10 Endovaginal Imaging: Slings

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Learning Objective

To understand the utility of multicompartment endovaginal three dimensional (3D) imaging in the visualization of retropubic and transobturator slings and the diagnosis and planning of future treatment in patients with failed slings.

Introduction

The introduction of the tension-free vaginal tape (TVT) in 1996 [1], followed by the transobturator tape (TOT) in 2001 [2], has led to a remarkable increase in the use of synthetic material in the surgical treatment of stress urinary incontinence (SUI) in the last decade. None of the graft materials is without problems, and therefore, imaging of the synthetic materials following surgery is evolving into a valuable diagnostic tool in the treatment algorithm for the patient.

Magnetic resonance imaging (MRI) and X-ray imaging have been found to be suboptimal in their ability to visualize graft materials when compared with ultrasound [3–5]. A study that compared the efficacy of introital sonography and MRI in the visualization of TVT tape found that the depiction of the tape by MRI was limited overall and particularly poor in visualizing the tape in a sub- or para-urethral location [3]. Synthetic grafts cannot be imaged by X-rays. Even in a research setting, X-ray imaging of synthetic tapes is tedious and requires marking of the tape intraoperatively, either with metal clips (titanium clips) or an X-ray-proof string [4]. In contrast, most of the modern synthetic implant materials are highly echogenic and easily visualized on ultrasound [6].

3D ultrasound improves on 2D ultrasound by allowing visualization of the tapes and the bulking materials in planes that cannot be assessed by conventional imaging techniques [7]. Real-time manipulation of the high-resolution 3D data volume obtained in sagittal, coronal, and axial planes enables the examiner to document the implant along its entire intrapelvic course. With experience, the data volume can be manipulated using a combination of oblique and straight planes and rendered volumes to follow the intrapelvic course of grafts even when it is very tortuous. 2D dynamic examination in the midsagittal or axial view during

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Valsalva, squeeze, and cough maneuvers allows real-time assessment of the in vivo functional behavior of the graft during periods of stress.

Multicompartment 3D imaging combines detailed anatomical examination with a combination of probes (transperineal scan with the BK curvilinear probe, endovaginal 180° scan with the BK 8848 probe, and 360° endovaginal scan with the BK 2052 or BK 8838 probe) (BK Ultrasound, Analogic, Peabody, MA, USA) with dynamic functional assessment to obtain a complete anatomic and functional understanding of all the pelvic floor compartments. Multicompartment imaging provides the "full picture," which is critical in the management of pelvic floor dysfunction, as it is often complex and involves more than one anatomical component and more than one pelvic floor function. Multicompartment imaging summates the benefits and compensates for the drawback of each probe to provide us a comprehensive high-resolution functional and anatomic assessment of the graft and surrounding tissue from various angles. Examination with one probe confirms the diagnosis obtained through the other while helping to differentiate between artifacts and true pathology.

In the last decade, research on the use of 3D ultrasound for the visualization of vaginal implants has focused mainly on the transperineal route. However, 3D endovaginal ultrasound imaging (3D EVUS), especially multicompartment imaging, is proving to be a useful tool to evaluate outcomes of sling surgery, to delineate the reason for complications or failure, and to plan treatment, especially in patients with a complicated treatment history. This chapter is an attempt to share our experience and to discuss future directions of research in endovaginal imaging as it pertains to synthetic tapes and bulking agents. For the purposes of this chapter, a BK Flex Focus machine (BK Ultrasound, Analogic, Peabody, MA, USA), with a variety of transperineal (8802) and endovaginal (8848 and 2052) probes was used as discussed in Chap. 2. Though the primary focus of the chapter is on endovaginal imaging, we shall touch upon transperineal imaging where necessary to provide a comprehensive review of our current understanding of imaging for synthetic implants.

Multicompartment Endovaginal Imaging in the Visualization of Slings

Multicompartment imaging following sling surgery is indicated for various reasons. Imaging may be useful to determine the type of sling surgery performed in patients who do not remember or do not know the exact nature of the surgery. It may be useful to determine the location, function, and in vivo biomechanical characteristics of the sling during the follow-up visit [6]. Clinically, complications such as recurrence of stress incontinence, voiding dysfunction, erosion, and postoperative irritative bladder symptoms may benefit from imaging assessment [6].

3D Imaging of Retropubic (Pubovaginal and Midurethral) and Transobturator Slings

We perform multicompartment 3D EVUS for the imaging of retropubic and transobturator slings with the 8848 and the 2052 probes. The technique of 180° scan of the anterior compartment using the 8848 probe and 360° scan with the 2052 probe and the pelvic floor structures seen is explained elsewhere in this book. However, we will mention a few important details regarding the technique as it pertains to imaging of tapes.

Technical Details of Performing 3D EVUS to Visualize Slings

180° Scan of the Anterior Compartment

Before performing the 180° 3D scan with the 8848 probe, it is important to peruse the 2D image in the midsagittal plane to ensure that the probe has been inserted correctly to obtain a satisfactory 3D data volume. Firstly, it is important to ensure that the probe has been inserted in the vagina in the neutral position in order to prevent compression of the anterior compartment structures. Secondly, it is also important to ensure that the midsagittal 2D image includes a portion of the bladder at its cephalad perimeter so as to ensure that the urethrovesical junction is included in the

3D scan. At the same time, it is important to ensure that the external urethral meatus is in view at the caudad end of the image so that the urethra is imaged in its entirety. If too much of the bladder is included in the image, the external urethral meatus may extend beyond the caudad boundary of the scan. The sling, whether retropubic or transobturator, is seen as a hyperechogenic horizontal structure beneath the urethra in the midsagittal 2D image (Fig. 10.1). The location will vary, depending on the type of sling surgery, bladder neck or midurethral. However, in a patient with poor outcome following sling surgery, the sling may not have fixated suburethrally and hence may be located proximally beneath the bladder. Hence if the sling is not seen as described above, beneath the urethra, it is important to extend the probe towards the vaginal apex so that the region between the vaginal wall and bladder can be imaged to locate the sling (Fig. 10.2). In such a situation, it may be useful to image the bladder and the urethra in two separate 3D data volumes so that all important details are captured for offline analysis and are available as a permanent record for the future.

360° Scan

Similarly, while scanning with the 2052 probe, it is important to ensure that the probe is inserted in the vagina in the neutral position and has been inserted cephalad enough to capture all important details. Though normally the cephalad extent of the 3D scan should begin just proximal to the urethrovesical junction, so that in the sagittal cut of the data volume a small portion of the bladder is seen narrowing into the urethrovesical junction, it must be kept in mind that in the case of slings that have not fixated suburethrally and hence are located proximally beneath the bladder, the 3D scan may need to begin even more cephalad. At the same time, it is necessary to ensure that the caudad extent of the 3D data volume is beyond the external urethral meatus so that the urethra is imaged along its entire length. Hence often it may be necessary to capture two 3D data volumes along the length of the urethra to ensure that all important structures are included. Increasing the depth may help to include the entire extent needed in a single data volume, but it must be remembered that increasing the depth reduces the resolution and decreases the image size.

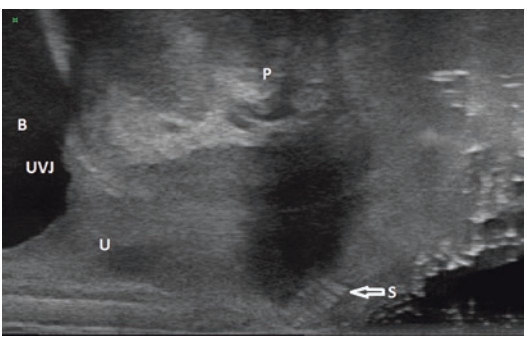

Fig. 10.1 180° scan of anterior compartment: midurethral retropubic sling seen as a hyperechogenic structure beneath midurethra. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), midurethral retropubic sling (S)

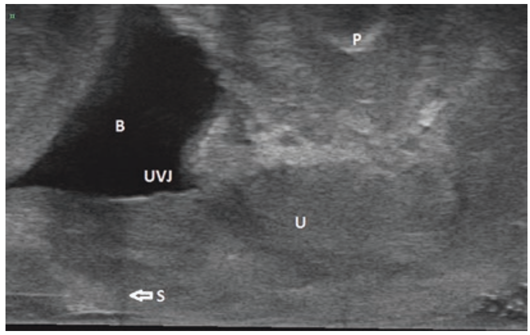

Fig. 10.2 180° scan of anterior compartment: retropubic sling seen proximal to the urethrovesical junction. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), retropubic sling (S)

Manipulation of the 3D Data Volume to Trace the Intrapelvic Course of Slings, Retropubic, and Transobturator

The 180° 3D data volume of the anterior pelvic compartment (probe 8848) can be manipulated in the sagittal, axial, or coronal planes. However, to track the intrapelvic course of a sling, it is preferable to begin with manipulation in the sagittal plane. It is important to first orient to the egocentric coordinates, i.e., the relative directions of the data volume, or more simply put, it is important to first understand which sagittal surface of the data volume denotes the left of the patient, and which surface the right. Depending on how the 3D external mover moves the probe, the 3D scan may begin on the left or right of the patient. If the 3D external mover is programmed to begin the scan on the left of the patient, then the data volume is constructed progressively in real time during scanning from the left to the right.

As one begins manipulating the 3D data volume in the sagittal plane, the arm of the sling on that side progressively comes into vision. The arm of the sling, in case of retropubic slings, can be seen, exhibiting a mesh-like weave, extending until the pubic symphysis. In the case of transobturator sling, the arm can be seen extending at a more obtuse angle beyond the pubic symphysis. The sling can be tracked behind the urethra in the midsagittal plane and then can be seen extending on the other side to the pubic symphysis in case of retropubic slings or beyond the pubic symphysis at a more obtuse angle in case of transobturator slings.

The location of the sling behind the urethra in the midsagittal plane will vary, depending on the type of sling. In case of TVT slings (see Fig. 10.1) and transobturator slings (Fig. 10.3), the sling will be seen as a hyperechogenic horizontal structure beneath the midurethra, and in the case of a bladder neck sling, it can be seen beneath the proximal urethra with its proximal end at the urethrovesical junction (Fig. 10.4).

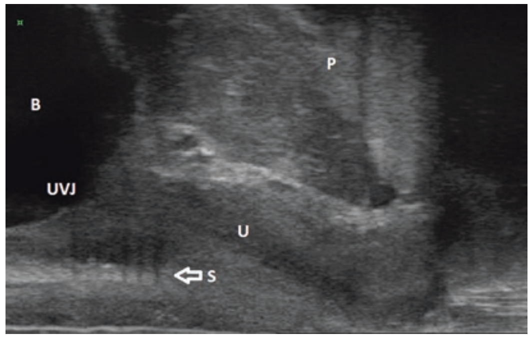

Fig. 10.4 180° scan of anterior compartment: pubovaginal sling seen at bladder neck. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), pubovaginal sling (S)

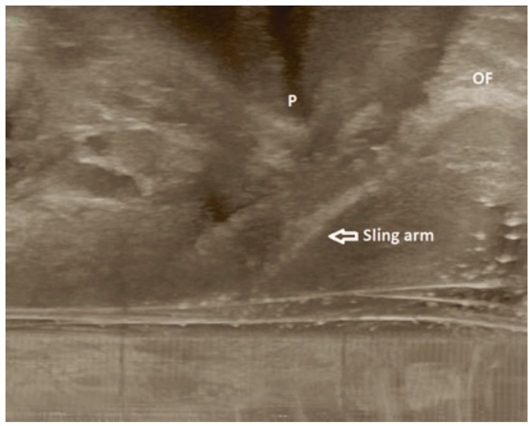

Fig. 10.5 180° scan of anterior compartment: rendered volume, single incision sling arm seen on the right of the patient extending beyond the pubic symphysis until the obturator foramen. Pubic symphysis (P), obturator foramen (OF)

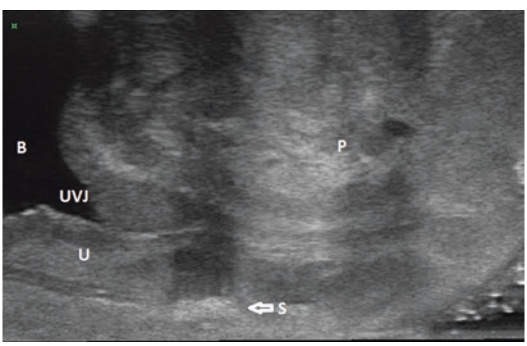

Fig. 10.3 180° scan of anterior compartment: transobturator sling seen as a hyperechogenic structure beneath midurethra. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), transobturator sling (S)

The intrapelvic course of the slings can be tracked more easily when the rendered volume of the data volume is manipulated (Fig. 10.5). Often one may need to manipulate the data volume in oblique parasagittal planes to be able to track the sling course better.

Manipulation of the 3D data volume obtained with the 2052 probe can also be done in the axial, sagittal, and coronal planes. However, transobturator and retropubic slings can be more easily differentiated in the axial plane. Manipulation in the axial plane adds to the information obtained from sagittal manipulation of the data volume obtained

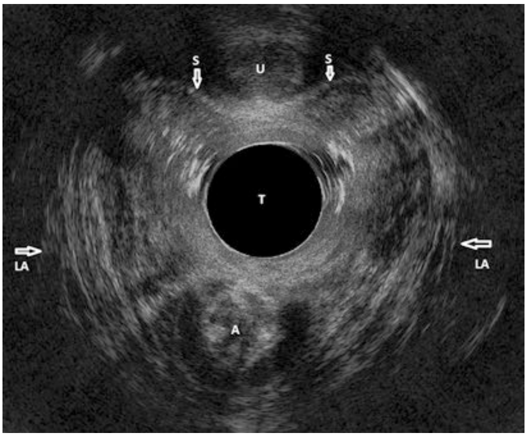

Fig. 10.6 360° scan. Retropubic sling seen hugging the urethra in a u-shape. Urethra (U), anal canal (A), levator ani muscles (LA), probe (T), midurethral retropubic sling (S)

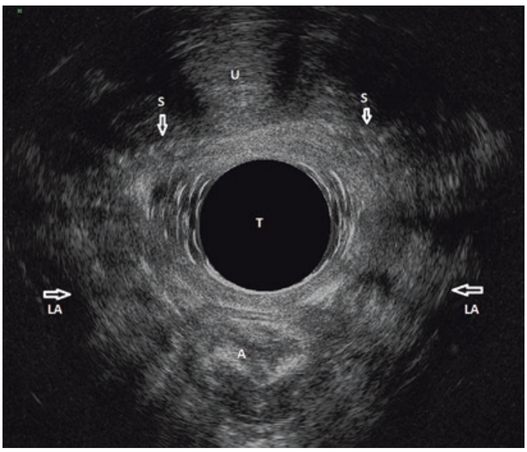

Fig. 10.7 360° scan. Transobturator sling seen extending hammock-like to the obturator foramina bilaterally. Urethra (U), anal canal (A), levator ani muscles (LA), probe (T), transobturator sling (S)

via the 8848 probe as we are able to look at the sling from a different angle. The retropubic sling can be seen in the axial plane in a u-shaped curve hugging the urethra (Fig. 10.6), while the transobturator sling can be seen extending hammock-like to the obturator foramen bilaterally (Fig. 10.7). The slings can be seen better when the rendered volume of the data volume is manipulated. We may also need to manipulate the data volume in oblique planes to follow the course of the sling until its insertion points bilaterally.

2D Dynamic Functional Assessment of the Slings

The in vivo behavior of the sling during periods of stress, namely, cough, Valsalva, and squeeze maneuvers, can be assessed by recording 20s 2D cineloops in the midsagittal plane or the axial plane using the 8848 probe (endovaginal ultrasound of the anterior compartment) or an abdominal curvilinear probe (transperineal ultrasound). These cineloops can also be stored for offline analysis and are available as a permanent record of in vivo sling behavior.

2D Dynamic Functional Assessment of Slings and Its Correlation with Outcome

Dynamic interaction of the urethra with the midurethral sling is a crucial determinant of the outcome following sling surgery [8]. Midurethral positioning of the sling has been regarded as important in achieving urinary incontinence, as it allows the tape to act as a fulcrum to produce dynamic kinking of the urethra [9] or as a mechanical device to enhance the increase of intraurethral pressure [10, 11] with stress. Dynamic kinking of the urethra with straining has been seen in 87–92% of women in whom a midurethral sling has been implanted [12]. Therefore, theoretically, dynamic changes in the interaction of the urethra with the sling during periods of sudden and/or sustained stress appear to be a crucial factor in ensuring successful outcomes following midurethral sling surgery [8]. Thus dynamic functional assessment of in vivo sling behavior may prove crucial for improving our understanding of the mechanism of action of the midurethral sling and help delineate reasons for failure [8].

We conducted an unmatched case study of 100 patients returning for their 1–2 year follow-up visit following transobturator sling surgery (Monarc, American Medical Systems, Minetonka, Minnesota, USA) in which we compared deformability of the sling on Valsalva, concordance of urethral movement with the sling, and sling location on maximal Valsalva between two groups: group A (n = 50) patients had successful outcomes and group B (n = 50) patients had suboptimal outcomes 1 year following surgery [8]. 3D cubes were manually obtained using transperineal probe over 30 s at rest and over 6 s in maximal Valsalva in addition to 2D cineloops on Valsalva.

Deformability of the Sling

The dynamic change in shape of the tape in the 2D cineloop film was used to categorize three types of sling deformability:

1. Parallel to the urethral lumen at rest (flat or slightly curved in shape along its width at rest) and deforms to a c-shape on maximal Valsalva
2. Parallel to the urethral lumen, both at rest and during maximal Valsalva: The tape remains flat or slightly curved in shape along its width and does not deform to a c-shape on maximal Valsalva
3. C-shaped at rest and during maximal Valsalva: The tape remains c-shaped along its width both at rest and during maximal Valsalva.

Location of the Sling on Maximal Valsalva

The 3D cube obtained over 6 s during maximal Valsalva across the mid sagittal plane was analyzed to determine location of the sling on maximal Valsalva.

Concordance of Urethral Movement with the Sling During Maximal Valsalva

The 3D cube obtained over 30 s at rest was analyzed to determine the location of the sling relative to the urethral length at rest. The sling location at rest was compared to that on maximal Valsalva. If the sling location on maximal Valsalva relative to the urethral length was identical to that at rest, the urethra was considered to move concordant with the sling [8]. If the sling location on maximal Valsalva relative to the urethral length differed from that at rest, the urethral movement in relation to the sling was considered discordant [8]. Concordance of urethral movement with sling was assessed on 2D dynamic assessment also.

When compared with group B, group A had a significantly greater number of patients in whom the sling deformed on Valsalva (flat at rest and curved into a c-shape on Valsalva), the urethral movement was concordant with the sling, and the sling was located beneath the midurethra ($p < 0.0001$). The urethrovesical junction moved distal to the sling in 8 (26.7%) patients in group B who had discordant movement of the urethra relative to the sling. Therefore the data suggest that on 2D and 3D transperineal ultrasound, the best outcomes following midurethral transobturator sling surgery are found to be associated with concordance of urethral movement with the sling and midurethral location at maximal Valsalva followed by deformability of the sling on dynamic assessment [8]. Thus dynamic assessment of sling function helps to understand the mechanism of sling action. Significantly, though dynamic kinking of the urethra is what has been considered the reason for continence achieved with the help of the sling previously, dynamic assessment shows that the effect is due more to dynamic compression than to actual kinking at the urethral knee.

Interestingly, a patient in whom the sling does not deform on Valsalva (i.e., does not curve into a c-shape from flat at rest along its width) may still have a successful outcome if the sling is located in the correct location (midurethral) at rest and the urethra moves in a concordant manner with the sling. Conversely, a patient, in whom the sling deforms on Valsalva may still have a poor outcome if the urethra moves in a discordant manner with the sling and/or the sling is not located beneath midurethra. We observed that this is because the three parameters often work together to compensate for the failure of an individual parameter to ensure successful outcome. Hence it is important to examine all three parameters of dynamic assessment while assessing a patient.

When the urethra and the sling do not move in a concordant fashion, i.e., the urethra moves independently of the sling, it may be that the sling has not fixated itself well to the suburethral connective tissue or that the sling has been inserted too loosely; therefore, even though the sling has scarred in following surgery, the urethra and surrounding tissue move independently of it [8]. Accordingly, even if the midurethral or bladder neck sling is confirmed on static 2D and 3D ultrasound to be placed in the correct location, dynamic assessment may show that the urethra moves independently of it on dynamic assessment. As seen in our study (unpublished data), in some patients with failed slings, the urethrovesical junction may even move distal to the sling on dynamic assessment. Therefore the sling does not have the desired functional effect and may fail.

Kociszewski et al. correlated the dynamic changes in TVT sling shape seen on transperineal ultrasound with outcomes following TVT sling surgery in 72 women [9]. They found that 98% of patients, in whom the tape was flat at rest along its width in the midsagittal plane and curved into a c-shape during straining, were continent after surgery. There was improvement in one case (2%), and none of these patients was classified as failure. However, in 39% of the patients, no change was visible in the sling shape along its width on straining in the midsagittal plane. In the 11% of patients in whom the tape position was flat along its width at rest and during straining (i.e., too far away from the urethra), the failure rate was highest at 25%. In the 28% of patients in whom the sling was c-shaped along its width at rest and on straining, the failure rate was 10%.

We followed up the previous study with a second study in which we correlated the dynamic assessment of sling function on transperineal ultrasound with outcomes 1 year following surgery in 94 patients who had undergone retropubic midurethral sling surgery (Gynecare TVT Retropubic System, Ethicon, Somerville, New Jersey, USA) [13]. Our hypothesis was that, due to its retropubic location, the TVT sling procedure may be associated with increased tape tension and urethral compression that may compensate for any inappropriate sling location while still maintaining continence [13]. We found that even in the case of retropubic midurethral slings, the best outcomes following surgery are found to be associated with concordance of urethral movement with the sling and midurethral location at maximal Valsalva followed by deformability of the sling on dynamic assessment.

2D Dynamic Assessment of Deformability of Different Sling Types

Since deformability of slings has been shown to have an impact on the outcomes following sling surgery [8], it may be beneficial to compare the deformability of different slings available on the market. This is especially important given the fact that surgeons differ in the sling types they use. At our center, we use an inelastic retropubic sling (I-STOP, CL Médical, Sainte Foy Les Lyon, France) placed at the bladder neck in patients with intrinsic sphincter deficiency. The I-STOP sling has lower elasticity and lower deformability as compared to other slings [14]. We find that an I-STOP sling lies flat at rest (see Fig. 10.4) against the urethra and, on dynamic assessment, it moves with the urethra and constricts the bladder neck without deforming or bending into a c-shape along its width. This is synonymous with its mechanism of action, which is increasing resistance at the bladder neck during periods of stress as opposed to that of elastic midurethral slings, which act by causing dynamic compression. Thus it is easy to distinguish the I-STOP sling from other slings that have higher elasticity and greater deformability: e.g., TVT, Monarc, and the SPARC Sling System (American Medical Systems, Minnetonka, Minnesota, USA) slings.

In an unmatched case-control study of 120 patients returning to our center for one-year follow-up following sling surgery, we compared the in vivo deformability of three different slings [15]. The study group A consisted of 40 patients who had undergone retropubic bladder neck sling surgery (I-STOP) and groups B and C consisted of 40 patients who had undergone retropubic midurethral TVT sling surgery and transobturator Monarc sling surgery, respectively. The change in the distance of the proximal, midpoint, and distal ends of the tape from the midpoint of the urethral lumen and the change in the TSd (distance between the midpoint of the tape and the inferior border of the symphysis pubis in the sagittal plane) and TSa (the angle between a line from the midpoint of the tape to the inferior border of the symphysis pubis and the midline of the symphysis pubis in the sagittal plane) did not vary between the three groups. The tape width at rest was significantly more in group A when compared with group B and C ($p < 0.001$). The number of patients in whom the tape lay flat against the urethra at rest was significantly more in group A than the other groups ($p < 0.001$). The change in tape angle was significantly less in group A when compared with groups B and C ($p < 0.001$).

We therefore concluded that different sling types vary in their deformability. The I-STOP sling is more likely to lie flat at rest and not to deform during dynamic stress events when compared with the TVT and Monarc sling tapes. However, we suggested that since the I-STOP sling is inserted under proximal urethra, the impact of the interaction between the location of the sling and deformability of the sling on outcomes needs to be assessed [15].

We also conducted a prospective study in which we compared an inelastic, i.e. non-deformable pubovaginal sling (I-STOP), with a deformable midurethral sling (TVT) with respect to dynamic assessment of the sling function (deformability, location of sling, and concordance of urethral movement with sling) on 2D and 3D transperineal ultrasound [16]. We found that on 2D and 3D transperineal ultrasound, concordance of urethral movement with the sling was correlated with successful outcome following sling surgery with both non-deformable and deformable slings. Also proximal placement of sling that does not deform on straining seems to enable application of steady compression effect at the proximal urethra in patients with intrinsic sphincter deficiency and achieve similar effects as that achieved with dynamic compression midurethrally with a deformable sling [16].

Diagnosis and Planning of Future Treatment in the Case of Failed Sling Surgery

In patients who have poor outcomes following sling surgery, multicompartment 3D imaging can often be invaluable in delineating the cause for failure and also in planning future treatment. In this section we will discuss various scenarios we encounter in such patients at our center.

Unknown Sling Type

Often the patient is unaware of the exact nature of the previous sling surgery. 2D imaging cannot delineate the type of sling on either transperineal ultrasound or endovaginal ultrasound. A midurethral sling, whether retropubic or transobturator, will appear as a hyperechogenic horizontal structure behind the midurethra (see Figs. 10.1 and 10.3). A bladder neck sling that is located correctly at the urethrovesical junction should ideally be easy to distinguish from a midurethral sling based on location. But in patients with poor outcome following surgery, a midurethral sling is often found to be located too proximally. Therefore a sling that is found to be located under the proximal urethra may not necessarily be a bladder neck sling, but could be a midurethral sling.

Multicompartment 3D imaging including dynamic functional assessment is very useful in determining the type of sling that was inserted in such patients. As described above, the intrapelvic course of the sling can be tracked by manipulating the 3D data volume. The sling can be examined in the three different data volumes obtained with transperineal ultrasound, 180° endovaginal scan with the 8848, and/or 360° scan, and hence the diagnosis obtained through one probe can be confirmed through the other. Rendered volumes can be used to track the sling better.

As detailed in the previous section, dynamic functional assessment helps to distinguish slings based on elasticity and deformability. It is also possible to distinguish different types of materials, with the previous-generation intravaginal slingplasty being much less echogenic than the TVT [6]. Because the I-STOP sling is less deformable, it appears fatter and wider than TVT or Monarc slings. Also since the SPARC sling carries a central suture that prevents pretensioning [17], it generally seems flatter and wider than TVT sling [6].

Determining the Location of a Failed Sling

Confirming the location of a failed sling may be useful preoperatively if sling takedown surgery is planned. It may also help to elucidate the reasons for failure of the surgery. There is controversy as to whether the location of the sling is important to ensure continence. Several authors contend that location of the midurethral sling does not have any impact on the outcome following surgery [4, 18, 19]. From a theoretical point of view, Dietz et al. contend that since midurethral slings work by "dynamic compression," i.e., compression of the urethra against the posteroinferior contour of the pubic symphysis whenever intraabdominal pressure is raised, it should not matter much for success as to whether the obstruction affects the proximal or distal urethra [6]. However, urethral pressure profile measurements and lateral urethrocystography have confirmed that the urethral zone between the point of maximal urethral closure pressure and the urethral knee is crucial for continence mechanism. This zone, termed as the high-pressure zone of the urethra, has been calculated to lie between 53 and 72% of the functional urethral length, where pubourethral ligaments attach [1].

We conducted an unmatched case-control study of 100 patients who underwent transobturator sling surgery at our center to determine the association of static and dynamic location of transobturator slings with outcomes 1–2 years following surgery [20]. These 100 patients constituted two groups: group A ($n = 50$) who had successful outcomes and group B ($n = 50$) who had poor outcomes 1–2 years following surgery. All patients underwent 2D transperineal dynamic assessment and 3D endovaginal ultrasound of the anterior pelvic compartment. Transobturator slings were found to be located more proximally on 3D EVUS in patients in whom sling surgery had failed when compared with patients with successful outcomes. Also dynamic functional assessment of the sling was found to help understand in vivo sling behavior in patients with suboptimal outcomes following surgery.

Kociszewski et al. [9], using transperineal ultrasound in 72 women, found that a TVT tape located between 50 and 80% of the urethral length was associated with a success rate of 91%, whereas the other tape positions failed in 36% of the patients ($P = 0.0085$). In another study of 61 patients who had poor outcome following sling surgery (49 patients had undergone transobturator sling surgery and the remaining, a retropubic procedure), 3D EVUS was performed with the 8848 probe [21]. Only 21.3% of the patients had the tape positioned between 50 and 75% of the urethral length. The tape was found below 50% of the functional urethral length in 73.8% of the patients examined and above 75% of functional urethral length in 4.9% of the patients [21].

Is this observed change in position a natural progression or iatrogenic? The position of TVT sling has not been observed to change much over time [22, 23]. A gradual caudal displacement of the TVT has been described, but it is concordant with the distal movement of the surrounding tissues, particularly in women who have undergone concomitant anterior repair. It therefore may reflect recurrence or progression of prolapse rather than natural tape movement [6]. One possible explanation is that the sling was inserted proximally rather than in the midurethral location at the time of surgery. In a study of 102 women who underwent TVT sling surgery, urethral length was measured by preoperative introital ultrasonography, and suburethral incision was initiated at one-third of the sonographically measured urethral length [24]. Six months following surgery, the TVT sling was found in the target range of 50–70% of the urethral length in 88.2% of patients. 91.1% of the patients were cured and 6.9% of the patients showed improved continence symptoms.

If location of the sling is important, does stitching the sling in place after insertion help? Rechberger et al. randomly allocated 463 patients with SUI to treatment with a standard transobturator sling procedure (232 patients) or to a transobturator sling procedure with additional 2-point tape fixation with absorbable sutures (231 patients). Both the subjective cure rate (85.15% vs. 75.77%) and the objective cure rate (85.37% vs. 75.59%) were significantly greater in the tape-fixation group [25]. Among patients with intrinsic sphincter deficiency, the outcomes were significantly better in the tape-fixation group when compared with the control group (95.1% vs. 73.8% cured or improved; $P = 0.0011$).

However, does suture-fixating the sling at the time of implantation ensure that the sling will remain in the desired location a year after surgery? We conducted an unmatched case-control study of 80 patients returning to our center for the

1-year follow-up visit following sling surgery for SUI [26]. The study group A consisted of 40 patients who had undergone transobturator sling surgery (Monarc) in which the sling was not suture-secured to the midurethra. Forty patients had undergone a suburethral pubovaginal sling procedure (I-Stop) during which the tape was suture-fixated to the proximal urethra and constituted the control group B. On 3D EVUS conducted at the 1-year follow-up visit, only 14 (35%) patients had the sling in the desired location in group A as compared to 31 (77.5%) patients in group B ($p < 0.001$). The odds of the sling being located at the desired position were significantly greater in group B when compared with group A (OR, 2.21; 95% CI, 1.027–4.77, $P = 0.04$). Thus, we found that suture-fixating the sling tape in place during implantation may ensure that the sling is in the desired location 1 year following sling surgery. In order to understand whether the transobturator route of the surgery was a potential confounder to the study results, we expanded the study to include 40 patients who had undergone TVT sling surgery in a third group (unpublished data). In the TVT group also, only 14 (35%) patients had the sling in the desired midurethral location when compared to 31 (77.5%) in the I-STOP group. Based on tape percentile (the distance of the midpoint of the sling from the urethrovesical junction divided by the urethral length), the tape location in the patients who had undergone transobturator sling surgery was more proximal than that in patients who had undergone TVT sling surgery; however, it was not statistically significant ($P = 0.254$). There may be other confounders that we have not accounted for, including the difference in elasticity and flexibility of the slings; however, the study results do suggest that suture-fixating the tape in place during implantation may help to ensure desired sling location a year following surgery. We are now conducting a pilot study in which we are stitching Monarc slings in place after insertion, and we will compare location of the slings in these patients with those in whom the sling has not been stitched in place.

One important conundrum with respect to sling location is whether in patients who undergo concomitant anterior vaginal wall repair and sling surgery, the placement of the transobturator sling through the same incision used for the anterior vaginal wall repair has an impact on the sling location. In a prospective cohort study of 100 patients who underwent transobturator sling surgery (Monarc), we attempted to answer this question [27]. The patients constituted two groups: group A ($n = 58$), who underwent concomitant anterior vaginal wall repair through the same incision, and group B ($n = 42$), who underwent transobturator sling surgery alone.

A significantly higher proportion of patients in group A had the sling located proximally when compared with group B [29 (50%) vs. 10 (23.8); $P = 0.007$]. Out of these, 11 (19%) patients had the sling located proximal to the urethrovesical junction as compared to 2 (4.8%) patients in group B ($P = 0.03$). All the patients who had the sling located proximal to the UVJ had poor treatment outcomes 1 year following surgery. Thus patients who undergo transobturator sling surgery, with concomitant anterior vaginal wall repair performed through the same incision, are more likely to have the sling located more proximally when compared with patients who undergo transobturator sling surgery alone.

Planning of Treatment in Patients with Complicated Treatment History

Many patients with incontinence who are referred to a center have a complicated treatment history. Many have history of multiple sling surgeries (Fig. 10.8) or multiple previous sling surgeries followed by multiple bulking agent injections (Fig. 10.9).

Multicompartment 3D imaging is useful in understanding the location of the slings and bulking agent injections and in planning future treatment. For example, in a patient with a previous sling and bulking agent injection, with improved but still persistent symptoms, multicompartment imaging may show that the sling is in the right location; however, the bulking agent is not distributed circumferentially around the urethra. In such a patient one may decide to inject the bulking agent in the bare area around the urethra where the bulking agent is not present. Conversely, one may see multiple slings; however, none of them may be located in the appropriate location.

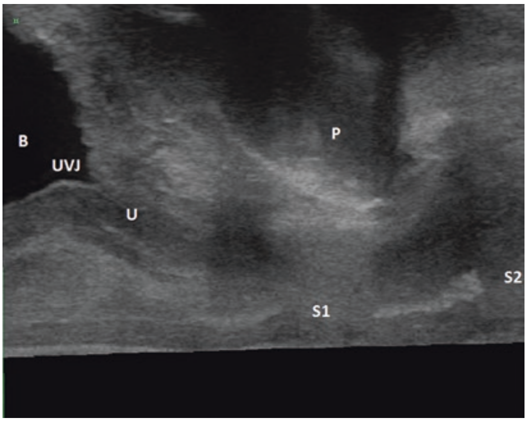

Fig. 10.8 180° scan of anterior compartment: multiple previous sling surgeries. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), midurethral retropubic sling (S1), transobturator sling displaced distally (S2)

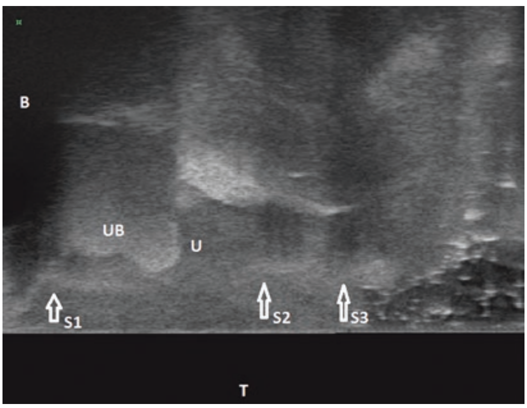

Fig. 10.9 180° scan of anterior compartment: previous three sling surgeries and Macroplastique (Cogentix Medical, Minnetonka, Minnesota, USA) injection. Bladder (B), urethra (U), urethral bulking agent (UB), probe (T), prolene patch sling (S1), midurethral retropubic sling (S2), transobturator sling (S3)

Dynamic functional assessment also aids in planning future treatment by elucidating the in vivo behavior of the slings inserted previously.

Planning of Treatment in Patients with Voiding Dysfunction Following Sling Surgery

Voiding dysfunction following sling surgery can often pose a diagnostic and treatment conundrum. While it is often severe enough for the future treatment plan to be clear, the symptoms and

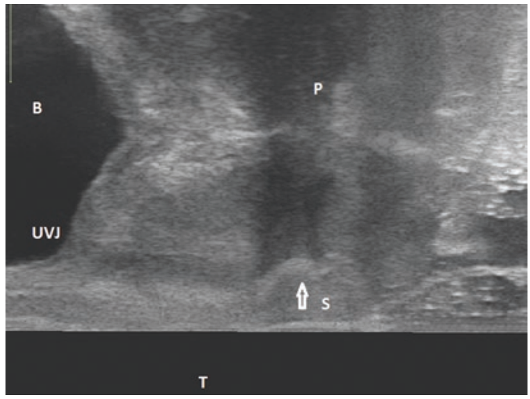

Fig. 10.10 180° scan of the anterior compartment: transobturator sling too close to the urethral lumen. Bladder (B), urethra (U), pubic symphysis (P), urethrovesical junction (UVJ), transobturator sling (S), probe (T)

signs are frequently indeterminate. Urodynamic parameters may also be borderline. In such a scenario, ultrasound examination that includes dynamic assessment may provide useful information to help make the correct diagnosis and plan future treatment. 3D EVUS with the 8848 probe may show the sling to be too close to the urethral lumen, thus causing obstruction (Fig. 10.10). Multicompartment imaging, particularly with transperineal ultrasound, helps to confirm the diagnosis and also to clarify that the reduced distance between the sling and the urethral lumen is not due to compression of the anterior compartment structures caused by the insertion of the probe in the vagina. Dynamic functional assessment may allow a real-time assessment of the obstruction of the urethra during Valsalva. Often patients with voiding dysfunction have Valsalva voiding, thereby compounding the obstruction.

There is no consensus in the literature on the sonographic diagnosis of urethral obstruction caused by the sling, but there are many studies confirmed using transperineal ultrasound that a reduced sling-symphysis pubis distance and a reduced sling-urethral lumen distance are associated with voiding dysfunction. Chantarasorn et al. measured the tape gap, i.e., the distance between the sling and symphysis pubis at maximal Valsalva, in 92 patients who had undergone Monarc sling surgery and found that patients who had voiding dysfunction had significantly reduced tape gap (9.91 mm as compared to 11.31 mm in patients without voiding dysfunction, $P = 0.014$) [28]. Yang et al., in a study of 56 women who had undergone Monarc transobturator sling surgery, found that compared to the patients who did not, the women who reported de novo or worsening voiding dysfunction postoperatively had larger resting sTA (symphysis pubis-tape angle, i.e., the angle between a line from the center of the tape to the inferior border of the symphysis pubis and the midline of the symphysis pubis in the sagittal plane) and higher incidence of urethral encroachment at rest [29]. Urethral encroachment was defined as the presence, in the sagittal plane, of an indentation in the urethral outer wall beside the tape, with a plateau-like elevation of the inner wall and narrowing of the echolucent urethral core, which encompassed the lumen and surrounding tissues [29]. Kociszewski et al., in their study mentioned above on the dynamic changes in TVT shape at rest and during straining, also studied whether the sling–urethral lumen distance was correlated with symptomatology following surgery. They found that the best outcome following surgery was obtained in patients in whom the tape was at least 3 mm from the urethral lumen. Complications such as voiding dysfunction and frequency/urgency with or without incontinence were seen only in patients with a distance between the tape and urethral lumen of less than 3 mm [9]. They contend that the c-shape along the width that the tape assumes on Valsalva indicates that tension is being exerted. They therefore extrapolated that a TVT tape that is already c-shaped along its width at rest is an indication of too much tension exerted on the urethra and therefore may be associated with voiding dysfunction. This is supported by Dietz et al., who also stated that most suburethral tapes can assume a tight c-shape, in particular on Valsalva [6]. The more pronounced this effect is at rest, the tighter one may assume the tape to be [6]. However, the c-shape seen at rest may be a reflection of tape bending or twisting following insertion and not necessarily a tight sling placement. A loosely placed tape can also assume a c-shape along its width; therefore, it is the distance of the tape from the urethral lumen at rest that would seem more predictive of voiding dysfunction than the presence of a c-shaped tape at rest.

Slings and the Overactive Bladder

There is some literature on the utility of 3D ultrasound in understanding the reasons for postoperative de novo urgency, but it is not conclusive. De novo urge symptoms have been found to increase significantly when the TVT tape was positioned less than 3 mm from the urethral lumen [9]. Conversely, another study found significantly higher rates of urgency incontinence if the tape gap (distance of the tape from the symphysis pubis) was higher [19]. Tape location has not been found to be associated with postoperative de novo urgency incontinence in one study [29]. Conversely, in a prospective observational study of 141 women who underwent transperineal ultrasound 5 weeks to 2.1 years (0.66 years) after TVT sling surgery, Dietz et al. found that more cranial tapes were weakly associated with urge incontinence ($P = 0.03$) and frequency ($P = 0.048$) [19]. However, tape position in this study was determined with reference to the symphysis pubis and not relative to the urethral length.

In order to correlate sling location at rest with de novo and persistent overactive bladder symptoms following sling surgery, we conducted a prospective cohort study in 104 patients with urodynamic stress or mixed incontinence [30]. Of these, 64 patients underwent Monarc sling surgery and 40 patients underwent TVT sling surgery. Midurethral location of the retropubic sling, as opposed to transobturator sling was found to be associated with reduced persistence of urgency symptoms, higher rates of resolution of urgency symptoms, lower severity of urgency symptoms, and better quality of life.

Comparison of Transperineal and Endovaginal Ultrasound in the Imaging of Slings

We conducted a prospective cohort study of 100 patients who underwent transobturator Monarc sling surgery in whom both transperineal ultrasound and 3D EVUS of the anterior pelvic compartment were performed at the 1-year follow-up visit [31]. The 3D volumes obtained were analyzed to determine sling location in the midsagittal view. Seventy of the patients included in the study had successful outcome at the 1-year follow-up visit (group A), and 30 patients had failed sling surgery (group B). Based on concordance of sling location using the two approaches, the location was called concordant proximal, concordant midurethral, or concordant distal if the location of the sling using the two approaches were both proximal, midurethral, or distal, respectively. The location was called discordant type 1 if the sling was found to be more proximal using 3D EVUS as compared to transperineal ultrasound and discordant type 2 if the sling was found to be more distal using 3D EVUS as compared to transperineal ultrasound. The number of patients with concordant midurethral location of the sling on both transperineal and endovaginal ultrasound was significantly higher in group A compared to group B ($p < 0.001$). The relative risk of failing sling surgery in patients with discordant type 1 profile of sling location was 4.01 (95% CI 2.47–6.52; $p < 0.001$) in comparison to patients who did not have discordant type 1 profile.

On dynamic assessment of the sling with transperineal ultrasound, in all 14 patients with discordant type 1 profile at rest, the urethra was seen to move distally dissonant to the movement of the sling. In six patients, the urethrovesical junction moved distal to the sling. However, in all patients with concordant midurethral sling location at rest as seen using the two probes, the sling and urethra moved in a concordant manner ($p < 0.001$). Thus, patients in whom the sling seems to be located more proximally on endovaginal ultrasound as compared to transperineal ultrasound are more likely to have poor outcome following sling surgery. In the patients who have a good outcome following surgery, the sling is seen at the same location with both probes. There are two possible explanations for the above finding. It may be that the sling has not fixated in place properly or that the sling has been inserted loosely at the time of surgery and therefore the bladder, urethra, and their surrounding tissues can move independently of the sling. In other words, the bladder and urethra move when the 8848 probe is inserted into the vagina. However, the sling does not move with them, as there is no tissue bridge connecting the sling with the urethra.

Anatomic Path of Transobturator Slings and Its Association with Pelvic Pain

In a recent retrospective study from Shobeiri's group [32] of women presenting with complications from TOT slings performed for SUI, the 3D EVUS volumes obtained were reviewed to determine the consistency of the anatomical path followed and to understand whether or not there is an association between the sling pattern/position and pelvic pain. The minimal levator hiatus (MLH) was used as the reference point, and the sling pattern and location, the urethral length, the sling to urethrovesical junction distance, the sling center and lateral arm insertion point distance to MLH, and the sling's width were assessed. Each sling pattern was visualized in axial, coronal, and sagittal views, respectively.

Of the 68 women studied, 49 patients reported pain on pelvic floor distress inventory/pain questionnaires and 19 patients did not. The mesh patterns were categorized as seagull or normal pattern (Fig. 10.11), flat (Fig. 10.12), folded (Fig. 10.13) and lopsided (Fig. 10.14). Although there were no statistically significant differences between the mid-sling to MLH and sling arm to MLH positions between the two groups, there were wide variations in the course of the slings. A greater proportion of women with pain (73%) had abnormal patterns compared to those without pain (27%) ($P = 0.001$).

Finally, endovaginal ultrasound can also diagnose tape bunching or twisting (Fig. 10.15) and asymmetry of the slings that results from the mesh shrinkage. In these cases the sling width is much smaller than the measurement at the time of implantation.

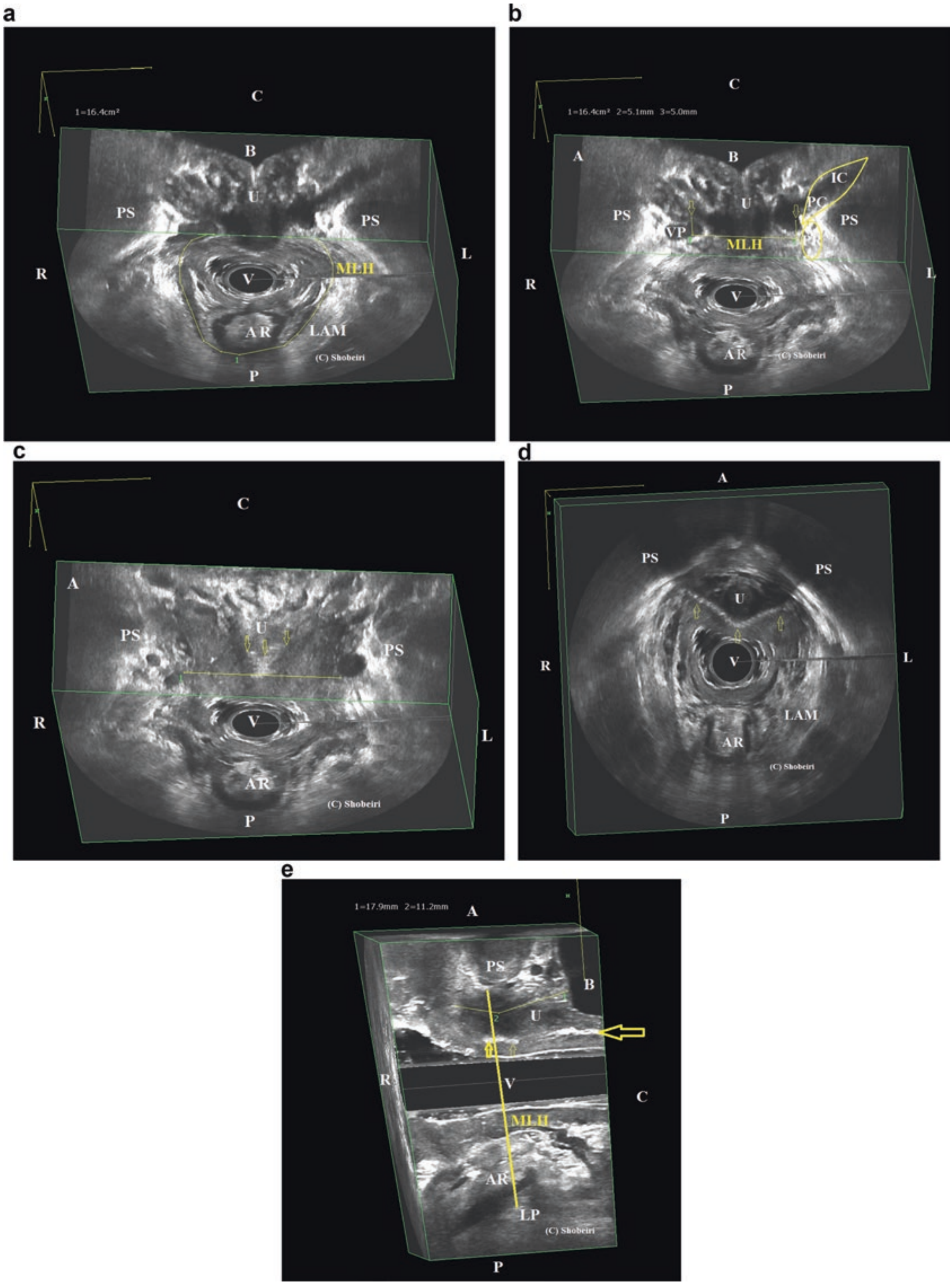

Fig. 10.11 (**a**) 360° scan using 8838 probe. 3D data volume manipulated in the coronal plane to demonstrate **seagull pattern**. Coronal (C), bladder (B), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), levator ani muscle (LAM), right (R), left (L), posterior (P); (**b**) 360° scan. 3D data volume manipulated in the coronal plane of a normal transobturator tape sling path [seagull pattern, see (**d**)]. It shows the relationship of the arms of

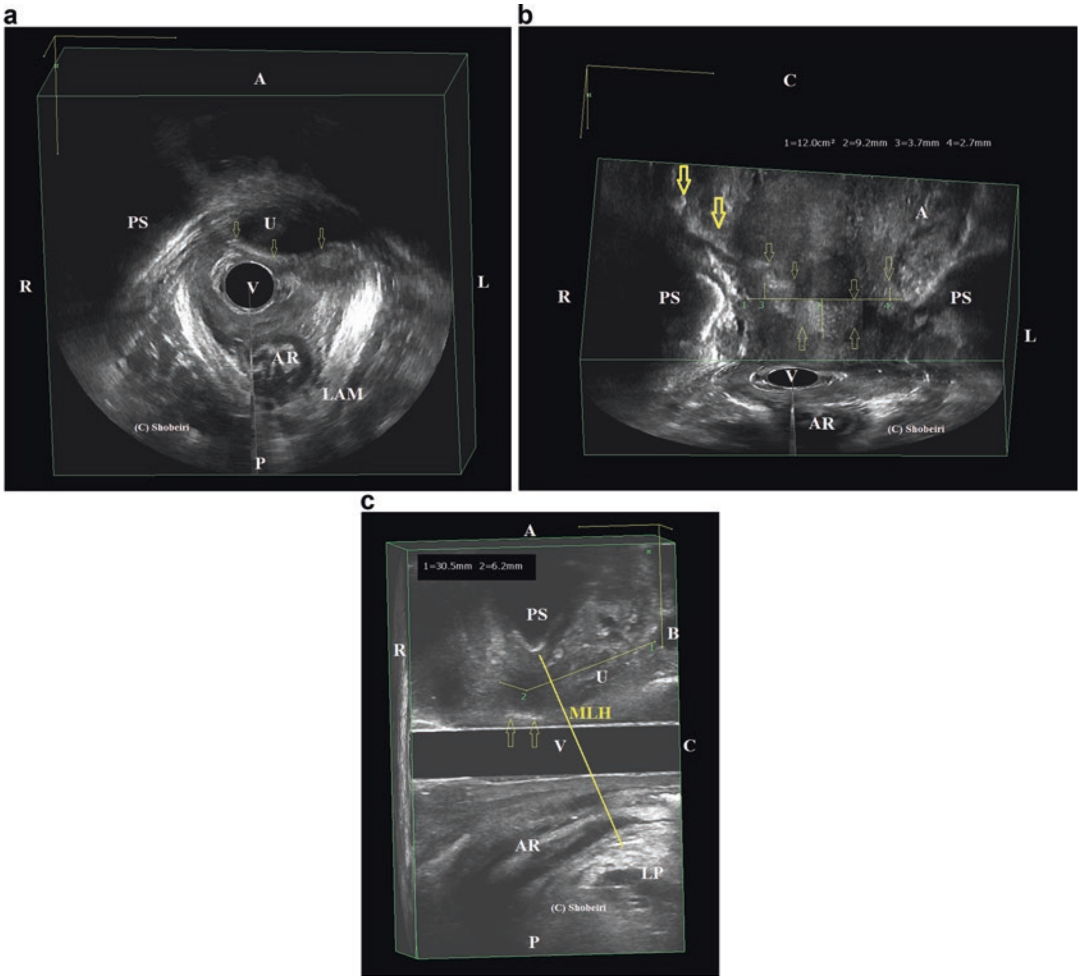

Fig. 10.12 (**a**) 360° scan. 3D data volume manipulated in the axial plane to demonstrate **flat pattern** (the *small yellow arrows* are the sling). Urethra (U), pubic symphysis (PS), vagina (V), anal canal (A), levator ani muscle (LAM), anterior (A), right (R), left (L), posterior (P); (**b**) 360° scan. 3D data volume manipulated in the coronal plane to demonstrate flat pattern. The *small arrows* show the sling. The sling is below the level of the minimal levator hiatus (MLH) in the center and enters the obturator at the expected location (number 4). Coronal (C), **urethra (U)**, pubic symphysis (PS), vagina (V), anorectum (AR), anterior (A), right (R), left (L); (**c**) 360° scan. 3D data volume manipulated in the sagittal plane to demonstrate flat pattern. Note that the sling is below the level of the MLH and at the distal one-third of the urethra. Bladder (B), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), minimal levator hiatus (MLH), levator plate (LP), anterior (A), right (R), left (L), posterior (P)

Fig. 10.11 (continued) the sling that lie parallel to the minimal levator hiatus (MLH) and its relationship with the levator ani subdivisions. Coronal (C), bladder (B), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), iliococcygeus (IC), pubococcygeus (PC), pelvic vein (VP), puborectalis (PR), right (R), left (L), posterior (P); (**c**) 360° scan. 3D data volume manipulated in the coronal plane to demonstrate the relationship of the MLH with respect to the central part of the sling (*yellow arrows*) Coronal (C), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), anterior (A), right (R), left (L), posterior (P); (**d**) 360° scan. 3D data volume manipulated in the axial plane to demonstrate seagull pattern (*yellow arrows*). Axial (A), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), anterior (A), right (R), left (L), posterior (P); (**e**) 360° scan. 3D data volume manipulated in the mid-sagittal plane to demonstrate seagull pattern. Bladder (B), urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), minimal levator hiatus (MLH), levator plate (LP), anterior (A), right (R), cephalad (C), posterior (P)

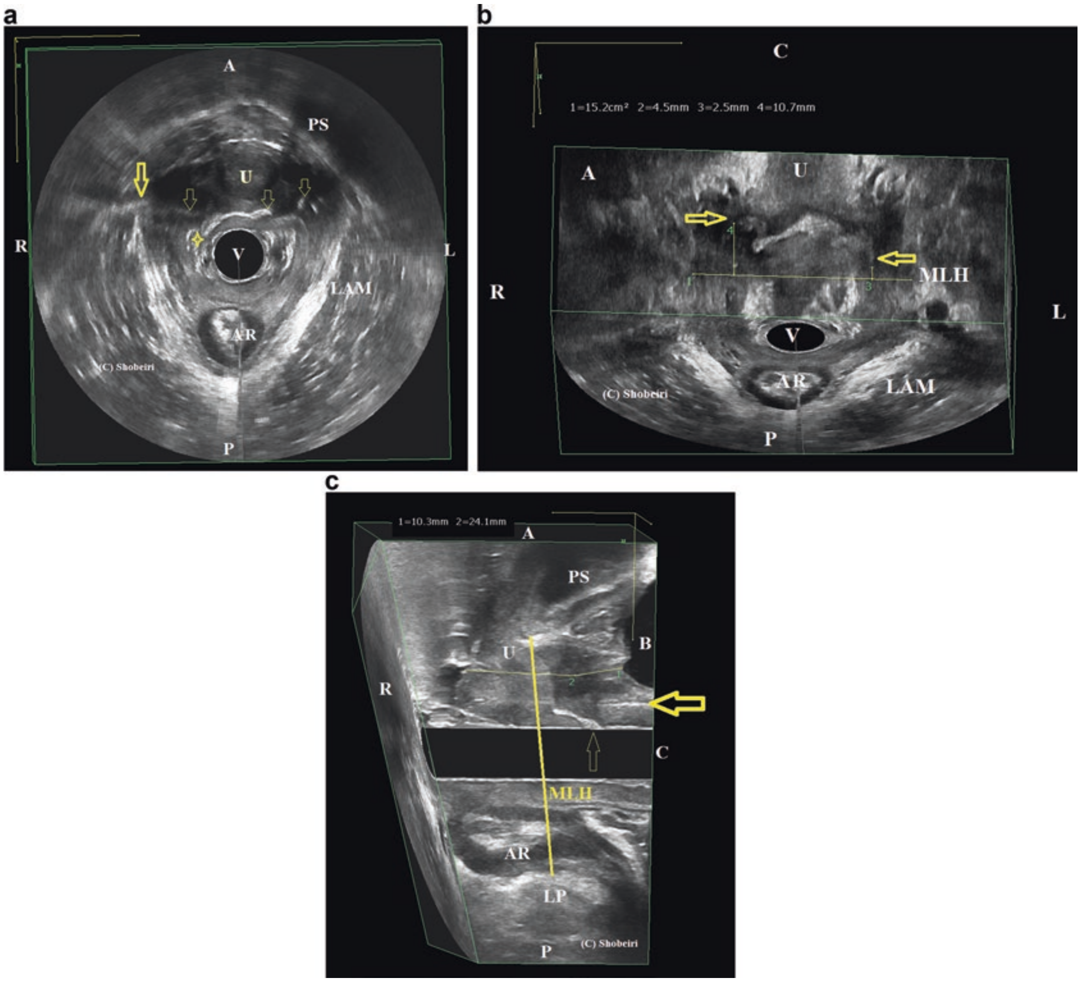

Fig. 10.13 (**a**) 360° scan. 3D data volume manipulated in the axial plane to demonstrate **folded pattern** (the *small yellow arrows* are the sling, the *star* denotes the area of folding, the *large arrow* denotes the entrance of sling into the obturator foramen). Urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), levator ani muscle (LAM), anterior (A), right (R), left (L), posterior (P); (**b**) 360° scan. 3D data volume manipulated in the coronal plane to demonstrate the folded pattern. Note the *large arrows* that demonstrates the asymmetry of the sling entering into right obturator foramen by a very cephalad arch. Coronal (C), urethra (U), vagina (V), anorectum (AR), minimal levator hiatus (MLH), anterior (A), right (R), left (L), posterior (P); (**c**) 360° scan. 3D data volume manipulated in the sagittal plane to demonstrate the sling location. Note that the sling is extruding cephalad and touching the probe. The *large arrow* denotes the right plane for the sling. The sling is in the upper one-third of the urethra cephalad to the minimal levator hiatus (MLH). Bladder (B), urethra (U), pubic symphysis (PS), **vagina (V),** anorectum (AR), levator plate (LP), anterior (A), right (R), left posterior (LP), **cephalad (C)**

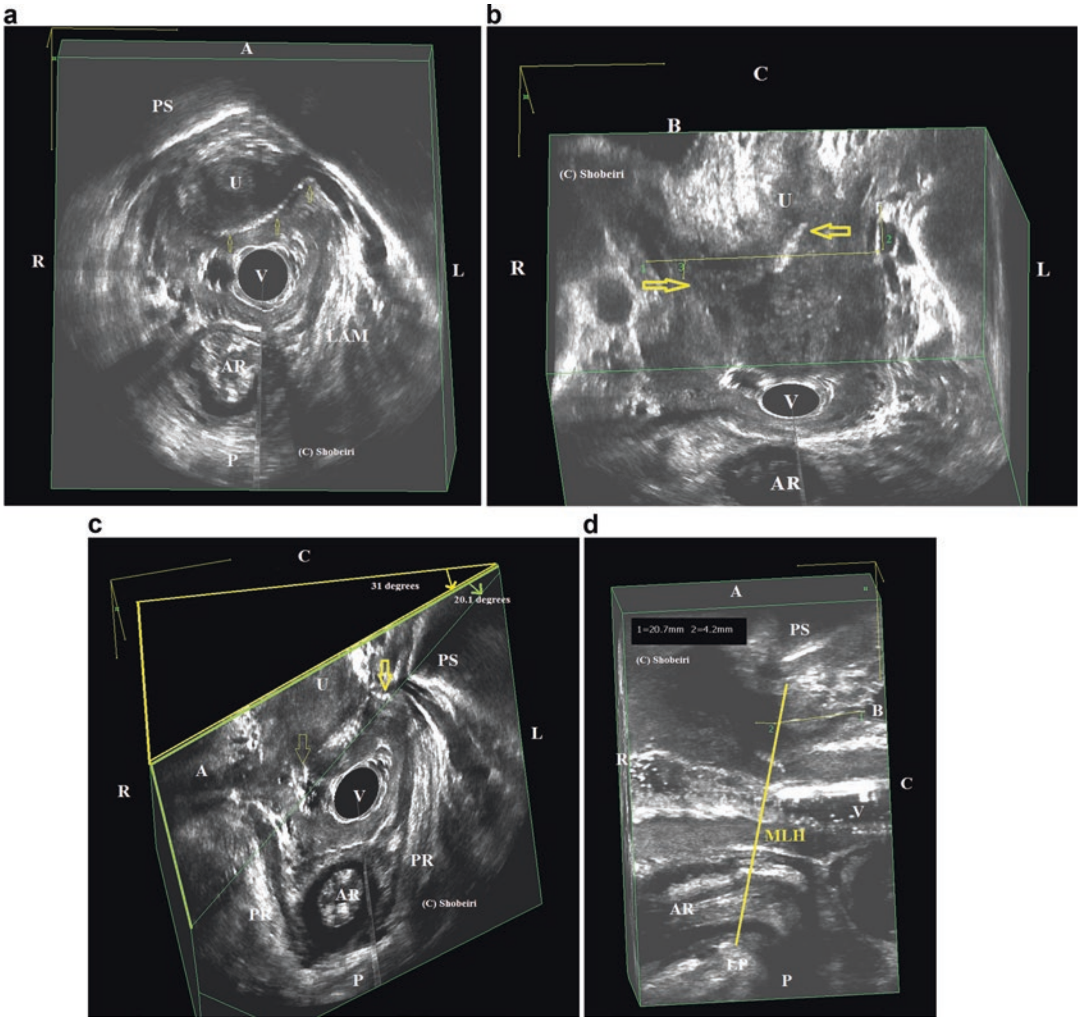

Fig. 10.14 (**a**) 360° scan. 3D data volume manipulated in the axial plane to demonstrate **lopsided pattern** (the *small yellow arrows* are the sling). Urethra (U), pubic symphysis (PS), vagina (V), anorectum (AR), levator ani muscle (LAM), anterior (A), right (R), left (L), posterior (P); (**b**) 360° scan. 3D data volume manipulated in the coronal plane to demonstrate lopsided pattern. Note that the sling is crossing the minimal levator hiatus (MLH) in the midline. On the left side the sling goes cephalad into the iliococcygeus (*large yellow arrows*). Coronal (C), bladder (B), urethra (U), vagina (V), anorectum (AR), right (R), left (L), posterior (P); (**c**) 360° scan. 3D data volume manipulated in an oblique plane showing both axia and coronal planes to demonstrate lopsided pattern. Note that the sling is travelling at 31° in coronal plane and 20.1° in the axial plane. The *solid arrow* on the *left* and the *small arrow* on the *right* show differential entry sites into the obturator area. Coronal (C), bladder (B), urethra (U), pubic symphysis (PS) vagina (V), anorectum (AR), puborectalis (PR), anterior (A), right (R), left (L), posterior (P); (**d**) 360° scan. 3D data volume manipulated in the mid-sagittal plane to demonstrate the lopsided sling's relationship to the minimal levator hiatus (MLH). Note that when there is levator ani deficiency, the levator plate moves and effects the intended location and perhaps the function of the sling. Bladder (B), **urethra (U)**, pubic symphysis (PS), vagina (V), anorectum (AR), levator plate (LP), anterior (A), right (R), cephalad (C), posterior (P), **puborectalis (PR)**

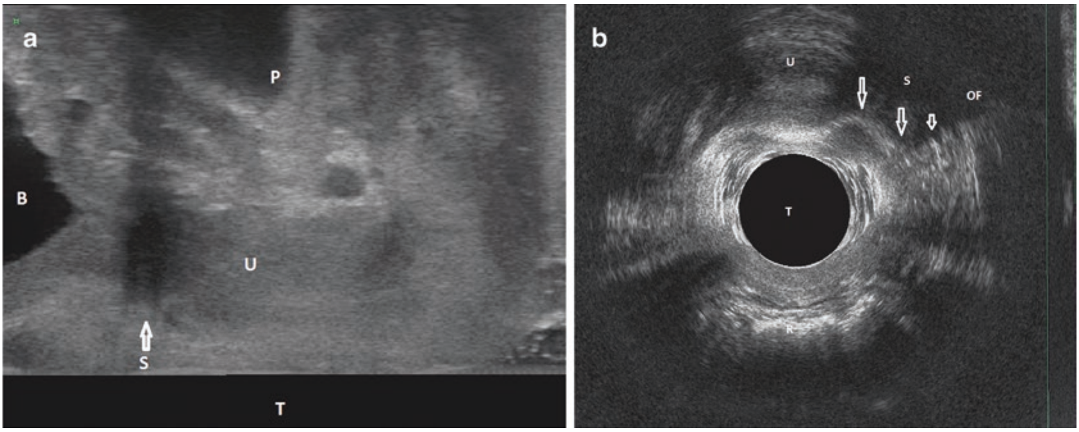

Fig. 10.15 (**a**) 180° scan of the anterior compartment: transobturator sling bunched and shifted proximally. Bladder (B), urethra (U), pubic symphysis (P), probe (T), transobturator sling (S); (**b**) 360° scan. 3D data volume manipulated in an oblique plane to demonstrate single incision sling twisted near its insertion. Urethra (U), rectum (R), probe (T), obturator foramen (OF), single incision sling (S)

Conclusions and Future Research

Multicompartmental 3D ultrasound imaging can be useful in the diagnosis and treatment of patients with complications and failure related to synthetic slings used for incontinence surgery. Assessment of the 3D data volumes obtained using the different probes and 2D dynamic assessment films adds entirely new spectra to understanding functional anatomy in the patient. The convenience with which pre- and post-treatment imaging data can be obtained and archived can help to maintain a visual record of the patient's pelvic floor treatment history. Thus multicompartment 3D imaging adds multiple dimensions to the diagnosis and treatment of the urogynecology patient, especially in patients in whom synthetic implants have been used. Perhaps this is the most important contribution of this technology: allowing the surgeon to better understand the goals of sling surgery and to avoid many common pitfalls.

But this is just the beginning. The potential uses have already made 3D multicompartmental imaging the diagnostic standard for management of problems related to synthetic implants. There is ample evidence currently supporting the routine use of endovaginal ultrasound imaging in such patients. It is necessary to conduct research whereby the efficacy of endovaginal ultrasound in imaging and diagnosing problems is established and compared to that of transperineal ultrasound. There is good consensus on the terminology and various measurements that can be made using 3D EVUS. Prospective studies are needed to validate the results of various retrospective studies in literature, especially prospective randomized studies in which treatment with/without 3D EVUS is compared to understand the effectiveness of its use in routine practice. Given the improved understanding of functional anatomy obtained with the 2D dynamic assessment films, ultrasound imaging is able to significantly enhance our understanding of the mechanism of action of various slings used and therefore potentially help develop better treatments.

This technology has become a part of routine practice for those who have mastered the 3D ultrasound methodology. Widespread use in places such as developing countries will depend on cost-effectiveness, availability of teaching resources, and dissemination of the knowledge about the clinical value of 3D EVUS.

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