

University of Szeged
Albert Szent-Györgyi Medical School
Doctoral School of Clinical Medicine

FUNCTIONAL ASSESSMENT OF SUBURETHRAL
TISSUE BIOMECHANICS USING STANDARDIZED
STRAIN ELASTOGRAPHY IN WOMEN WITH
STRESS URINARY INCONTINENCE

PhD Thesis Booklet

Lóránt Csákány, M.D.

Supervisors

Norbert Pásztor, M.D., PhD, habil.

Prof. Gábor Németh, M.D., PhD, habil.

Szeged

2026

PUBLICATIONS

Csákány L, Kozinszky Z, Kovács F, Krajczár S, Várbíró Sz, Keresztúri A, Németh G, Surányi A, Pásztor N. *Evaluation of Suburethral Tissue Elasticity Using Strain Elastography in Women with Stress Urinary Incontinence.*

JCM. 2025 Aug 8;14(16):5617.

doi:10.3390/jcm14165617

Original article

SJR: Q1; IF: 2.9

Csákány L, Surányi A, Kovács F, Várbíró Sz, Németh G, Keresztúri A, Pásztor N. *Strain Elastography in Urogynecology: Functional Imaging in Stress Urinary Incontinence.* Women. 2025 Dec;5(4):48.

doi:10.3390/women5040048

Review article

IF: 1.6

Csákány L, Pásztor N, Németh G, Várbíró Sz, Surányi A. *Identifying Weak Points of the Pelvic Floor by Sonoelastography in Stress Urinary Incontinence. Ultrasound in Obstetrics & Gynecology*, 64(Suppl. 1): 97–98 (2024). doi: 10.1002/uog.27990

Conference abstract

Σ IF: 4.5

1. INTRODUCTION

Stress urinary incontinence (SUI) is a common pelvic floor disorder that significantly affects women's quality of life. It is defined as involuntary urine leakage during physical exertion, coughing, or sneezing, reflecting the inability of urethral closure mechanisms to counteract increases in intra-abdominal pressure. SUI is increasingly considered a functional disorder of the pelvic floor support system rather than an isolated urethral dysfunction. Continence depends on the coordinated interaction of connective tissues, pelvic floor muscles, and neural control. Structural changes in periurethral tissues—caused by childbirth, aging, hormonal alterations, and chronic mechanical loading—may reduce tissue stiffness and impair suburethral support. Continence is now understood as a dynamic biomechanical model. According to DeLancey's hammock hypothesis, urethral closure relies on an intact suburethral support layer, with the midurethra playing a key role. Conventional ultrasound imaging primarily assesses anatomical structures and does not directly capture tissue biomechanics, thereby limiting the detection of functional abnormalities. Elastography

enables the in vivo assessment of tissue stiffness. Strain elastography (SE) provides qualitative and semi-quantitative information on relative tissue stiffness based on tissue deformation, whereas shear wave elastography (SWE) quantitatively assesses tissue stiffness, expressed as shear wave velocity (m/s) or as values derived from the Young's modulus (kPa).

2. AIMS AND OBJECTIVES

The aim of this study was to evaluate the feasibility, reproducibility, and diagnostic utility of introital SE for the in vivo functional assessment of suburethral tissues in women with pure SUI.

The dissertation comprises two complementary components:

I. Prospective observational cohort study: comparison of women with SUI and continent controls using standardized introital SE with predefined regions of interest (ROIs) and internal reference tissue normalization.

II. Structured literature review: evaluation of elastography in pelvic floor disorders associated with SUI in the context of current international evidence.

Specific objectives:

1. **Protocol development:** to establish a standardized and reproducible SE protocol.
2. **Biomechanical characterization:** to assess level-specific differences at the internal urethral orifice (IUO), midurethra (MU), and external urethral orifice (EUO).
3. **Diagnostic evaluation:** to determine diagnostic performance using ROC (receiver operating characteristic) curve analysis and to identify the most informative suburethral level.
4. **Measurement reliability:** to evaluate reproducibility using the intraclass correlation coefficient (ICC) and Cronbach's α .
5. **Literature synthesis:** to summarize current evidence on the application of elastography in SUI.

3. MATERIALS AND METHODS

3.1. Original prospective cohort study

A prospective observational cohort study was conducted between 16 August 2024 and 1 January 2025 at the Department of Obstetrics and Gynecology, Albert Szent-

Györgyi Medical School, University of Szeged, Hungary. Twenty women with clinically confirmed pure SUI were compared with 20 continent controls. Inclusion criteria included age ≥ 35 years and a positive cough stress test; controls were asymptomatic with a negative test. Exclusion criteria included pelvic organ prolapse, mixed incontinence, prior pelvic surgery, elevated postvoid residual urine, pregnancy, infection, malignancy, connective tissue disease, and inadequate image quality. Sample size calculation (G*Power; Cohen's $d = 0.7$; $\alpha = 0.05$; power = 80%) indicated 20 participants per group.

3.1.1. Strain elastography protocol

SE was used to assess relative suburethral tissue stiffness. The technique is based on controlled tissue deformation induced by externally applied compression, whereby softer tissues deform more than stiffer tissues under comparable loading conditions. Introital ultrasound was performed with the transducer placed at the level of the EUO and aligned parallel to the longitudinal body axis. The examination was conducted in the supine position, with the hips abducted and the knees slightly flexed to

facilitate relaxation of the pelvic floor musculature. Midsagittal B-mode images were obtained at rest and during Valsalva for visualization of the urethra, bladder neck, symphysis pubis, and anterior vaginal wall. Real-time color-coded elastograms were superimposed on B-mode images, enabling direct spatial correlation between anatomical structures and tissue elasticity. A dual-panel visualization mode displayed the B-mode image and the corresponding elastogram simultaneously (**Figure 1**).

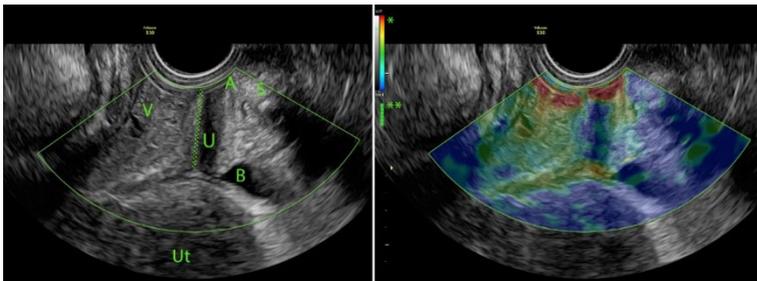


Figure 1. Introital B-mode ultrasound (left) and corresponding strain elastography image (right). Tissue stiffness is visualized using a color-coded strain scale (red/yellow = softer tissue; blue/green = stiffer tissue).

Legend: V: vagina; A: periurethral adipose layer; S: symphysis pubis; U: urethra; dotted line: suburethral support; B: bladder; Ut: uterus; *: stiffness scale; **: compression indicator.

System: GE Voluson S10 (BT18) with RIC5-9A-RS transvaginal transducer (GE HealthCare, Austria).

Bladder neck descent was measured relative to the inferoposterior symphyseal margin, urethral hypermobility was defined as displacement > 10 mm. Tissue deformation was quantified by analyzing changes in speckle patterns before and after compression. Compression quality was continuously monitored using the system's six-point strain indicator, which reflects elastographic signal quality and the adequacy of transducer compression.

Placement of regions of interest (ROIs)

For standardized assessment, circular ROIs (5 mm diameter) were placed at predefined anatomical locations between the urethra and the anterior vaginal wall, based on reproducible landmarks to enable level-specific analysis (Figure 2).

- **Yellow ROI:** periurethral adipose tissue, used as an internal reference for strain normalization
- **Blue ROI:** internal urethral orifice level, proximal suburethral region at the level of the bladder neck
- **Purple ROI:** midurethral level, suburethral support region with a key biomechanical role

- **Green ROI:** external urethral orifice level, distal suburethral region

Five measurements were obtained per ROI, and the maximum strain value was used for analysis.

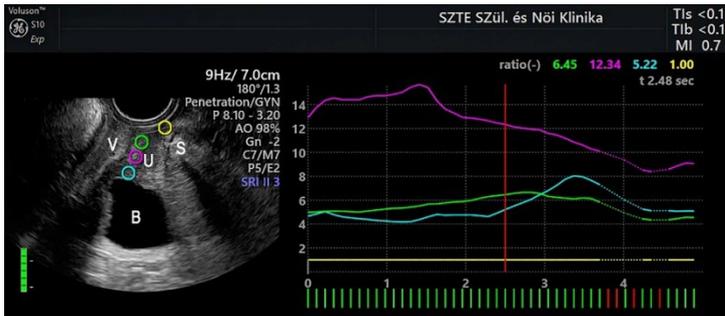


Figure 2. Anatomical locations of regions of interest (ROIs) for strain elastography (SE).

Legend: V: vagina; U: urethra; B: bladder; S: symphysis pubis. The blue ROI represents the suburethral tissues at the level of the internal urethral orifice (IUO). The purple ROI indicates the endopelvic fascia at the level of the midurethra (MU). The green ROI represents the suburethral tissues located near the external urethral orifice (EUO). The yellow ROI represents periurethral adipose tissue located between the EUO and the symphysis pubis and serves as an internal reference region for normalization of strain values. The strain–time curve illustrates the measurement process, with the vertical red line indicating the time point used for strain ratio calculation. The six-point strain indicator reflects signal quality and the adequacy of transducer compression.

3.1.2. Statistical analysis

Statistical analyses were performed using R (version 4.2.1). Continuous variables are presented as mean \pm standard deviation (SD), and categorical variables as percentages. Between-group differences were assessed using the χ^2 test, independent samples t-test, or Wilcoxon test, as appropriate. Differences across ROIs were analyzed using multivariate analysis of variance (MANOVA), adjusted for age and body mass index (BMI). Measurement reliability was evaluated using the ICC and Cronbach's α , and diagnostic performance was assessed using ROC curve analysis. A p-value < 0.05 was considered statistically significant.

3.2. Methodology of the structured literature review

A structured qualitative literature review was conducted to evaluate the application of SE in women with SUI, focusing on diagnostic performance, methodology, and biomechanical interpretation. A systematic PubMed search (January 2000–October 2025) was performed using predefined keyword combinations (“strain elastography” AND “female stress urinary incontinence”; “stress

incontinence” AND “elastography”). The search was limited to peer-reviewed English-language articles. Studies were included if they assessed the elastic properties of periurethral or pelvic floor tissues in adult women. Due to the limited number of SE studies and substantial methodological heterogeneity, quantitative synthesis was not feasible; therefore, findings were interpreted qualitatively. Selected SWE studies and relevant international guidelines were included to provide broader methodological context.

4. RESULTS

4.1. Results of the original prospective cohort study

A total of 40 women were included (20 SUI, 20 controls). Body weight and BMI were higher in the SUI group. During Valsalva, urethral hypermobility and funneling were observed in 60% and 40% of women with SUI, respectively. SE revealed significantly higher strain values in the SUI group across all regions ($p < 0.05$), indicating reduced tissue stiffness. The greatest difference was observed at the MU level. MANOVA confirmed a significant group effect (Wilks' $\lambda = 0.588$; $F(3,35) =$

8.189; $p < 0.001$). Reproducibility was excellent (Cronbach's $\alpha > 0.95$; high ICC values). ROC analysis demonstrated the highest diagnostic performance at the MU level (AUC = 0.813), followed by the EUO (0.763) and IUO (0.728).

4.2. Results of the structured literature review

Of 19 identified studies, 12 met the inclusion criteria. The application of SE for suburethral assessment in SUI remains limited, highlighting the underrepresentation of direct biomechanical evaluation. Across studies, women with SUI consistently demonstrated altered periurethral or pelvic floor biomechanics, characterized by reduced tissue stiffness, increased deformability, and impaired load-dependent support.

5. DISCUSSION

SUI is a functional disorder of the pelvic floor support system in which impaired load transfer plays a central role. Conventional ultrasound primarily provides morphological information, underscoring the need for functional imaging methods capable of *in vivo*

biomechanical assessment. Women with SUI demonstrated higher strain values across all suburethral regions (IUO, MU, EUO), indicating reduced tissue stiffness and increased deformability. The most pronounced difference and highest diagnostic performance were observed at the MU level, supporting its central biomechanical role. Increased deformability reflects reduced mechanical resistance and may impair effective pressure transmission to the urethra during increases in intra-abdominal pressure. A major strength of this study is the excellent reproducibility of the standardized SE protocol, supported by high ICC and Cronbach's α values. The use of predefined ROIs with internal reference normalization reduced measurement variability and enabled reliable, level-specific assessment. These findings indicate that introital SE is a feasible, reproducible, and clinically informative method for in vivo assessment of suburethral biomechanics. Given the limited number of previous SE studies, this field remains underexplored. The present study provides novel in vivo evidence of impaired suburethral support in SUI, consistent with DeLancey's hammock hypothesis and

prior SWE findings. From a clinical perspective, SE may complement routine pelvic floor ultrasound by providing additional functional information. Region-specific stiffness patterns may improve understanding of SUI pathomechanisms and support evaluation of treatment outcomes.

6. CONCLUSION

Standardized introital SE is a feasible and reproducible method for the in vivo functional assessment of suburethral tissues in women with SUI. Increased suburethral deformability was observed in SUI, particularly at the MU level, indicating impaired suburethral support. Introital SE may represent a promising tool for the diagnosis of SUI and for monitoring therapeutic effectiveness.