The Application of Shear Wave Elastography to Determine the Elasticity of the Levator Ani Muscle and Vaginal Tissue in Patients With Pelvic Organ Prolapse

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Objectives—The changes of the extracellular matrix of the connective tissue have significantly contributed to the incidence of pelvic organ prolapse (POP). It seems reasonable that sonoelastography could be a useful tool to evaluate the elasticity of pelvic floor tissue in patients with POP and compare it to those without POP. The main aim of this pilot study was to determine if there are differences in the elasticity of the levator ani muscle (LAM) and vaginal tissue between patients with and without POP.

Methods—Prospective observation study, including 60 patients (30 with POP and 30 without POP). Sonoelastography was performed to evaluate the elasticity (in kilopascals, kPa) of the following regions of interest: vagina at the level of middle third of the urethra; vagina at the level of the bladder trigone; vagina in the anterior and posterior fornix; vagina at the level of middle third of the anorectal canal; posterior third of the LAM.

Results—A total of 60 patients completed the study (30 with POP, 30 without POP). In the POP group, 18/30 (60%) had an anterior vaginal wall prolapse, 3/30 (10%) a uterine prolapse, 15/30 (50%) a rectocele, and 6/30 (20%) a enterocele. Patients with POP had higher elasticity in all anatomical study areas, with statistically significant differences in the anterior fornix (13.6 vs 11.2 kPa; *P*: .012). A multiple regression (controlling age, menopausal stage, and parity) allowed to detect statistically significant differences in the elasticity of the middle third of the urethra (*P*: .03) and the middle third of the anorectal canal (*P*: .019).

Conclusion—It is possible to evaluate the elasticity of the LAM and vaginal tissue using sonoelastography, detecting a higher elasticity in patients with POP than in those without POP.

Key Words—elasticity; levator ani muscle; pelvic organ prolapse; sonoelastography; vaginal

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Abbreviations
BMI, body mass index; CIs, confidence intervals; ICS POP-Q, International Continence Society Pelvic Organ Prolapse Quantification; LAM, levator ani muscle; POP, pelvic organ prolapse

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Pelvic organ prolapse (POP) is defined as the descent of one or more of the anterior vaginal wall, posterior vaginal wall, the uterus (cervix) or the apex of the vagina (vaginal vault or cuff scar after hysterectomy).[1] The pathophysiology behind the origin of POP is difficult to pinpoint as there are several factors involved such as the musculature, ligaments and other supporting tissue of the pelvic floor. Numerous risk factors have been described for the appearance of POP, mainly associated with damage of pelvic floor muscles and connective tissue, which are directly caused by pregnancy and vaginal delivery.[2,3] Amongst them, the changes of the extracellular matrix of the connective tissue have significantly contributed to the appearance of POP.[4,5] The most common types of collagen in the pelvic tissue are type I and III.[6] Type I collagen as a high resistance to traction, while type III provides more flexibility. Patients with POP have been described to possess changes in the proportion of collagen type and reticulation.[7,8] In fact, a recent meta-analysis showed that patients with POP have a lower expression of type I collagen than patients without POP,[9] without significant differences after stratification in terms of biopsy site (utero-sacral ligaments, cardinal ligaments, and vaginal tissue).[9] Furthermore, it must be remembered that POP is associated with the size of the muscular hiatus,[10] especially in cases of levator ani muscle (LAM) avulsion.[11–15] In fact, patients with POP more often have defects in the levator ani and generate less vaginal closure force during a maximal contraction.[12] It seems reasonable that, likewise, an increased elasticity of the LAM might facilitate the appearance of POP.

Sonoelastography has been established as a new ultrasound technique to assess tissue elasticity.[16–21] Tissue elasticity changes throughout pathological processes such as trauma, inflammation and tumors. Furthermore, the stiffness of any new formation associated with a higher risk for the appearance of dysplasias in the tissue studied.[22] The mechanism in which sonoelastography is based is in the evaluation of the deformation caused on the tissue by the pressure made, which is higher in softer tissues.[16–21] The pressure on the tissue may be made by either a light mechanic compression (strain elastography, SE), or ultrasound waves (shear-wave sonoelastography, SWE). Interpretation of the signal is software-analyzed, expressing the stiffness by either colors (qualitative or semi-qualitative) or numbers (quantitative).[17–23] Currently, sonoelastography is used in the assessment of several organs such as prostate, liver, breast, or uterine cervix.[24–31] However, its application to pelvic floor assessment is relatively unknown, with very few published studies.[32–34] It seems reasonable that sonoelastography should be an useful tool to evaluate the elasticity of pelvic floor tissue in patients with POP and compare it to those without POP, allowing in vivo knowledge of the characteristics of the tissues of patients affected by POP. Thus, the main aim of this pilot study was to determine if there are differences in the elasticity of the LAM and vaginal tissue between patients with and without POP.

Materials and Methods

Study Population

A pilot observational and prospective study was conducted, including 60 patients (30 with POP and 30 without POP), who were consecutively recruited (first 30 patients with POP and first 30 patients without POP) in the Gynecology Unit at the Valme University Hospital (Seville, Spain) between September 1, 2022 and December 31, 2022.

Subjects

Patients were consecutively recruited, including 30 patients with POP and 30 patients without pelvic floor dysfunctions. The patients were recruited from the general gynecology clinic by a single specialist gynecologist who performed the clinical examination of each of them. All patients with a prior history of pelvic floor corrective surgery, hysterectomy or pelvic radiotherapy were excluded from the study.

Clinical Examination

All patients were submitted to a physical examination after a directed medical history, to evaluate the type (anterior vaginal wall prolapse, uterine prolapse, rectocele, or enterocele) and stage of prolapse of each compartment, according to the pelvic organ prolapse quantification system of the international continence society (ICS-POP-Q). Stage 0: No prolapse is demonstrated. Stage I: Most distal portion of the prolapse is more than 1 cm above the level of the hymen. Stage II: The most distal portion of the prolapse is situated between 1 cm above the hymen and 1 cm below the hymen. Stage III: The most distal portion of the prolapse is more than 1 cm beyond the plane of the hymen but everted at least 2 cm less than the total vaginal length. Stage IV: Complete eversion or eversion at least within 2 cm of the total length of the lower genital tract is demonstrated.[1]

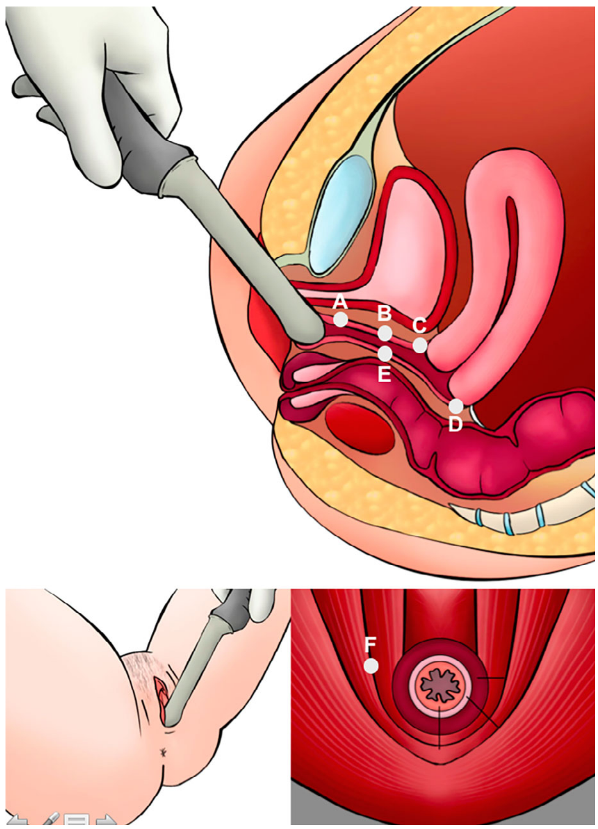
Ultrasound Assessment

The mechanism in which sonoelastography is based is in the evaluation of the deformation caused on the tissue by the pressure made, which is higher in softer tissues.[16–21] Ultrasound assessment was performed using a Toshiba Aplio i700 ultrasound scanner (Canon Medical systems, Japan) with a transvaginal probe with the following machine settings for sonoelastography: elastogram speed map between 6.5 cm/s (red) and 0.5 cm/s (blue) meters/second with blue being indicative of softer tissues; 11C3, diffT7, 0.4 fps, G: 100, DR: 75, SW 6, 10.0 k, SF: 1. The probe transvaginal prove was introduced without any pressure, and was placed to obtain a midsagittal plane of the different study areas: vagina at the level of middle third of the urethra; vagina at the level of the trigone; vaginal in the anterior and posterior fornix; vagina at the level of middle third of the anorectal canal (Figures 1 and 2). Afterwards, we obtained an axial plane of the anal canal at the level of the LAM, and then the probe was lightly tilted to the right side of the patient, capturing the posterior third of the LAM (Figures 1 and 2). First, we performed an anatomical ultrasonography evaluation in B mode. Then, the sonoelastography region of interest is centered on the study area and the shear wave activated to obtain an elastogram speed map with an adequate propagation, which is confirmed with the visualization of parallel lines in the study area in the wavefront propagation map. The elastogram map should stay stable for at least 3 seconds before obtaining the elasticity measurements. Measurements were made in each study area by means of a 2-mm circular study window to obtain the mean, standard deviation and median of the elasticity, in kilopascals (kPa). That way we obtained quantitative measurements of the anatomical study areas of the study.

Statistical Analysis

Numeric variables were summarized by means, median, and standard deviation, while percentages were used for qualitative variables. The Shapiro–Wilk test was used to evaluate the normality of the data. The Student's *t*-test or the non-parametric Mann–Whitney test was used according to the normality of the data. For the comparison between more than two study groups, the following tests were used: ANOVA test for parametric data with equal variances (Levene test); ANOVA test with Welch correction for parametric data with different variances; and Kruskal–Wallis test for non-parametric data. Finally, we performed multiple linear regression models predictive of elastography variables. The hypotheses of linearity, normality, independence and equality of variances were verified. Based on a previously published study,[34] we calculated the sample size needed to detect a difference of 20 kPa in the elasticity of the LAM between the groups with and without POP, considering a common standard deviation of 25 kPa, an 5% alpha error and a 10% beta error

Figure 1. Anatomical study areas in the midsagittal plane [vagina at the level of middle third of the urethra (**A**); vagina at the level of the trigone (**B**); vagina in the anterior fornix (**C**); vagina in the posterior fornix (**D**); vagina at the level of middle third of the anorectal canal (**E**)] and axial plane [posterior third of the LAM (**F**)].



(Power 90%). Thus, we needed at least 26 patients per study group.

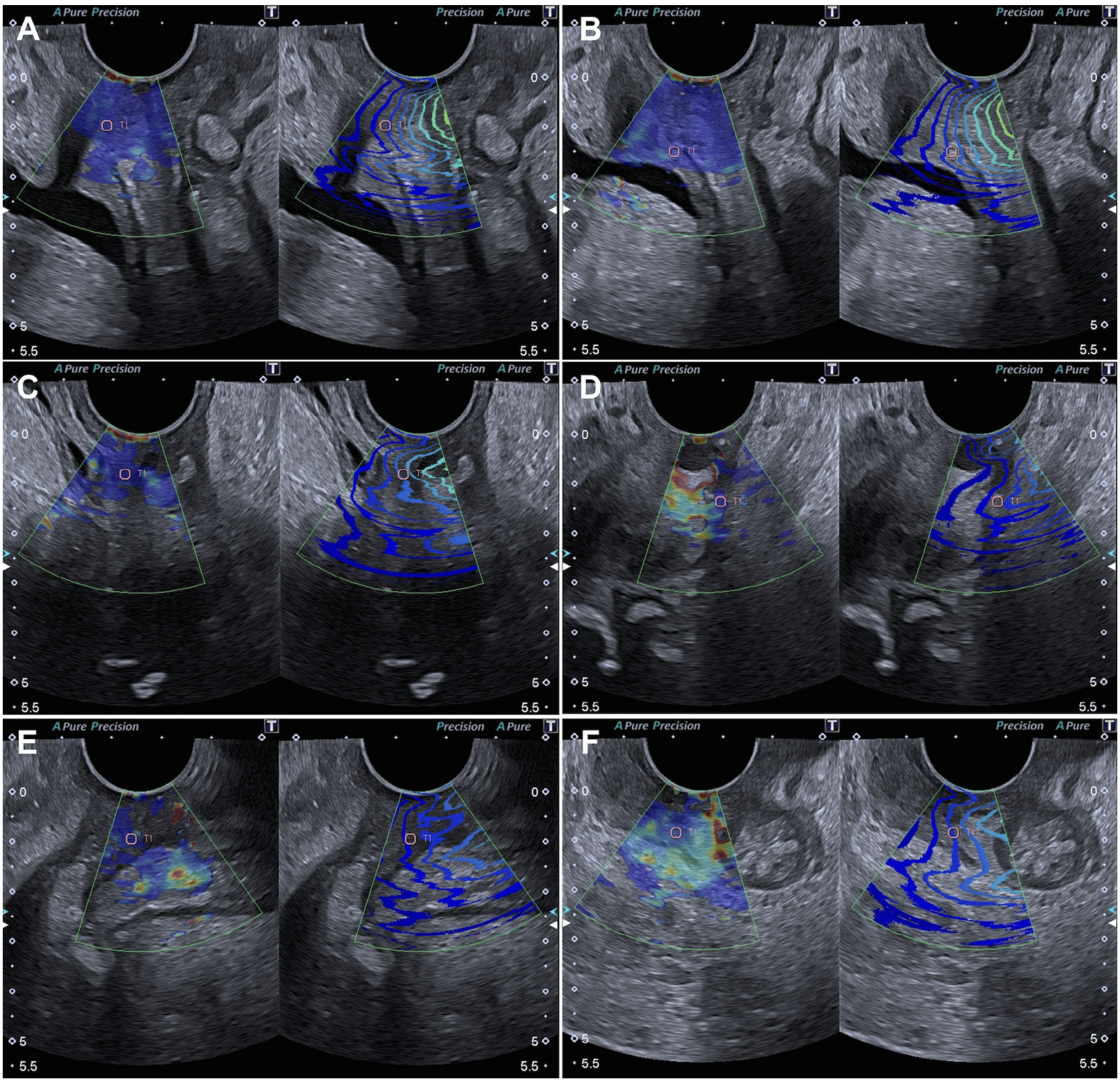
Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study (0554-N-21) was approved by the local Ethics and Research Committees on April 13, 2021. All patients gave their written informed consent before starting the study.

Results

A total of 60 patients completed the study: 30 patients with POP and 30 without POP. In the POP group,

Figure 2. Sonoelastographic captures of the anatomical study areas in the midsagittal plane [vagina at the level of middle third of the urethra (**A**); vagina at the level of the trigone (**B**); vagina in the anterior fornix (**C**); vagina in the posterior fornix (**D**); vagina at the level of middle third of the anorectal canal (**E**)] and axial plane [posterior third of the LAM (**F**)].



18/30 (60%) had an anterior vaginal wall prolapse [stage I: 3/30 (10%); stage II: 6/30 (20%); stage III: 9/30 (30%)], 3/30 (10%) a uterine prolapse [stage II: 3/30 (10%)], 15/30 (50%) a rectocele [stage II: 3/30 (10%); stage III: 12/30 (40%)], and 6/30 (20%) a enterocele [stage II: 3/30 (10%); stage III: 3/30 (10%)]. General characteristics of patients in both groups are displayed in Table 1. There were statistically significant differences between groups in terms of age (44.7 vs 56.6; $p < .0005$), parity (1.4 vs 2.3; $P < .0005$) and menopausal stage (20% vs 50% P: .029).

Sonoelastographic parameters are shown in Table 2. We can observe that patients with POP had values suggesting higher elasticity in all anatomical study areas, with statistically significant differences in the anterior fornix (13.6 vs 11.2 kPa; P: .012). However, when controlling age and parity with a multiple regression (Table 2) we can see that other areas also had statistically significant differences, such as the posterior fornix (P: .034) and LAM (P: .014).

Likewise, we performed the multiple linear correlation coefficient adjusting for age, menopausal stage, parity and POP (Table 3), observing statistically significant values in the vagina at the level of the middle third of the urethra (r: .531; P: .003), in the vagina in the anterior fornix (r: .563; $P < .001$), in the vagina at the level of the middle third of the anorectal canal (r: .420; P: .049) and in the posterior third of the levator ani muscle (r: .501; P: .008). Table 4 shows the

Table 1. General and Clinical Characteristics of the Patient Included

	Without Pelvic Organ Prolapse (n = 30)	With Pelvic Organ Prolapse (n = 30)	*P*	95% CI
Age (years)	44.7 ± 6.6	56.6 ± 5.6	<.0005	9.0 to 16.0
Parity	1.4 ± 0.5	2.3 ± 0.9	<.0005	0.6 to 1.4
Menopause	6/30 (20%)	15/30 (50%)	.029	−49.8% to −6.6%
Age menopause (years)	48.0 ± 7.7	48.2 ± 5.1	.850	−9.0 to 6.0
BMI	26.3 ± 3.1	28.4 ± 4.3	.184	−0.3 to 5.2

Table 2. Sonoelastographic Parameters

	Without Pelvic Organ Prolapse (n = 30)	With Pelvic Organ Prolapse (n = 30)	*P*	95% CI
Vagina at the level of the middle third of the urethra (kPa)	25.4 ± 10.6	24.2 ± 9.7	.663	−6.6 to 4.1
Vagina at the level of the trigone (kPa)	17.6 ± 8.8	15.9 ± 7.0	.706	−6.0 to 3.0
Vagina in the anterior fornix (kPa)	13.6 ± 3.7	11.2 ± 8.0	.012	−6.6 to −1.0
Vagina in the posterior fornix (kPa)	15.0 ± 4.4	14.2 ± 5.9	.537	−3.5 to 1.9
Vagina at the level of middle third of the anorectal canal (kPa)	14.5 ± 4.8	13.3 ± 4.2	.344	−3.0 to 1.4
Posterior third of the levator ani muscle (kPa)	28.2 ± 12.8	33.2 ± 26.7	.469	−7.0 to 9.4

Table 3. Sonoelastographic Parameters—Square Multiple Correlation Coefficient Adjusting by Age, Menopausal Stage, Parity, and POP

	R	*P*	95% CI
Vagina at the level of the middle third of the urethra (kPa)	0.531	.003	0.29 to 0.71
Vagina at the level of the trigone (kPa)	0.280	.407	−0.0001 to 0.52
Vagina in the anterior fornix (kPa)	0.563	<.001	0.34 to 0.73
Vagina in the posterior fornix (kPa)	0.376	.120	−0.001 to 0.59
Vagina at the level of middle third of the anorectal canal (kPa)	0.420	.049	0.16 to 0.63
Posterior third of the levator ani muscle (kPa)	0.501	.008	0.26 to 0.68

Table 4. Sonoelastographic parameters—Multiple Linear Regression Adjusting by Age, Menopausal Stage, Parity, and POP

	Constant (*P*)	Age (*P*); 95% CI	Parity (*P*); 95% CI	Menopausal Stage (*P*); 95% CI	POP (*P*); 95% CI
Vagina at the level of the middle third of the urethra (kPa)	76.1	−1.1 (.001); −1.7 to −0.5	−3.1 (.102)[a]; −6.8 to 0.6	16.3 (<.001); 7.8 to 24.7	9.3 (.030); 0.9 to 17.7
Vagina at the level of the trigone (kPa)	2.5	0.3 (.219)[a]; −1.7 to −0.5	3.0 (.844)[a]; −2.8 to 3.4	−0.5 (.887)[a]; −7.5 to 6.5	−5.8 (.098)[a]; −12.8 to 1.1
Vagina in the anterior fornix (kPa)	13.5	0.2 (.369)[a]; −1.7 to −0.5	−4.8 (<.001); −6.8 to 0.6	−0.1 (.980)[a]; 7.8 to 24.7	−1.0 (.701)[a]; 0.9 to 17.7
Vagina in the posterior fornix (kPa)	15.6	−0.03 (.872)[a]; −0.4 to 0.3	0.4 (.656)[a]; −1.5 to 2.4	3.6 (.114)[a]; −0.9 to 8.1	−2.7 (.220)[a]; −7.2 to 1.7
Vagina at the level of middle third of the anorectal canal (kPa)	1.4	0.4 (.021); 0.06 to 0.7	−0.7 (.399)[a]; −2.5 to 1.0	−3.9 (.055)[a]; −7.9 to 0.1	−4.8 (.019); −8.7 to −0.8
Posterior third of the levator ani muscle (kPa)	48.3	0.04 (.956)[a]; −1.3 to 1.4	−13.3 (.002); −21.3 to −5.4	−6.7 (.457)[a]; −24.8 to 11.4	17.2 (.060)[a]; −0.8 to 35.1

[a]Variables without predictive capacity.

multiple linear regression adjusting by age, menopause stage, parity, and POP.

Discussion

Patients with POP have a higher elasticity of vaginal tissue and LAM than patients without POP, as measured by sonoelastography. These sonoelastographic differences observed in patients with POP have been previously described in a study on the LAM.[34] In fact, it has been established that, in patients with POP, LAM elasticity is significantly higher in patients with POP at rest (27.9 vs 31 kPa; $P < .001$), and lower during Valsalva maneuver (57.3 kPa vs 53.1 kPa; $P < .05$), describing lower elastic changes between rest and Valsalva maneuver in patients with POP and patients without POP, given the lower passive stretching capacity of LAM in patients with POP.[34] This increased elasticity of the LAM in patients with POP could influence the presence of ballooning, being this hiatal ballooning is independent risk factors for symptoms and signs of prolapse..[35] Now, our study shows by sonoelastography that patients with POP also present a higher degree of elasticity of vaginal tissues than patients without POP, as in a previous work applying vaginal tactile imaging.[36] For correct sonoelastographic assessment, it is important to control the pressure exerted by the vaginal probe on the tissue to avoid erroneous measurements. To avoid this possible effect, we applied an elastogram speed map with an adequate propagation, confirming it with the visualization of parallel lines in the study area in the auxiliary wave front map (Figure 2).

Nevertheless, the integrity of the LAM is not the only mechanism behind POP, as it origin is also influenced by the quality of the ligament support[37] and collagen type.[7,8] A meta-analysis showed that patients with POP have a lower expression of type I collagen than patients without POP,[9] without significant differences after stratification in terms of biopsy site (utero-sacral ligaments, cardinal ligaments, and vaginal tissue).[9] This could support our general results, as we observed a higher elasticity of vaginal tissue in patients with POP. Although POP is influenced by age, the biomechanical evaluation of vaginal tissue showed little difference between pre and postmenopausal patients.[38] However, there are different in vaginal cells between premenopausal patients with and without POP.[39] Likewise, significant changes in the extracellular matrix have been observed in postmenopausal patients in contrast with premenopausal patients, which causes a lower resistance to traction in the uterosacral ligaments in the former,[40] with age being considered an influential factor in the diagnosis of POP.[41–43] Based on these premises, we adjusted our results controlling the age, menopausal stage and parity of patients, observed statistically significant differences in elasticity in the vagina at the level of the middle third of the urethra (r: .531; P: .003), in the anterior fornix (r: .563; $P < .001$), at the level of the middle third of the anorectal canal (r: .420; P: .049) and in the posterior third of the levator ani muscle (r: .501; P: .008). This increased elasticity in these specific areas might be explained by the type of POP that was included in the study as the majority were prolapse of the anterior and posterior compartment (30% anterior vaginal wall prolapse, 50% rectocele). We might presume that the high elasticity in these anatomical areas might enable the appearance of prolapse in these compartments. The main strength of this study was its novel design. To date, there are no other studies applying sonoelastography to evaluate vaginal elasticity in patients with POP. Currently, the lack of knowledge behind this aspect is quite relevant and, although we may not yet establish definite conclusions, these results pave the way for future studies in this field, where elasticity cutoff points are determined to optimize the type of treatment in each patient. The design of this work was based on the previously published study[34] in which we needed to recruit a small sample per study group. This might have facilitated the observed differences in the clinical characteristics of both study groups included, which might pose a limitation. However, we tried to reduce its impact on our results by controlling the age, parity, and menopausal stage when comparing study groups. However, with the data presented we cannot determine sonoelastographic values that allow us to make clinical decisions about our patients. Another limitation of this study is the small number of cases with uterine prolapse, which were all stage II. Furthermore, the measurement area could vary from patient to patient depending on the anatomical characteristics of each woman's vagina. In future studies that should include more severe prolapse in this compartment might show sonoelastographic differences between study groups, as well as determine the inter- and intraobserver variability of said technique.

Conclusions

In conclusion, we observed that it is possible to evaluate the elasticity of the LAM and vaginal tissue using sonoelastography, with a higher elasticity in patients with POP than in those without POP.

References

1. Bump RC, Mattiasson A, Bø K, et al. The standardization of terminology of female pelvic organ prolapse and pelvic floor dysfunction. *Am J Obstet Gynecol* 1996; 175:10–17. https://doi.org/10.1016/s0002-9378(96)70243-0.
2. Akın Y, Young M, Elmussareh M, Charalampogiannis N, Zen AS. The novel and minimally invasive treatment modalities for female pelvic floor muscle dysfunction; beyond the traditional. *Balkan Med J* 2018; 35:358–366.
3. Deng Z-M, Dai F-F, Yuan M-Q, Yang D-Y, Zheng Y-J, Cheng Y-X. Advances in molecular mechanisms of pelvic organ prolapse (review). *Exp Ther Med* 2021; 22:1009.
4. Vulić M, Strinić T, Buković D, et al. Expression of matrix metalloproteinase-1 in uterosacral ligaments tissue of women with genital prolapse. *Coll Antropol* 2010; 34:1411–1417.
5. Huang L, Zhao Z, Wen J, Ling W, Miao Y, Wu J. Cellular senescence: a pathogenic mechanism of pelvic organ prolapse (review). *Mol Med Rep* 2020; 22:2155–2162.
6. Gong R, Xia Z. Collagen changes in pelvic support tissues in women with pelvic organ prolapse. *Eur J Obstet Gynecol Reprod Biol* 2019; 234:185–189.
7. Vulic M, Strinic T, Tomic S, Capkun V, Jakus IA, Ivica S. Difference in expression of collagen type 1 and matrix metalloproteinase-1 in uterosacral ligaments of women with and without pelvic organ prolapse. *Eur J Obstet Gynecol Reprod Biol* 2011; 155:225–228.
8. Marcu RD, Mischianu DLD, Iorga L, et al. Oxidative stress: a possible trigger for pelvic organ prolapse. *J Immunol Res* 2020; 2020:3791934.
9. Saputra AND, Rizal DM, Ayuandari S, Pangastuti N. The difference in collagen type-1 expression in women with and without pelvic organ prolapse: a systematic review and meta-analysis. *Int Urogynecol J* 2022; 33:1803–1812.

10. Chen L, Ashton-Miller JA, DeLancey JO. A 3D finite element model of anterior vaginal wall support to evaluate mechanisms underlying cystocele formation. *J Biomech* 2009; 42:1371–1377.
11. Dietz H, Simpson J. Levator trauma is associated with pelvic organ prolapse. *Br J Obstet Gynaecol* 2008; 115:979–984.
12. DeLancey JO, Morgan DM, Fenner DE, et al. Comparison of levator ani muscle defects and function in women with and without pelvic organ prolapse. *Obstet Gynecol* 2007; 109:295–302.
13. Rooney K, Kenton K, Mueller ER, FitzGerald MP, Brubaker L. Advanced anterior vaginal wall prolapse is highly correlated with apical prolapse. *Am J Obstet Gynecol* 2006; 195:1837–1840.
14. Summers A, Winkel LA, Hussain HK, DeLancey JO. The relationship between anterior and apical compartment support. *Am J Obstet Gynecol* 2006; 194:1438–1443.
15. Volloyhaug I, Morkved S, Salvesen K. Association between pelvic floor muscle trauma and pelvic organ prolapse 20 years after delivery. *Int Urogynecol J* 2016; 27:39–45.
16. Ophir J, Alam SK, Garra B, et al. Elastography: ultrasonic estimation and imaging of the elastic properties of tissues. *Proc Inst Mech Eng H* 1999; 213:203–233.
17. Ophir J, Céspedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: a quantitative method for imaging the elasticity of biological tissues. *Ultrason Imaging* 1991; 13:111–134.
18. Parker KJ, Doyley MM, Rubens DJ. Imaging the elastic properties of tissue: the 20 year perspective. *Phys Med Biol* 2011; 56:1–29.
19. Wilson LS, Robinson DE, Dadd MJ. Elastography – the movement begins. *Phys Med Biol* 2000; 45:1409–1421.
20. Greenleaf JF, Fatemi M, Insana M. Selected methods for imaging elastic properties of biological tissues. *Annu Rev Biomed Eng* 2003; 5:57–78.
21. Kishimoto R, Kikuchi K, Koyama A, et al. Intra- and inter-operator reproducibility of US point shear-wave elastography in various organs: evaluation in phantoms and healthy volunteers. *Eur Radiol* 2019; 29:5999–6008.
22. Castro L, García-Mejido JA, Holgado A, García R, Fernández-Palacín A, Sainz JA. Reliability of shear-wave elastography (SWE) for investigating cervix elastic properties in normal and benign pathological situations. *Clin Exp Obstet Gynecol* 2021; 48:583–589.
23. Hernandez-Andrade E, Hassan SS, Ahn H, et al. Evaluation of cervical stiffness during pregnancy using semiquantitative ultrasound elastography. *Ultrasound Obstet Gynecol* 2013; 41:152–161.
24. Itoh A, Ueno E, Tohno E, et al. Breast disease: clinical application of US elastography for diagnosis. *Radiology* 2006; 239:341–350.
25. Sebag F, Vaillant-Lombard J, Berbis J, et al. Shear wave elastography: a new ultrasound imaging mode for the differential diagnosis of benign and malignant thyroid nodules. *J Clin Endocrinol Metab* 2010; 95:5281–5288.
26. Castro L, García-Mejido JA, Arroyo E, Carrera J, Fernández-Palacín A, Sainz JA. Influence of epidemiological characteristics (age, parity and other factors) in the assessment of healthy uterine cervical stiffness evaluated through shear wave elastography as a prior step to its use in uterine cervical pathology. *Arch Gynecol Obstet* 2020; 302:753–762. https://doi.org/10.1007/s00404-020-05671-7.
27. Alam F, Naito K, Horiguchi J, Fukuda H, Tachikake T, Ito K. Accuracy of sonographic elastography in the differential diagnosis of enlarged cervical lymph nodes: comparison with conventional B-mode sonography. *AJR Am J Roentgenol* 2008; 191:604–610.
28. Xiang LH, Fang Y, Wan J, et al. Shear-wave elastography: role in clinically significant prostate cancer with false-negative magnetic resonance imaging. *Eur Radiol* 2019; 29:6682–6689.
29. Yin Z, Murphy MC, Li J, et al. Prediction of nonalcoholic fatty liver disease (NAFLD) activity score (NAS) with multiparametric hepatic magnetic resonance imaging and elastography. *Eur Radiol* 2019; 29:5823–5831.
30. Ferraioli G, Wong VW, Castera L, et al. Liver ultrasound elastography: an update to the World Federation for Ultrasound in Medicine and Biology Guidelines and Recommendations. *Ultrasound Med Biol* 2018; 44:2419–2440.
31. Sainz JA, Castro L, Romo JM, Holgado A, Fernández-Palacín A, García-Mejido JA. Evaluation of pre-malignant lesions of the uterine cervix by shear wave elastography: a new diagnostic tool. *Ultrasound Med Biol* 2021; 47:3275–3282. https://doi.org/10.1016/j.ultrasmedbio.2021.06.021.
32. Yu H, Zheng H, Zhang X, Zhou Y, Xie M. Association between elastography findings of the levator ani and stress urinary incontinence. *J Gynecol Hum Reprod* 2021; 50:101906. https://doi.org/10.1016/j.jogoh.2020.101906.
33. Maßlo K, Möllers M, Oelmeier de Murcia K, Klockenbusch W, Schmitz R. New method for assessment of levator avulsion injury: a comparative elastography study. *J Ultrasound Med* 2019; 38:1301–1307.
34. Tang JH, Zhong C, Wen W, Wu R, Liu Y, Du LF. Quantifying levator ani muscle elasticity under normal and prolapse conditions by shear wave elastography: a preliminary study. *J Ultrasound Med* 2020; 39:1379–1388.
35. Dietz HP, Franco AV, Shek KL, Kirby A. Avulsion injury and levator hiatal ballooning: two independent risk factors for prolapse? An observational study. *Acta Obstet Gynecol Scand* 2012; 91:211–214.
36. Egorov V, van Raalte H, Sarvazyan AP. Vaginal tactile imaging. *IEEE Trans Biomed Eng* 2010; 57:1736–1744.
37. Swenson CW, Smith TM, Luo J, Kolenic GE, Ashton-Miller JA, DeLancey JO. Intraoperative cervix location and apical support stiffness in women with and without pelvic organ prolapse. *Am J Obstet Gynecol* 2017; 216:155e1–155e8.
38. Goh JT. Biomechanical properties of prolapsed vaginal tissue in pre- and postmenopausal women. *Int Urogynecol J Pelvic Floor Dysfunct* 2002; 13:76–79.
39. Kufaishi H, Alarab M, Drutz H, Lye S, Shynlova O. Comparative characterization of vaginal cells derived from premenopausal women with and without severe pelvic organ prolapse. *Reprod Sci* 2016; 23:931–943.

40. Aznal SS, Meng FG, Nalliah S, Tay A, Chinniah K, Jamli MF. Biochemical evaluation of the supporting structure of pelvic organs in selected numbers of premenopausal and postmenopausal Malaysian women. *Indian J Pathol Microbiol* 2012; 55:450–455.
41. García-Mejido JA, Martín-Martinez A, García-Jimenez R, et al. Is the presence of levator ani muscle avulsion relevant for the diagnosis of uterine prolapse? *J Ultrasound Med* 2024; 43:265–272. https://doi.org/10.1002/jum.16356.
42. García-Mejido JA, Martín-Martinez A, García-Jimenez R, et al. Identification of surgical uterine prolapse in premenopausal patients with clinical or ultrasound criteria? A multicenter comparative study. *J Ultrasound Med* 2023; 42:2269–2275.
43. García-Mejido JA, Martín-Martinez A, García-Jimenez R, et al. Is it possible to diagnose surgical uterine prolapse with Transperineal ultrasound? Multicenter validation of diagnostic software. *J Ultrasound Med* 2023; 42:2673–2681.