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2

Ultrasound in the assessment of pelvic organ prolapse

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A B S T R A C T

Imaging is increasingly being used in urogynaecology. Because of low cost and universal availability, ultrasound (US) is the most commonly used diagnostic modality, which allows the observation of manoeuvres such as Valsalva and pelvic floor muscle contraction in real time. The ability to see beyond surface anatomy is particularly important in the posterior compartment and in obstructed defecation where this method may replace defecation proctography. Imaging is especially useful in the form of 3D/4D multiplanar and tomographic translabial US, as these modalities give access to the axial plane and the levator ani. This allows assessment of both avulsion, i.e. major maternal birth trauma, and hiatal overdistension, i.e. ballooning. Both are major risk factors for both prolapse and prolapse recurrence. This review will outline current clinical utility, introduce recent research in the respective field and provide an overview of likely future utility of imaging in the investigation of pelvic organ prolapse.

Introduction

It has taken over 20 years for imaging to develop as a mainstream diagnostic tool in the investigation of female pelvic organ prolapse (POP). Clinical assessment alone is a rather inadequate tool to assess pelvic floor function and anatomy. Our examination skills focus on surface anatomy rather than true structural abnormalities, and our knowledge of underlying pathoanatomy is very poor. The use of ultrasound (US) by clinicians has varied from one speciality to

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another, with gynaecologists having an advantage compared to urologists and colorectal surgeons owing to the easy availability of equipment in OB/GYN units, a result of the universal use of US in antenatal care.

Methodology and instrumentation

Two-dimensional imaging

Basic requirements for translabial pelvic floor US include a B-mode capable two-dimensional (2D) US system with cine loop function, a 3.5–6 MHz curved array transducer and a video printer. A midsagittal view is obtained by placing a transducer (usually a curved array with frequencies between 3.5 and 8 MHz) on the perineum (Fig. 1), after covering the transducer with a glove, condom or thin plastic wrap. Air bubbles can cause reverberation artefacts and need to be avoided by covering the entire transducer surface with gel. This is particularly important with 3D/4D transducers, as bubbles lateral to the main transducer plane may not be noticed during acquisition. Sterilisation with regard to intracavitary transducers is usually considered unnecessary. We use alcohol wipes to clean the transducer between patients, but regulations may vary between jurisdictions.

Powdered or coated gloves can impair imaging quality because of reverberations, and hence, they should be avoided. It is worthwhile testing several types of probe covers for their effect on image quality and ease of application. Imaging is performed in dorsal lithotomy, with the hips flexed and slightly abducted, or in the standing position. Requiring the patient to place heels close to the buttocks and move hips towards the buttocks may result in an improved pelvic tilt, rotating the symphysis pubis more ventrally. Bladder filling should be specified; usually, prior voiding is preferable. The presence of a full rectum can cause very substantial artefact and sometimes necessitates a repeat assessment after bowel emptying. Parting of the labia can improve image quality, which tends to be the best in pregnancy and the poorest in menopausal women with marked atrophy, likely due to varying tissue hydration. Vaginal scar tissue can also impair visibility. Fortunately, obesity rarely affects imaging conditions for this application.

The transducer can be placed firmly without causing discomfort, unless there is marked atrophy or skin irritation. The resulting image includes the symphysis pubis anteriorly, the urethra and bladder neck, the vagina, cervix, rectum, and anal canal (see Fig. 1). The anorectal angle indicates the location of the levator plate in the midline. The cul-de-sac may also be visible, filled with anechoic intraperitoneal fluid, echogenic intraperitoneal fat, peristalsing small bowel or sigmoid colon [1].

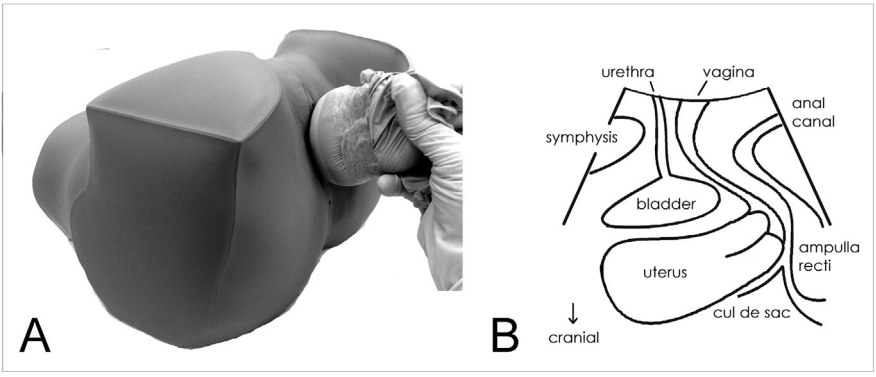

Fig. 1. Transducer placement (*left*) and field of vision (*right*) for translabial/perineal ultrasound, midsagittal plane. From (Dietz HP. The role of 2D and 3D dynamic ultrasound in pelvic organ prolapse. Journal of Minimally Invasive Gynecology 2010; 17: 282–294), with permission (Elsevier).

Three-dimensional/four-dimensional imaging

3D imaging has enhanced diagnostic capabilities, nowhere more so than in pelvic floor assessment. It gives access to the axial plane, much simpler and at a superior quality than that achieved with intracavitary transducers in the past. A single volume obtained at rest with aperture and acquisition angles of $\geq$70° will encompass the entire levator hiatus. 4D imaging, i.e. a succession of volumes obtained during Valsalva or pelvic floor contraction, enhances capabilities even further [2].

Basic requirements for 3D/4D pelvic floor US include a system that allows acquisition, reconstruction and analysis of volume datasets. Any system that allows 3D imaging using an abdominal obstetric probe will be suitable for pelvic floor US, if the transducer allows an acquisition angle of at least 70°. One should be able to obtain volumes at an acquisition angle of 85° and store at least 5 s of volume data blocks at a minimum of 1 Hz on the hard disk of the system for later evaluation.

Display modes

Fig. 2 demonstrates two basic display modes currently in use on 3D US systems. The multiplanar or orthogonal display mode shows cross-sectional planes through the volume being investigated. For pelvic floor imaging, this most conveniently means the midsagittal (top left), coronal (top right) and axial (bottom left) planes. Imaging planes on 3D US can be varied in a completely arbitrary fashion to enhance the visibility of a given anatomical structure, either at the time of acquisition or offline later. The levator ani, for example, usually requires an axial plane that is tilted, and the direction of the tilt can vary greatly between manoeuvres such as Valsalva or pelvic floor contraction and the resting state.

The three orthogonal images are complemented by a 'rendered image', i.e. a semi-transparent representation of all voxels in an arbitrarily definable 'box' and the 'region of interest'. Fig. 2D shows a standard rendered image of the levator hiatus, with the rendering direction set from caudally to cranially, which is the most appropriate for imaging the hiatus. Usually, a rendered volume of 1–2 cm is

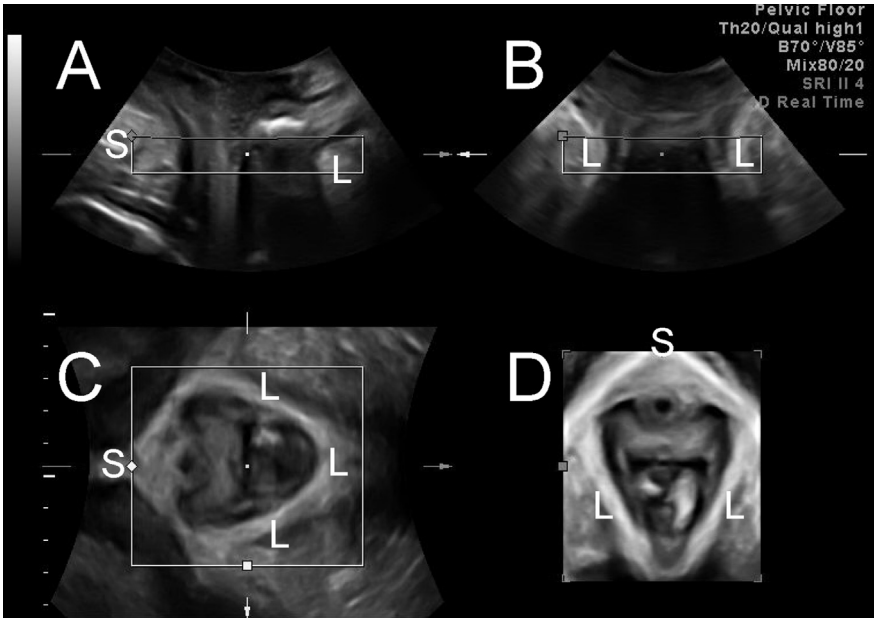

Fig. 2. Standard representation of 3D pelvic floor ultrasound. The usual acquisition/evaluation screen on Voluson-type systems shows the three orthogonal planes: sagittal (A), coronal (B) and axial (C) as well as a rendered volume (D), which is a semi-transparent representation of all grey-scale data in the rendered volume (i.e. the box visible in A-C). S= symphysis pubis, L= levator ani muscle.

optimal for imaging of the hiatus. The possibilities for post-processing are restricted only by the software used for this purpose.

Four-dimensional imaging

Four-dimensional imaging implies the real-time acquisition of volume US data, which can then be represented in orthogonal planes or rendered volumes. Systems are now capable of storing cine loops of dozens of volumes, which is of major importance in pelvic floor imaging, as it allows enhanced documentation of functional anatomy. Even on 2D single plane imaging, a static assessment at rest gives little information compared with the evaluation of manoeuvres such as a levator contraction and Valsalva. Their observation will allow assessment of levator function and delineate levator or fascial trauma more clearly.

The ability to perform a real-time 3D (or 4D) assessment of pelvic floor structures during functional manoeuvres makes the technology superior to magnetic resonance imaging (MRI). Prolapse assessment by MRI requires ultra-fast acquisition, which is of limited availability and will not allow optimal resolutions. Alternatively, some systems allow imaging of the patient in a sitting or erect position, but again, accessibility will be limited for the foreseeable future. The sheer physical characteristics of MRI systems make it difficult for the operator to ensure efficient manoeuvres, as over 50% of all women will not perform a proper pelvic floor contraction when asked and a Valsalva is often confounded by concomitant levator activation. Without real-time imaging, these confounders are impossible to control for, and this is the reason why to date there is virtually no research on dynamic MRI in the axial pane.

As a result, US has major potential advantages with regard to describing prolapse, especially when associated with fascial or muscular defects, and in terms of defining functional anatomy. Offline analysis packages allow distance, area and volume measurements in any user-defined plane (oblique or orthogonal), which is much superior to what is currently possible with Digital Imaging and Communications in Medicine (DICOM) viewer software on a standard set of single-plane MRI images.

Functional assessment

Valsalva

The Valsalva manoeuvre, i.e. a forced expiration against a closed glottis and contracted diaphragm and abdominal wall, is used to reveal the symptoms and signs of female POP and demonstrate distensibility of the levator hiatus. The result is downwards and backwards displacement of urethra and bladder neck that is quantified against the symphyseal margin (Fig. 3). There is also a downward movement of other pelvic organs such as bladder, uterus, rectal ampulla and, sometimes, abdominal

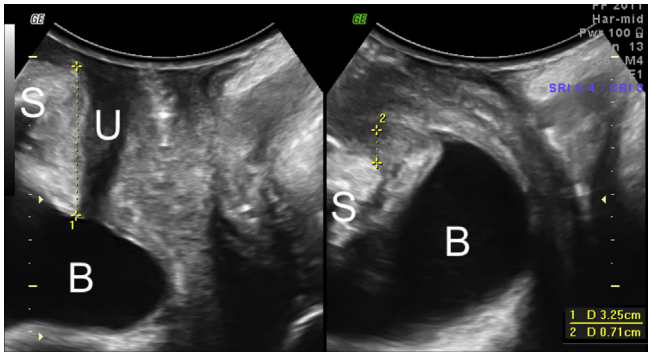

Fig. 3. The midsagittal plane at rest (A) and on maximal Valsalva (B). Bladder neck descent is measured against the inferoposterior margin of the symphysis pubis: 3.25 + 0.71 = 3.96 cm. S = symphysis pubis, B = bladder, U = urethra.

contents. At the same time, the levator hiatus, the largest potential hernia portal in the human body, is distended both laterally and caudally, thereby resulting in a varying degree of perineal descent. It is of crucial importance to not impede such downwards movement by applying pressure with the transducer, which has to move with the tissues. The main factor in achieving the full effect of a Valsalva is time, i.e. a manoeuvre lasting at least 6 s [3]. Pressure, on the other hand, is difficult to standardise, and such standardisation may well be unnecessary [4].

In the axial plane, the hiatus is distended and the posterior aspect of the levator plate is displaced caudally, resulting in a varying degree of perineal descent. All these can be observed on US of the pelvic floor, but it is important to let the transducer move with the tissues, avoiding undue pressure on the perineum, which would prevent full development of a prolapse.

In addition to time and pressure, there are many other confounders of an effective Valsalva manoeuvre. In women with an intact, strong levator muscle, a Valsalva is frequently confounded by levator activation [5]. Levator co-activation during Valsalva is evident as a reduction in the anteroposterior diameter of the levator hiatus on Valsalva (Fig. 4) and needs to be avoided by real-time observation, especially if leakage from bladder or bowel is likely. At times, it is necessary to repeat imaging in the standing position, which seems to increase the likelihood of an adequate bearing-down effort. Consistent co-activation may be a sign of inappropriate levator activation at other times, such as on defecation, when it is termed 'anismus'.

Pelvic floor muscle contraction

Because a levator contraction reduces the size of the levator hiatus in the sagittal plane and elevates pelvic organs, it can be quantified on imaging [6,7] (Fig. 5). In the standard orientation, the pelvic

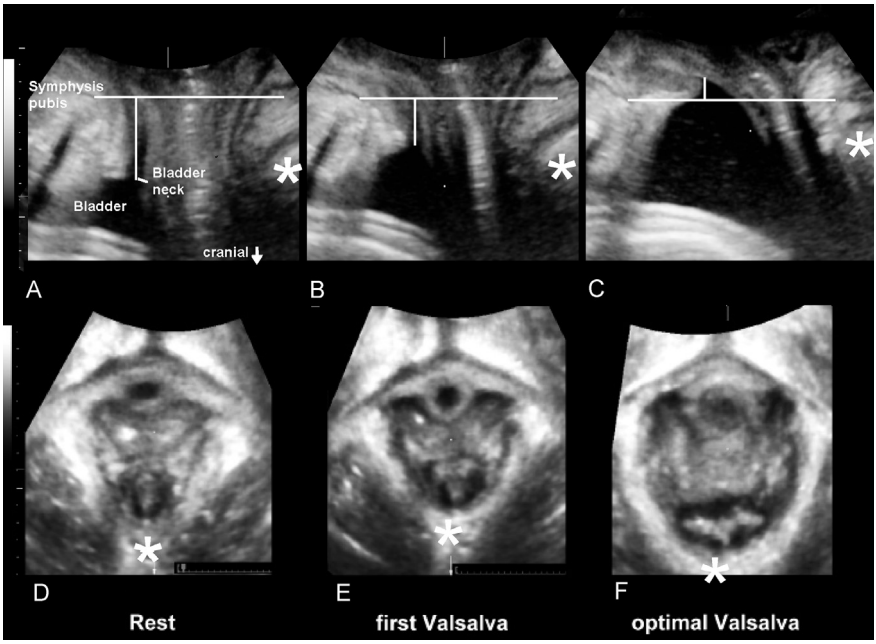

Fig. 4. Evidence of levator co-activation as seen in the midsagittal plane (*top three images*) and the axial plane (*bottom three images*). The left images of each group (A and D) show the situation at rest; the central ones (B and E) show findings on a suboptimal Valsalva with levator co-activation, evident in a narrowed hiatus visible in (E). The right images (C and F) of each group demonstrate the effect of an adequate Valsalva manoeuvre without levator co-activation, as evidenced by an enlarged hiatus. The asterisk marks the posterior aspect of the puborectalis loop in all images. From (Oerno A, Dietz HP. Levator co-activation is a significant confounder of pelvic organ descent on Valsalva. Ultrasound Obstet Gynecol 2007; 30: 346–350), with permission.

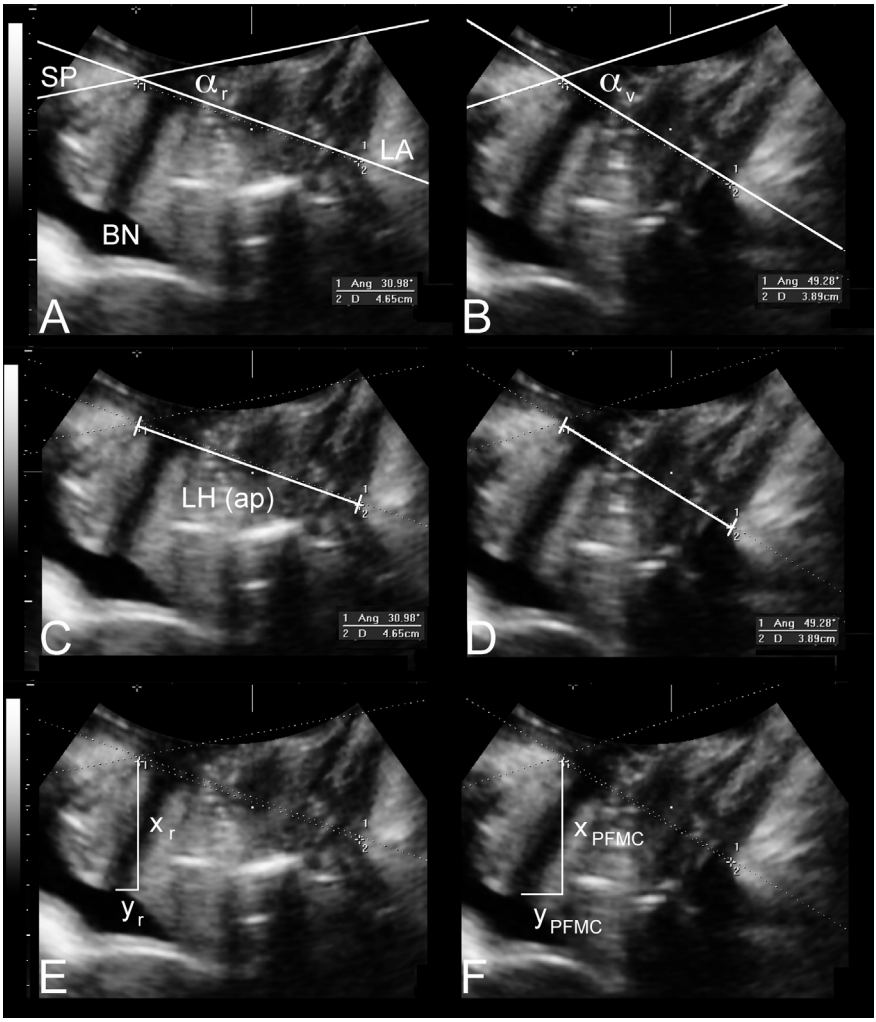

Fig. 5. Three methods of determining the effect of a pelvic floor muscle contraction (PFMC) in the midsagittal plane, using 2D translabial ultrasound. The left images in each pair (a, c and e) represent the resting state; the right images show findings on PFMC. The top pair illustrates measurement of the levator plate angle (angle between symphyseal axis and levator hiatus in the midsagittal plane), the middle pair shows reduction of the anteroposterior diameter of the levator hiatus (LH (ap)), and the bottom pair illustrates bladder neck displacement on PFMC, analogous to the way bladder neck descent is measured on Valsalva. From (Dietz, H.P., Pelvic Floor ultrasound in incontinence: What's in it for the surgeon? Int Urogynecol J, 2011. 22 (9): p. 1085–1097), with permission.

organs are shifted to the bottom left corner of the image (i.e. cranio-ventrally) when the patient performs a pelvic floor contraction. The appropriate instruction for the patient is to 'pull up and tighten the vagina and back passage', or 'do as if you would want to stop wind or urine from escaping.' Co-contraction of abdominal muscles is common and visible as a dorsocaudal shift of the bladder neck, i.e. a shift towards the top right corner of the image. This is prevented by having the patient place one hand on the abdomen to avoid any contraction of these muscles. The method can be utilised for pelvic floor muscle exercise teaching by providing visual biofeedback [8] and has helped validate the concept of 'the knack,' i.e. of a reflex levator contraction immediately before increases in intra-abdominal pressure such as those resulting from coughing [9]. Usually, reflex pelvic floor activity can be documented on coughing, but clinical utility seems to be limited [10].

Prolapse assessment in the midsagittal plane

Cystocele

Clinical examination is limited to quantifying descent of the anterior vaginal wall. In its most sophisticated form, this involves determining the coordinates Aa and Ba of the prolapse quantification (POP-Q) system of the International Continence Society [11]. Imaging, however, will not just identify conditions that mimic cystocele, such as urethral diverticula or Gartner cysts; it will also show two types of cystoceles with different functional implications (Fig. 6). A cystourethrocele is associated with good urine flow rates and urodynamic stress incontinence (A), whereas a cystocele with intact retrovesical angle (B) is associated with voiding dysfunction and a low likelihood of stress incontinence [12]. A cut-off of 10 mm below the symphysis pubis has been proposed for the definition of 'significant prolapse', i.e. a degree of bladder descent that is likely to cause symptoms of prolapse [13], equivalent to a measurement of −0.5 cm for the coordinate 'Ba' on POPQ [14]. In women after Burch colposuspension, an anterior enterocele may mimic a cystocele. This is detected easily because of the isoechoic to hyperechoic nature of enterocele contents and associated peristalsis.

Central compartment

Uterine descent

A false-negative clinical assessment seems most likely in the central compartment, as the uterus requires more time to descend than bladder or rectal ampulla [15], but it is also the most difficult to identify on imaging. The isoechoic echotexture of the cervix uteri is similar to vaginal muscularis and mucosa and may result in the uterus being overlooked, especially if it is atrophic and/or retroverted. Provided it descends far enough, (Fig. 7) and is not obscured by rectocele or enterocele, the lowest edge of the isoechoic cervix appears as a specular line, and often nabothian follicles help with identification. An anteriorised cervix in women with an enlarged, retroverted uterus can explain symptoms of voiding dysfunction. On the other hand, mild descent of an anteverted uterus can result in compression of the anorectum and intussusception, causing symptoms of obstructed defecation (Fig. 8).

While uterine descent in Caucasians is often associated with cystocele and levator trauma, uterine retroversion also seems to be a potential cause of abnormal descent of the organ. This may be more common in East and South Asians. The well-documented high rates of prolapse in Nepalese, for example, may be due to retroversion, which has been documented in 60% of Nepalese women [16]. The uterus does not need to descend as much as bladder or rectum to cause symptoms of prolapse, with a

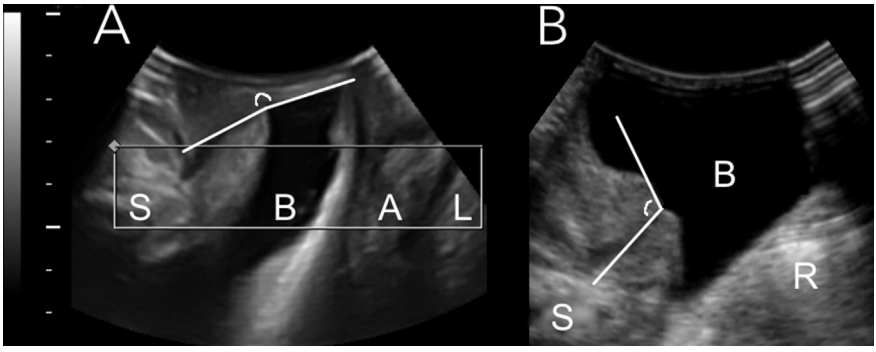

Fig. 6. The two most common presentations of cystocele. The left image shows typical findings in a patient with mild stress urinary incontinence and anterior vaginal wall descent (Ba at +0.5). The right image demonstrates appearances in a patient with a cystocele with intact retrovesical angle. Bladder neck and proximal urethra are virtually inverted on Valsalva, and there is marked urethral kinking (Ba = +2). Usually, such women present with prolapse and voiding dysfunction and are often continent. S = symphysis pubis, B = bladder, R = rectal ampulla, A = anal canal, L = levator ani.

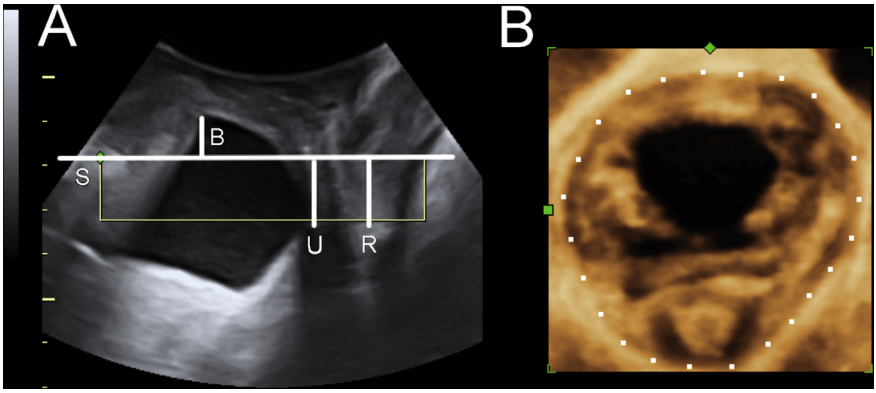

Fig. 7. Prolapse assessment on maximal Valsalva in the midsagittal (A) and rendered axial (B) planes. Descent of bladder (B), uterus (U) and rectal ampulla (R) is measured against a reference line placed through the inferior symphyseal margin. The hiatus is outlined by dots in (B), which is an axial plane representation of the box ('region of interest') seen in A.

position of 15 mm above the symphysis defined as the optimal cut-off for the definition of 'significant uterine descent' [17].

Vault prolapse

After hysterectomy, the vaginal vault can often be identified as the blunt termination of isoechoic vaginal walls, with more echogenic bowel above, but often it is obscured by a descending rectocele or enterocele. If imaging of the vault is required, depositing 20–50 ml of US gel in the vagina will help with delineation of the upper vagina. Vault descent to a given position seems to be just as likely to cause symptoms of prolapse as equivalent descent of the cervix.

Posterior compartment

Given the high prevalence of symptoms of obstructed defecation, imaging is most useful in the posterior compartment, where a variety of findings can explain the clinical observation of a 'rectocele', which really should be termed 'descent of the posterior vaginal wall'. A second-degree 'rectocele' may

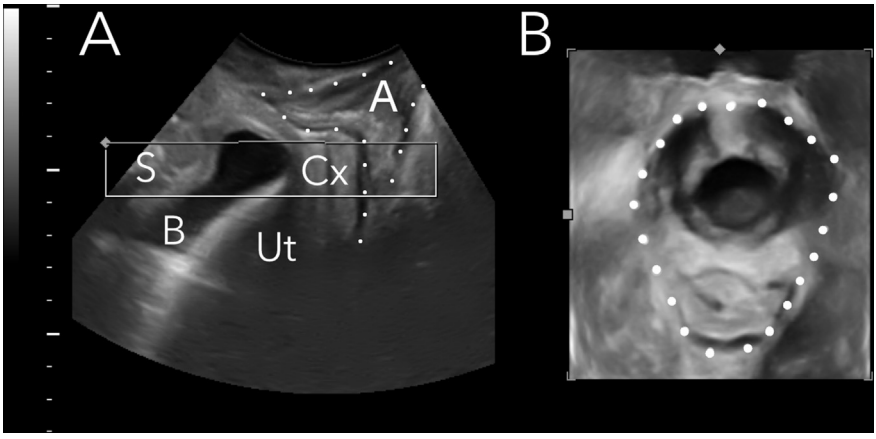

Fig. 8. Rectal intussusception with the cervix acting as intussuscipiens ('colpocele'). The midsagittal plane on the left shows a three-compartment prolapse, with the cervix (Cx) inverting the anal canal (A). The splayed anal canal is outlined with dots. Ut = uterine fundus, S = symphysis, B = bladder. Panel B shows the hiatus in the axial plane, outlined by dots.

be due to a true or 'radiological' rectocele, i.e. a defect of the rectovaginal septum or Denonvilliers' fascia (most common and associated with symptoms of prolapse, incomplete bowel emptying and straining when passing stool) [18]; an abnormally distensible, intact rectovaginal septum (associated only with prolapse symptoms); a combined recto-enterocele (less common); an isolated enterocele (uncommon); a rectal intussusception (uncommon) or just a deficient perineum giving the impression of a 'bulge' [19].

Rectocele

An anterior rectocele is a diverticulum of the anterior wall of the rectal ampulla into the vagina, more obvious on Valsalva than at rest and easily observed on imaging (Fig. 9). Posterior rectoceles are uncommon and are associated with more severe anatomical abnormalities such as intussusception. Occasionally, a rectocele may also form laterally in the sense of a herniation through the iliococcygeus muscle, but such a condition is rarely properly diagnosed and difficult to treat.

A rectocele usually contains isoechoic to hyperechoic faeces, and often, there is bowel gas as well, resulting in specular echoes and reverberations. Acoustic shadowing is common. Large rectoceles can obscure much of the hiatus and may necessitate repeat assessment after bowel emptying. Occasionally, there is no stool in the ampulla to be propelled into the rectocele, and as a result, it remains smaller and is more difficult to identify. Appearances can vary considerably from one day to the next, which explains why posterior compartment descent is less reproducible [20]. A rectocele is quantified by measuring descent relative to the symphyseal margin and by determining the maximal depth of the diverticulum (Fig. 9). 'Significant descent of the posterior compartment' is diagnosed if the ampulla is seen $\geq$ 15 mm below the symphysis pubis [13]. There have been attempts at producing a cut-off for 'significant true rectocele', but this may not be possible because of multiple confounders

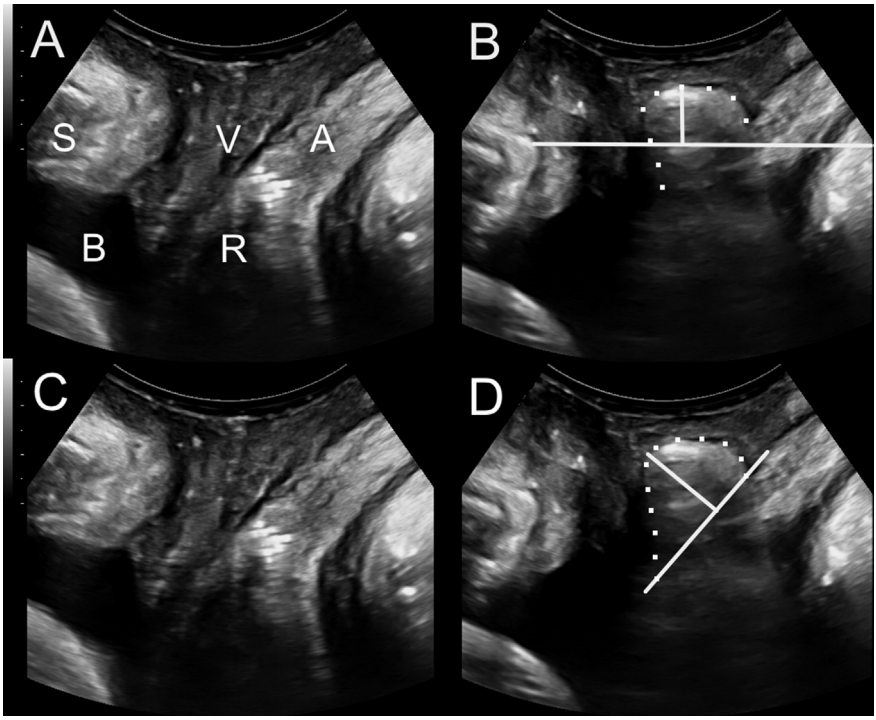

Fig. 9. A true rectocele imaged at rest (A and C) and Valsalva (B and D). B shows measurement of maximal descent, D of the maximal depth of the resulting pocket or sacculation (outlined by dots). S = symphysis pubis, B = bladder, R = rectal ampulla, V = vagina, A = anal canal.

[21]. Findings on translabial US seem to be comparable to those of defecation proctography, provided the same criteria are used in the evaluation of sonographic and radiological imaging (see [22] for an overview).

Enterocele

An enterocele is evident as a downward displacement of abdominal contents into the vagina, dorsal to the anechoic bladder and ventral to the (usually hyperechogenic) rectal ampulla and anal canal. Small bowel may show peristalsis, and intraperitoneal fluid may outline the apex of the enterocele. Contents tend to have an irregular isoechoic or ground-grass-like appearance (Fig. 10) and are not usually difficult to distinguish from stool in the ampulla or a rectocele due to peristalsis.

In a minority of women with posterior compartment descent, imaging will identify a rectal intussusception, a condition that is found in approximately 4% of patients in an urogynaecology clinic and strongly associated with symptoms of obstructed defaecation [19]. An intussusception is diagnosed when there is splaying of the (normally tubular) anal canal, with the anterior wall of the rectal ampulla (and sometimes the posterior wall as well) inverted into the anal canal (Fig. 11). A rectal intussusception is most commonly due to small bowel, but other abdominal contents such as sigmoid colon (as in Fig. 11), omentum, and even the uterus can descend to cause a so-called 'colpocele' (see Fig. 8). Rectal intussusception is more common in women with abnormal levator ani [23].

Visual biofeedback, i.e. showing the patient the effect of straining on anorectal anatomy, may help in modifying defaecatory behaviour, which often is a major factor in obstructed defaecation. The same is true for anismus, which may be evident as an inability to relax the levator ani, which can be diagnosed by observing a reduction in anteroposterior hiatal diameters on Valsalva. Comparative findings to date suggest that translabial US is a simple, cheap and well-tolerated alternative to radiological methods in the initial investigation of defaecation disorders and posterior compartment prolapse [24].

Postoperative findings

Anterior colporrhaphy/vaginal paravaginal repair

Anatomical results after traditional anterior repair and vaginal paravaginal repair are highly variable, and there are no distinct features on imaging. In the short term, small haematomata may be seen and they usually do not require any action. Suture material, detritus and patient discomfort will impair imaging conditions for the first few post-operative weeks. In the medium term, US sometimes

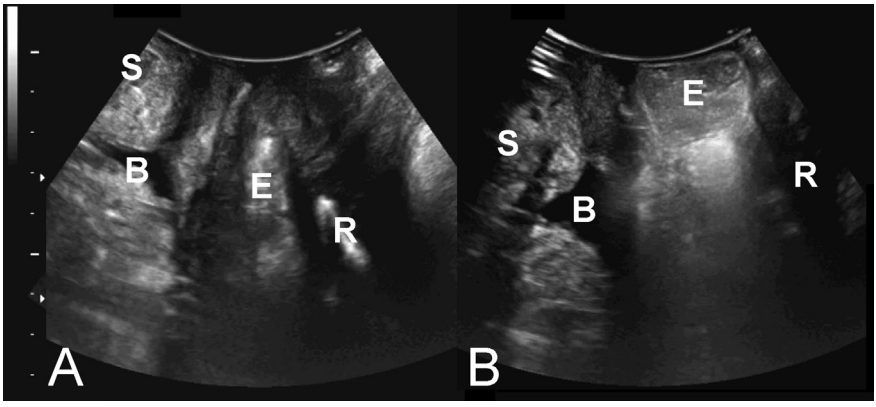

Fig. 10. Isolated enterocele (E) in a patient after hysterectomy. There is no significant descent of the rectal ampulla (R). (A) shows the midsagittal plane at rest, (B) the same on Valsalva. S, symphysis pubis; B, bladder; E, enterocele; R, rectum. From (Dietz HP (2010). The role of two- and three-dimensional dynamic ultrasonography in pelvic organ prolapse. J Min Invas Gynecol 17:282–294), with permission.

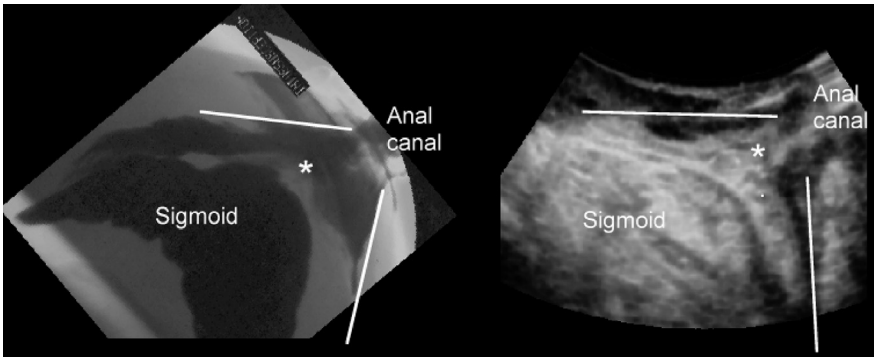

Fig. 11. A rectal intussusception due to a sigmoid enterocele as seen on defaecation proctogram (*left*) and translabial ultrasound (*right*). It is generally not possible to distinguish as to what part of the small or large bowel propels the intussuscipiens, although in this case the coarse appearances of the intussuscipiens are suggestive of large rather than small bowel. From (Perniola G, Dietz HP, Shek KL, Chew S, Cartmill J, Chong C. Defecation proctography and translabial ultrasound in the investigation of defecatory disorders. Ultrasound Obstet Gynecol 2008; 31: 567–571).

demonstrates no significant change after such surgery, even in patients currently asymptomatic for prolapse.

Mesh implants

Since 2005, there has been a worldwide trend towards implantation of permanent vaginal wall meshes, especially for recurrent prolapse. Unfortunately, patient selection was never optimised, and the adversarial medicolegal environment in the USA has by now resulted in the disappearance of the most effective prolapse meshes. Further development of mesh implants seems unlikely at present, which is unfortunate because several engineering issues remain unresolved. However, imaging specialists are increasingly asked to identify such meshes and comment on their function and complications, which presents distinct challenges.

Polypropylene meshes such as the Perigee™, Prolift™, Avaulta™ and Apogee™ are highly echogenic [25], and their visibility is limited only by persistent prolapse and transducer distance (Fig. 12). As hyperechogenic findings in the anterior vaginal wall can be artefactual, imaging in sectional planes is essential to demonstrate mesh in all three dimensions (Fig. 13). Position and mobility of vaginal wall mesh on Valsalva can be determined, as well as dislodgement of anchoring arms and prolapse recurrence. These meshes do not shrink in vivo, as sometimes claimed [26,27] Surgical technique certainly is important in determining mesh appearance and the likelihood of post-operative stress urinary incontinence [25]. Non-anchored mesh ('overlay techniques') has not been shown to be effective, and transobturator mesh strips seem to be more effective than plastic barbs in providing mid-vaginal support [28].

There are three distinct forms of cystocele recurrence after anterior compartment anchored mesh placement (Fig. 14a–c) [28], two of which are related to the state of the levator ani muscle. In recurrence, imaging may allow the mesh to be used as an asset rather than a liability that needs to be removed. An anterior recurrence requires fixation of the dislodged bladder neck to the inferior mesh margin, and an apical recurrence needs apical suspension. In all instances, recurrence is likely to be exacerbated by mesh removal.

While anterior compartment anchored mesh is effective in reducing recurrence, especially in women with major levator trauma (see below) [29], there is no evidence that posterior compartment mesh can reduce recurrence rates, and consequently, mesh has been used less frequently in this location. In such instances where the mesh has been implanted to treat rectocele or recto-enterocele, it will be found anterior to the anorectum, frequently extending to the perineal body (pB); in most instances, it is less mobile than mesh placed anteriorly. Again, several forms of recurrence have been described: there may be enterocele development anterior to a well-anchored mesh, or posterior to the

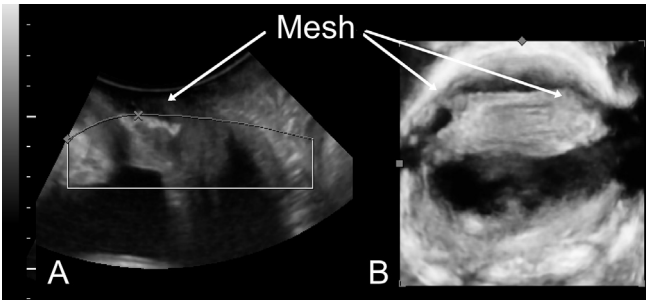

Fig. 12. Perigee anterior compartment mesh in the midsagittal plane (A) and in a rendered volume (B), the latter showing the entire central aspect of the mesh, and the two transobturator arms on the patient's right side. The left side arms are invisible due to asymmetry. From (Dietz HP (2007) Pelvic floor ultrasound. Australasian Society for Ultrasound in Medicine Bulletin 10:17–23), with permission.

mesh as intussusception, or a true rectocele that develops behind the mesh, into the perineum, as shown in Fig. 15 [30]. Unfortunately, imaging has little to offer in women suffering from mesh complications such as pain and erosion.

The levator hiatus and muscle

The main utility of 3D/4D translabial US imaging lies in the axial plane where it allows assessment of the levator ani muscle and its hiatus, the triangular opening between the symphysis pubis anteriorly and the puborectalis part of the levator ani laterally and posteriorly. The levator hiatus is the largest potential hernial portal in the human body, and all POPs including rectal intussusception and rectal prolapse are herniations through the hiatus [31]. Hence, its dimensions matter for pelvic organ support, as does the integrity of the muscle that defines the hiatus.

Major morphological abnormalities of levator structure and function are common in vaginally parous women [32]. Disconnection of the levator ani from its insertion on the inferior pubic ramus (avulsion) and, of less importance, detachment of the iliococcygeus muscle from the arcus tendineus of the levator ani over the obturator internus muscle are due to vaginal delivery; see Fig. 16 for a comparison of clinical findings, US and MRI in a patient with unilateral levator avulsion after normal vaginal delivery at term [33]. Avulsion is visible on 2D US on oblique parasagittal views [34], but tomographic imaging (Figs. 17–19) is likely to be more repeatable [35]. The standard methodology uses an inter-slice interval of 2.5 mm, with the central slice at the plane of minimal hiatal dimensions [36]. Usually, imaging of the muscle is undertaken during maximal pelvic floor muscle contraction, but while tissue

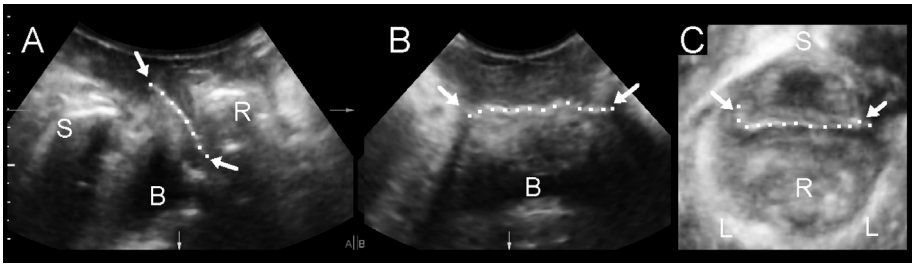

Fig. 13. Identification of anterior compartment mesh on Valsalva (A, midsagittal plane; B, coronal plane and C, axial plane). Arrows show mesh length in the midsagittal (left), the coronal (centre) and axial (right) planes. From (Dietz HP, Erdmann M, Shek KL. Mesh contraction: myth or reality? Am J Obstet Gynecol. 2011 Feb; 204 (2):173.e1-4), with permission.

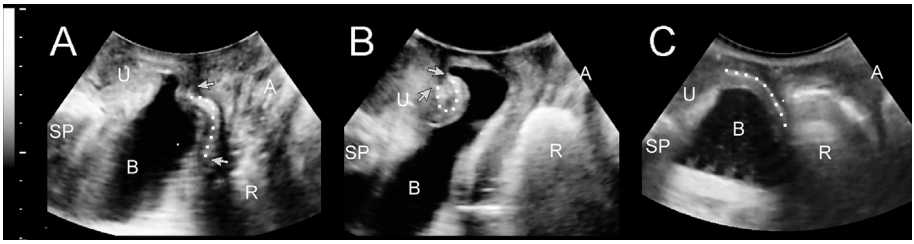

Fig. 14. Three different forms of cystocele recurrence after anterior compartment mesh, midsagittal plane. (A) shows an 'anterior recurrence' anterior to a well-suspended mesh, (B) an 'apical recurrence' with apical aspects of the mesh no longer anchored and (C) a 'global recurrence' with all aspects of the mesh highly mobile and no longer suspended. SP = symphysis pubis, B = bladder, U = urethra, R = rectal ampulla, A = anal canal. From (Dietz HP. Mesh in prolapse surgery: an imaging perspective. *Ultrasound Obstet Gynecol* 2012; 40: 495–503), with permission.

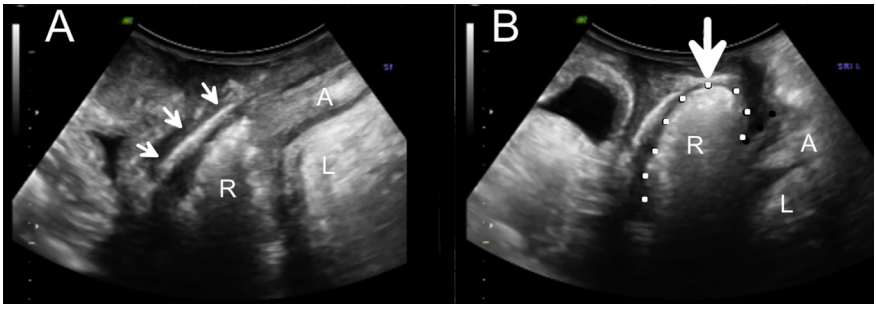

Fig. 15. Rectocele (large arrow) developing behind well-supported posterior compartment mesh (small arrows). The pocket is outlined by dots. A is at rest, B at maximal Valsalva. R = rectal ampulla, A = anal canal, L = levator ani.

discrimination is lower at rest, diagnostic performance does not seem to be greatly impaired [37,38] The diagnosis of avulsion with this method correlates well with MRI findings [39].

The location of slices 3–5 (the central row of slices) on the tomographic image is adjusted in the cranio-caudal direction until the symphysis pubis appears as in Figs. 17–19: open on the left central slice, closing in the central and closed in the right central slice. The more caudad the slice, the more

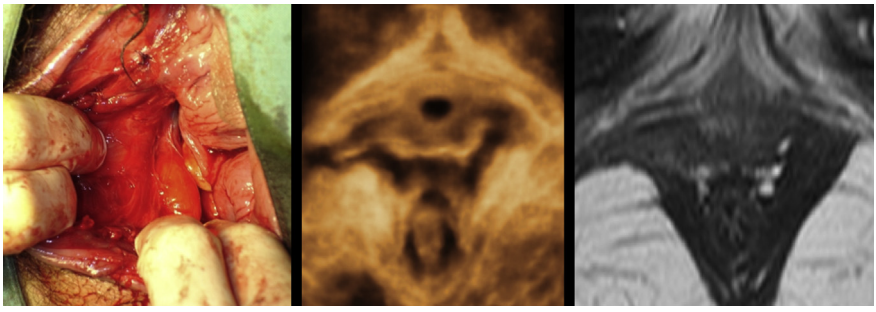

Fig. 16. Typical right-sided levator avulsion injury as diagnosed in the delivery suite after a normal vaginal delivery at term (left), on 3D ultrasound (centre) and on magnetic resonance imaging (right) 3 months postpartum. This patient was initially asymptomatic apart from deep dyspareunia but developed symptomatic prolapse 7 years after the event. From (Dietz HP, Gillespie A, Phadke P. Avulsion of the pubovisceral muscle associated with large vaginal tear after Normal Vaginal Delivery at term. A Case Report. ANZJOG 2007; 47: 341-44).

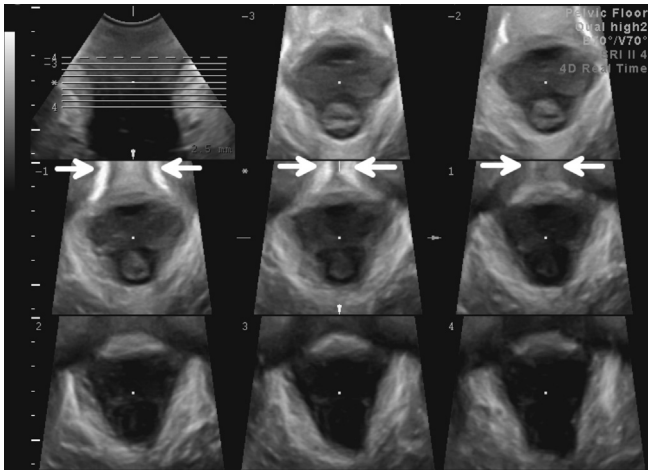

Fig. 17. Tomographic representation of the puborectalis muscle, obtained on pelvic floor muscle contraction, with 2.5 mm interslice interval. The central slice (*) represents the plane of minimal hiatal dimensions as identified in the midsagittal plane. The three middle slices are adjusted to show the symphysis pubis open (left), closing (centre) and closed, i.e. no longer visible, on the right (arrows).

open the appearance of the symphysis pubis, i.e. more distance between the most medial aspects of the hyperechogenic oblique linear structures identifying the inferior margin of the inferior pubic rami. This technique allows adjustment of the location of axial plane slices to approximately one-third of 1 mm, optimising repeatability. However, in order to achieve high repeatability it is crucial that the plane of minimal dimensions be identified accurately as any error in that regard will affect the appearance of the symphysis pubis relative to the muscle insertion, potentially resulting in false positive assessments.

A full avulsion is diagnosed if at least the three central slices show an abnormal insertion (Figs. 18 and 19) [36]. Trauma that falls short of those 'minimal criteria' does not seem to be associated with prolapse or prolapse recurrence [40]. If the operator is unsure of whether to rate an individual slice as abnormal or not, the 'levator' urethra gap or LUG (Fig. 19) can be measured to help with decision-making, especially if visual appearances are equivocal. In Caucasians 25 mm seems to be the most approriate cut- off for defining an abnormal LUG [41,42].

There are bound to be other factors, including microtrauma or altered biomechanics of otherwise intact muscle, that are pathophysiological pathways for the development of prolapse, but major levator

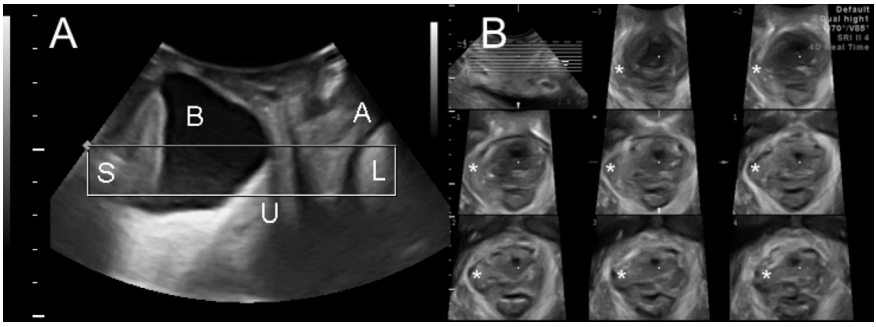

Fig. 18. Patient with large cystocele evident in the midsagittal plane (A) and complete right-sided avulsion (*) on tomographic imaging (B). The tomographic imaging was obtained on pelvic floor muscle contraction.

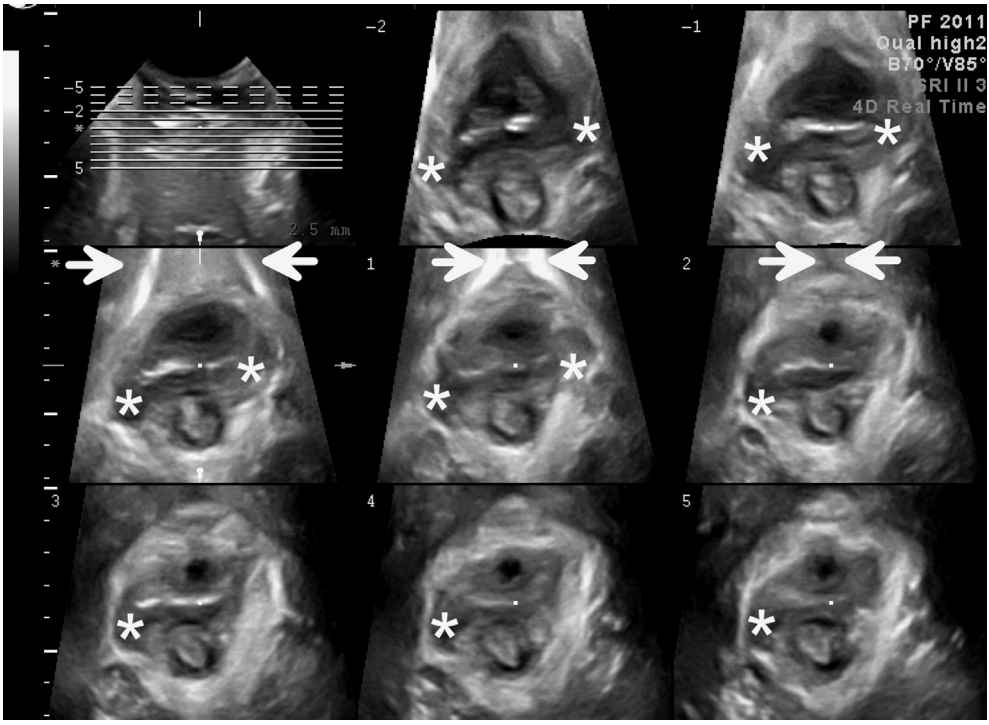

Fig. 19. Complete right-sided and partial left-sided avulsion on tomographic imaging in a patient with major three-compartment prolapse. Arrows show the required appearance of the pubic rami.

trauma ('avulsion') is bound to be a large part of the 'missing link' between vaginal childbirth and prolapse, which is clearly evident in epidemiological studies (see [43] for an overview). Avulsion enlarges the hiatus [44], results in anterior and central compartment prolapse [32,45–47] and reduces pelvic floor muscle function by approximately one-third [46,48] Urinary and anal incontinence seem to be much less affected [49,50]. Levator defects may well be the strongest independent risk factors for prolapse recurrence, especially in the anterior compartment [51]. Avulsion defects are palpable, but palpation requires significant teaching and is clearly less repeatable than identification by US [52–54] The primary risk factor for avulsion is forceps (see [55] for an overview), with vacuum being only slightly riskier than normal vaginal birth. Other risk factors variously include the length of the second stage, birth-weight, maternal age, head circumference and perineal/vaginal tears [56–61]. Levator trauma occurs almost exclusively with the first vaginal birth [62–64], and substantial healing seems unlikely [65].

While the levator ani muscle remains virtually unchanged in at least half of all women giving birth vaginally, the levator hiatus may be over-distended in vaginal childbirth, even if there is no major degree of macroscopic trauma. In addition, there is a substantial degree of congenital variation in hiatal dimensions [66], which is a major issue given that the levator hiatus is the largest potential hernial portal in the human body. Fig. 20 illustrates the identification of the plane of minimal hiatal dimensions. After locating the minimal distance between the dorsal aspect of the symphysis pubis and the ventral aspect of the anorectal angle, this location is identified in the axial plane. As the true hiatal plane is non-euclidean, i.e. warped [67], it may be more appropriate to use a rendered volume, i.e. a 1–2 cm thick slice, to measure the dimensions of the levator hiatus (Fig. 20) [68].

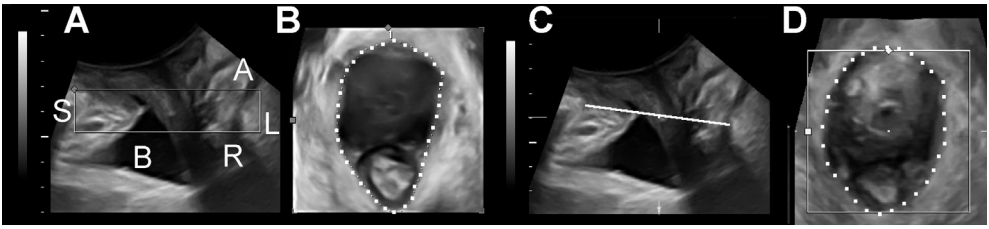

Fig. 20. Measuring hiatal dimensions as shown in a rendered volume (A and B) and in an oblique single axial plane (C,D). The region of interest (ROI) box in (A) (approx. 1.8 cm deep) is located between the symphysis pubis and the levator ani posterior to the anorectal angle. Image (B) represents a semi-transparent view of all pixels in the ROI box on the left. From (Dietz HP, Wong V, Shek KL. A Simplified method for the determination of levator hiatal dimensions. Aust NZ J Obstet Gynecol 2011; 51: 540–543).

Measures of hiatal dimensions obtained in this way are highly repeatable [20,69,70] and correlate well with findings on MRI [71]. Hiatal enlargement to over 25 cm^2 on Valsalva is defined as 'ballooning' on the basis of receiver operating characteristic statistics and normative data in young nulliparous women [31,66] Hiatal dimensions are strongly associated with the distance between urethra and anus (genital hiatus, gH, and pB), a clinical measurement that is obtained as part of the POP-Q examination for POP [72]. Hiatal dimensions are associated with prolapse and symptoms of prolapse [31] including rectal intussusception [23] and prolapse recurrence [51].

Hiatal dimensions and the state of the puborectalis muscle insertion on the inferior pubic ramus are very likely to be the major factors in the pathophysiology of prolapse and should be assessed as part of the primary investigation of prolapse, especially if surgical treatment is envisaged. A combination of both can serve to estimate the likelihood of recurrence and the potential utility of anchored mesh implants [29]. Unfortunately, the medicolegal implications of mesh use have greatly reduced options with regard to this in many jurisdictions. In women with a high risk of recurrence due to avulsion or ballooning, surgical reconstruction of the puborectalis [73] or a hiatal reduction procedure may be attempted [74]. Both approaches are currently being tested in surgical trials.

Summary

The increasingly widespread use of imaging in the investigation of female POP has the potential to change management of this condition very substantially. This is particularly true for the assessment of posterior compartment prolapse and for the identification of levator trauma and hiatal ballooning. Even in units where imaging is not easily accessible, the insights provided by sonographic imaging or MRI will enhance diagnostic and therapeutic capabilities. Imaging studies published over the last 10 years suggest that a clinical examination should include vaginal palpation of the levator ani muscle for structural integrity and measurement of Gh and Pb on Valsalva for distensibility. In addition, women with symptoms of obstructed defaecation and posterior compartment prolapse, in the absence of imaging, should be examined per rectum, including during a Valsalva manoeuvre, to allow diagnosis of a true rectocele and intussusception by palpation.

With regard to treatment, the realisation that prolapse is a hernia through the hiatus of the levator plate is likely to trigger a paradigm shift in therapeutic approaches. Because this hernial portal cannot be obliterated as, for example, in the case of an umbilical hernia, area reduction is the obvious alternative. This is a bioengineering issue that should pose surmountable challenges. Once we learn how to reduce the dimensions of this hernial portal without negatively interfering with the multiple bodily functions dependent on a functional levator hiatus, we may find that a whole range of difficult clinical situations may become much easier to treat and cure.

For further information, see my web site, http://sydney.edu.au/medicine/people/academics/profiles/hans.dietz.php.

Practice points

Imaging is an important adjunct to clinical examination in women with pelvic organ prolapse (POP).
Prolapse assessment can be performed with 2D systems, but 3D/4D capabilities are essential for the assessment of the levator ani muscle.
For quantitation of prolapse, the reference line is placed through the inferoposterior margin of the symphysis pubis and is horizontal to the transducer, which must not be angled during the manoeuvre.
Optimise the quality of a Valsalva manoeuvre: try to control for confounders (bladder and bowel emptying and levator co-activation) and ensure sufficient duration of $\geq$6 s.
It is important to allow full descent of organs by avoiding undue pressure on tissues during Valsalva: let the prolapse descend!
Assessment of levator ani for function and morphological integrity should be performed by 3D/4D axial plane imaging, using abdominal 3D transducers with an aperture of at least 70° and an acquisition angle of 85°.
Any volumes acquired for prolapse imaging and levator assessment must include the symphysis pubis.
Avulsion of the puborectalis muscle is best diagnosed on tomographic axial plane imaging with an interslice interval of 2.5 mm. The central tomographic slice should show closure of the symphysis pubis.
Hiatal ballooning on Valsalva can be determined in the axial plane, either in single planes at the plane of minimal hiatal dimensions or in a rendered volume of 1–2 cm thickness containing this plane.

Research agenda

The distinction between congenital and acquired forms of prolapse
Ethnic variations in pelvic organ support
Ethnic variations in levator functional anatomy
Ethnic variations in birth trauma
Prevention/minimisation of birth trauma
Obstructed defaecation and posterior compartment prolapse: pathophysiology and treatment.
How to mitigate the effect of levator trauma on prolapse recurrence: compensatory measures for birth trauma
Surgical levator reconstruction and hiatal reduction
Patient selection for high-risk intervention: sacrocolpopexy and vaginal mesh use.
Optimisation of mesh engineering and biomechanics.

Conflicts of interest

None.

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