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Levator Bowl Volume during Straining and its Relationship to Other Levator Measures

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Abstract

INTRODUCTION AND HYPOTHESIS—This study aimed to: 1) measure levator ani bowl volume at rest and while straining, 2) compare women with and without prolapse (controls), and 3) assess the ability of measures of mid-sagittal bowl area, levator hiatus (LH), and urogenital hiatus (UGH) to predict bowl volume.

METHODS—Forty MRI scans previously acquired in case-control prolapse studies including 20 women with prolapse and 20 women without prolapse, of similar age and parity, were selected. 3D models of rest and strain bowl volumes were made using sagittal scans and 3D Slicer®. Mid-sagittal bowl area, UGH, and LH were measured with ImageJ. Data were analyzed using two sample t-tests, effect sizes, and Pearson's correlation coefficients at the 0.05 significance level.

RESULTS—Data were acquired in a total of 40 total women. Levator bowl volume at strain had a correlation coefficient of 0.5 with bowl volume at rest. During straining, prolapse subjects had a 53% larger bowl volume than control subjects (254 ± 86 cm^3 vs. 166 ± 44 cm^3, $p<0.001$), but at rest, the difference was 34% (138 ± 40 cm^3 vs. 103 ± 25 cm^3, $p=0.002$). Effect sizes for all parameters were large ($d>0.75$). The strongest correlation with straining bowl volume was straining bowl area ($r=0.86$), followed by LH strain ($r=0.80$), then UGH strain ($r=0.76$).

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CONCLUSIONS—Straining levator bowl volume is substantially different than measures made at rest, with only a quarter of straining values explained by resting measurements. The bowl area at strain is the best 2D measurement estimating bowl volume and explains 74% of straining bowl volume.

Brief summary:

Levator bowl volume captures aspects of levator ani muscle failure not completely captured by other measures, and mid-sagittal bowl area forms a reasonable estimate for this measure.

Keywords

Levator bowl volume; pelvic organ prolapse; urogenital hiatus; levator hiatus

Introduction

Pelvic organ prolapse is a highly prevalent and distressing problem.[1] Unfortunately, even the “gold standard” surgical procedure in the best of hands has an anatomical failure rate of 25% at 7 years.[2] Although there is progress on finding the causes of prolapse, our understanding of why operations fail remains incomplete. If structural failures occur in the pelvic organ support system that are not currently addressed by operative approaches, then focusing on improving current strategies may not completely address the reasons for operative failure.

The Pelvic Organ Prolapse Quantification (POP-Q) examination provides important information on anterior and posterior vaginal wall location, apical support status, and dimensions of the urogenital hiatus (UGH). Information on structural failures that result in downward descent of the vaginal walls and apical structures has recently been made possible by Stress 3D Magnetic Resonance Imaging (MRI).[3] One study showed that a collinear triad of structural failure sites is associated with anterior prolapse: 1) apical descent, 2) paravaginal separation, and 3) levator ani muscle (LAM) impairment, and that these are highly correlated with one another.[3] In understanding the mechanism of failure, it is clear how surgery might improve the first two causes, but it is not as clear how surgery changes the status of the levators. Therefore, a more accurate picture of the nature of levator failure is needed.

Most research concerning the levator ani muscle’s role in pelvic organ support has focused on quantifying levator injury and assessing the size of the levator hiatus (LH) and UGH through which prolapse occurs. In addition to these factors, there is also an overall downward sagging of the levators seen in women with prolapse.[4–7] In simple terms, the levator forms a bowl-like floor to the abdominopelvic cavity. On one side of the bowl there is a gap formed by the urogenital and levator hiatus. There can be varying degrees of change in either the depth of the bowl, size of the hiatus, or both. The relationships between these parameters are currently not known.

Bowl deepening has recently been assessed at rest by measuring the volume of the entire levator “bowl” below the plane of the pubococcygeal line on MRI; this was the levator ani subtended volume introduced by Rodrigues et al.[4] For simplicity’s sake, we have chosen to call this the levator ani bowl volume ("bowl volume") because the term subtended, although technically accurate, is unfamiliar to clinicians. A larger bowl volume at rest is seen in prolapse and surgical failure.[4–6] Bowl volume can capture many elements of pelvic floor movement including descent and lateral bulging of the iliococcygeal muscle that occurs with prolapse, but is not fully captured by hiatal and POP-Q measurements. This is important because current surgical strategies may not address these changes in the pelvic floor. Posterior repair could change the size of the hiatuses, but whether the sagging of the muscle is affected is not known. Therefore, having techniques to evaluate these phenomena will be useful in assessing not only causes of prolapse, but also how they relate to surgical outcomes. However, at present, the levator bowl volume has only been measured at rest.

Other simpler assessments, such as the levator ani bowl mid-sagittal area ("bowl area") between the sacrococcygeal inferior pubic point (SCIPP) line and the upper surface of the levator,[7] have been investigated as linear measures to estimate the bowl volume.[5] The measurements of the bowl area, urogenital, and levator hiatuses can be used to show important differences between rest and strain; however, measuring the bowl volume additionally captures changes that may not be seen in the midline, such as lateral bulging of the iliococcygeal muscle.[8] Volume studies and measures of the hiatuses performed only at rest might not provide a full assessment of this phenomenon.

The goal of this study was to create a novel way to measure the volume of the pelvic floor (bowl volume) during straining, as well as at rest, in women with and without prolapse and use it to compare these 3D volumes to 2D bowl area, LH, and UGH measures. We tested the null hypotheses that 1) there is no difference in bowl volume between women with prolapse and controls during rest and during straining, and 2) there is no significant correlation between bowl volume and bowl area or the hiatuses.

Material and Methods

MRI scans were acquired as part of two institutional review board-approved case-control studies on the mechanisms of pelvic organ prolapse (University of Michigan IRBMED HUM00043445 and HUM00031520). There were two groups of women: 20 with pelvic organ prolapse and 20 asymptomatic control women without prolapse. Cases were recruited from the Urogynecology Service at the University of Michigan and controls, by using registries of women volunteering for research and advertisement. On POP-Q assessment, the control group did not have prolapse to or beyond the hymen. The women with prolapse had a symptomatic bulge and a vaginal wall or cervix that extended at least 1 cm beyond the hymen. These cases were selected to represent equal numbers of women with anterior and posterior predominant prolapse.

The imaging protocol has been previously described.[3] Briefly, sagittal MRI images were acquired in the supine position during maximal Valsalva and while resting using a 3-T Philips Achieva scanner (Philips, Andover, MD) with a 6-channel, phased-array coil. During Valsalva, subjects were coached to bear down to recreate prolapse seen during clinical POP-Q examination. This Valsalva was held for approximately 17 seconds to create "strain and hold" imaging. Only women who could recreate (during imaging) a prolapse similar in size to that seen in clinic were included in the study.

Measurements were made on the mid-sagittal image and included the cross-sectional bowl area, LH, and UGH (Figure 1). The present study used a subset of women from our previous work from which we obtained the 2D measurements, and details of the measuring protocol have been described there.[7] The mid-sagittal bowl area was defined as the cross-sectional area in the mid-sagittal plane bordered by the SCIPP line superiorly and a line approximating the inferior edge of the LAM from the inferior pubic point to the top of the external anal sphincter—the origin and insertion of the lowest part of the pubovisceral muscle. This lower border of the levator ani is also at the level of the hymen on physical exam. The area was completed by the top of the anal sphincter and the levator plate caudally. The LH was defined as the minimal diameter from the pubic bone to the levator plate. The UGH was defined as the minimal diameter from the pubic bone to the perineal body.

Levator bowl volume measurements were made upon a maximal straining maneuver in accordance with our established protocol.[3] The bowl volume was defined as the volume contained above the LAM and below the SCIPP line, which is the superior border. We chose the SCIPP line because it better approximates the arcus tendineus fascia pelvis origin of the levator ani than the pubococcygeal line, which has been used by others previously.[4] Using 3D slicer software (v 4.5.0, Brigham and Women's Hospital, Boston, MA), a plane through the SCIPP line was identified in the mid-sagittal plane and transferred to the parasagittal planes. Then, in each sagittal slice, the area above the levator and anal sphincter complex and below the SCIPP line was outlined using the same landmarks that were used in the mid-sagittal area measurements. Using this label map, a model of the volume was constructed (Figure 2) and the volume of the model was recorded from the software. All measurements were taken at maximal Valsalva (straining) and at rest using ImageJ software (v1.44, National Institutes of Health, Bethesda, MD).

Demographic and clinical information including age, BMI, race, and POP-Q scores were compared in both groups. Two sample t-tests, effect sizes, and Pearson's correlation coefficients were used to compare the hiatuses, 2D, and 3D measures. Statistical significance was determined at $\alpha=0.05$ and statistical analyses were performed using SPSS (version 24.0, IBM Corp., Armonk, NY).

Results

Data were acquired in a total of 40 women. The two groups were similar in terms of age, height, parity, BMI, and race (Table 1). POP-Q scores were significantly different comparing both groups by study design. The measurements of the volumes, areas, and dimensions for the study measures are presented in Figure 3, and the percent differences between the two groups, as well as numerical values of the standard deviations, are presented in the Appendix. Bowl volume during straining was 53% greater in women with prolapse compared to those with normal support. In the resting state, this difference was 35% between prolapse and control groups. These values were 51% and 32% respectively for

UGH, and 30% and 11% respectively for LH. Straining bowl area was 60% larger in women with prolapse compared to controls, and 30% larger for resting areas.

The differences between women with and without prolapse were greater during strain than at rest. Bowl volume in women with prolapse showed the largest change from rest to strain, demonstrating an 83% increase. The corresponding difference was 62% in controls. These values were 29% and 5% (prolapse and controls, respectively) for bowl area, 30% and 14% for UGH, and 15% and −2% for LH. All parameters had large effect sizes (d>0.75), which quantify the difference in values between prolapse cases and controls, irrespective of measurement units (Table 2). Levator bowl mid-sagittal area during strain and UGH strain had the greatest effect sizes, followed closely by LH at strain.

Pearson's correlation coefficients between bowl volume and the other assessments (hiatal diameters and bowl area) during straining and at rest are shown in Table 3. It is noteworthy that bowl volume during straining is substantially different than that measured at rest, as shown by the correlation coefficient of 0.48. This value indicates that only 23% (R^2) of the variation in straining volumes is explained by the resting volumes. The strongest correlations occurred between straining bowl volume and straining bowl area, followed by straining bowl area and UGH at strain, then straining bowl area and LH at strain. All correlation coefficients were significant at α=0.05. We also considered the relationship between prolapse size as measured by the most caudal POP-Q point and the other measures of hiatal, area, and volume. In women with prolapse, the only positive correlation is between levator bowl volume at rest (r=.472, p=.036). When all subjects are included and both those with prolapse and those with normal support are evaluated, all measurements are significantly correlated with Pearson Coefficients between 0.55 and 0.72 and p< 0.000, except for LH Rest with a correlation of 0.39 and p=0.01. This indicates that it is the difference between prolapse and normal support, not the size of the prolapse when present, that is related.

Discussion

The importance of levator ani muscle impairment in the pathogenesis of pelvic organ prolapse is well-established[9] and progress is being made to understand the specific nature of this failure. Levator injury and increased hiatus size are also well-established as being related to prolapse. These are, however, incomplete assessments of levator shape variation. The shape and deformation of the levator ani muscle are complex and no single measurement reveals a complete picture of this deformation. An overall downward displacement of the levator ani muscle occurs with prolapse and this increase is of larger magnitude than the size of the visible prolapse protruding through the urogenital hiatus.[7] Although one might assume that the increase in hiatus size is due to visible injury, in fact, only a small portion of the hiatal enlargement is associated with muscle defect grading.[10] Other factors such as connective tissue injury at birth or the dilating effect of a prolapse can also result in hiatal enlargement. Furthermore, the factors contributing to increased levator volume when the pelvic floor is loaded must also be considered. For example, the effect of the muscle surface area may play an additional role[11] with hiatus size and bowl volume, and future studies integrating these several parameters are likely to provide a more complete understanding of levator morphology.

In this study, we have shown that there are important differences between measuring bowl volume during the straining maneuver and that seen at rest. Only one-quarter of the variation in levator bowl volume during straining was predicted by measures made at rest. Bowl volume showed the greatest change between rest and strain, with increases of 83% and 62% for prolapse and control subjects, respectively. This was much larger than changes seen in the hiatus measures, which were all under 30%; this suggests that the increased loads on the pelvic floor affect volume more than hiatus size. For all measurements, there were large effect sizes between those with and without prolapse, showing how greatly our measures are associated with prolapse. Importantly, these differences were greatest in the straining measure, so the ability to estimate volume during straining demonstrated in our study is novel.

The measurements of the levator bowl volume, mid-sagittal bowl area, and hiatus diameters during straining are strongly related to one another as indicated by large correlation coefficients. Levator bowl area at strain was the best predictor of levator bowl volume at strain, explaining 74% of its variation. Hiatus measures will continue to be useful in directly assessing the opening through which prolapse occurs, as these can be made in the clinical setting. However, they do not assess the overall downward displacement of the pelvic floor, and even a strong correlation coefficient of 0.75 only explains 56% of the variation in volume. Therefore, continued consideration of bowl volume in certain questions has value. The strong correlations also suggest that there are different ways to assess one phenomenon.

The clinical relevance of any new measurement takes time to understand. When the levator ani muscles sag, the abdominal and pelvic organs shift downward. This would logically place increased loads on suspending ligaments and connective tissues. This downward displacement is captured by the levator bowl volume, but is not necessarily captured by evaluating the size of the hiatus or degree to which organs protrude below the hymen.[7] Although operations such as posterior colporrhaphy can narrow the size of the hiatus, it is unlikely to correct the downward movement of the pelvic organs, leaving this aspect of prolapse unaddressed. It has been demonstrated that even resting measures of bowl volume are associated with operative failure,[6] as is increased hiatal size.[12] Whether simple removal of the prolapse or operations such as posterior colporrhaphy or abdominal sacrocolpoperineopexy[13] affect these volumes remains to be determined by pre- and post-operative evaluation. In addition, whether levator sagging in the absence of a protruding bulge post-operatively leads to symptoms of pressure and discomfort so that it is clinically important remains to be determined. For example, if the bowl increases in volume with straining and the hiatus does not change, the increased compliance of the levator ani muscle might “cushion” the hiatus from dilating. Now that these parameters can be objectively measured, studies can be carried out to answer these and other clinical questions.

Several limitations should be kept in mind when interpreting the results of this study. Although we only had 20 patients in each group (prolapse and control), we were still able to achieve significant results with the sample size—indicating large differences between the groups. However, our analysis could be improved by a larger sample size. In addition, straining images did not extend quite far enough to reach the farthest lateral extremes of the levator bowl volume, as the resting scans did, due to difficulty in analyzing dynamic images.

Because there is very little movement in this area, the effect on the measures would be small. With improved scanners and software, this can be overcome in the future. This limitation would make the strain bowl volume measurements in this study a slight underestimate of actual size. Although area and hiatus measures were made by two raters and averaged, bowl volume measures were only performed by one rater, so we are planning inter-rater reliability testing for future studies. Finally, our sample is not population-based; hence estimates of how this relates to all women with prolapse will require a different study design. A major strength of this study is that we identified a measure—bowl volume during maximal straining—to assess the downward descent of the pelvic floor in prolapse that could be utilized consistently in these women, and this measure correlates with the literature on levator ani subtended volume, bowl area, and UGH/LH measures. We have chosen to study levator bowl volume because it represents the increased volume occupied by the descending abdominal and pelvic viscera. Others have studied the surface area of the levator ani muscles to show expected movement with the contraction and strain of the muscle, as well as anticipated shape variations between different women.[11] Each of these techniques addresses different aspects of levator pathoanatomy, and with accumulating data from a variety of individuals should form a more complete picture of levator structure/function relationships in health and disease.

With this research, a more complete analysis of changes that occur in the levator is emerging. Further mechanistic research can then determine the causes of these structural changes, and clinical outcomes research can determine which are most strongly associated with the all-too-common operative failures. This research can also help guide development of better prevention and novel treatment strategies.

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Appendix.

Mean ± standard deviation for all measures

	Controls (n=20)	Prolapse (n=20)	% difference	p-value*
Bowl Volume Rest (cm^3)	103 ± 25	138 ± 40	35	0.002
Bowl Volume Strain (cm^3)	166 ± 44	254 ± 86	53	<0.001
Bowl Area Rest (cm^2)	21 ± 4.8	27 ± 5.8	30	0.001
Bowl Area Strain (cm^2)	22 ± 6.9	35 ± 8.4	60	<0.001
Urogenital Hiatus Rest (cm)	3.4 ± 0.7	4.5 ± 0.8	32	<0.001
Urogenital Hiatus Strain (cm)	3.9 ± 0.6	5.9 ± 1.0	51	<0.001
Levator Hiatus Rest (cm)	5.5 ± 0.7	6.1 ± 0.9	11	0.024
Levator Hiatus Strain (cm)	5.4 ± 1.1	7.0 ± 1.1	30	<0.001

* p-value compares means of prolapse and control groups with an independent 2 sample t-test

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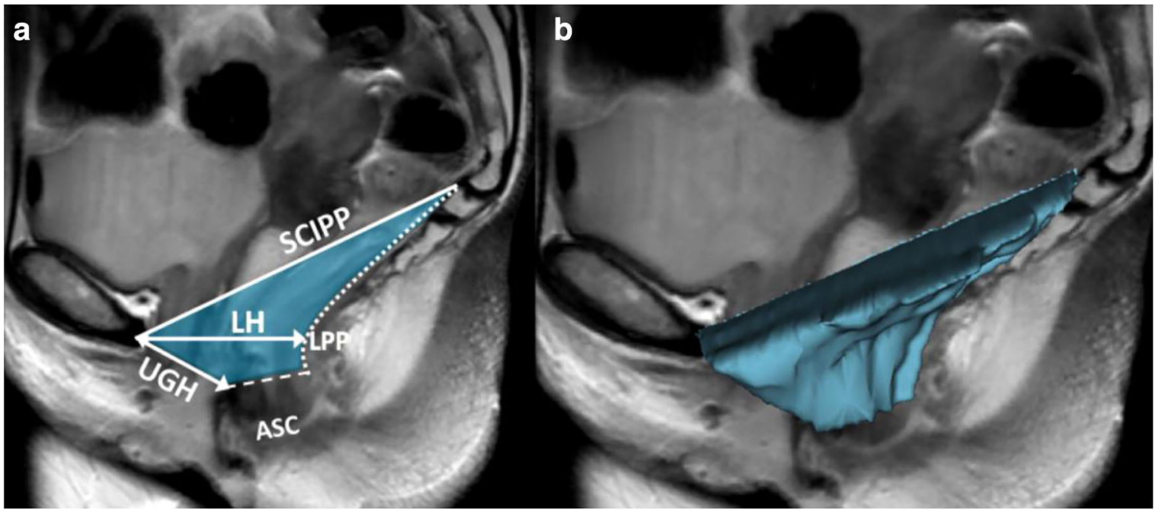

Figure 1: 2D and 3D measures in the mid-sagittal plane.

Panel a: Sacrococcygeal inferior pubic point line (SCIPP), levator plate profile (LPP) (dotted line), levator hiatus (LH), urogenital hiatus (UGH), and upper aspect of the anal sphincter complex (ASC) (dashed line) are shown. Mid-sagittal bowl area (blue) in a control patient. Panel b: 3D model of levator bowl volume in the same control patient.

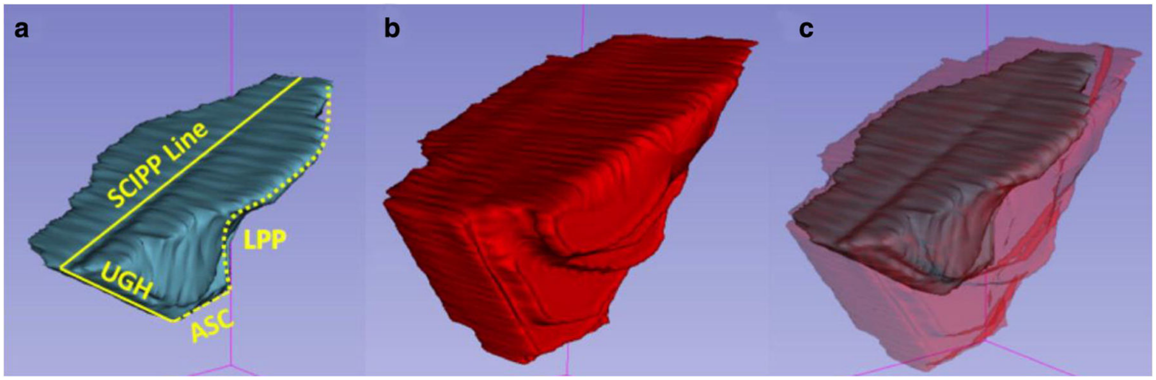

Figure 2: Sample 3D bowl volumes

Sample 3D models shown on a patient with posterior wall prolapse of a) rest bowl volume with borders, b) straining bowl volume, c) superimposed rest and straining bowl volume. SCIPP Line, Sacrococcygeal Inferior Pubic Point Line; UGH, Urogenital Hiatus; Dotted lines denotes LPP, Levator Plate Profile; Dashed line denotes top of ASC, anal sphincter complex.

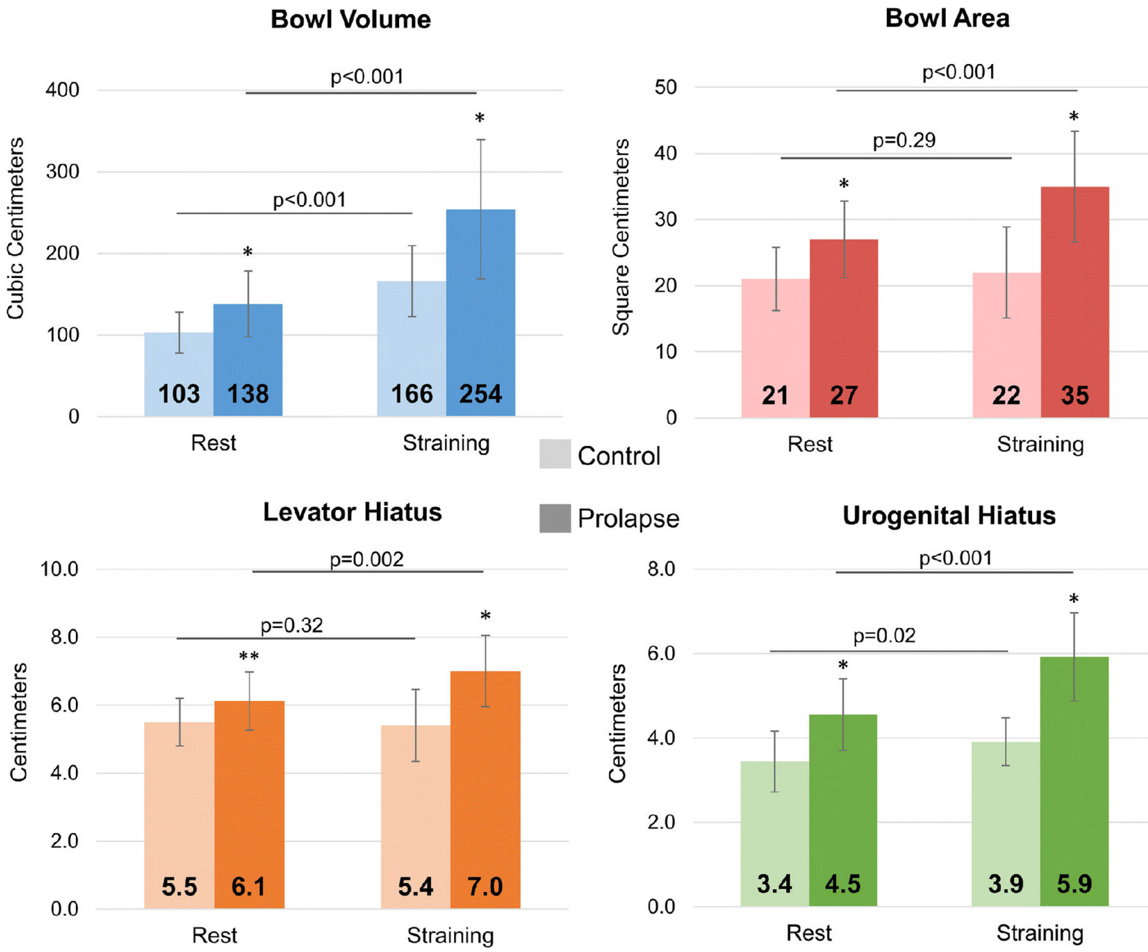

Figure 3: Average values of all 4 measures

Light bar is control group, dark bar is prolapse group

*indicates significant difference from control group at the 0.01 level

#indicates significant difference from control group at the 0.05 level

Numerical values of standard deviation are presented in Appendix.

Table 1.

Demographics

Characteristics[a]	**Controls (n=20)**	**Prolapse (n=20)**	**p-value**[*]
Age, y	58.4 ± 5.2	60.6 ± 10.1	0.39
BMI, kg/m^2	26.8 ± 5.1	26.1 ± 3.3	0.60
Height, in	63.9 ± 2.5	64.0 ± 2.1	0.82
Vaginal Delivery	2.8 ± 1.4	2.5 ± 1.3	0.41
Race, n (%)			0.15[b]
White	19 (95.0)	16 (80.0)	
Other	1 (5.0)	4 (20.0)	
POP-Q points, cm			
Ba	−1.9 ± 0.9	1.1 ± 2.5	<0.001
Bp	−2.1 ± 0.8	0.1 ± 2.4	0.001
C	−6.9 ± 1.7	−4.2 ± 1.6	<0.001
Max Prolapse, cm	−1.6 ± 0.7	2.6 ± 1.5	<0.001

[a] Data presented as mean ± standard deviation, unless otherwise specified

[b] Two proportion z test comparing prolapse and control group percentages

[*] p-value compares means of prolapse and control groups with an independent 2 sample t-test Max Prolapse: maximum value of Ba or Bp on POP-Q assessment

Table 2.

Effect size comparing control and prolapse group means

	Effect size	p-value
Bowl Volume Rest (cm^3)	1.07	0.002
Bowl Volume Strain (cm^3)	1.29	<0.001
Bowl Area Rest (cm^2)	1.17	0.001
Bowl Area Strain (cm^2)	1.69	<0.001
Urogenital Hiatus Rest (cm)	1.41	<0.001
Urogenital Hiatus Strain (cm)	1.69	<0.001
Levator Hiatus Rest (cm)	0.75	0.023
Levator Hiatus Strain (cm)	1.55	<0.001

Table 3.

Pearson's Correlation Coefficients

		Strain				Rest			
		Bowl Volume	**Bowl Area**	**Levator Hiatus**	**Urogenital Hiatus**	**Bowl Volume**	**Bowl Area**	**Levator Hiatus**	**Urogenital Hiatus**
Strain	Bowl Volume	1.0							
	Bowl Area	0.86 **	1.0						
	Levator Hiatus	0.80 **	0.83 **	1.0					
	Urogenital Hiatus	0.76 **	0.85 **	0.79 **	1.0				
Rest	Bowl Volume	0.48 **	0.45 **	0.45 **	0.55 **	1.0			
	Bowl Area	0.53 **	0.53 **	0.46 **	0.67 **	0.76 **	1.0		
	Levator Hiatus	0.37 *	.0.46 **	0.68 **	0.53 **	0.64 **	0.53 **	1.0	
	Urogenital Hiatus	0.43 **	0.54 **	0.52 **	0.76 **	0.69 **	0.73 **	0.59 **	1.0

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)