A review of functional pelvic floor imaging modalities and their effectiveness

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1. Introduction

Pelvic floor dysfunction affects approximately 15% of multiparous women [1]. This may lead to faecal incontinence, pelvic organ prolapse, and urinary incontinence with 10% of patients requiring surgery [2]. The pelvic floor, in conjunction with the bladder and anorectum, is responsible for the storage and expulsion of urine and stool, a function that requires coordination between the somatic external anal sphincter and visceral components such as the rectum and internal anal sphincter [3].

It is expected that, over the next 30 years, there will be a 45% increase in the demand for pelvic floor services, including imaging [2]. Current pelvic floor imaging techniques include ultrasound imaging, magnetic resonance imaging (MRI), and dynamic defaecating proctography or cystocolpoproctography (DCP).

The support provided by the pelvic floor for the pelvic organs depends on the coordination of genital tract suspension by the endopelvic fascia and ligaments and the closure of the pelvic floor by the levator ani muscle [4]. Weakness of one component may be temporarily compensated for by action of the others, but this will increase the likelihood of occurrence of an eventual pelvic floor defect [5].

The endopelvic fascia (although it may be more accurately described as endopelvic connective tissue) refers to the tissue that forms a continuous sheet over the levator ani and pelvic organs, attaching to the bony pelvis [5]. Additional support of the urethra and bladder neck is provided by three condensations of this fascia—the perirethral, paraurethral, and pubourethral ligaments, with the pubourethral ligament acting as a fulcrum between the bladder and external urethral meatus [6]. The levator ani muscle, also known as the pelvic diaphragm, is subdivided into four muscles—pubococcygeus, iliococcygeus, coccygeus, and puborectalis, although the last can be considered a component of the external anal sphincter [3].

The female pelvis is divided into three compartments for the purposes of describing pelvic floor disorders [5], shown in Fig. 1 below. The compartments and their associated disorders are further described in Table 1.

Pelvic floor dysfunction can also be caused by atrophy, previous injury to, or other weaknesses of levator ani, which can lead due global descent of the pelvic viscera due to loss of muscular support [5].

2. Results

2.1. Imaging of the pelvic floor

Diagnosing pelvic floor pathology by physical examination alone has many shortcomings, including its tendency to focus on surface anatomy instead of structural abnormalities of the pelvic viscera [7]. As a result of this, imaging in conjunction with physical examination should be relied upon for the diagnosis, measurement, and treatment of pelvic floor defects.
2.2. Pelvic floor ultrasound

Various ultrasound techniques have been developed to image the pelvic floor, and these are able to visualise a range of pathological features, as well as mesh, slings, and implants [8]. Most slings are highly echogenic [9], and therefore, their type [10] and mode of action [8] are easily visualised on an ultrasound. In the future, this will become more relevant when investigating the increasing number of patients with transvaginal tapes, sacral coloposuspension, and ventral mesh rectopexy. A normal pelvic floor ultrasound is shown below in Fig. 2.

Indications for pelvic floor ultrasound imaging include recurrent urinary tract infections, stress or urge urinary incontinence, symptoms of voiding dysfunction, persistent dysuria, prolapse, faecal incontinence, and obstructed defaecation. Postpartum trauma of levator ani is one of the most important contributing factors to pelvic organ prolapse and can be diagnosed using two-dimensional (2D), three-dimensional (3D), or four-dimensional (4D) ultrasound technology [7]. Ultrasound imaging is more reliable than MRI in assessment of the anterior compartment, where funnelling of the urethra and hypermobility of the bladder neck are typical findings in cases of urinary incontinence [11]. Dynamic 2D transperineal ultrasound taken at rest shows the anatomical relationships of the pelvic organs, and bladder neck descent is measured to assess urethral mobility [12]. Funnelling of the urethra is present in almost all women with stress incontinence examined under optimal conditions (full bladder with intravesical injection of contrast medium [13]). Colour Doppler 2D ultrasound imaging shows urine leakage when coughing or performing the Valsalva manoeuvre [14]. Translabil ultrasound of the anterior compartment can also detect bladder tumours, foreign bodies [7], or residual urine [15].

Ultrasound imaging of the middle compartment can be used to visualise uterine prolapse (although this is usually clinically obvious) and to provide information to guide surgical repair of voiding dysfunction in patients with a retroverted uterus. This is especially useful if the uterus has atrophied following the menopause, making it more difficult to visualise [7]. Ultrasound imaging of the posterior compartment can identify rectocele, rectal intussusception, and enterocoele [7]. In Fig. 3, a rectocele and a cystocele can be seen on a perineal ultrasound.

3D ultrasound imaging, which uses a transducer to provide information either in the axial or sagittal plane, is used in conjunction with dynamic 2D imaging to enable the visualisation of the levator ani muscle, the lower urinary tract, and the anal sphincter, as well as pelvic organ prolapse [12]. In cases of urinary incontinence, 3D ultrasound assesses the urethral position in three different planes, giving more complete diagnostic information than the single plane measurements obtained by 2D ultrasound [16]. It also allows assessment of pelvic floor structures after muscle training [12]. Fig. 4 shows an axial section of a 3D pelvic ultrasound scan, whilst Fig. 5 shows a sagittal section.

4D ultrasound imaging provides dynamic real-time ultrasound data; for example, morphological changes can be observed during pelvic floor

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Contents</th>
<th>Abnormality</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Bladder</td>
<td>Cystocele</td>
<td>Urinary incontinence</td>
</tr>
<tr>
<td></td>
<td>Bladder neck</td>
<td>Bladder neck descent</td>
<td>Urinary urgency</td>
</tr>
<tr>
<td></td>
<td>Urethra</td>
<td>Urethral hypermobility</td>
<td>Difficulty in initiating urination</td>
</tr>
<tr>
<td>Middle</td>
<td>Uterus</td>
<td>Cystourethrocele</td>
<td>Pelvic pain</td>
</tr>
<tr>
<td></td>
<td>Cervix</td>
<td>Cervical, uterine, or vaginal vault prolapse</td>
<td>Organ prolapse (bulge at the vaginal introitus)</td>
</tr>
<tr>
<td></td>
<td>Vagina</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>Anus</td>
<td>Rectocele</td>
<td>Incomplete evacuation</td>
</tr>
<tr>
<td></td>
<td>Anal canal</td>
<td>Intussusception</td>
<td>Incomplete evacuation</td>
</tr>
<tr>
<td></td>
<td>Sigmoid</td>
<td>Enterocoele</td>
<td>Sensation of incomplete evacuation</td>
</tr>
<tr>
<td></td>
<td>Rectum</td>
<td>Rectal prolapse</td>
<td>Pelvic pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anal sphincter injury</td>
<td>Organ prolapse</td>
</tr>
</tbody>
</table>

The table above summarises common defects and their presentation, as well as the contents of the pelvic compartment.
constrictions or during the transition from rest to Valsalva. This allows levator function and fascial trauma to be assessed [7]. It can be used to evaluate lower grade prolapse and can be used before and after pelvic floor surgery to assess the outcome [12].

A study by Beer-Gabel et al. in 2008 that compared dynamic transperineal ultrasound (DTP-US) with defaecation proctography showed that DTP-US was able to diagnose 100% of cystoceles, 92% of rectoceles, 71% of perineal descent, and 75% of rectal prolapse in 17 patients with cul-de-sac hernias. This included 11 cystoceles that could only be diagnosed using ultrasonography due to the anechoic aspect of urine in the bladder and 3 incidences of perineal descent that were also missed by defaecation proctography [17].

2.3. Pelvic floor MRI

MRI provides a global view of the viscera and musculature and has no known adverse biologic effects [18]. In addition to diagnosing existing defects, it can identify patients who have an increased risk of developing disorders. Variations in the shape of the pelvis (particularly in the cases of a wide pelvic inlet and midpelvis and a shallow pelvic outlet) are more common in women with pelvic organ prolapse [19]. Early identification of these risks could theoretically be used to decrease maternal and neonatal trauma during and after childbirth [19].

In order to diagnose and grade pelvic organ prolapse, a number of reference lines and measurement points are used during pelvic MRI. The most common line used is the pubococcygeal line (PCL), which connects the inferior pubic symphysis with the inferior coccyx. First described by Agildere in 2003 [20], it is thought to approximate the plane of the levator plate. Another reference line is the midpubic line (MPL), which extends along the longitudinal axis of the pubic bone, passing through its midequatorial point [21]. Singh et al. [22] introduced this line in order to overcome the lack of a standard line used for both clinical and MRI staging of prolapse. It corresponds to the level of the vaginal hymen [22], which is conventionally used for the clinical staging of pelvic organ prolapse with the Pelvic Organ Prolapse Quantification system [23]. As dynamic MRI permits observation of the movement of the entire levator ani during contraction and strain (an advantage over pelvic ultrasound), these reference points are important to prevent classification problems during the scan [24] but the high number of reference lines and lack of standardisation is one of the biggest problems with this imaging method [21].

Once a reference line has been selected, pelvic organ prolapse in all three compartments can be visualised and staged by measuring the perpendicular distance from a set anatomical reference point (usually the posterior and inferior aspect of the bladder in the anterior compartment, the anterior cervical lip in the middle compartment, and the anterior aspect of the anorectal junction in the posterior compartment) to the reference line. The measurement used is the maximum obtained during strain or evacuation [5].

The accuracy of these lines as diagnostic tools is debatable, forming another disadvantage of this imaging method. Although pelvic organ prolapse diagnosed using the PCL in the anterior and in the middle compartments was found to be accurately staged when compared to clinical examination, rectoceles in the posterior compartment were inaccurately staged [25]. Similarly, the MPL was accurate only in the posterior compartment [26].

MRI is used to assess defaecation and the causes of obstructive defaecation including rectoceles and intussusception [5]. Diagnostic sensitivity compared to DCP is 70% despite the fact that soft-tissue-resolution MRI allows better differentiation of full wall thickness and mucosal intussusceptions [27]. It is as accurate as ultrasound imaging for the visualisation of anal sphincter defects, with a sensitivity of 91% [28]. MRI is more accurate than ultrasound at diagnosing atrophy of the sphincters, with a sensitivity of 92% [29]. A study by Gousse et al. in 2000 [25] evaluated the clinical utility of pelvic MRI in a variety of pathologies. Results from this study are shown in Table 2.

Gousse et al. concluded that MRI carried out in their study accurately detected and staged all conditions studied except for rectocele, which was more sensitive than physical examination in the diagnosis of enterocoele and provided superb anatomical information from a single
dynamic study. In their opinion, dynamic half Fourier acquisition, single shot turbo spin-echo sequence MRI is likely to replace ultrasound imaging in the evaluation of women with pelvic pain [25].

In 2013, Foti et al. evaluated the diagnostic capabilities of MRI in comparison to the gold-standard imaging method of defaecography in outlet obstruction syndrome, a term that refers to all pelvic floor disorders that cause incomplete evacuation of faeces from the rectum. In addition to comparing the two methods, they also investigated whether adding an evacuation phase to MRI improves diagnostic accuracy. Nineteen patients ranging from 36 to 77 years in age were evaluated [30]. Their results are summarised in Table 3.

In all conditions evaluated, with the exception of descending perineum, MRI with an evacuation phase was equal or close to defaecating proctography in terms of diagnostic accuracy. However, MRI without an evacuation phase was significantly less accurate in every condition except sphincter hypotonia (which is studied during the voluntary contraction phase, rendering an evacuation phase unnecessary). The study concluded that, whilst MRI is a useful diagnostic tool, it should supplement defaecating proctography instead of replacing it and that an evacuation phase is necessary for accurate diagnosis [30].

Supporting structures of the pelvic floor are visualised using MRI scanning. The periurethral, paraurethral, and puborectal ligaments were described by Macura et al. in 2006 [6] using a high-resolution MRI and an endourethral MRI coil. MRI provides rapid images of the entire pelvic floor [18]. As 95% of patients have defects in multiple compartments [31], global pelvic floor evaluation is usually necessary [32]. A pelvic MRI showing a rectocele and a cystocele is shown in Fig. 6.

### 2.4. Dynamic proctography and cystocolpoproctography

DCP differs from defaecating proctography by the opacification of the vagina. Defaecating proctography is the current gold standard for diagnosis of prolapse of the posterior pelvic compartment [33]. It involves videofluoroscopy at rest and during rectal evacuation whilst the patient sits on a specially designed commode [18]. Opacification of the small bowel, rectosigmoid, and vagina with liquid barium contrast is used for posterior compartment imaging [33]. During the procedure, the patient is exposed to ionising radiation—an average dose of 4.9 mSv [34]. Although this dose is not extremely high, prevention of exposure to radiation is desirable in female patients of childbearing age, and this

<table>
<thead>
<tr>
<th>Condition</th>
<th>Compartments</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive predictive value (PPV)</th>
<th>Negative predictive value (NPV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cystocele</td>
<td>Anterior</td>
<td>100</td>
<td>83</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>Cuff prolapse</td>
<td>Middle</td>
<td>100</td>
<td>54</td>
<td>33</td>
<td>100</td>
</tr>
<tr>
<td>Uterine prolapse</td>
<td>Middle</td>
<td>83</td>
<td>100</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Enterocoele</td>
<td>Posterior</td>
<td>87</td>
<td>80</td>
<td>91</td>
<td>83</td>
</tr>
<tr>
<td>Rectocele</td>
<td>Posterior</td>
<td>76</td>
<td>50</td>
<td>66</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 3

A study by Foti et al. (2013) evaluating the sensitivity, specificity, PPV and NPV of MRI used as a diagnostic tool in outlet obstruction syndrome. MRI was carried out using a closed-configuration superconducting unit with a 1.5-T field strength and an 8-channel torso coil. The results in Table 3 are calculated using defaecating proctography as the gold standard [30]. WE, with evacuation phase; WOE, without evacuation phase

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphincter hypotonia</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Rectocele</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Rectal Prolapse</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Enterocoele</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Descending perineum</td>
<td>28.6</td>
<td>0</td>
<td>100</td>
<td>28.6</td>
</tr>
</tbody>
</table>
value is high when compared to the radiation dose of 0.01 mSv from a chest X-ray [33]. A normal proctogram, showing the rectum and anal canal is shown below in Fig. 7.

In the anorectum, most abnormalities can only be seen at the end of evacuation, giving DCP an advantage over MRI scans comparing rest to strain. DCP can be used to visualise a variety of structural abnormalities caused by excessive straining (common in patients with defaecatory disorders), such as rectocele, enterocele, pelvic floor descent, and intussusception [32]. It is of significant benefit in 40% of patients, allowing surgical management to be substituted by medical management in 14% of cases [35]. A defaecating proctogram showing a rectocele and an intussusception is shown in Fig. 8.

3. Discussion

3.1. Comparison of techniques

Of the three techniques, ultrasound is the cheapest. It is better tolerated than DCP in 87% of patients [33] and is able to identify suburethral slings (an advantage over MRI). In addition, 3D ultrasound can provide detailed information on the urethral complex, the bladder neck, and the superficial structures of the perineum [16]. Real-time 4D ultrasound scans allow further advantages over MRI when visualising prolapse, as it is easier to have the patient perform manoeuvres such as pelvic contractions when not limited by the physical characteristics of an MRI machine. A final, important advantage in clinical practise is the stored volume data sets and postprocessing software that allow preoperative and postoperative data to be easily compared. This aspect of the procedure is likely to contribute to future surgical development and teaching [7].

However, disadvantages of ultrasound include the possibility of inaccurate assessment of organ position and morphology due to compression by the transducer, and the limited field of view does not allow global assessment of the pelvic floor in the same way that MRI does [5].

Although MRI is highly sensitive in the diagnosis of sphincter defects, it also has disadvantages, such as the lack of standardised reference lines and the inaccuracy of measurements taken using these lines. Analysis of data found by Lockhart et al. in 2008 found that measurements obtained by MRI scans had poor reproducibility, especially for soft tissue measurements [19]. Handa et al. [19] recommend that future studies relying on MRI measurements should develop quality controls measures to address this problem and that enhanced training should be carried on those using pelvic MRI scans in clinical practise.

The supine position adopted for defaecation during MRI defaecography is unnatural [36] and is a position in which patients may be asymptomatic [32]. The high number of false negatives on MRI in the anterior and middle compartments is likely due to this position [37]. Access to scanners that allow imaging in the erect position is limited.

Contrasting opinions of the diagnostic capability of MRI appear in the literature. Although Gousse et al. conclude that MRI has the
capability to replace ultrasound imaging in the evaluation of women with pelvic pain, Foti et al. state that an evacuation stage is necessary for MRI to be a useful diagnostic tool and that, even with this stage in place, it cannot replace DCP.

DCP has several advantages as an imaging technique. The seated position used is preferable to most patients, meaning that, in cases where the primary clinical symptoms are related to defaecation, DCP is a more effective imaging technique. It also takes much less time than a conventional MRI, taking 10–15 min [38] and is cheaper (although it is still more expensive than ultrasound imaging [33]).

Disadvantages include that, without opacification of the bladder, no information can be obtained on the anterior and middle compartments, whereas MRI and ultrasound both allow visualisation of the entire pelvic floor, without opacification of any structures. It is also the only technique that involves exposing the patient to ionising radiation and lacks the soft tissue imaging resolution and multiplanar imaging ability of MRI, which is able to provide much more anatomical information regarding the pelvic floor and its support structures [32].

A summary of the clinical utility of each technique is shown in Table 4.

4. Conclusion

Functional pelvic floor pathology results in a significant decrease in quality of life for women of all ages throughout the world, with urinary incontinence affecting between 17% and 45% of adult women [39]. Physical examination is now thought to be an increasingly unreliable method of diagnosis, as it produces results that are difficult to quantify and are also examiner dependent. Imaging techniques such as ultrasound, MRI, and DCP are increasingly important in assessment of the pelvic floor.

As this review has outlined, the current gold standard for the posterior compartment, DCP, has significant disadvantages, most notably the fact that without opacification of the bladder, it can only visualise the posterior compartment and is therefore usually unsuitable for patients with anterior, middle, or multicompartmental defects. It also requires exposing the patient to ionising radiation. However, it is still regarded as the best technique for imaging of abnormalities that can only be seen at the end of evacuation.

Ultrasound imaging is cheap, dynamic, and can visualise all three pelvic compartments, although it lacks the ability of MRI to provide a global view with detailed anatomical information. It is generally well tolerated and especially useful for visualising the results of previous surgery. It has been shown to have especially high sensitivity for cystoceles.

Despite the lack of standardised reference lines for MRI, it can provide a detailed global view of the pelvic floor and has been shown to have high sensitivity in diagnosing a variety of conditions in all three compartments such as cystocele, rectocele, rectal prolapse, and sphincter hypotonia, although an evacuation phase is necessary to achieve many of these results.

Further research is required to assess whether MRI is indeed able to replace ultrasound in the imaging of the anterior and middle compartments and whether DCP should remain the gold standard for posterior compartment imaging.

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### Table 4

A summary of the clinical utility of each technique in the diagnosis of pelvic floor dysfunction, along with their significant advantages and disadvantages

<table>
<thead>
<tr>
<th></th>
<th>Ultrasound</th>
<th>MRI</th>
<th>Defaecating proctography/DCP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compartments visualised</strong></td>
<td>All (although limited field of view)</td>
<td>All (provides global view)</td>
<td>Posterior only unless opacification of bladder</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>Varies with condition and scan type; refer to Table 2</td>
<td>91% in anal sphincter defects, 92% in anal sphincter atrophy</td>
<td>Gold standard for imaging of the posterior compartment</td>
</tr>
<tr>
<td><strong>Significant advantages</strong></td>
<td>Cheapest, Well tolerated, Ability to visualise slings, No ionising radiation exposure</td>
<td>High soft tissue imaging resolution provides detailed anatomic information, No ionising radiation exposure</td>
<td>Physiological position for defaecation, Visualises abnormalities only seen at the end of defaecation</td>
</tr>
<tr>
<td><strong>Significant disadvantages</strong></td>
<td>Limited field of view, Possibility of inaccurate assessment due to organ compression by transducer</td>
<td>Lack of standardised reference lines, Measurements have poor reproducibility, ‘Unnatural’ and possibly asymptomatic position for defaecation, Expensive</td>
<td>Exposes patient to ionising radiation, Normally only visualises the posterior compartment</td>
</tr>
</tbody>
</table>
References


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