examination to new imaging modalities to establish diagnosis and optimise treatment. The advent of three-dimensional/four-dimensional ultrasound imaging of the pelvic floor functional anatomy has opened new horizons in the assessment of the patient in the urogynaecology clinic, without the need for complex and interventional imaging techniques. Much as urodynamics investigation remains the gold standard for the investigation of lower urinary tract symptoms, the use of non-invasive imaging modalities such as three-dimensional/four-dimensional pelvic floor ultrasound has added to our understanding of anatomical defects resulting in pelvic organ prolapse. Pelvic floor ultrasound in patients with previous pelvic surgery or defaecatory symptoms offers a non-invasive alternative for evaluating recurrent stress urinary incontinence and prolapse or rectal intussusception. Before such new imaging modalities are well established in clinical practice though, well-designed and sufficiently powered studies will have to prove their ability in linking clinical manifestations with image findings. In this way, such modalities could possibly lead to new, more promising methods of managing pelvic floor dysfunction.

Ultrasound and its application to imaging in urogynaecology have not been validated by imaging cadavers. This is a major weakness which needs to be corrected particularly with reference to the newer techniques, such as three-dimensional ultrasound. The imaging of a structure is very different from assessing its physiological or histological components. This means that an "injury" seen on endoanal sonography is a change in the image of the structure, but it does not necessarily imply a weakness of the anal sphincter, which could be measured with anal manometry.

Lastly, many different techniques are currently being used, and the images presented in the literature vary in orientation and magnification. An international standard method of reporting imaging in the literature is overdue and should perhaps take the lead of the German Association of Urogynecology which published their report in 1996 [71].

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