Pelvic floor dysfunction refers to disorders of the pelvic floor characterized by a combination of pelvic floor relaxation, pelvic organ prolapse, and urinary or fecal incontinence or obstruction (Fig 1). These syndromes are frequently accompanied by pelvic pain and sexual dysfunction (1–5).

Stress urinary incontinence is one of the most common manifestations of pelvic floor disorders, with a prevalence of 8.5%–38.0% (6). First-line treatment includes behavioral modifications such as fluid and diet changes or bladder training, and pelvic floor physical therapy, whereas surgical therapy is reserved for failed conservative treatment. The surgical treatment of choice is the placement of a synthetic midurethral sling, also known as a mesh (Fig 2). The goal is to support the midurethra at times of increased abdominopelvic pressure (7–10). The traditional Burch colposuspension and pubovaginal fascial sling placement are commonly reserved for patients with previous complications related to mesh or those who require additional pelvic floor operation (7). Midurethral sling placement for stress urinary incontinence (Fig 2) has excellent outcome, with greater than 80% 5-year objective and subjective cure rate with both retropubic and transobturator approaches (11,12,13).

Complications of midurethral sling repair can be intraoperative (eg, organ injury), early postoperative (eg, bleeding or urinary retention), or delayed, which result in new symptoms after a relatively symptom-free postoperative period (7,13). Delayed complications are usually related to mesh migration, disintegration, and degrees of so-called perforation into the pelvic organs, most commonly the urethra (7,12,13). Because the terms exposure, extrusion, or erosion are inconsistently used in literature (14–16), we will hereby collectively refer to all these complications as erosion. The etiologic cause of erosion is multifactorial, including operative and patient tissue factors. When symptomatic treatment consists of surgical exploration, removal of synthetic material, and defect repair. Whereas the reported incidence of mesh erosion is as high as 19%, the mean incidence of mesh erosion was reported as approximately 3% in a recent meta-analysis (13). The routine preoperative diagnostic modality is cystourethroscopy.
Additional mesh imaging for diagnosis and optimal surgical planning is only performed at select centers. Imaging usually consists of TL US, which has been reported to be a sensitive technique for viewing synthetic mesh products in the periurethral region (Fig 3, Appendix E1 [online]) (17–23). To our knowledge, the diagnostic performance of TL US has not been studied in a large cohort of women with surgical confirmation of the sonographic findings.

The purpose of our study is to evaluate the diagnostic performance of TL US in the detection of pelvic organ erosion with cystourethoscopic and intraoperative correlation.

Materials and Methods

The study was approved by the institutional review board, and is compliant with the Health Insurance Portability and Accountability Act with waiver of informed consent.

A retrospective observational study was performed at a subspecialized tertiary university hospital referral center, where women suspected of having sling erosion who previously underwent placement of midurethral slings at a variety of outside institutions were referred or self-referred. The study cohort, derived from the institutional surgical database, was composed of women who underwent surgical intervention for complications in the setting of previously placed synthetic midurethral slings for stress urinary incontinence with preoperative TL US and cystourethroscopy.

The reference standard (ie, ground truth) for determination of sling erosion into pelvic organs was on the basis of findings at surgical exploration by the operating attending specialist urologist. As part of routine practice, the surgeon was aware of all available preoperative TL US and cystourethroscopy results, and patient clinical findings (history, physical examination, and additional clinical data). At our institution, one of two attending urologists performed over 90% of the surgeries for women suspected of having mesh complications.

The mesh complication database for all patients in the study cohort included age, parity, symptom-profile (pelvic pain, dysuria, urinary obstruction, hematuria, urinary tract infections, dyspareunia, and other or unknown), mesh placement technique (approach, type of mesh, year of placement), presence or absence of sling erosion intraoperatively, and preoperative imaging results (TL US, cystourethroscopy).

TL US studies (Fig 3) were performed in an American College of Radiology–accredited university US department by trained institutionally used sonographers (previous experience, >300 examinations) by using contemporary US systems (Epic or IU22 Philips, Bothell, Wash) with curved 3–6 MHz transducers. With the patient in dorsal lithotomy position, longitudinal (sagittal) and transverse (coronal) two-dimensional gray-scale and three- or four-dimensional static images were obtained at rest, followed by sagittal dynamic cine images with cough, Valsalva maneuver, and Kegel pelvic floor muscle contraction (17,18). For additional

Figure 1: Illustration shows the anatomy of the (a) pelvis and (b) pelvic floor. The pelvis is composed of four major organ compartments: anterior (1, bladder and urethra), middle (2, uterus and vagina), posterior (3, rectum and anus), and superior (4, peritoneum). The pelvic floor is the inferior boundary of the pelvis consisting of connective tissue and the pelvic diaphragm muscle complex, which includes the pubococcygeus (*), ileococcygeus (**), and the ischiococcygeus muscles (***)

Figure 2: Illustration shows common midurethral sling insertion techniques for stress urinary incontinence. (a) Retropubic approach and (b) transobturator approach. The anatomic location of the blue sling material (*) is shown with respect to the public symphysis (0) and urinary bladder of urethra (1).
Radiologists were trained regarding the definition of sling location, and comprehension was confirmed with illustrative drawings and normal and abnormal sonographic examples (not included in the analysis). The radiologists were then provided with a randomized list of patients included in the study cohort and blinded to the clinical information and the intraoperative findings (ie, manifestation of sling erosion). The studies were reviewed in their entirety (including static, dynamic, and three- and four-dimensional images) and a final assessment of mesh location was performed for each study. Because this was a retrospective study of patients with prior operations (many of which with multiple prior surgical procedures), there were no normal examinations available (ie, women who had midurethral sling placed with subsequent resolution of stress urinary incontinence).

Mesh location (Fig 4) was defined as extraluminal (if a fat plane was seen between the mesh and a pelvic organ), mural (if the mesh abutted or invaded the organ wall without identifiable intervening fat plane, but without definite intraluminal protrusion), and intraluminal (if the mesh clearly protruded into a pelvic organ). The exact suburethral anatomic location of the mesh (eg, proximal, mid, or distal urethra), mesh migration, or fragmentation were not specifically described in our study, although an attempt is usually made to describe these findings in routine clinical practice. For the purposes of

**Figure 3:** Longitudinal (sagittal) static gray-scale translabial US images with labeled overlay (B) of pelvic and perineal anatomy. Translabial US is performed with 3–6-MHz curved probes in dorsal lithotomy position.

**Figure 4:** Longitudinal (sagittal) gray-scale translabial US images with labeled overlays help to identify mesh fragments (arrows) at different locations with respect to the urethra. A, B, Intraluminal location; mesh fragment is visible within the urethral lumen. C, D, Extramural location; mesh fragment is outside the urethra, separated by a distinct hypoechoic fat plane (*). E, F, Mural location; mesh fragment is inseparable from urethral wall, but without definite intraluminal extension.
analysis, the following two sonographic definitions of mesh erosion were used: A narrower, high-specificity definition of mesh erosion included only those cases in which intraluminal location of the mesh product was detected at TL US; and a broader, high-sensitivity definition also included cases with mural location of mesh material in addition to the cases with intraluminal mesh product location (Fig 5). The cystourethroscopy reports were reviewed retrospectively by an urologist to identify the cases with erosion at cystourethroscopy. Of note, the urologist who originally performed the cystourethroscopy was generally unaware of the TL US findings, which may or may not have been available at the time of the cystourethroscopy.

The diagnostic performance of TL US and cystourethroscopy was evaluated by calculating sensitivity, specificity, positive and negative predictive values, as well as accuracy, with corresponding 95% confidence intervals (24). The consensus interpretation was recorded and the interobserver agreement was evaluated by using the Cohen \(k\) statistic (25). Data analysis was performed by using Excel (Microsoft Corporation, Redmond, Wash) and the Evidence-Based Medicine Toolbox (https://ebm-tools.knowledgetranslation.net/calculator).

**Results**

The study cohort (Table 1, Fig 6) consisted of 124 consecutive women (mean age, 57.5 years \(\pm\) 11.1 [standard deviation]; age range, 31–85 years) suspected of having sling erosion who underwent surgical intervention at our university hospital between 2008 and 2016 in the setting of suspected erosion of previously placed synthetic midurethral slings at outside institutions and had available preoperative imaging.

All women previously underwent midurethral sling placement without or with revision between 1999 and 2012 at a variety of outside institutions. The surgical placement techniques were as follows: transobturator approach in 43 of 124 women (34.6%), retropubic approach in 42 of 124 women (33.8%), or other approach (single-incision, multiple surgeries of revisions, or unknown procedure of mesh product) in 39 of 124 women (31.4%). At least 15 different types of synthetic mesh products were used, and the most common ones were the Gynecare Tension-free Vaginal Tape (Ethicon, Sommerville, NJ) and the Monarc (American Medical Systems, Minnetonka, MN). None of the patients had known significant intraoperative or immediate perioperative complications after their initial sling placement or previous revisions (bleeding > 500 mL, sepsis, known neurovascular injury), but 100% of patients (124 of 124) developed new pelvic floor-related symptoms leading to second opinion evaluation and subsequent surgical exploration at our institution. In decreasing order of frequency (Fig 7), these pelvic symptoms included the following: pelvic pain in 58.8% of patients (73 of 124); dyspareunia in

---

**Table 1: Study Cohort Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of women</td>
<td>124 (100)</td>
</tr>
<tr>
<td>Mean age (y)*</td>
<td>57.5 (\pm) 11.1 (31–85)</td>
</tr>
<tr>
<td>No. of parous women</td>
<td>110 (89)</td>
</tr>
<tr>
<td>No. of synthetic mesh types</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Placement approach</td>
<td></td>
</tr>
<tr>
<td>Transobturator</td>
<td>43 (35)</td>
</tr>
<tr>
<td>Retropubic</td>
<td>42 (34)</td>
</tr>
<tr>
<td>Other</td>
<td>39 (31)</td>
</tr>
</tbody>
</table>

Note.—Except where otherwise indicated, data in parentheses are percentages. Eligibility was history of midurethral synthetic mesh placement, delayed complications requiring surgical exploration, and availability of preoperative imaging examinations (ie, translabial US).

* Data in parentheses are range.
urethra and/or the bladder were involved in all these cases (Fig 5). No other organ involvement (ie, bowel and/or vagina) was noted at operation. Preoperative cystourethroscopy helped to detect 10 of these 15 cases of mesh erosion by visualizing mesh products within the urethral and/or urinary bladder lumen. TL US helped to detect eight of 15 cases of mesh erosion into the urethra or urinary bladder if intraluminal mesh location was used as the definition of mesh erosion (high-specificity definition) compared with 14 of the 15 cases if both intraluminal and mural cases were considered to be erosion (high-sensitivity definition). No other complication or other organ perforation (ie, vaginal and/or colorectal) was noted at TL US.

The diagnostic performance of TL US for the detection of mesh erosion was dependent on the sonographic definition of erosion. When the high-specificity definition was used (ie, only cases with intraluminal visualization of mesh products), the specificity (100%) and positive predictive value (100%) were similar to cystourethroscopy, but sensitivity (53%) was lower than cystourethroscopy, likely because of technique. When the high-sensitivity definition was used (ie, mural and intraluminal detection of mesh products), sensitivity improved to 93% because of the inclusion of superficial erosions, but specificity decreased to 72% and the positive predictive value decreased to 32%. Of note, the negative predictive value was high for both definitions of mesh erosion (high specificity and high sensitivity, 94% and 99%, respectively).

41.9% of patients (52 of 124); urinary obstruction in 41.1% of patients (51 of 124); urinary tract infections in 41.1% of patients (51 of 124); dysuria in 27.4% of patients (34 of 124); hematuria in 25.8% of patients (32 of 124); and other symptoms in 16.1% of patients (20 of 124), such as back or groin pain, incontinence, or prolapse. Of note, 104 of 124 women (83.8%) reported more than one symptom and 110 of 124 women (88.7%) were parous.

At surgical exploration, mesh erosion was diagnosed in 15 of 124 women (12.1%; reference standard definition of erosion). The

Figure 6: Study design flowchart. The diagram demonstrates the number of women identified by translabial US and cystourethroscopy.

Figure 7: Symptom profile. All women (n = 124) in the study cohort presented with recurrent pelvic symptoms, which are shown in decreasing frequency.
The complete performance data (sensitivity, specificity, positive predictive value, negative predictive value, and accuracy) for both cystourethroscopy and TL US are in Table 2.

<table>
<thead>
<tr>
<th>Erosion by Operation</th>
<th>Positive Findings</th>
<th>Negative Findings</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion at TL US</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraluminal and mural sling location</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive findings</td>
<td>14*</td>
<td>1†</td>
<td>93 (89, 98)</td>
<td>72 (65, 80)</td>
<td>32 (24, 40)</td>
</tr>
<tr>
<td>Negative findings</td>
<td>30‡</td>
<td>79§</td>
<td>99 (97, 100)</td>
<td>76 (68, 83)</td>
<td></td>
</tr>
<tr>
<td>Diagnostic performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraluminal sling location only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive findings</td>
<td>8*</td>
<td>7†</td>
<td>53 (45, 62)</td>
<td>100 (97, 100)</td>
<td></td>
</tr>
<tr>
<td>Negative findings</td>
<td>0‡</td>
<td>109§</td>
<td>94 (90, 98)</td>
<td>95 (91, 99)</td>
<td></td>
</tr>
<tr>
<td>Diagnostic performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion at cystourethroscopy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive findings</td>
<td>10*</td>
<td>5†</td>
<td>67 (58, 75)</td>
<td>100 (97, 100)</td>
<td></td>
</tr>
<tr>
<td>Negative findings</td>
<td>0‡</td>
<td>109§</td>
<td>96 (92, 99)</td>
<td>97 (94, 100)</td>
<td></td>
</tr>
</tbody>
</table>

Notes.—Data in parentheses are 95% confidence intervals. The 95% confidence intervals were established on the basis of the simple asymptotic formula (https://ebm-tools.knowledgetranslation.net/calculator/diagnostic). Intraluminal and mural sling location is a high-sensitivity definition; intraluminal sling location only is a high-specificity definition. The study cohort consisted of 124 consecutive women who were symptomatic for sling erosion. Erosion at TL US (intraluminal and mural sling location) high-sensitivity definition: intraluminal + mural = positive findings; extramural = negative findings. Erosion at TL US (intraluminal sling location only) high-sensitivity definition: intraluminal = positive findings; extramural + mural = negative findings. TL = translabial.

As we expected, when mesh fragments were directly viewed within the urinary bladder or urethral lumen, both TL US and cystourethroscopy were highly specific in helping to predict mesh erosion (100% specificity and 100% positive predictive value). However, mesh fragments outside the lower urinary tract or with only superficial erosion into the organ wall without intraluminal extension cannot be viewed at cystourethroscopy because of obscuration by inflammatory changes, edema, underdistended tissue, or mucosal folds. This is reflected in the lower sensitivity of cystourethroscopy (67%). At intraoperative exploration, removal of superficially-eroded intramural mesh fragments could easily leave an organ defect that would necessitate surgical repair. TL US may improve sensitivity to 93% when mural location of mesh products is detected at the cost of decreased specificity (72%). This leads to improved management of patient expectations because the manifestation of erosion can be associated with multiple additional pelvic surgeries and prolonged indwelling urinary catheterization, which can affect the length of hospitalization, quality of life, and subsequent morbidity. TL US also provides excellent images of extramural mesh products, which is associated with high negative predictive value (94 and 99%) for erosion. Although cystourethroscopy showed similar high negative predictive value...
(96%), this would be expected to be lower if more superficial erosions happened. Finally, the localization of mesh fragments in the periurethral tissues at TL US leads to better surgical planning by helping to guide surgical incision and exploration.

TL US imaging complements cystourethroscopy by not only providing better sensitivity in the detection of erosion when minimal mucosal changes are noted, but also by creating a roadmap for subsequent surgical repair and improving patient management. As a screening test, TL US is also preferred over MRI because it is less expensive and more widely available. Optimized MRI sequences show potential, but they have yet to be validated to help detect suburethral mesh products and erosions. CT in general has a limited role in pelvic floor imaging, with the exception of evaluation for immediate postoperative complications.

Whereas the symptom profile was recorded for all patients, a case-control analysis correlating the symptoms, the type of mesh used, or the type of surgical approach was deemed unreliable for several reasons. First, pelvic floor symptoms are multifactorial and subjective in nature. Second, many women in the study cohort underwent multiple surgical revisions or multiple sling products placed at outside institutions before they were referred to our center. Third, the number of mesh erosions proven at operation was too low for subgroup analysis.

Our study had several limitations. First, it was a retrospective observational study in which the results will need to be validated prospectively. Second, the study reflected the experience of a single, high-volume, subspecialty referral center and the results may only apply in this setting. Therefore, given the technical challenges, it is possible that the performance of TL US may be less robust in routine clinical practice with a less experienced team of sonographers, radiologists, and surgeons. Dedicated sonographers and ongoing feedback at multidisciplinary meetings may be necessary to reproduce outside subspecialized centers to achieve high performance and consistency. Third, whereas the size of the study cohort was sufficient for our analysis, the variation reported may only apply in this setting. Therefore, given the technical challenges, it is possible that the performance of TL US may be less robust in routine clinical practice with a less experienced team of sonographers, radiologists, and surgeons. Dedicated sonographers and ongoing feedback at multidisciplinary meetings may be necessary to reproduce outside subspecialized centers to achieve high performance and consistency. Third, whereas the size of the study cohort was sufficient for our analysis, the percentage of true mesh perforations was low, despite the large referral volume to our center specializing in mesh revision surgical procedures. Finally, the rate of organ erosion in the current study cohort was 12%, which was within the reported range (up to 19%), but higher than the expected 3% for the general population likely because of the higher pretest probability that is observed in a subspecialty referral center. The variation reported in literature was partially because of inconsistent terminology and reporting, which is a known limitation. Because the performance parameters are dependent on prevalence, they may be different in another patient population.

In conclusion, our retrospective study of 124 symptomatic women who underwent surgical exploration in the setting of failed midurethral sling placement for stress urinary incontinence demonstrates that TL US performed by experienced sonographers in a subspecialty hospital center is a good imaging tool for the detection and localization of mesh products and has a complementary role to cystourethroscopy for optimal patient management.

Acknowledgments: We thank the UCLA Radiology Department Ultrasound Section for their tremendous work in building a successful mesh imaging program. We also thank Leah Nakamura, MD, for creating the initial surgical database.

Author contributions: Guarantors of integrity of entire study, K.A.V., S.A.C., S.S.R.; study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, K.A.V., S.A.C., N.K., S.S.R.; clinical studies, K.A.V., S.A.C., N.K., S.R., S.S.R.; statistical analysis, K.A.V., L.S.; and manuscript editing, K.A.V., S.A.C., L.S., N.K., S.S.R.

Disclosures of Conflicts of Interest: K.A.V. disclosed no relevant relationships. S.A.C. Activities related to the present article: disclosed no relevant relationships. Activities not related to the present article: author is a consultant for Allergan, Trophikos, and MicrobeDx; gave lectures for the Medical Educations Speakers Network and the Los Angeles Radiologic Society. Other relationships: disclosed no relevant relationships. L.S. disclosed no relevant relationships. S.R. disclosed no relevant relationships. S.S.R. disclosed no relevant relationships.

References