UROGYNECOLOGY

Levator ani subtended volume: a novel parameter to evaluate levator ani muscle laxity in pelvic organ prolapse

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OBJECTIVE: We describe a new parameter based on magnetic resonance 3-dimensional (3D) reconstructions proposed to evaluate levator ani muscle (LAM) laxity in women with pelvic organ prolapse (POP).

STUDY DESIGN: This is an institutional review board–approved, retrospective chart review of 35 women with POP, stages I-IV. The 3D Slicer software package was used to perform 2-dimensional and 3D measurements and the levator ani subtended volume (LASV) was described. Basically, the LASV represents the volume contained by LAM between 2 planes, which coincides with pubococcygeal line and H line. Correlations among measurements, ordinal POP stages, POP Quantification (POPQ) individual measurements, and validated questionnaires were performed.

RESULTS: The LASV differentiated major (III and IV) from minor (I and II) POPQ stages, which positively correlated to POP stages and POPQ individual measurements.

CONCLUSION: The LASV is a promising parameter to evaluate the LAM laxity.

Key words: levator ani muscle, levator ani subtended volume, levator hiatus, magnetic resonance imaging, pelvic organ prolapse

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The levator ani muscles (LAM) have an important function to support the pelvic floor. They interact with the supportive ligaments and stabilize the closure of the levator hiatus and the positions of the pelvic organs.[1] The morphology of the muscle has a critical role in the levator ani function, and evaluations can be performed through magnetic resonance imaging (MRI) and ultrasound.[2,3] Using MRI, the specific muscle subdivisions can be identified, including the pubovisceral (puboanal, puboperineal, and pubovaginal), puborectal, and iliococcygeal. MRI can also evaluate the integrity of the supportive structures associated with muscle laxity, such as defects, disruptions, pelvic distortions, alterations in levator hiatus dimensions, and increased mobility of pelvic viscera.[4-7] Three-dimensional (3D) reconstructions add an advantage over traditional examination, neutralizing discrepancies in acquisition angles and improving the interobserver and intraobserver reliability of pelvic floor measurements.[8,9]

The shape and dimensions of LAM differ among race and parity.[10,11] Defects and architectural distortions of the LAM are more common among parous than nulliparous women and are considered risk factors for pelvic floor dysfunctions.[6] In fact, these muscle defects are more frequent among women with all described types of pelvic floor disorders, such as pelvic organ prolapse (POP), rectal intussusception, urinary incontinence, and fecal incontinence.[12-14] Women with POP have decreased LAM volumes (LAMV),[15] and reduced thickness and cross-sectional areas of the anterior portions of these muscles.[16] Women with high-grade prolapses and larger muscle disruptions demonstrate impaired function or weakness.[17-19]

The levator hiatus can be assessed to indirectly evaluate the function of the LAM.[20,21] Muscle rest, contraction, Valsalva, and evacuation affect the dimensions of the levator hiatus.[22] The levator hiatus increases with POP Quantification (POPQ) stage progression, aging, impairment of levator ani function, severity of levator ani defects, and after delivery.[22-25] The 2-dimensional (2D) measurements of the levator hiatus have been correlated with POPQ stages and with validated symptom questionnaires with different success rates.[21,26,27]

The aim of this study was to describe the levator ani subtended volume (LASV), a novel parameter based on MRI 3D reconstructions, proposed to evaluate the levator ani laxity in women with POP. Basically, the LASV represents the volume contained by LAM; these limits are defined by levator hiatus, pubococcygeal line (PCL), and H line planes. The secondary objectives are to: (1) compare different POP stages using this parameter and 2D measurements; (2) test the correlation of this parameter with POP

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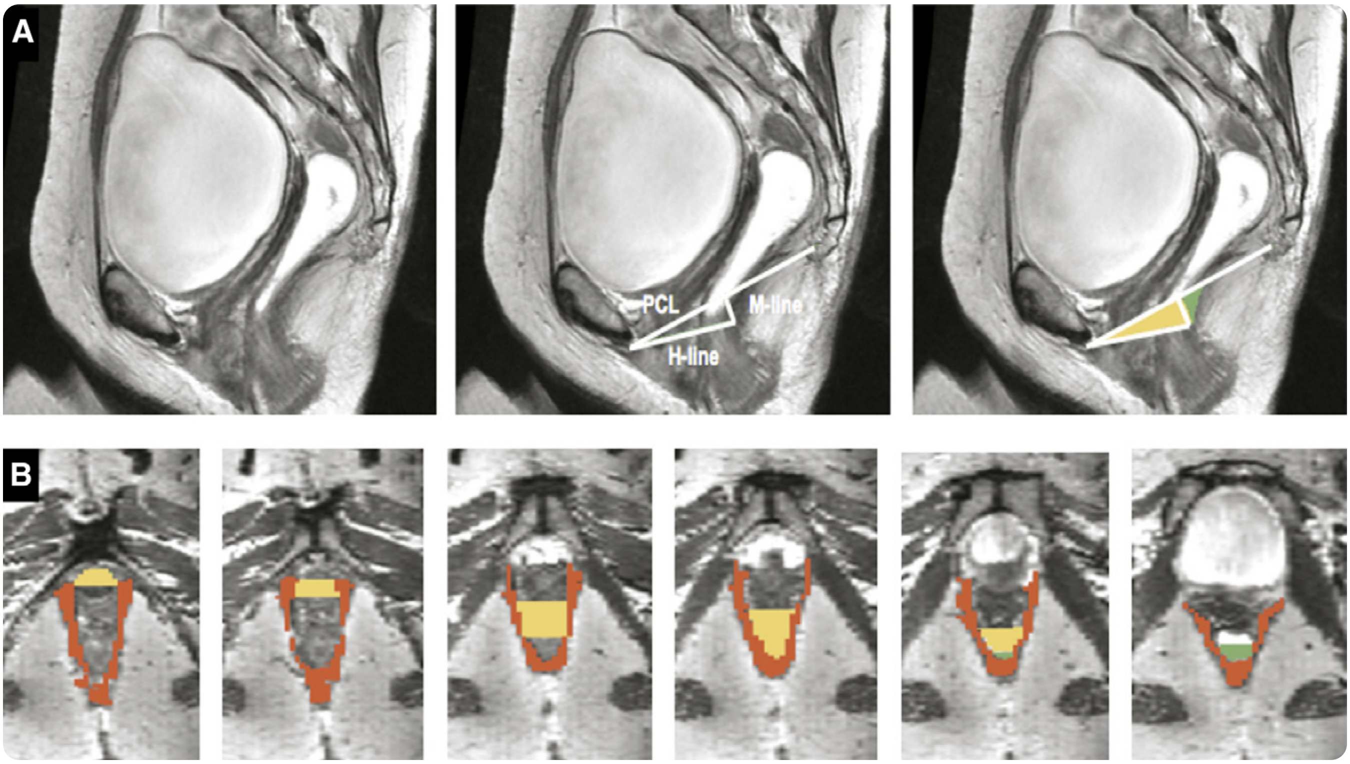
FIGURE 1
Two sequences showing segmentation process



A, Midsagittal views of pelvic floor; representations of pubococcygeal line (PCL), H line, and M line (*white*); and anterior (*yellow*) and posterior (*green*) limits of levator hiatus volume. **B,** Levator ani muscle (LAM) and levator hiatus segmentation following caudal-cranial orientation. Levator hiatus was segmented based on previous limits obtained from midsagittal slice and inner boundaries of LAM, obturator internus muscle, and pubic bone.

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ordinal stages, POPQ individual measurements, and validated questionnaires of symptoms; and (3) perform a repeatability analysis through the determination of the LASV interclass correlation coefficient.

MATERIALS AND METHODS

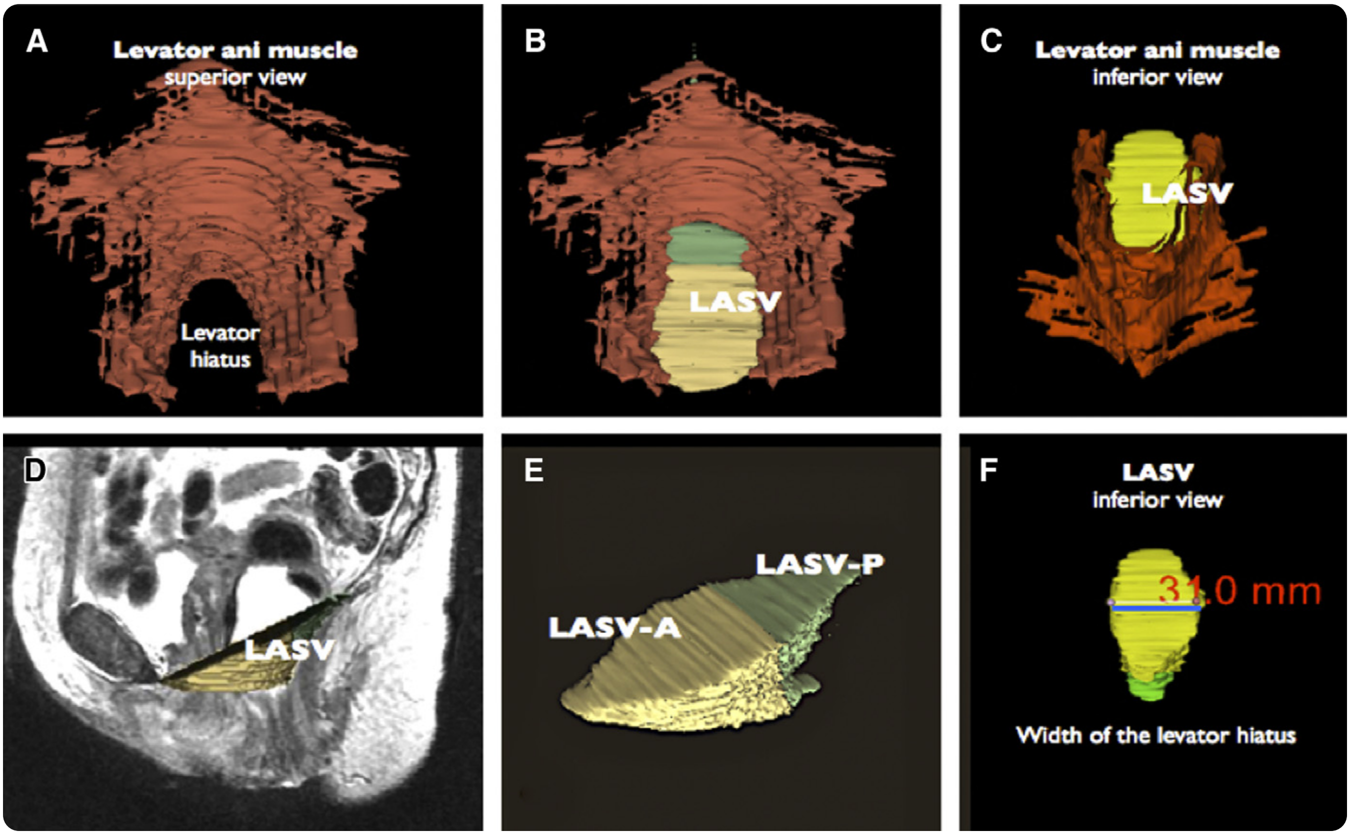
Charts of patients followed up at the Urogynecology Department of the University of South Florida from August 2008 through August 2010 were reviewed. The study included women between 18-80 years of age with pelvic floor symptoms, who completed validated symptom questionnaires and underwent dynamic pelvic MRI as part of their initial evaluation, following a complementary investigative protocol. Subjects were excluded if they were pregnant or underwent prior pelvic irradiation. Subjects were grouped according to their stage of pelvic support, ranging from POPQ stages I-IV. This study was considered a pilot project and the plan proposed to include 10 subjects in each group. Charts were reviewed in the same order as recruited by the clinic, and the first subjects to meet the inclusion/exclusion criteria were selected for each group. A total of 35 patients were included, 10 patients each in groups 1-3. Only 5 subjects with stage IV prolapse met the inclusion criteria, and were included in group 4. The retrospective chart review was approved by the University of South Florida Institutional Review Board.

Diagnosis, age, ethnicity, medical history, surgical history, obstetrical history, body weight, body mass index, and POPQ measurements, for each patient, were extracted from the medical charts. Pelvic floor, urinary, sexual, and colorectal symptoms were assessed through the following validated questionnaires of symptoms: Pelvic Floor Distress Inventory-short form 20; and Medical, Epidemiological, and Social Aspects of Aging and Pelvic Floor Impact Questionnaire-short form 7. The total scores and subcategorical scores were recorded for analysis.

Imaging protocol

MRI was performed on a 3-Tesla GE system (General Electric Company, GE Healthcare, Buckinghamshire, UK) using an 8-channel torso phased-array coil with the patient in the supine position. Standard imaging for detailed anatomic evaluation of the pelvic floor muscles was performed using T2-weighted fast-recovery-fast-spin-echo sequence acquired in the axial, coronal, and sagittal planes. These standard imaging acquisitions were used for 3D rendering. Each T2 sequence presented the field of view 26 cm and the slice thickness of 3 mm. For T1 imaging, a spoiled gradient sequence in the axial plane was acquired. Prior to imaging,

FIGURE 2
3D models



A-C, Three-dimensional (3D) models of levator ani muscle and its relationship with levator ani subtended volumes (LASV). Inferior images show: **D,** LASV in relation to midsagittal view; **E,** 3D representations of LASV anterior (LASV-A) and LASV posterior (LASV-P) models; **F,** Inferior view of LASV showing measurement of width of levator hiatus under H line plane (*blue line*).

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60 mL of ultrasound gel was placed in the rectum for visualization of the colon.

Dynamic imaging was performed in the supine position. Dynamic imaging is a multiphase, single-slice sequence. This was acquired midsagittally for 23-27 seconds using a T2-weighted single-shot fast-spin-echo sequence. According to the imaging protocol, subjects were coached on how to perform an adequate Valsalva and a pelvic floor contraction. Dynamic imaging was performed through cycles of Valsalva and pelvic muscle contraction.

MRI source (2D) images were transferred to a computer workstation with appropriate graphics capability. Specialized software was used to measure linear parameters on the 2D source images. The images were also segmented into anatomically significant organs, eg, levator ani, bony pelvis, and selected anatomic enclosures, as described below.

Two-dimensional measurements

The 3D Slicer software version 3.6 (www.slicer.org, a open source software; Brigham and Women's Hospital, Boston, MA) was used to measure the PCL, H line, and M line on the midsagittal slice, according to the definitions described by Law and Fielding[3] in 2008. A representation of these reference lines is shown in Figure 1, A. The point in the posterior wall of the rectum, at the level of anorectal junction, used to define both H line and M line is referred to as "Fielding point." A urogynecology clinical fellow, blinded to the POPQ staging of the patients, chose the Fielding points in the midsagittal slices, and another specialist used this reference point to draw and measure the H lines and M lines on the gray-scale images.

Three-dimensional measurements

The segmentation process

The 3D Slicer software was used to display and manually segment the gray-scale MRI into anatomically significant organs or structures. For each organ, a label map was created with records of all corresponding segmented MRI slices. The volume measurements were obtained by a preprogrammed tool. The organ volume measurements were expressed as cubic centimeters. The same specialist who drew the gray-scale reference lines also built the 3D models based on these lines. The time consumed in this process was about 2 hours for each patient. The segmentation process is represented in Figure 1.

Determination of the LAMV

The LAM was identified and segmented in each axial MRI slice and complementary corrections were performed using

FIGURE 3
3D models of LAM and LASV in different stages of pelvic organ prolapse

3D models of levator ani muscles (*red*) and respective levator ani subtended volumes (LASV) from women with different stages of pelvic organ prolapse. LASV anterior (*yellow*) + posterior (*green*) = LASV.

LAM, levator ani muscle; *3D,* 3 dimensional.

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the sagittal and coronal views. All the subdivisions of the LAM were included in these reconstructions, following the description of Margulies et al.[4]

LASV

For segmentation purposes, the levator hiatus was considered a specific organ inside the pelvis, delimited by the inner boundaries of the pubis, the LAM, and the obturator internus muscles in axial views. Three planes were defined to more easily delimitate the levator hiatus volume. The PCL plane is defined as a transverse plane including the PCL and passing through the left and right acetabulae. The H line plane is the plane of the levator hiatus. The M line plane is coronal, incorporating the M line. The LASV is the volume bounded inferolaterally by the levator ani, superiorly by the PCL plane, and anteroinferiorly by the H line plane. This volume is demonstrated in Figure 2. The LASV is further divided into anterior (LASV-A) and posterior (LASV-P) portions, delimited by the M line plane. The part of LASV anterior to the M line plane is the LASV-A, and the portion posterior to the M line plane is defined as the LASV-P (Figure 2). The volume of the LASV, LASV-A, and LASV-P is expressed in cubic centimeters.

Determination of the width of the levator hiatus

The width of the levator hiatus was measured in an axial plane correspondent to the H line, in the inferior surface of the LASV 3D model, the widest measurement being perpendicular to the model midline axis (Figures 2 and 3). This measurement was expressed as millimeters and was included as a 2D linear measurement for the analysis of results.

Repeatability analysis

The 2D linear measurements, segmentation, and 3D reconstruction were repeated by the same observer, 1 month later, on a random selection of 15 of 35 MRI datasets. The subtended volumes were recalculated. To establish the intraobserver repeatability, the interclass correlation coefficients for LASV were calculated with a confidence interval of 95%.

POPQ

As part of the routine clinical assessment, the POPQ examination was performed on all subjects. The POPQ evaluation was performed according to the description of the International Continence Society,[28] using the following denominations: Ba, the most descended edge on the anterior vaginal wall; Bp, the most descended edge of posterior vaginal wall; and C, the most distal edge of the cervix or the leading edge of vaginal vault after total hysterectomy. The examination was performed by 1 of 2 urogynecology specialists, a clinical fellow, or an advanced registered nurse practitioner.

Statistical analysis

Statistical analysis was performed using SPSS Statistics, version 19.0 software (SPSS Inc, Chicago, IL). Fisher exact test was used to compare the clinical characteristics between groups. The following variables presented normal distribution and the analyses between groups were performed by 1-way analysis of variance: age, weight, body mass index, PCL, H line, M line, width of levator hiatus, LAMV, LASV, LASV-A, and LASV-P. The M line, width of levator hiatus, LASV, LASV-A, and LASV-P did not present homogeneity of variances in the Levene test and the Games-Howell test was used as the post hoc test. In the remaining cases, the Bonferroni post hoc test was applied. The nonparametric bivariate Spearman rank correlation indices and Pearson correlation coefficients

TABLE 1
Characteristics of the patients included (n = 35)

Variable	Total (range)	POP stages				P value
		Stage I (n = 10)	Stage II (n = 10)	Stage III (n = 10)	Stage IV (n = 5)	
Age, y	55.7 ± 13.4 (22–74)	45.1 ± 14.6 (22–71)	55.8 ± 9.3 (43–70)	60.7 ± 11.9[a] (40–74)	66.6 ± 6.3[a] (57–73)	.007[b]
Weight, lbs	161.3 ± 37.7 (60.0–240.0)	160.1 ± 31.4 (120.0–225.0)	164.0 ± 53.3 (60.0–240.0)	164.3 ± 29.4 (127.0–228.0)	152.4 ± 37.3 (118.0–209.0)	.95[c]
BMI, kg/m^2	27.4 ± 5.5 (19.0–39.0)	26.1 ± 5.9 (19.0–35.0)	28.6 ± 6.1 (22.0–38.0)	28.0 ± 5.0 (20.0–39.0)	26.8 ± 4.9 (23.0–35.0)	.76[c]
Ethnicity						
Caucasian, %	88.6 (31/35)	25.7 (9/10)	25.7 (9/10)	28.6 (10/10)	8.6 (3/5)	.31[c]
African American, %	5.7 (2/35)	0.0 (0/10)	2.9 (1/10)	0.0 (0/10)	2.9 (1/5)	.31[c]
Other, %	5.7 (2/35)	2.9 (1/10)	0.0 (0/10)	0.0 (0/10)	2.9 (0/5)	.31[c]
Past medical history						
Diabetes, %	5.7 (2/35)	5.7 (2/10)	0.0 (0/10)	0.0 (0/10)	0.0 (0/5)	.15[c]
Past surgical history						
Hysterectomy, %	31.0 (11/35)	0.0 (0/10)	8.6 (3/10)	14.3 (5/10)	8.6 (3/5)	.04[b]
Incontinence, %	2.9 (1/35)	0.0 (0/10)	0.0 (0/10)	2.9 (1/10)	0.0 (0/5)	.46[c]
Prolapse repair, %	14.3 (5/35)	0.0 (0/10)	5.7 (2/10)	2.9 (1/10)	5.7 (2/5)	.18[c]
Past obstetric history						
Nulliparous, %	2.9 (1/35)	2.9 (1/10)	0.0 (0/10)	0.0 (0/10)	0.0 (0/5)	.46[c]
Uniparous, %	25.7 (9/35)	11.4 (4/10)	5.7 (2/10)	8.6 (3/10)	0.0 (0/5)	.38[c]
Multiparous, %	62.9 (22/35)	8.6 (3/10)	20.0 (7/10)	20.0 (7/10)	14.3 (5/5)	.04[b]
C-sections, %	14.3 (5/35)	5.7 (2/10)	2.9 (1/10)	5.7 (2/10)	0.0 (0/5)	.67[c]
Forceps/vacuum, %	11.4 (4/35)	5.7 (2/10)	0.0 (0/10)	2.9 (1/10)	2.9 (1/5)	.49[c]

POP, pelvic organ prolapse.

[a] Different from stage I; [b] Statistically significant; [c] Not significant.

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TABLE 2
2D linear measurements and width of levator hiatus obtained from MRIs of women with different stages of POP, at rest

	POP stages (n)				
Variable	Stage I (10)	Stage II (10)	Stage III (10)	Stage IV (5)	*P* value
PCL	91.88 ± 13.49	103.95 ± 4.85	98.33 ± 7.51	99.32 ± 11.39	.07[a]
H-line	47.47 ± 9.88	56.57 ± 9.57	62.37 ± 11.61[b]	67.04 ± 8.27[b]	.004[c]
M-line	19.76 ± 5.85	18.83 ± 6.44	29.52 ± 14.52[b]	31.46 ± 4.90[b]	.02[c]
WLH	36.98 ± 7.13	35.41 ± 4.02	42.83 ± 7.18	52.84 ± 4.02[b,d,e]	< .001[c]

MRIs, magnetic resonance images; *PCL*, pubococcygeal line; *POP*, pelvic organ prolapse; *2D*, 2 dimensional; *WLH*, width of the levator hiatus.

[a] No significant difference; [b] Different from stage I; [c] Significant difference; [d] Different from stage II; [e] Different from stage III.

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were used to test the correlations among 2D linear measurements, 3D measurements, POP nominal stages, POPQ measurements, and validated questionnaires of symptoms, and total and subcategorical scores. The comparisons and correlations were considered significant when *P* was < .05.

Detailed analysis of the data demonstrated a breakpoint between minor prolapse (stages I and II) and major prolapse (stages III and IV). Therefore, a secondary comparison of means and variance was performed using the nonpaired Student *t* test, assuming significance when *P* was < .05. Also we included a receiver operating characteristic (ROC) curve analysis to evaluate the relationship between the 2D and 3D measurements and the grouped stages.

RESULTS

The groups differed in age, surgical history, and obstetric history, as shown in Table 1.

Two-dimensional linear measurements

The H line and width of levator hiatus showed differences across POP ordinal stages. The PCL did not differ between POP stages. The H line and M line were greater in stages III and IV when compared with stage I. The width of levator hiatus was greater in stage IV when compared with stages I, II, and III. Table 2 shows these results. All the 2D linear measurements, except PCL, showed differences between minor and major POP stages, as shown in Table 3.

TABLE 3
Differences between women with minor (stages I and II) and major (stages III and IV) POP stages

	POP grouped stages (n)		
Variable	Minor (20)	Major (15)	*P* value
2D linear measurements (mm ± SD)			
PCL	97.91 ± 11.65	98.66 ± 8.57	.83[a]
H line	52.02 ± 10.55	63.92 ± 10.55	.002[b]
M line	19.29 ± 6.01	30.17 ± 11.97	.001[b]
WLH	36.20 ± 5.69	46.17 ± 7.85	< .001[b]
3D measurements (cm^3 ± SD)			
LAMV	37.19 ± 10.83	41.08 ± 12.77	.34[a]
LASV	20.78 ± 10.05	58.68 ± 36.14	< .001[b]
LASV-A	16.17 ± 7.27	42.00 ± 22.44	< .001[b]
LASV-P	4.61 ± 3.78	13.32 ± 12.66	.006[b]

A, anterior; *LAMV*, levator ani muscles volumes; *LASV*, levator ani subtended volume; *P*, posterior; *PCL*, pubococcygeal line; *POP*, pelvic organ prolapse; *SD*, standard deviation; *3D*, 3 dimensional; *2D*, 2 dimensional; *WLH*, width of the levator hiatus.

[a] Not significant; [b] Statistically significant.

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Three-dimensional measurements

LASV, LASV-A, and LASV-P showed differences between minor and major POP stages, as shown in Table 3. LASV and LASV-A showed differences across POP ordinal stages. However, the LASV-P did not differ across groups. The Games-Howell post hoc test did not identify the LASV intergroup differences. LASV-A was greater in stages III and IV when compared with stage I. The LAMV had a mean value of 38.86 cm^3, but showed no differences across POP stages. Results are shown in Table 4.

Correlations with POP ordinal stages

The H line, M line, width of levator hiatus, LASV, and LASV-A were positively correlated with POP ordinal stages. The PCL, LAMV, and LASV-P were not correlated with POP ordinal stages. These data are shown in Table 5.

Correlations with POPQ individual measurements

The H line, M line, width of levator hiatus, LASV, and LASV-A were positively correlated with Ba. The width of levator hiatus, LASV, and LASV-A showed a positive correlation with Bp and C. There were no correlations observed with total vaginal length. These data are shown in Table 5. The POP ordinal stages correlated with all POPQ individual measurements, except total vaginal length, *P* = .01. The correlation indices between POP ordinal stages and Ba, Bp, and C were 0.80, 0.80, and 0.67, respectively.

Correlations with symptoms

The 2D linear measurements, 3D measurements, POP ordinal stages, and POPQ individual measurements showed no correlation with the tested questionnaires of

TABLE 4
3D measurements from women with different stages of POP, at rest

Variable	POP stages (n) Stage I (10)	Stage II (10)	Stage III (10)	Stage IV (5)	*P* value
LAMV	33.06 ± 10.74	41.32 ± 9.71	42.87 ± 12.66	37.52 ± 13.67	.25[a]
LASV	20.40 ± 11.75	21.16 ± 9.41	52.52 ± 38.06	71.01 ± 32.06	.001[b]
LASV-A	15.53 ± 7.55	16.81 ± 7.33	38.36 ± 25.56[c]	49.28 ± 13.89[c]	< .001[b]
LASV-P	4.86 ± 4.51	4.36 ± 3.10	14.16 ± 13.19	11.63 ± 12.81	.57[a]

A, anterior; *LAMV*, levator ani muscles volumes; *LASV*, levator ani subtended volume; *P*, posterior; *POP*, pelvic organ prolapse; *3D*, 3 dimensional.

[a] Not significant; [b] Significant difference; [c] Different from stage I.

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TABLE 6
Correlation between 2D and 3D measurements and LASVs

Variable	Pearson's correlation coefficient - r LASV	LASV-A	LASV-P
PCL	0.21[a]	0.20[a]	0.19[a]
H line	0.76[b]	0.78[b]	0.56[b]
M line	0.87[b]	0.89[b]	0.81[b]
WLH	0.66[b]	0.63[b]	0.44[c]
LAMV	0.19[a]	0.15[a]	0.03[a]

A, anterior; *LAMV*, levator ani muscles volumes; *LASV*, levator ani subtended volume; *P*, posterior; *PCL*, pubococcygeal line; *3D*, 3 dimensional; *2D*, 2 dimensional; *WLH*, width of the levator hiatus.

[a] Not significant; [b] Statistically significant at the 0.01 level; [c] Statistically significant at the 0.05 level.

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symptoms, even excluding the stage I group from the analysis.

Correlation between 2D linear measurements and 3D measurements

The H line, M line, and width of levator hiatus showed positive correlation with LASV, LASV-A, and LASV-P. All these data are shown in Table 6.

ROC curve analysis

The ROC curve analysis between 2D and 3D measurements and the grouped stages showed a similar area under the curve for all measurements: 0.84, 0.817, 0.80, 0.79, and 0.79 for width of levator hiatus, LASV-A, M line, H line, and LASV, respectively. The sensitivity and specificity of LASV and LASV-A to identify major POP stages were, respectively, 87% and 75% for LASV with cutoff of 14 cm^3; and 93% and 65% for LASV-A with cutoff of 10 cm^3.

The reliability analysis

Reliability analysis showed LASV intraclass correlation coefficient of 0.98, ranged from 0.95–0.99, with $P < .001$, indicating very good intraobserver reliability.

TABLE 5
Correlations between 2D and 3D measurements and women's POPQ individual measurements

Variable	Spearman's - rho POP ordinal stages	Pearson's - r Ba	Bp	C	TVL
2D linear measurements					
PCL	0.13[a]	−0.12[a]	0.05[a]	−0.12[a]	−0.07[a]
H line	0.59[b]	0.48[b]	0.43[c]	0.35[a]	−0.05[a]
M line	0.48[b]	0.54[b]	0.35[a]	0.30[a]	0.19[a]
WLH	0.57[b]	0.63[b]	0.61[b]	0.65[b]	0.45[a]
3D measurements					
LAMV	0.15[a]	−0.11[a]	−0.10[a]	−0.11[a]	0.20[a]
LASV	0.51[b]	0.61[b]	0.53[b]	0.44[c]	0.14[a]
LASV-A	0.55[d]	0.62[b]	0.52[b]	0.42[c]	0.15[a]
LASV-P	0.29[a]	0.30[a]	0.16[a]	0.16[a]	0.09[a]

A, anterior; *LAMV*, levator ani muscles volumes; *LASV*, levator ani subtended volume; *P*, posterior; *PCL*, pubococcygeal line; *POP*, pelvic organ prolapse; *POPQ*, pelvic organ prolapse quantification; *3D*, 3 dimensional; *TVL*, total vaginal length; *2D*, 2 dimensional; *WLH*, width of levator hiatus.

[a] Not significant; [b] Statistically significant at the 0.01 level; [c] Statistically significant at the 0.05 level; [d] Statistically significant at the 0.001 level.

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COMMENT

We believe that the LASV is an indirect measure of the laxity of the LAM. Our data suggest that it correlates well with worsening stages of POP. It is most interesting to note that the LASV-A correlates well with worsening stages of prolapse, whereas the LASV-P appears not to vary with stage of prolapse. This supports that the LASV-A, bounded by the puborectalis portion of levator ani and the M line plane, is subject to the most variability across stages of prolapse, and that the puborectalis muscle may play a role in the development of POP.[18,29-32]

The strength of this study is that it was conducted with well-characterized patients, using a standardized MRI protocol. The LASV is a relatively well-defined region on MRI, which appears to afford high intraobserver reliability. The main weakness is the small number of patients studied in each group. A future study is under way to evaluate this parameter in a larger group of subjects. We also suspect that the previous pelvic surgeries have an effect in this parameter, and another study to evaluate this factor is necessary.

Volume measurements of the LAM have been performed in different populations using the 3D reconstruction process.[10,15,33-35] The current study demonstrated no differences in LAMV across stages of POP, which was not previously reported. Also, we noticed a higher

LAMV compared to other works, likely attributable to our inclusion of all LAM portions in the segmentation process. However, it has also been shown that volume measurement of levator ani based on manual segmentation is known to suffer from relatively low repeatability, possibly stemming from the difficulty in reliably identifying the portions of levator ani during segmentation.[9]

This study did not demonstrate correlation between traditional 2D or 3D MRI-based measurements and validated symptom questionnaires, including the POPQ individual measurements. This is consistent with the literature, which reports poor correlation between 2D MRI measurements and symptoms reported on questionnaires.[36,37]

The labor process to build the LASV is a limitation to incorporating this parameter in the clinical practice. However, improvements in 3D modeling techniques can probably overcome this limitation in the near future. Also, in our interpretation, the LASV is a compound of 3 linear parameters, with potential to be more useful and reliable than the individual linear parameters themselves. We demonstrated that H line, M line, and width of levator hiatus were highly correlated with LASV. The LASV and LASV-A were highly associated with POP stages; and all 3D based parameters, including the width of levator hiatus, presented positive and significant correlation with POPQ individual measurements. Finally, following the Cavalieri principle,[38] these parameters based on volume measurements do not suffer influence from MRI acquisition angles and discrepancies due to patient's position; and virtually any volume inside the pelvis can be measured by the same process just by changing the referential landmarks.

Conclusion

We demonstrated in this study that it is possible to quantify the muscle laxity in women based on a 3D parameter. The LASV and LASV-A presented a positive correlation with POPQ individual measurements, demonstrating that these new parameters can be used as tools to investigate the interrelationship between muscle laxity and clinical presentation of POP. New studies will be necessary to prove reproducibility and clinical utility of these parameters. ■

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