Role of imaging in urogynaecology

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INTRODUCTION

Imaging has been suggested as an adjunct to manometric-based evaluation of the lower urinary tract and surrounding structures. It is attractive in allowing investigators to observe and measure anatomical landmarks at rest and dynamically. In reviewing the role of imaging in female urinary incontinence this paper will examine the evidence relating to the various imaging modalities and their clinical usefulness.

X-RAYS

Anteroposterior and lateral X-ray images of the lumbo-sacral spine have been used to identify vertebral defects associated with nervous system anomalies such as sacral agenesis or spina bifida occulta. It can be used in women with suspected congenital neurogenic incontinence, with or without abnormalities on neurological physical examination. In women with a neurological abnormality this test has been superseded by magnetic resonance imaging of the spine. X-ray imaging of the symphysis pubis is of use after continence surgery particularly to investigate osteitis pubis where a woman complains of pubic pain.

X-ray visualization of the lower urinary tract can be achieved using contrast agents to demonstrate urinary incontinence, vesico-ureteral reflux, fistula, diverticulum (Fig. 1) and stones. Contrast can be instilled during urodynamic study and fluoroscopic images obtained during filling, provocation tests and voiding. The fluoroscopic images can be stored and reproduced individually or as continuous clips during a key part of the study. This is known as video cystourethrogram (VCU) or voiding cystourethrogram (VCUG) depending when images were taken (i.e. during filling or voiding, respectively).

Instilling contrast with or without the use of a bead chain to delineate the urethra has been used in an attempt to diagnose the causes of lower urinary tract dysfunction. Unfortunately this technique cannot discriminate between stress incontinent and continent women.1–4 The specificity in diagnosing urodynamic stress incontinence using static bead chain cystourethrography is between 44% and 76% with a sensitivity of 53%–100%.13 Bladder neck mobility is also poorly demonstrated with VCUG5,9 with a positive predictive value of 0.56 and a negative predictive value of 0.74. Postoperative changes to the bladder neck are not seen after vaginal repairs but colposuspension does produce changes in the position of the bladder neck which can be seen with X-ray screening,6 but this does not predict success or failure of the colposuspension.2,5,7–12 It is also not possible to distinguish postoperative failures from success.2,5,8–13 Colposuspension produces a typical image of the bladder neck being pulled forwards towards the back of the symphysis pubis and pelvic floor training improves the ability of the women to contract their pelvic floor and thereby compress the urethra, but there is no suspension effect.6

Clinical value of test

Videocystourethrography is a useful investigation for selected women with neurological or symptoms suggestive of specific abnormalities such as urethral diverticula.

ULTRASOUND

Ultrasound can be used to visualise fluid-filled structures without the use of a contrast medium. Ultrasonography allows soft tissues such as the kidney, urethra, urethral sphincter and bladder wall to be visualised and measured. The main advantage of ultrasound is that no ionising radiation is used in imaging, thus examinations can be easily repeated.

The main disadvantage of ultrasound is that the probe needs direct contact and a coupling medium to image structures adequately. The ultrasound probe also has a limited field of view and only certain parts of the urinary tract can be visualised at one time and until recently this was only possible in one plane. The ultrasound image itself depends on the ability of the tissue to reflect ultrasound waves (echogenicity) of the tissues rather than density, thus tissues that have a high echogenicity appear white (hyperechoic) on the ultrasound image while structures
with a low echogenicity appear black (hypoechoic). Certain tissues are hyperechoic when insonated in one orientation and hypoechoic when the ultrasound waves are incident from a different direction, this is seen particularly when imaging striated muscle. The striated muscle fibres and the intervening collagen fibres are orientated in a single direction. If the ultrasound passes through the tissue along the long axis of the fibres then there is minimal reflection of the incident ultrasound waves and the tissue appears hypoechoic (Fig. 2). However, when the ultrasound waves pass perpendicular to the long axis of the striated muscle fibres (Fig. 3) then the tissue appears hyperechoic. This is important when interpreting scans of the urethral sphincter as there are many layers of muscle fibres orientated in different directions to each other.

The bony enclosure of the pelvis bone limits ultrasound imaging to the transabdominal, transvaginal, transrectal and transperineal approaches. The images rendered do require experience to interpret and each approach has limitations and advantages. The type of probe and frequency of ultrasound wave (1–10 MHz) emitted determines which tissues are seen and the quality of the image obtained. The higher the ultrasound frequency the better the resolution of the image, unfortunately an increased frequency has a reduced depth of penetration due to increased attenuation. The highest ultrasound frequency usefully utilised in urogynaecology is 7.5 MHz.

Transabdominal ultrasound

Many methods of calculating bladder volume using ultrasound have been proposed, and most involve the bladder volume being measured by imaging the maximal cross-sectional area in sagittal and transverse planes, then measuring the bladder’s maximum dimensions. All calculations approximate the bladder to the volume of a sphere, thus correction factors need to be applied. The accuracy of bladder volume measurements is approximately ±20%. 14–20 Below 50 mL of volume transvaginal scanning has been proposed as a more accurate method of measurement21; however, at larger volumes it is certainly as inaccurate.22

Bladder diverticula can be detected easily with transabdominal ultrasound of a full bladder. Dynamic assessment of diverticula is important as expansion of the pocket may occur during bladder filling and this distension may worsen during micturition. The efficiency of bladder emptying is then impaired producing a postmicturition urinary residual. Calculi due to urinary stasis and transitional cell carcinoma occur within bladder diverticula in 5% of cases.23

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Fig. 1. Videocystourethrography of a woman with a urethral diverticulum.

Fig. 2. Ultrasound waves pass along the long axis of a striated muscle. This tissue would appear black on the ultrasound machine screen.

Fig. 3. Ultrasound waves pass perpendicular to the long axis of the striated muscle. The tissue reflects a high proportion of the ultrasound waves thus the tissue appears hyperechoic.
Clinical value of test

Transabdominal ultrasound is clinically accurate as a measure of bladder volume and can be used to investigate bladder diverticula.

Transvaginal ultrasound

The transvaginal approach allows the bladder and peri-urethral structures to be clearly visualised as the probe is close to the relevant structures and high ultrasound frequencies (5 MHz and above) can be used to better the resolution. The urethra is seen as a hyperechoic line and urine entering the proximal urethra is seen as a dark area (Fig. 4). The urethral sphincter can be seen as an ovoid structure around the urethra. The rhabdosphincter appears hypoechoic lateral to the urethra. However, during dynamic tests such as coughing the vaginal probe can compress the urethra and prevent bladder neck movement,24 thus the transvaginal approach is not recommended for observing urinary leakage caused by an increase in intra-abdominal pressure. It is also important to emphasise that ultrasound used in this way cannot be used to diagnose urodynamic stress incontinence as detrusor overactivity cannot be excluded.

Increased mobility of the bladder neck has been thought to be diagnostic of urethral sphincter incompetence25–27; however, continent women with uterovaginal prolapse have even more bladder neck mobility.28–30 Anterior vaginal wall mobility and bladder neck movement has been assessed using ultrasound, and they correlate well with the International Continence Society prolapse score.31–34

In nulliparous pregnant women increased antenatal bladder neck mobility appears to predict the development of postnatal stress incontinence. If the bladder neck moves more than 10 degrees during a Valsalva manoeuvre of 30 mmHg it is associated with an increase risk of postpartum urinary incontinence (50% vs 5%).35

Transvaginal ultrasound can be used to assess the outcome of continence procedures postoperatively. The Burch colposuspension has been shown to increase the approximation of the bladder neck to the symphysis pubis and arrests the descent of the bladder neck during a Valsalva manoeuvre.25,36 The absence of these features was found in those failing after surgery. Failure of a continence procedure is associated with a return of bladder neck mobility.

Clinical value of test

No specific use of this approach.

Translabial ultrasound

The urethra looks like a hypoechoic tube and the rhabdosphincter is an ovoid hyperechoic structure surrounding it. This technique does not impede movement of the bladder neck39,40 or vaginal prolapse during a Valsalva manoeuvre or pelvic floor contraction.

The position of the bladder neck before and after Burch colposuspension has been found to change when visualised with translabial sonography43 but cure is not predicted by these measurements. Vaginal prolapse can be assessed using

Fig. 4. Urethral on transvaginal ultrasound. Note the hyperechoic urethra.
this method. Good correlation has been found in the quantification of prolapse with translabial ultrasound and the International Continence Society prolapse assessment system.\textsuperscript{38}

This technique has been suggested as a replacement for radiological screening\textsuperscript{41} and a chair has been designed for scanning during voiding. The probe is fixed in a steerable mount that is controlled at a distance.\textsuperscript{42} Assuming that the urethral sphincter is an ellipsoid structure the volume of the urethral sphincter can be calculated by measuring the maximum diameters in two planes. Symptomatic women with urethral sphincter incompetence have smaller volume sphincters than asymptomatic women and these women in turn have smaller sphincters than women with detrusor overactivity.\textsuperscript{37}

\subsection*{Transrectal ultrasound}

Transrectal ultrasonography requires the patient to be in the left lateral or supine position. The probe can be used to measure post void residuals and visualise movement of the bladder neck.\textsuperscript{44} Transrectal ultrasound has been suggested as an alternative method of imaging during urodynamic studies and this has been compared with radiology.\textsuperscript{44,45} The position of the probe in the rectum does not appear to alter the pressures measured during urodynamics.\textsuperscript{45} However, the woman may feel inhibited to void because of sensation from the probe.\textsuperscript{46}

The bladder neck and proximal urethra have been visualised with transrectal ultrasound during voiding and this has been found to be an aid to diagnosis. The images are similar to those obtained during videocystourethrogrammetry,\textsuperscript{45,47} and have been used to diagnose catheter-induced hyperreflexia, posterior ledge at the bladder neck during voiding and lastly, false passages in the proximal urethra.\textsuperscript{46,48–50} Occasionally dilated ureters may be visualised and although the ureteric urine jets can be visualised entering the bladder\textsuperscript{51} vesico-ureteric reflux cannot be diagnosed.

\textit{Clinical value of test}

Transrectal ultrasound can be used to visualise the lower urinary tract in women with neurologically impaired anal sensation.

\subsection*{Transperineal ultrasound}

The function of the pelvic floor muscles has been indirectly assessed using ultrasound by visualisation of bladder neck movement during pelvic floor contraction.\textsuperscript{39,56–58} Transperineal imaging of the levator ani muscle is difficult as only a section of the muscle is visualised using two-dimensional ultrasound at one time.\textsuperscript{57} The pelvic floor muscles can be difficult to image directly with two-dimensional ultrasound. Using a 5-MHz probe applied laterally to the posterior fourchette the levator ani muscle has been described.\textsuperscript{59,60} Unfortunately the structure imaged was less than 2 cm from the skin suggesting that it was the deep transverse perineal muscles rather than the pelvic floor muscles, which are at least 3–4 cm from the skin.

\textit{Clinical value of test}

Transperineal ultrasound is not clinically useful for assessing the pelvic floor.

\subsection*{Intraurethral ultrasound}

Images can be obtained from high-frequency ultrasound probes inserted into the urethra. The probe is shaped like a catheter and a 360° section perpendicular to the main axis of the intraurethral probe is imaged. An oblique image through the urethra is obtained using intraurethral ultrasound, this has been correlated with histology.\textsuperscript{52,53} Unfortunately this technique is limited as it does not allow clear visualisation of the outer border of the rhabdosphincter. The maximum cross-sectional area of the striated urethral sphincter has been found to be significantly smaller in women with urinary incontinence than continent controls.\textsuperscript{54} But the high ultrasound frequencies used by the intraurethral probe only allow clear visualisation of all the periurethral structures in 60% of women studied. Artefacts associated with measurement can also occur if the urethra is not straight. The axis of the probe changes as the probe is drawn along the urethra and thus the plane imaged through the urethra is not constant. This limits the usefulness of this approach in viewing the peri-urethral structures.\textsuperscript{54,55}

\textit{Clinical value of test}

Intraurethral ultrasound is not clinically useful.

\subsection*{THREE-DIMENSIONAL ULTRASOUND}

Three-dimensional ultrasound shows the rhabdosphincter is thicker anteriorly, thinning symmetrically at its lateral aspects and is thinnest on the dorsal surface. The intraurethral approach visualises the rhabdosphincter as a hypoechoic cylindrical structure around the urethra, and the hypoechoic core consisting of the longitudinal smooth muscle, urethral lumen and urethral epithelium and submucosal plexus (Fig. 5), this has been confirmed by imaging cadaveric tissue then comparing the histological measurements.\textsuperscript{52} These ultrasonographic findings have also been validated by the use of electromyography of the urethral sphincter. The electrical activity of striated
A muscle was identified in the hypoechoic cylinder around the urethra.61,62

Diverticula can also be visualised using vaginal ultrasound with a benefit of imaging the soft tissue and the position of the ostium in relation to the urethral sphincter. With three-dimensional ultrasound the urethral sphincter can be seen clearly and the position of the ostium leading to the diverticulum can also be determined (Fig. 6). The additional benefit of ultrasound is that contents of the urethral diverticulum can be identified, e.g. whether they are calculi or a soft tissue growth.

ULTRASOUND OF THE LEVATOR ANI MUSCLE

The pelvic floor can be scanned using two techniques: the transperineal technique can scan the entire pelvic floor, and using three-dimensional ultrasound one can reconstruct an image perpendicular to the passage of the ultrasound waves through the tissues in the plane of the pelvic floor. This approach has the benefit of making the entire pubococcygeus muscle hyperechoic and the fibres can easily be seen passing dorsally around the anorectal junction. Vaginal prolapse makes the transperineal approach difficult as air trapped in the vagina impairs the image obtained.

Using a 7.5-MHz transrectal probe a transverse section of the pelvic floor can be obtained by inserting the probe vaginally (Fig. 7). To image the levator hiatus correctly the insertion of the levator ani muscle into the pubic bone should be identified. The insertion of the muscle into the inferior posterior aspect of the pubic bone is 5 mm wide and can be used as a fixed point on both sides of the pubic bone. The posterior landmark is the anorectal angle that can be identified in the transverse plane by determining where the rectum is most anterior. The medial margin of the pubococcygeus sling is demarcated clearly and the surface area and width of the levator ani hiatus can be measured. Defects laterally in the vaginal walls can also be visualised using this technique. The area of the levator hiatus has been found to be larger in women with vaginal prolapse than those without prolapse.63 However, women who have urodynamic stress incontinence and prolapse appear to have the same sized levator ani hiatus as women with prolapse alone. Interestingly women who do not have prolapse but have urodynamic stress incontinence do not have an enlarged levator ani hiatus. Thus it appears that an enlarged levator ani hiatus is associated with the development of urogenital prolapse. This has been confirmed by measurements of the urogenital hiatus. Women who have prolapse or fail surgical treatment have larger urogenital hiatus.64

When imaging the urethral sphincter and the pelvic floor in women before and after delivery, the levator ani surface area was increased in those women who had had a vaginal delivery. However, there were no volume changes of the urethral sphincter in those women who were continent postnatally.

Clinical value of test

The ultrasound image of the levator ani muscle is useful only for research.

BLADDER WALL THICKNESS

Bladder wall thickness is best measured after voiding and after the intravesical volume has been measured as less than 50 mL. The bladder wall thickness is measured in the parasagittal plane, as the urethra sometimes obscures the dome of the bladder. Measurements are made at maximum magnification, perpendicular to the inner surface of the bladder dome, anterior wall and trigone. The mean of the three measurements is used as a test for detrusor overactivity. A pilot study comparing women with detrusor overactivity and urodynamic stress incontinence showed those women with DOA all had a mean bladder wall thickness greater than 5 mm. In an unselected group of 184 symptomatic women, 108 were found to have DOA of whom 102 (94%) had DOA on VCU or ambulatory urodynamics; of 17 women with a bladder wall thickness of less than 3.5 mm, three were found to have DOA.

In another study transvaginal ultrasound assessment of mean bladder wall thickness was found to be a sensitive screening tool, which can detect detrusor overactivity in those women with equivocal laboratory urodynamics. In women who have no evidence of USI on laboratory studies, a cut-off of 6.0 mm was highly suggestive of detrusor overactivity. However, in those women with USI then ambulatory studies probably remain the investigation of choice.

Clinical value of test

Bladder wall thickness appears to be a useful second line test if the results of laboratory urodynamics do not match the urinary symptoms described by the patient.

MAGNETIC RESONANCE IMAGING

Static, dynamic and three-dimensional magnetic resonance imaging (MRI) studies of normal subjects have enhanced our understanding of normal pelvic anatomy. The use of MRI to analyse the pelvic floor musculature has also contributed greatly to our understanding of pelvic floor dysfunction. MRI has been used to study the normal female pelvic anatomy, as well as the anatomy of the ageing female and the symptomatic patient. It has been shown that in the supine position the female pelvic floor is dome shaped at rest. During voluntary pelvic floor contractions the levator musculature straightens and becomes more horizontal. With bearing down the muscle descends, becomes basin shaped, and the width of the genital hiatus widens. One limitation of MRI in the evaluation of the female pelvis is that the studies are usually done with the patients supine.
The advantages of MRI include: no need for urethral catheterisation, no exposure to ionising radiation, detailed anatomical views of the three pelvic floor compartments at rest and maximal pelvic strain, direct visualisation of pelvic organs for evaluation of concomitant pathology, determination of urethral hypermobility, and evaluation of ureteral obstruction and post-void residual. Its main disadvantage at this time is that the study is performed in the supine position and therefore the effects of gravity have not been clearly evaluated. In addition, organ space competition in the vagina can also interfere with accurate interpretation of coexisting organ prolapse.

Three-dimensional MRI allows volumes to be measured; in a study of nulliparous continent female volunteers it was found that the muscle morphology, signal intensity and volume are relatively uniform. Goh et al. described an average volume of the levator ani of 46.6 mL, a width of the levator hiatus of 41.7 mm and an average posterior urethovesical angle of 143.5°. It appears that the levator ani width is enlarged in multiparous women and women with uterovaginal prolapse.

Changes are seen with MRI in the levator ani and pelvic floor musculature immediately after delivery, which appear to change over time. Tunn studied women the first day after delivery and compared the images obtained with those at 1, 2 and 6 weeks and 6 months after delivery.75 After delivery there were changes in the signal intensity of the levator ani with significant decreases in the area of the levator ani hiatus. There was no statistically significant difference seen in muscle thickness over time.

Tunn et al. compared women with stress incontinence and controls. The women with incontinence had higher intensity levator ani musculature with a loss of the hammock-like configuration of the anterior vaginal wall.

**Clinical value of test**

MRI is restricted to a research setting.

**CONCLUSION**

Imaging does give additional insights into the aetiology and the diagnosis of lower urinary tract dysfunction. However, at present it cannot be used as the sole diagnostic tool and must be used with urodynamic investigations.

**References**


