Pelvic floor ultrasound: a review

Hans Peter Dietz, MD, PhD

It has taken more than 2 decades for imaging to develop as a mainstream diagnostic tool in the investigation of female pelvic organ prolapse, urinary and fecal incontinence, and defecation disorders. Physicians have been slow in realizing that clinical assessment alone is a poor tool to assess pelvic floor function and anatomy. Our examination skills are quite simply inadequate, focusing on surface anatomy rather than true structural abnormalities. Because the best procedure in the hands of a highly competent surgeon will be a failure if performed on the wrong patient, it is not at all surprising that recurrence after pelvic reconstructive surgery is common. The problem is not poor treatment—it is poor diagnostics. Sonography is an accepted component of any clinical assessment in both obstetrics and in gynecology—so why should it be any different in urogynecology at present due to cost and access limitations and due to the fact that it is generally a static, not a dynamic, method. However, none of those limitations apply to sonography, a diagnostic method that is very much part of general practice in obstetrics and gynecology. Translabial or transperineal ultrasound is helpful in determining residual urine; detrusor wall thickness; bladder neck mobility; urethral integrity; anterior, central, and posterior compartment prolapse; and levator anatomy and function. It is at least equivalent to other imaging methods in visualizing such diverse conditions as urethral diverticula, rectal intussusception, mesh dislodgment, and avulsion of the puborectalis muscle. Ultrasound is the only imaging method able to visualize modern mesh slings and implants and may predict who actually needs such implants. Delivery-related levator trauma is the most important known etiologic factor for pelvic organ prolapse and not difficult to diagnose on 3-/4-dimensional and even on 2-dimensional pelvic floor ultrasound. It is likely that this will be an important driver behind the universal use of this technology. This review gives an overview of the method and its main current uses in clinical assessment and research.

Key words: female pelvic organ prolapse, levator ani, pelvic floor, 3-dimensional ultrasound, translabial ultrasound

Imaging currently plays a limited role in the investigation of pelvic floor disorders. It is obvious that magnetic resonance imaging has limitations in urogynecology and female urology. Imaging to develop as a mainstream diagnostic tool in the investigation of female pelvic organ prolapse, urinary and fecal incontinence, and defecation disorders. Physicians have been slow in realizing that clinical assessment alone is a poor tool to assess pelvic floor function and anatomy. Our examination skills are quite simply inadequate, focusing on surface anatomy rather than true structural abnormalities. Because the best procedure in the hands of a highly competent surgeon will be a failure if performed on the wrong patient, it is not at all surprising that recurrence after pelvic reconstructive surgery is common. The problem is not poor treatment—it is poor diagnostics. Sonography is an accepted component of any clinical assessment in both obstetrics and in gynecology—so why should it be any different in urogynecology at present due to cost and access limitations and due to the fact that it is generally a static, not a dynamic, method. However, none of those limitations apply to sonography, a diagnostic method that is very much part of general practice in obstetrics and gynecology. Translabial or transperineal ultrasound is helpful in determining residual urine; detrusor wall thickness; bladder neck mobility; urethral integrity; anterior, central, and posterior compartment prolapse; and levator anatomy and function. It is at least equivalent to other imaging methods in visualizing such diverse conditions as urethral diverticula, rectal intussusception, mesh dislodgment, and avulsion of the puborectalis muscle. Ultrasound is the only imaging method able to visualize modern mesh slings and implants and may predict who actually needs such implants. Delivery-related levator trauma is the most important known etiologic factor for pelvic organ prolapse and not difficult to diagnose on 3-/4-dimensional and even on 2-dimensional pelvic floor ultrasound. It is likely that this will be an important driver behind the universal use of this technology. This review gives an overview of the method and its main current uses in clinical assessment and research.

Key words: female pelvic organ prolapse, levator ani, pelvic floor, 3-dimensional ultrasound, translabial ultrasound

Equipment and examination technique

This review will be limited to translabial/transperineal ultrasound, and this is reflected in the following comments on equipment and examination technique. However, many clinical questions can be answered just as well by what some investigators call “introital ultrasound,” a technique that is generally understood to involve the use of front-firing vaginal endoprobes placed in the introitus. Although such probes can provide higher resolutions, there are obvious downsides to their use, especially when it comes to assessing the effect of maneuvers and imaging of the levator ani, and this technique will not be discussed further in this review.

Standard requirements for basic 2-dimensional (2D) translabial pelvic floor ultrasound include a B-mode capable 2D ultrasound system with cineloop func-

| TABLE
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<th>Indications for pelvic floor ultrasound</th>
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<td>Recurrent urinary tract infections</td>
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<td>Urgency, frequency, nocturia, and/or urge urinary incontinence</td>
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<td>Symptoms of prolapse, ie, sensation of lump or dragging sensation</td>
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<td>Symptoms of obstructed defecation, eg, straining at stool, chronic constipation, vaginal or perineal digitation, and sensation of incomplete bowel emptying</td>
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<td>Fecal incontinence</td>
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tion, a 3.5- to 6-MHz curved array transducer and a monochrome videoprinter. In essence, any setup used for imaging of the fetus (or a child’s or adult’s kidney) will be appropriate. We obtain a midsagittal view by placing a transducer (usually a curved array with frequencies between 3.5-6 MHz) on the perineum (Figure 1, A) after covering the transducer with a nonpowdered glove, condom, or thin plastic wrap. Powdered gloves should be avoided as they can substantially impair imaging quality due to reverberations. Alcohol wipes are usually considered sufficient for transducer cleaning after removal of gel and debris.

Imaging is performed in dorsal lithotomy position, with the hips flexed and slightly abducted, or in the standing position. Requiring the patient to place her heels close to the buttocks will often result in an improved pelvic tilt. Bladder filling should be specified; usually prior voiding is preferable. The presence of a full rectum may impair diagnostic accuracy and sometimes necessitates a repeat assessment after bowel emptying—especially if there is a degree of fecal impaction. Parting of the labia can improve image quality. The latter will also depend on the hydration state of tissues, which generally is best in pregnancy and poorest in elderly women with marked atrophy. Vaginal scar tissue can also reduce visibility, especially in the posterior compartment, but obesity virtually never seems to be a problem.

The transducer can be placed firmly against the symphysis pubis without causing significant discomfort, unless there is marked atrophy. A cough will part the labia, expel air bubbles and detritus, and ensure good contact between the transducer and tissues. It is essential to not exert undue pressure on the perineum so as to allow full development of pelvic organ descent. The standard midsagittal view includes the symphysis anteriorly, the urethra and bladder neck, the vagina, cervix, rectum, and anal canal (Figure 1, B). Posterior to the anorectal junction a hyperechogenic area indicates the central portion of the levator plate. The cul-de-sac may also be seen, filled with a small amount of fluid, echogenic fat, or bowel. Parasagittal or transverse views often yield additional information, eg, confirming urethral integrity, enabling assessment of the puborectalis muscle, and for imaging of mesh implants.

There is no agreement on image orientation, and the published literature contains at least 3 different options. The first published translabial images were either obtained with the perineum at the top and the symphysis pubis on the left or the same rotated by 180 degrees. Other authors have used mirrored versions of the same. The author of this review

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**FIGURE 1**

Transducer placement for translabial/perineal ultrasound

A, Transducer placement on perineum and B, schematic representation of imaging in midsagittal plane.

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**FIGURE 2**

Standard acquisition screen of 3-dimensional pelvic floor ultrasound

A, Midsagittal, B, coronal, and C, axial planes and D, rendered axial plane (ie, semitransparent representation of all pixels in box [region of interest] seen in A-C).

A, anal canal; P, puborectalis muscle; R, rectal ampulla, S, symphysis pubis; U, urethra; V, vagina.

prefers the original orientation as on conventional transvaginal ultrasound (craniocaudal aspects to the left, dorso-caudal to the right). This orientation is very convenient when using 3-dimensional (3D)/4-dimensional (4D) systems as shown in Figure 2, a representation of a 3D volume of the pelvic floor. The top left represents the midsagittal plane, with the bottom left an axial-plane slice, and the bottom right representing a rendered volume showing the levator hiatus.

In the following paragraphs, I’ll describe the main clinical applications of transabdominal ultrasound in urogynecologic imaging.

**Anterior compartment**

As clinicians, we say “cystocele” when we really mean “anterior vaginal wall descent.” Of course, anterior vaginal wall descent usually implies descent of the bladder, ie, a “cystocele,” but behind this term there may hide a number of different conditions. Ultrasound can be very helpful in determining whether it is really the bladder that is descending and in ascertaining the configuration of urethra and bladder neck. The original indication for pelvic floor ultrasound, however, is the assessment of bladder neck mobility and funneling of the internal urethral meatus, both of which are important in women with urinary incontinence. Figure 3 shows the standard orientation used to describe bladder neck mobility. The position of the bladder neck is determined relative to the infero-posterior margin of the symphysis pubis or relative to a system of coordinates based on the central axis of the symphysis pubis. Measurements are taken at rest and on maximal Valsalva, and the difference yields a numerical value for bladder neck descent. Comparative studies have shown good correlations with radiological methods. The reproducibility of measurements of bladder neck mobility are high.

On Valsalva, the proximal urethra will be seen to rotate in a postero-inferior direction to a greater or lesser degree, due to the fact that the urethra and anterior vaginal wall are tethered to the symphysis pubis and the pelvic sidewall. Incidentally, this rotation markedly changes the echogenicity of the longitudinal smooth muscle of the urethra, which becomes isoechoic and less easy to identify, as evident in Figure 3. Proximal urethral rotation can be measured by comparing the angle of inclination between the proximal urethra and any other fixed axis. Some investigators measure the retrovesical angle (or posterior urethrovesical angle) between proximal urethra and trigone, others determine the angle γ between the central axis of the symphysis pubis and a line from the inferior symphyseal margin to the bladder neck.

There is no definition of normal for bladder neck descent although cutoffs of 20, 25, and 30 mm have been proposed to define hypermobility. Bladder filling, patient position, and catheterization all have been shown to influence measurements and it can occasionally be quite difficult to obtain an effective Valsalva maneuver, especially in nulliparous women who frequently coactivate the levator muscle. Perhaps not surprisingly, publications to date have presented widely differing reference measurements in nulliparous women. I have obtained measurements of 1.2–40.2 mm (mean, 17.3 mm) in a group of 106 stress-continent nulligravid young women of 18–23 years of age. It is likely that methodologic differences account for the above discrepancies, with all known confounders tending to reduce descent.

The etiology of increased bladder neck descent is likely to be multifactorial. The wide range of values obtained in young nulliparous women suggests a congenital component. Vaginal childbirth is probably the most significant environmental factor, with a long second stage of labor and vaginal operative delivery associated with increased postpartum descent. This association between increased bladder descent and vaginal parity is also evident in older women with symptoms of pelvic floor dysfunction.

In patients with stress incontinence, but also in asymptomatic women, funneling of the internal urethral meatus may be observed on Valsalva and sometimes even at rest. Funneling is often (but not necessarily) associated with leakage. Marked funneling has been shown to be associated
with poor urethral closure pressures.\textsuperscript{29,30}
Other indirect signs of urine leakage on B-mode real-time imaging are weak gray-scale echoes (streaming) and the appearance of 2 linear (specular) echoes defining the lumen of a fluid-filled urethra. Color Doppler ultrasound can directly demonstrate urine leakage on Valsalva maneuver or coughing,\textsuperscript{31} if this is desired. Agreement between color Doppler and fluoroscopy was high in a controlled group with indwelling catheters and identical bladder volumes.\textsuperscript{32} Color Doppler imaging may also facilitate the documentation of leak point pressures.\textsuperscript{33}

Clinical examination is limited to grading anterior compartment prolapse, which we call “cystocele.” In fact, imaging will identify a number of anatomic situations that are difficult, if not impossible, to distinguish clinically. There are at least 2 types of cystoceles with very different functional implications (Figure 4), which were first described in this Journal in the 1970s.\textsuperscript{34} A cystourethrocele is associated with above-average flow rates and urodynamic stress incontinence whereas a cystocele with intact retrovesical angle is generally associated with voiding dysfunction and a low likelihood of stress incontinence.\textsuperscript{35}

Occasionally, a cystocele will turn out to be due to a urethral diverticulum (Figure 5, for a 3D representation of an unusual anterior urethral diverticulum), a Gartner duct cyst, or an anterior enterocele.\textsuperscript{36,37} Urethral diverticula are often overlooked for years in women with recurrent bladder infections and symptoms of frequency, urgency, and pain or burning on voiding, until imaging is undertaken.\textsuperscript{38–40} Urethral structure and spatial relationships are much better ap-
preciated in the axial plane (Figure 5), which is particularly useful in the differential diagnosis of Gartner cyst and urethral diverticulum.

Finally, translabial ultrasound may detect foreign bodies or bladder tumors and can be used to determine residual urine, using a formula originally developed for transvaginal ultrasound. Although detrusor wall thickness has probably been overrated as a diagnostic tool in the context of detrusor overactivity, increased detrusor wall thickness seems associated with symptoms of the overactive bladder, and may be a predictor of postoperative de novo urge incontinence and/or detrusor overactivity after anti-incontinence procedures. As opposed to the situation in men, detrusor wall thickness in women is not predictive of voiding dysfunction.

Central compartment
Generally, uterine prolapse is obvious clinically, as is vault descent. Having said that, ultrasound can graphically show the effect of an anteriorized cervix in women with an enlarged, retroverted uterus, explaining symptoms of voiding dysfunction and supporting surgical intervention to improve voiding in someone with a retroverted fibroid uterus. On the other hand, mild descent of an acutely antverted uterus can result in compression of the anorectum, explaining symptoms of obstructed defecation—a situation that is described as a “colpocele” on defecation proctography. The uterus can be difficult to identify due to its isoechoic nature, sim-

Distinction among true rectocele, ie, defect of rectovaginal septum (left); perineal hypermobility, ie, descent of rectal ampulla without fascial defect (middle); and rectal intussusception (right). All 3 conditions can manifest as clinical rectocele and are impossible to distinguish on examination.

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ilar in echotexture to the vaginal wall, especially in postmenopausal women with small, atrophic uteri. In premenopausal women the uterus is often quite obvious, especially if anteverted. Sometimes Nabo- 
thian follicles help identify the cervix.

Posterior compartment

Pelvic floor ultrasound is particularly useful in the posterior compartment, although we have in no way realized its potential benefits for clinical practice. We see descent of the posterior vaginal wall and diagnose a rectocele, usually quite unaware that at least 5 different anatomically distinct conditions can cause this appearance. A stage II rectocele could be due to a true rectocele, ie, a defect of the rectovaginal septum (most common, and associated with symptoms of prolapse, incomplete bowel emptying, and straining at stool), an abnormally distensible, intact rectovaginal septum (common and associated only with prolapse symptoms); perineal hypermobility, ie abnormal candad dis- placement of the levator plate; a combined recto-enterecele (common); and an isolated enterecele (uncommon); or just a deficient perineum giving the impression of a bulge. Occasionally a rectocele turns out to be a rectal intus- susception, an early stage of rectal prolapse, where the wall of the rectal ampulla is inverted and enters the anal canal on Valsalva; see Figure 6 for a comparison of 3 of those conditions. Figure 7 shows a simple true rectocele in the 3 orthogonal planes and in a ren- dered volume. Images in the coronal and axial plane demonstrate that this rectocele, as most others, is symmetri- cal, suggesting a high transverse defect of the rectovaginal septum.

It is not surprising that colorectal sur- geons have started using this technique in the initial investigation of women with defecatory disorders, although they tend to use ultrasound gel as a contrast medium. Several studies have recently shown that ultrasound is much better tolerated than defecation proctogra- phy, and of course it is much cheaper. If there is a rectocele or a rectal intussusception/prolapse on ultrasound, this condition is very likely to be found on x-ray imaging. Consequently, it is likely that ultrasound will replace radiologic techniques in the initial investigation of women with defecatory symptoms.

Although it is not always clear what kind of therapeutic consequences one should draw from imaging findings, one would not expect a rectocele repair to al- leviate symptoms caused by rectal intus- suspension. If there is a defect of the rec- tovaginal septum then the patient is an obvious candidate for a defect-specific rectocele repair as first popularized by Cullen Richardson. If a clinical recto- 
cele is due to a hyperdistensible fascia or levator hiatus (perineal hypermobility) then one should not be too surprised if on surgical dissection one does not find any defect to close—which is what has prevented the universal acceptance of defect-specific rectocele repair. Such pa- tients probably respond best to fascial plication or even a levatorplasty. Need- less to say, it makes no sense whatsoever to remove rectal wall in someone who has a herniation of that rectal wall through a defect in the rectovaginal sep- tum as with transanal methods such as the stapled transanal rectal resection procedure.

Assessment of the anal sphincter will not be discussed in any detail here. The anal sphincter is generally imaged by endoanal ultrasound. This method is firmly established as one of the corner- stones of a colorectal diagnostic workup for anal incontinence and is beyond the scope of this review. Due to the limited availability of such probes in gynecology, obstetricians and gynecologists have used high-frequency curved array or en-

![FIGURE 8](image-url) Suburethral slings as seen on translabial ultrasound

A and C, In midsagittal plane 2 slings, 1 a transretzius (A), the other transobturator sling (C), are essentially indistinguishable. Both are hyperechogenic and located dorsal to midurethra. B and D, In axial plane, distinction is quite obvious: B, a tension-free vaginal tape (TVT) is curving ventrally toward symphysis pubis, whereas D, a Monarc tracks laterally toward insertion of puborectalis muscle and obturator foramen.

dovaginal probes placed exoanally, ie, transperineally, in the coronal rather than the midsagittal plane. There are advantages to this approach—not just from the point of view of the patient. Exoanal imaging reduces distortion of the anal canal and allows dynamic evaluation of the anal sphincter and mucosa at rest and on sphincter contraction, which seems to enhance the definition of muscular defects. However, resolutions are quite likely to be inferior to those obtained by endoanal ultrasound, and good comparative studies are lacking at present.

Implants
Since the late 1990s, synthetic suburethral slings have become very popular. Ultrasound can confirm the presence of such a sling, distinguish between transobturator and trans-Retzius implants, especially when examining the axial plane (Figure 8), and even allow an educated guess regarding the type of implant. As these meshes are highly echogenic, ultrasound is superior to magnetic resonance (MR) in identifying implants and has helped elucidate their mode of action. It is also very helpful when assessing women with complications of suburethral slings such as voiding dysfunction and de novo symptoms of urgency, helping the surgeon to decide whether to cut a sling. Sling division usually results in a 5- to 10-mm gap between mesh arms (Figure 9).

There is a worldwide trend toward the use of permanent vaginal wall meshes, especially for recurrent prolapse, and complications such as support failure, mesh erosion, and chronic pain are not that uncommon. Polypropylene meshes such as the Perigee (American Medical Systems, Minnetonka, MI), Prolift (Ethicon Gynecare, Somerville, NJ), and Apogee (American Medical Systems, Minnetonka, MI) are highly echogenic (Figure 10), and their visibility is limited only by persistent prolapse and distance from the transducer. Three-dimensional translabial ultrasound has demonstrated that the implanted mesh often is nowhere near as wide as it is supposed to be, and this finding has been interpreted as evidence of mesh
shrinkage, contraction, or retraction.\textsuperscript{68} In the view of the author, the phenomenon of mesh retraction remains unproven to date. A more likely explanation is that the mesh did not remain flat but folded up on itself, either during the implantation or immediately after closure. Surgical technique seems to play a role here as fixation of mesh to underlying tissues results in a flatter, more even appearance. The position, extent, and mobility of vaginal wall mesh can be determined, helping with the assessment of individual technique, and ultrasound may uncover complications such as dislodgment of anchoring arms.\textsuperscript{69}

Clearly, translabial 4D ultrasound will be useful in determining functional outcome and location of implants, and will help in optimizing both implant design and surgical technique. Finally, although this is not much more than an afterthought in this age of minimally invasive slings, most of the injectables used in anti-incontinence surgery are also highly echogenic and can be visualized as a hyperechoic donut shape surrounding the urethra.\textsuperscript{20} Sometimes the material turns out in unexpected locations, such as underneath the bladder neck, protruding into the bladder itself, in the space of Retzius, or even tracking toward the obturator foramen.

**The axial plane**

Access to the axial plane, previously the domain of cross-sectional imaging, has markedly increased the usefulness of ultrasound in the assessment of pelvic floor disorders. Although side-firing vaginal transducers can image the axial plane on 2D, such instruments were never very common and have major disadvantages. In the mid-1990s, such systems were used in clinical research,\textsuperscript{70,71} but the most significant abnormality visible in the axial plane, levator avulsion, was overlooked. In consequence, results of such studies were published only 10 years later,\textsuperscript{72} well after the “rediscovery” of levator trauma by translabial 3D imaging.

Clearly, the translabial use of abdominal 4D probes has major advantages over endosonography, even if resolutions are potentially lower. A single volume obtained at rest with an acquisition angle of 70° or higher will include the entire levator hiatus with symphysis pubis, urethra, paravaginal tissues, the vagina, anorectum, and puborectalis muscle, from the pelvic sidewall in the area of the arcus tendineus of the levator ani to

**FIGURE 11**

**Rendered volume (axial plane) of typical unilateral avulsion**

Prior insertion of muscle (long arrow), now completely devoid of any hyperechogenic tissue, and retracted puborectalis muscle (short arrow).

P, puborectalis muscle; R, rectum; S, symphysis pubis; V, vagina.


**FIGURE 12**

**Right-sided avulsion of the puborectalis muscle**

Delivery-related levator trauma as seen on exploration of large vaginal tear after vaginal delivery (left), as imaged on translabial 4-dimensional ultrasound (middle), and on magnetic resonance (MR) (right).

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the posterior aspect of the anorectal junction. A Valsalva maneuver, however, may result in lateral or posterior parts of the puborectalis being displaced outside the field of vision, especially in women with significant prolapse. For this reason higher acquisition angles of 80° or 85° are preferable in pelvic floor imaging. Further technical details on volume data acquisition are available in a recent review article.73

Display modes
Figure 2 demonstrates the 2 basic display modes on 3D pelvic floor ultrasound. The orthogonal display mode shows cross-sectional planes through the volume in question, each plane at right angles to the 2 others. For pelvic floor imaging, this means the midsagittal, the coronal, and the axial plane. Contrary to the situation on MR, imaging planes on 3D ultrasound can be varied in arbitrary fashion to enhance the visibility of a given anatomical structure, either in real time during the examination or offline at a later time. The levator ani, for example, usually requires an axial plane that is slightly tilted in a dorsocaudal to ventrocaudal direction, and the required tilt may change substantially with maneuvers. This is what makes it so difficult to obtain predictable axial planes on dynamic MR imaging (MRI), with a consequent reduction in accuracy.74

The 3 orthogonal images are complemented by a rendered image, ie, a semi-transparent representation of all voxels in an arbitrarily definable region of interest. Figure 2 shows a standard rendered image of the levator hiatus, with the rendering direction set from caudally to cranially. The result is an image that corresponds to observing the patient’s pelvic floor from below, that is, from the
perspective of the examining clinician. In some instances, rendering greatly enhances the visibility of a given structure and helps patients and caregivers understand anatomic relationships much better (see Figure 7 for an orthogonal and rendered representation of a rectocele).

4D imaging

Four-dimensional, as opposed to 3D, imaging implies the real-time acquisition of volume ultrasound data, that is, a succession of volumes over time, not just a single volume. Typically, modern systems acquire anywhere between 0.5-20 volumes per second, depending on acquisition angle and quality settings. For pelvic floor imaging, that is, with acquisition angles of 70-85°, 4 volumes per second can usually be achieved without compromising quality. The resulting cineloops of volume data are particularly useful for the evaluation of functional anatomy, that is, for observing morphologic changes during maneuvers such as a pelvic floor contraction or a Valsalva. Even on 2D single-plane imaging, a static assessment at rest gives little information compared with the evaluation of maneuvers to assess levator function and delineate levator or fascial trauma.

The ability to perform a real-time 3D (or 4D) assessment of pelvic floor structures makes pelvic floor ultrasound superior to MRI for this application. Prolapse assessment by MR requires ultrafast acquisition, which is of limited availability and does not allow optimal resolutions. Alternatively, some systems allow imaging of the sitting or erect patient, but again accessibility will be limited for the foreseeable future. The sheer physical characteristics of MR equipment make it much harder for the operator to ensure efficient maneuvers as >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, it is impossible to control for these confounders. Therefore, ultrasound has major potential advantages when it comes to describing prolapse, especially when associated with fascial or muscular defects, and in terms of defining functional anatomy. In addition, the offline analysis packages marketed by manufacturers of such equipment allow distance, area, and volume measurements in any user-defined plane (oblique or orthogonal), which is much superior to what is currently possible with DICOM (Digital Imaging and Communications in Medicine) viewer software on a standard set of single-plane MRI.
Clinical applications

Axial-plane imaging is particularly suited to the assessment of the levator ani muscle, extending to paraurethral tissues in patients with diverticula or strictures. Translabial ultrasound has vindicated 60-year-old clinical data showing that morphologic abnormalities of levator structure and function are common in vaginally parous women. Although MR images showing morphologic abnormalities of the levator ani were usually considered to be the result of pudendal nerve trauma, this interpretation became untenable on considering findings on rendered volumes. Clearly, appearances (as in Figure 11) suggest trauma rather than atrophy, with the muscle completely removed from the pelvic sidewall.

It can now be regarded as proven that such morphologic abnormalities are usually due to traumatic avulsion of the muscle at the time of vaginal delivery (see Figure 12 for a comparison of MR, ultrasound, and clinical findings in patients with unilateral levator avulsion). Such trauma can be documented on 2D ultrasound—either with a side-firing endocavitary probe or with a parasagittal probe orientation. However, the most convenient and reproducible approach is by using an abdominal 3D/4D probe—the technology that is used to image the face of a fetus in utero. Just as in that situation, a rendered volume, with the rendering direction set from distally to proximally, results in very graphic, impressive images, but for the reproducible diagnosis of levator trauma multislice or tomographic imaging (Figure 13) is preferred.

Major delivery-related levator trauma, affecting the inferomedial aspects of the puborectalis muscle, seems to be part of the missing link between vaginal childbirth and prolapse. Although there are bound to be other factors, including microtrauma or altered biomechanics of otherwise intact muscle, and fascial trauma, levator avulsion enlarges the hiatus and results in anterior and central compartment prolapse. The larger the defect, the higher is the likelihood of prolapse, as quantified on multislice or tomographic ultrasound (Figure 13). Levator defects seem to be associated with cystocele recurrence after anterior repair, hysterectomy and antiincontinence and prolapse surgery substantially increase the likelihood of anterior and central compartment prolapse, and are associated with reduced contractile strength. These defects are palpable, but palpation requires significant teaching and is clearly less repeatable than identification by ultrasound (kappa = 0.83 on analysis of whole volumes and kappa = 0.61 for single slices in own data). There seems to be a high prevalence of levator defects in women with anal sphincter defects, which is not really surprising given the overlap in risk factors. Bilateral defects are more difficult to detect because there is no normal side to compare with, but they have a particularly severe impact on pelvic floor function and organ support.

Another factor only apparent on axial-plane imaging is the degree of hiatal distension on Valsalva. Figure 14 gives an impression of the range of hiatal area measurements in patients attending a pelvic floor clinic. Measures of hiatal dimensions seem highly repeatable and correlate well with findings on MRI. Hiatal enlargement to >25 cm² on Valsalva is defined as “ballooning” on the basis of receiver operator characteristic statistics and normative data in young nulliparous women. It can

FIGURE 15
Surgical audit with translabial ultrasound

A and B, Patient with A, large cystocele who developed B, rectocele 6 months after successful Perigee anterior compartment mesh (which is invisible due to shadowing from air-filled rectocele). C and D, Patient with large rectocele (C, imaged here before full development of rectocele to improve visualization) who developed D, cystocele 6 months after successful defect-specific rectocele repair.
be measured in axial-plane slices at the plane of minimal hiatal dimensions or in rendered volumes, and because the hial plane is non-Euclidean (warped rather than flat), measurements obtained in rendered volumes may be more valid and more reproducible as well as easier to obtain.\textsuperscript{101} The degree of distension is strongly associated with prolapse and symptoms of prolapse,\textsuperscript{100} and both avulsion and ballooning seem to be independent risk factors.\textsuperscript{102} It seems that ballooning is associated with prolapse recurrence after rectocele repair,\textsuperscript{103} and the same probably holds for other forms of prolapse surgery.

If delivery-related trauma and excessive distensibility of the levator are in deed risk factors for female pelvic organ prolapse and recurrence after reconstructive surgery, then these conditions need to be diagnosed preoperatively, and in future we will have to adjust our surgical approach accordingly. Some forms of prolapse are probably impossible to cure surgically unless one uses mesh implants. We should aim to develop surgical methods that reduce the size and distensibility of the hiatus or reconnect the detached muscle in an attempt to prevent recurrence—and in 2009 this is no longer a hypothetical goal.\textsuperscript{80,104} As always, proper diagnosis has to come before treatment, and ultrasound imaging is now an indispensable part of a complete preoperative workup.

Finally, but most important in clinical practice, another major advantage of the new technology is the ease with which preoperative and postoperative data can be compared using stored volume data sets and postprocessing software (see Figure 15 for a comparison of preoperative and postoperative findings in 2 patients with recurrent prolapse). This capability is already enhancing postoperative audit and our understanding of how certain procedures work (or do not work). In future it very likely will influence surgical development and teaching.

Conclusion

Even before the widespread introduction of 3D/4D imaging, pelvic floor ultrasound was a highly useful diagnostic tool for physicians dealing with pelvic floor disorders. As of 2009, this includes not just gynecologists, urologists, urogynecologists, and radiologists, but also colorectal surgeons and gastroenterologists. Current trends, ie, the near universal introduction of 4D ultrasound, new software options, and increasing availability of training, will likely lead to more general acceptance of ultrasound as a standard diagnostic option in pelvic floor medicine. The issue of levator trauma, one of the most significant developments in clinical obstetrics since the introduction of fetal monitoring, will take pelvic floor ultrasound from a niche application into the mainstream and speed the convergence of clinical specialties dealing with pelvic floor disorders. The crucial issue, as always, is teaching and the provision of up-to-date resources, and it may still be another decade or 2 before this method truly becomes a fully accepted part of the diagnostic workup in women with pelvic floor disorders.


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