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ORIGINAL ARTICLE

Descent and hypermobility of the rectum in women with obstructed defecation symptoms

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Abstract

Introduction and hypothesis Obstructed defecation symptoms (ODS) are common in women; however, the key underlying anatomic factors remain poorly understood. We investigated rectal mobility and support defects in women with and without ODS using pelvic floor ultrasound and MR defecography.

Methods This prospective case-control study categorized subjects based on questions 7, 8 and 14 on the PFDI-20, which asks about obstructed defecation symptoms. All subjects underwent an interview, examination and pelvic floor ultrasound, and a subset of 16 subjects underwent MR defecography. The cul de sac-to-anorectal junction distance at rest and during maximum strain was measured on ultrasound and MRI images. The 'compression ratio' was calculated by dividing the change in rectovaginal septum length by its rest length to quantify rectal folding and hypermobility during dynamic imaging and to correlate with ODS.

Results Sixty-two women were recruited, 32 cases and 30 controls. There were no statistically significant differences in age, parity, BMI or stage of rectocele between groups. A threshold analysis indicated the risk of ODS was 32 times greater (OR 32.5, 95% CI 4.8–217.1, $p = 0.0003$) among women with a high compression ratio (≥ 14) compared with those with a low compression ratio (< 14) after controlling for age, BMI, parity, stool type and BM frequency.

Conclusions Female ODS are associated with distinct alterations in rectal mobility and support that can be clearly observed on dynamic ultrasound. The defects in rectal support were quantifiable using a compression ratio metric, and these defects strongly predicted the likelihood of symptoms; interestingly, the presence or degree of rectocele defects played no role. These findings may provide new insight into the anatomic factors underlying female ODS.

Keywords Obstructed defecation · Pelvic floor ultrasound · Rectocele · Hypermobile rectum · MR defecography

Introduction

The processes of normal rectal continence and evacuation are regulated through the coordinated interaction of multiple neuromuscular pathways [1]. While these processes are complex, the functional endpoint that must be achieved is simple—the body must generate intraabdominal pressures that exceed atmospheric pressures externally, and the direction of that pressure gradient should pass through the anal sphincter. Similar to a balloon in which the air is allowed to escape through its neck, the contents of the abdomen will follow the path of least resistance in order to occupy the area of lower pressure. Failure to accomplish this results in symptoms of obstructed defecation, which are described as prolonged straining at defecation, with a sensation of incomplete emptying resulting from a partial or complete blockage and stool entrapment.

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While some of the mechanisms responsible for obstructed defecation symptoms result from functional issues related to neuromuscular control, those resulting from a structural defect, such as a loss of the mechanical integrity of a pelvic organ or its supporting tissues, are the more likely to be considered for surgical repair [2]. Within the pelvis, the visceral organs are normally restrained in their motion, allowing for the passage of feces. However, when key structural defects exist, the motions of pelvic organs may no longer be optimally restrained, resulting in outlet obstruction or redirection of feces away from the anal canal. Severe defects can result in clinically observable lesions such as a rectal intussusception or rectal prolapse.

It has been previously suggested that for complete rectal prolapse to occur some, if not all, of the major supporting mechanisms of the rectum must be at least partially compromised [3, 4]. While the rectum measures 12 to 15 cm in length, it is the lower half to one third that bears supportive attachments to other structures. Apically, the rectum is limited by the anterior peritoneal reflection that occurs 7–9 cm from the anal verge in men and 5–7.5 cm from the anal verge in women [5, 6]. Lateral support is provided by the lateral ligaments or stalks of the rectum, while anterior and posterior support is provided by the visceral pelvic fascia of Denonvilliers and the rectosacral fascia (a.k.a. the fascia of Waldeeyer), respectively [5, 6]. The superior/posterior aspect, which closely follows the sacral hollow, is entirely extraperitoneal.

Despite this functional and anatomical knowledge, a generally weak association between symptomology and measurable factors such as stage of rectocele and abnormal findings on defecography remains. Moreover, there are often only limited to modest improvements in obstructed defecation symptomology after pelvic floor reconstructive surgery regardless of surgical approach [7–10]. This suggests that there is likely a key aspect to this issue that is being overlooked or misunderstood, or has yet to be quantified sufficiently. MR defecography and dynamic pelvic floor ultrasound both have an established role in evaluation of obstructed defecation symptoms [11–13].

In this study, we utilized both MR defecography and endovaginal pelvic floor ultrasound to assess differences in rectal support and mobility in women with and without obstructed defecation symptoms. We hypothesized that rectal hypermobility (i.e., an increase in rectal descent as a result of an increased in intraabdominal pressure) is correlated with obstructed defecation symptoms, independent of the stage of rectocele.

Methods

This was a prospective case-control study, approved by the Institutional Review Board committee at NorthShore University HealthSystem. Women presenting to our tertiary urogynecology center with pelvic floor dysfunction symptoms were approached during their initial visit to enter the study between July to October 2018. Cases were defined as women reporting ODS symptoms, according to positive answers to questions 7, 8 and 14 on the PFDI-20 (CRADI) questionnaire. Any subject in the case group who reported abnormal bowel movement frequency or denied the urge to defecate was required to undergo a Sitz marker study or anal manometry to rule out a colon motility disorder or anorectal sensation dysfunction. Controls were defined as women not reporting ODS, according to answering “no” to all three of the above-mentioned CRADI screening questions. Exclusion criteria included a prior history of chronic opioid use or colorectal cancer. In total, 62 women were recruited to the study, with the final analysis including 32 cases and 30 controls.

Enrolled subjects returned for a comprehensive study visit that included a symptom interview detailing the presence of straining, frequency of incomplete emptying of stool and areas of splinting. All subjects completed the Bristol Stool Scale to identify stool type, and all underwent vaginal examination, quantitative prolapse (POPQ) assessment, and endovaginal pelvic floor static and dynamic ultrasound.

The study budget allowed us to perform MR defecography on ten subjects (4 cases, 6 controls), and additionally we were able to incorporate MR defecography results for six case subjects who had previously undergone imaging ordered by referring colorectal surgeons. Thus, a total of 16 MR defecography scans (10 cases, 6 controls) were included in the final analysis.

Pelvic floor ultrasound

Imaging was obtained at the time of the study visit using the BK Medical Ultrafocus (Peabody, MA) and 8838 12-MHz transducer. All ultrasound studies were performed in the office setting with the patient in the dorsal lithotomy position, with hips flexed and abducted. No preparation was required, and no rectal or vaginal contrast was used. Patients were instructed to arrive at the office with a partially full bladder and to avoid excessive pressure on surrounding structures that might distort the anatomy. The probe was inserted into the vagina in a neutral position. Three hundred sixty-degree endovaginal ultrasound volumes and dynamic ultrasound videos were saved for further analysis. It has been previously shown that the endovaginal probe has no adverse effect on anatomy compared with transperineal ultrasound [14].

Three-dimensional pelvic floor ultrasound measurement protocol

Levator ani muscle deficiency (LAD)

This axial view analysis involves scoring of levator ani muscle subdivisions (puborectalis and illiococcygeus) and is based on previously published work [15, 16]. LAD scores range from 0 to 3 for each muscle subdivision based on the presence of an avulsion from the pubic bone and the thickness of that subdivision.

Levator plate descent angle (LPDA)

This midsaggital view measurement quantifies the levator plate location relative to the pubic symphysis. LPDA is established by calculating the angle between a vertical mid-symphysial reference line and extending a second line that represents the shortest distance between the pubic symphysis and levator plate. The resulting angle between these lines measures the relative location of the levator plate in relation to the pubic symphysis in the resting position [17, 18].

Minimal levator hiatus (MLH) area

This axial view measurement is defined as the area located within the levator muscles and pubic bone [15].

Rectal area

This was measured in the axial view and also within the plane of the minimal levator hiatus. The rectum was delineated by its outer border, and its area was reported [17].

Dynamic posterior compartment ultrasound measurements

The distance between the posterior cul de sac and anorectal junction ("rectovaginal septum length") was measured both at rest and during Valsalva straining efforts using a dynamic imaging protocol in the mid-sagittal plane, allowing posterior compartment structures to be visualized. It should be noted that for Valsalva straining efforts, patients were instructed to relax their pelvic floor while increasing the intraabdominal pressure. All images included the cul de sac apically and the levator plate/anorectal junction caudally in order to standardize framing of the anatomy, and the dynamic recording was started with the patient at rest and captured for 5 s of Valsalva straining (Fig. 1a–b).

The "compression ratio" was calculated as a means to quantify the relative change in length of the rectovaginal septum (RVS), in other words, the degree of hypermobility/sliding rectum, and was expressed as a percentage using the following formula: Compression ratio = 100 * (RVS length at rest – RVS septum length at Valsalva)/RVS length at rest.

MR defecography

All 16 patients who underwent MR imaging were in the supine position using a closed-configuration 1.5-T magnet (Siemens, Magnetom Avanto) and a Synergy phased-array body coil. As for routine dynamic pelvic floor MRI examinations performed at our institution, intravenous contrast was not used. No bowel preparation or intraluminal contrast material was administered. Subjects were instructed to empty their bladder 3 h before the examination to result in a moderately full urinary bladder during MRI. Static multiplanar images of the pelvis were acquired for anatomic evaluation using a 4-mm slice thickness with a 0-mm gap for sagittal and axial T2-weighted sequences (echo time, 105 ms; repetition time, 3000 ms). The rectum was then filled with 60 ml ultrasound gel (1% Gd-DTPA-GEL mixture). Images were collected (1.5-T MRI, Magnetom Symphony; Siemens, Erlangen, Germany) with patients in the supine position with hips and knees bent at 45°. The pelvic floor was visualized in three planes (transversal, coronal, sagittal, T1 and T2) to find the appropriate sagittal plane in which all relevant pelvic floor organs could be acquired during defecation. The sequence lasted 36 s at a frequency of one shot per 1.1 s (True Fast Imaging with Steady-State Precession; TR: 1.8 ms, TE: 1.01 ms). Slice thickness was 6 mm (field of view: 300 mm × 270 mm, image matrix: 256 × 256). During the examination, patients were instructed via headphones to first relax and then to perform a squeeze maneuver. This was followed by instructions to perform straining and evacuation maneuvers with the goal of emptying the rectum as completely as possible. The sequences were acquired digitally and analyzed.

MR defecography measurements

Three anatomic measurements relating to rectal support were recorded at rest and then also at the moment of maximum evacuation, which was defined as the image in which the posterior cul de sac made its closest approach to the anorectal junction. The first measurement was the straight distance between the posterior cul de sac and anorectal junction, as illustrated in Fig. 2a–b. The second measurement was the perpendicular distance between the cul de sac and the pubo-coccygeal line. The third measurement was the perpendicular distance between the anorectal junction and the pubo-coccygeal line.

Similar to the compression ratio measured via ultrasound, the relative change in length of the straight distance between the posterior cul de sac and anorectal junction (CDS to ARJ) as observed on MR defecography was used to define the compression ratio, which was again calculated as a percentage using the following formula: Compression ratio = 100 *

(CDS to ARJ length at rest – CDS to ARJ septum length at evacuate)/CDS to ARJ length at rest.

Visualization of rectal shape change

The 3D rectal/pelvic shapes of two representative subjects (1 case, 1 control) were obtained at rest by segmenting the axial T2-weighted sequences using open source software (Seg3D v2.4.2, University of Utah). Isosurfaces were exported to 3DCoat v4.8.2 (3dcoat.com) for manual voxel smoothing. Triangular surface meshes were then exported to Blender v2.78b (blender.org). Within Blender, midsagittal images representing rest and maximal evacuation were imported using the "Planes from Images" script. Imported images were registered by matching boney landmarks on the pubic bone and sacrum. Geometries from case and controls were then manually registered to match their respective rest images. Rectal geometries were then warped to match their respective evacuation images utilizing a lattice modifier. This approach, while not quantitative, provides a 3D representation of the rectal shape and position observed for two patients. Each was chosen to be representative of their group without rectoceles such that the descent of the rectum could be visualized (Fig. 3).

Statistics

The sample size calculation was based on a preliminary study [17]. We powered for a moderate composite effect size of 0.5, which was clinically relevant for the proposed study outcome. Using an alpha of 0.05, a total sample size of 58 (29 in each group) was required to achieve 90% power for rejecting the null hypothesis with a mean difference of 50% in the levator plate descent angle and rectal area using a two-sided two-sample t-test. The sample size was calculated using PASS 12 (NCSS LLC., Kaysville, UT).

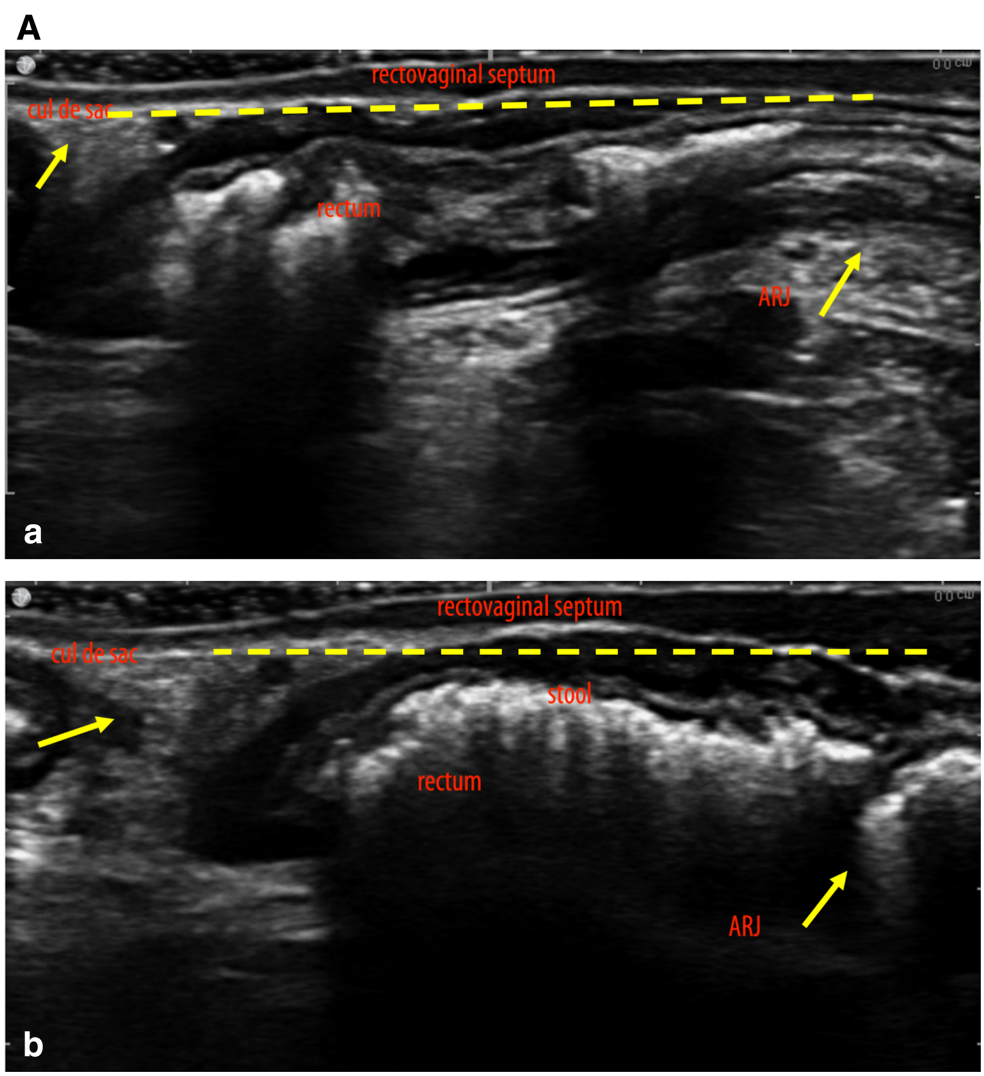

Fig. 1 **a** Mid-sagittal view of dynamic ultrasound imaging: **a** at rest; **b** at maximum strain. Control is a 46-year-old patient who denies any obstructed defecatory symptoms, POP-q Point C −1, Bp +0.5. **b** Mid-sagittal view of dynamic ultrasound imaging: **a** at rest; **b** at maximum strain. Case is a 56-year-old patient who reports incomplete emptying of rectum in 100% of bowel movements and need to splint on perineum, POP-q Point C −6, Bp −1.5

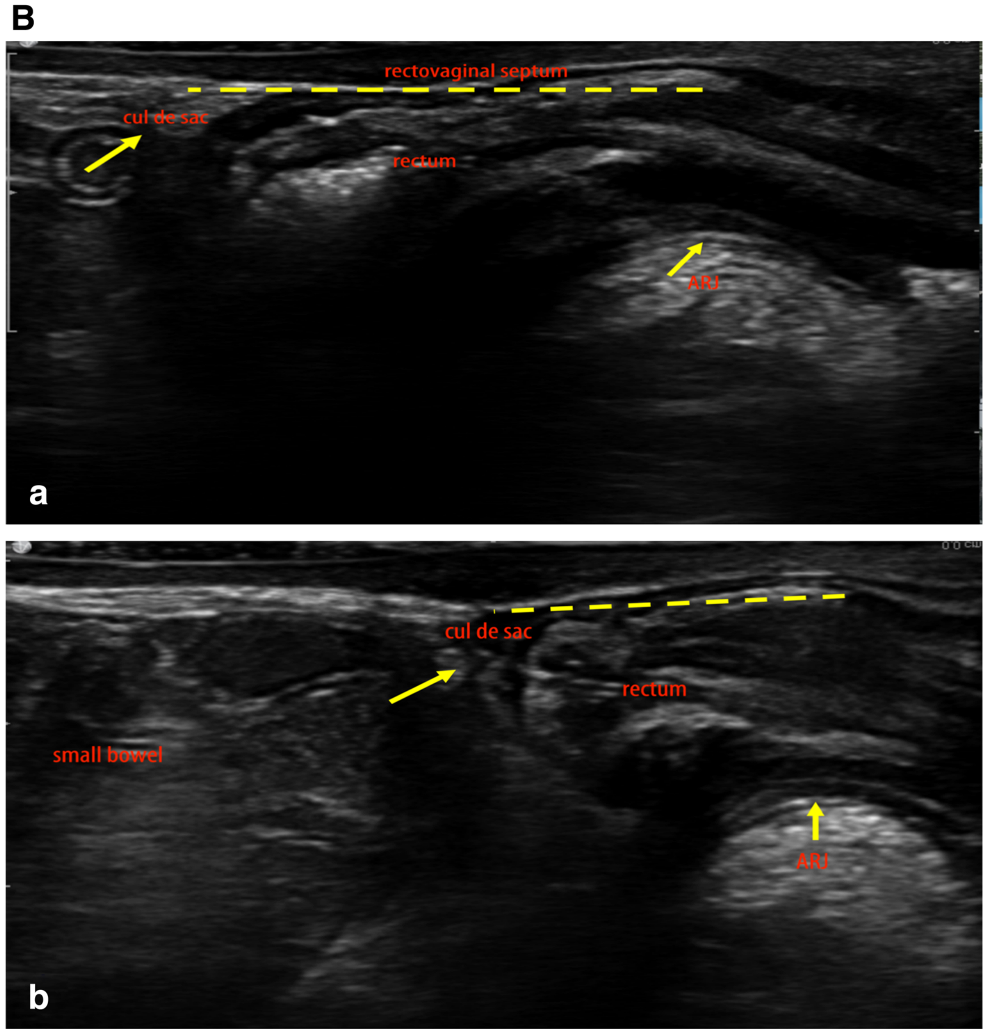

Fig. 1 (continued)

Demographics, symptoms, ultrasound and MR defecography measurements were compared between groups using chi-squared tests, Student *t*-tests (parametric) or Mann-Whitney *U* tests (nonparametric) where appropriate. The Pearson correlation

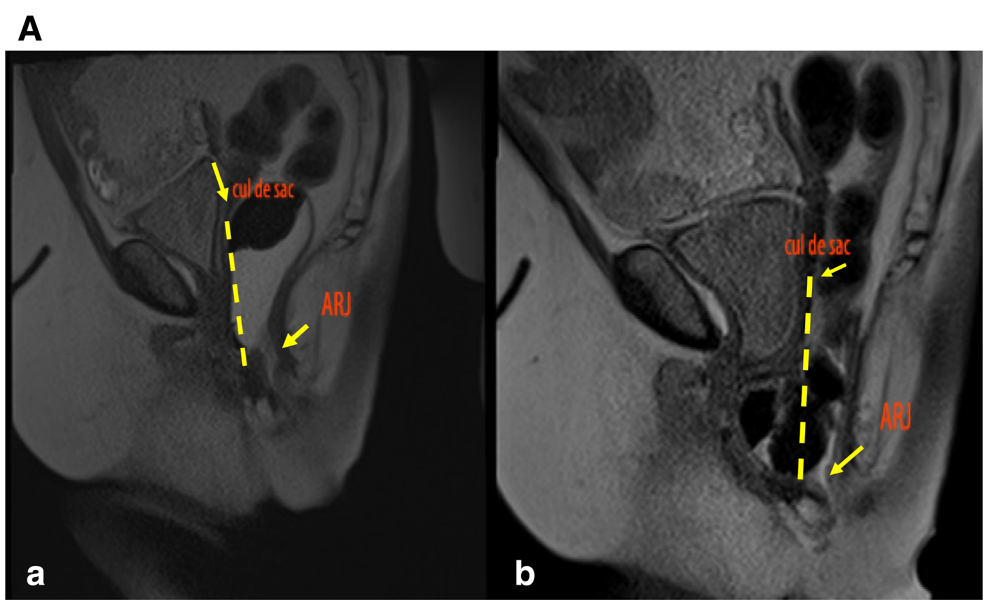

Fig. 2 **a** MR defecography measurements; cul de sac to ARJ distance at rest and evacuation and distance from pubo-coccygeal line. Control is an 80-year-old patient who denies any obstructive defecatory symptoms, POP-q point C −6, Bp +0.5. **b** Case is a 56-year-old patient who reports incomplete emptying of stool in 40% of bowel movement and splinting inside the vagina, POP-q point C −5, Bp + 2.5

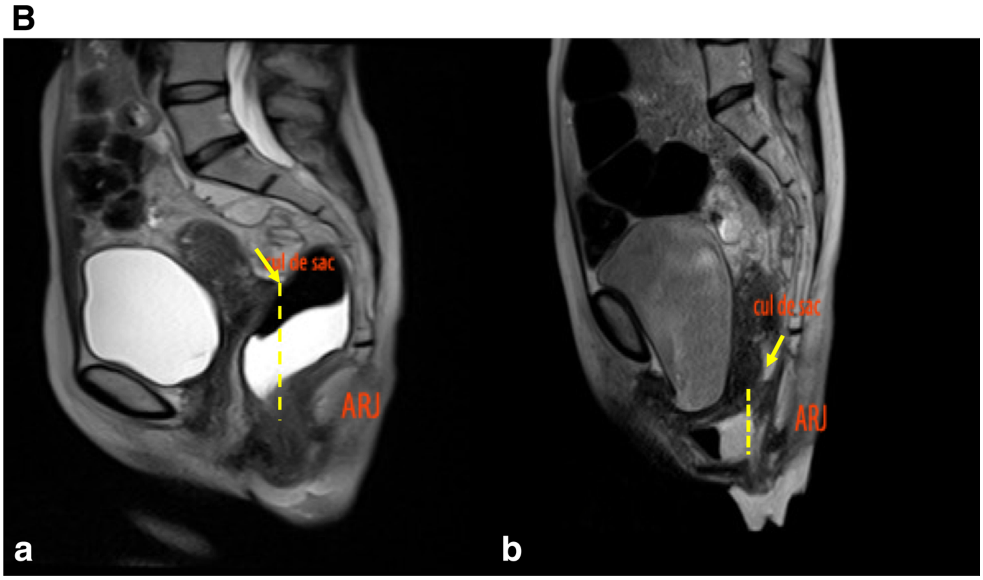

Fig. 2 (continued)

coefficient was calculated to assess the association between RVS length at rest/at strain and the compression ratio calculated from ultrasound and MR images. To quantify inter- and intra-rater reliability of MRI measurements, we calculated an intraclass correlation coefficient. A receiver-operating characteristic (ROC) curve was used to evaluate the ability of the compression ratio (calculated from ultrasound) to discriminate between groups. Univariate and multivariable logistic regressions with Firth's penalized maximum likelihood estimates were performed to predict the presence of symptoms. All the statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC), and $p < 0.05$ was considered statistically significant.

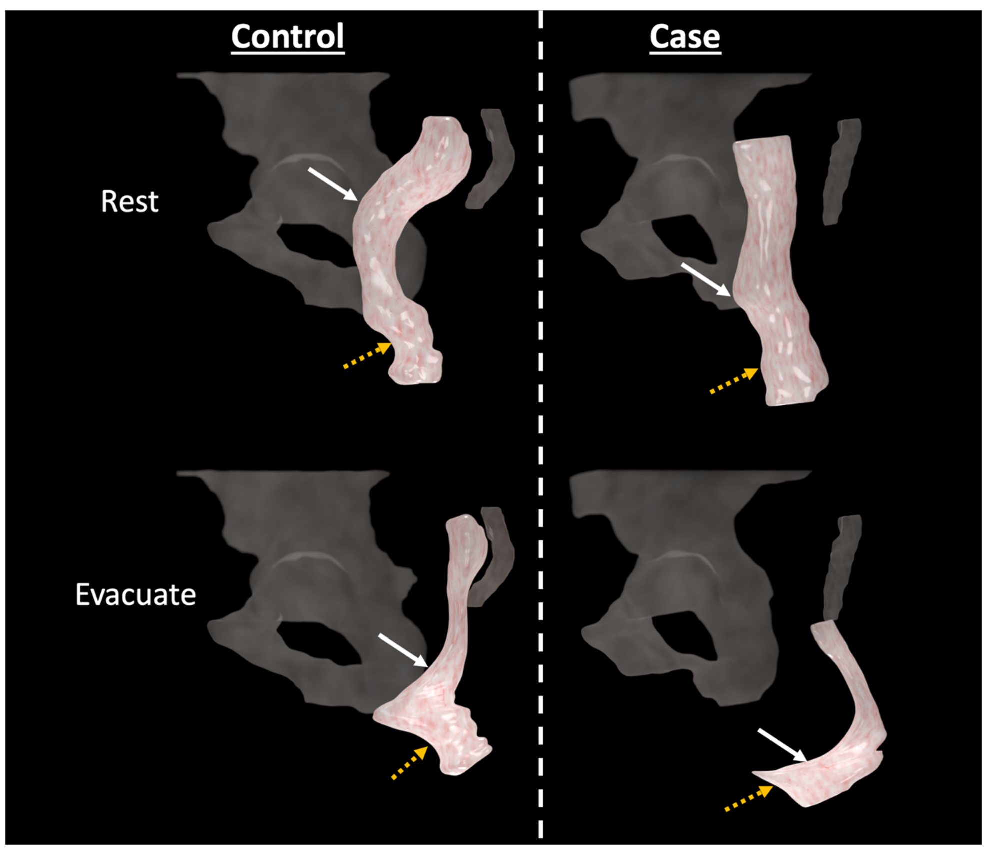

Fig. 3 Three-dimensional model based on axial T2 pelvic MRI of a control and case subjects that were deformed based on their MR defecography at evacuation phase to demonstrate the rectum deformation. White arrow points to cul de sac and dotted yellow arrow points to anorectal junction

Results

This study included 62 women (32 cases, 30 controls), with demographic characteristics summarized in Table 1. There were no statistically significant differences in age, parity, BMI or stage of rectocele between groups. Cases and controls had similar rectocele stages. The distribution of obstructed defecation symptoms in the case group is summarized in Table 2.

Among cases, we diagnosed colon motility disorder in eight patients, dyssynergic defecation in two patients and impaired rectal sensation in one patient. The remaining cases (21 in total) were grouped as "cases with outlet obstruction." Thus, for the ultrasound data, to avoid possible confounding factors between anatomic and functional abnormalities, comparisons of cases with controls are dichotomized in the following way: (1) total cases ($n = 32$) compared with controls and (2) cases with outlet obstruction ($n = 21$) compared with controls. For the smaller subset of subjects undergoing MR defecography, comparisons were dichotomized similarly: (1) total cases ($n = 10$) compared with controls ($n = 6$) and (2) cases with outlet obstruction ($n = 8$) compared with controls ($n = 6$).

Static and dynamic ultrasound measurements

While comparing the static ultrasound measurements among groups, both the total cases and cases with outlet obstruction groups had a higher levator deficiency score compared with controls (7.09 ± 2.52 and 7.38 ± 2.75 vs. 5.07 ± 3.24, p of 0.008 and 0.007, respectively). Both case groups also had a more descended levator plate [LPDA 8.5° (−16°, 25°) and 10° (−16°, 22°) vs. 15° (−7°, 33°), $p = 0.030$ and 0.035, respectively].

Dynamic ultrasound measurement showed shorter RVS length at rest and during strain with a higher compression ratio in cases (regardless of dichotomization) compared with controls, as summarized in Table 3.

MR defecography measurements

The distance from the cul de sac to anorectal junction was shorter in cases (total: 2.98 ± 1.31 cm and with outlet obstruction: 2.63 ± 1.18 cm) compared with controls (5.96 ± 1.32 cm), but only at maximal evacuation (p = 0.001; Table 3). This corresponded to an average compression ratio of 45.7% and 49.8%, respectively, in the dichotomized case groups compared with an average 8.2% compression ratio observed among controls (Table 3).

ROC curve and multivariable analysis

The area under the ROC curve was 0.93 (95% CI 0.86–1.00) (Fig. 4), indicating an excellent ability to distinguish between case and control groups based on the compression ratio calculated by ultrasound. The sensitivity and specificity were both 90%. Based on the value maximizing sensitivity (1-specificity), the optimal threshold for the ultrasound compression ratio was determined to be 14.29%. Using the optimal threshold of the ultrasound compression ratio, the risk of having symptoms was 32 times greater (OR 32.51, 95% CI 4.87–217.10, p = 0.0003) among those with a high compression ratio (≥ 14.29) compared with those with a low compression ratio (< 14.29), after controlling for age, BMI, parity, stool type, BM frequency per week and LPDA, and stage of rectocele (Table 4).

Correlations between ultrasound and MRI measurements

We examined the correlation between RVS length at rest and strain as measured by ultrasound with similar measurements performed by MR defecography, for instance, the distance between the cul de sac and anorectal junction. There was a poor correlation for these measurements at rest (Pearson correlation coefficient = 0.35); however, a strong correlation for strain (ultrasound) with evacuation (MR) measurements was observed (Pearson correlation coefficient = 0.82, $p < 0.05$). This translated to a correlation in the compression ratio of 0.57 ($p < 0.05$).

Inter- and intra-rater reliability analysis

Intra-rater reliability (rater GR) and inter-rater reliability of MR defecography measurements (GR and SA) at rest and during evacuation (Table 3) were evaluated and demonstrated good-to-excellent reliability ranging from 0.83 to 0.96. Inter-rater reliability for ultrasound measurements of RVS length at rest and strain were 0.85 and 0.81, respectively.

Discussion

This study utilized both MR defecography and endovaginal dynamic posterior compartment ultrasound to test the hypothesis that rectal hypermobility is correlated with obstructed defecation symptoms and furthermore to explore whether this finding is independent of the stage of rectocele. Our findings strongly supported this hypothesis. Women with obstructed defecation symptoms had a significantly shorter span of attachment between the rectum and posterior vaginal wall (i.e., deeper cul de sac) and also had significantly increased descent of the cul de sac toward the anorectal junction when intraabdominal pressure was increased. The above anatomic changes result in a hypermobile 'sliding rectum' that appears to alter the fundamental biomechanics of defecation and that we were able to quantify using a compression ratio metric.

Table 1 Demographic summary and prevalence comparison between groups

	Total		Case		Control		*p* value
	n	%	*n*	%	*n*	%	
No. of patients	62	100.00	32	51.61	30	48.39	
Demographics							
Age (years), mean ± SD	61.52 ± 16.13		62.47 ± 11.85		60.50 ± 19.88		0.6407
Race							
African American	3	4.84	1	3.13	2	6.67	0.7479
Asian	2	3.23	1	3.13	1	3.33	
Caucasian	48	77.42	25	78.13	23	76.67	
Hispanic	4	6.45	2	6.25	2	6.67	
Indian	3	4.84	1	3.13	2	6.67	
Middle Eastern	2	3.23	2	6.25	0	0.00	
Weight (kg), mean ± SD	71.58 ± 19.10		73.31 ± 21.29		69.78 ± 16.72		0.4753
Height (m), mean ± SD	1.59 ± 0.07		1.58 ± 0.07		1.60 ± 0.07		0.2190
BMI (kg/m^2), mean ± SD	28.33 ± 7.69		29.44 ± 8.84		27.19 ± 6.23		0.2559
Parity, median (range)	2 (0–11)		3 (0–11)		2 (0–11)		0.1583
Vaginal deliveries, median (range)	2 (0–11)		2 (0–10)		2 (0–11)		0.5809
Forceps							
Yes	9	14.52	6	18.75	3	10.00	0.3284
No	53	85.48	26	81.25	27	90.00	
Hypertension							
Yes	22	35.48	10	31.25	12	40.00	0.4718
No	40	64.52	22	68.75	18	60.00	
DM							
Yes	7	11.48	4	12.90	3	10.00	0.7221
No	54	88.52	27	87.10	27	90.00	
Cardiac							
Yes	8	12.90	5	15.63	3	10.00	0.5091
No	54	87.10	27	84.38	27	90.00	
CNS							
Yes	7	11.48	4	12.90	3	10.00	0.7221
No	54	88.52	27	87.10	27	90.00	
Spine							
Yes	12	20.00	8	25.00	4	14.29	0.3006
No	48	80.00	24	75.00	24	85.71	
Stroke							
Yes	2	3.23	1	3.13	1	3.33	0.9630
No	60	96.77	31	96.88	29	96.67	
Depression/anxiety							
Yes	23	37.70	14	45.16	9	30.00	0.2219
No	38	62.30	17	54.84	21	70.00	
IBS							
Yes	14	22.58	11	34.38	3	10.00	**0.0218**
No	48	77.42	21	65.63	27	90.00	
Breast cancer							
Yes	3	4.84	1	3.13	2	6.67	0.5160
No	59	95.16	31	96.88	28	93.33	
Other cancer							
Yes	5	8.06	3	9.38	2	6.67	0.6955
No	57	91.94	29	90.63	28	93.33	
Gastric bypass							
Yes	4	6.45	4	12.50	0	0.00	**0.0453**

Table 1 (continued)

	Total		Case		Control		*p* value
	n	%	*n*	%	*n*	%	
No	58	93.55	28	87.50	30	100.00	
Colon surgery							
Yes	3	4.84	3	9.38	0	0.00	0.0856
No	59	95.16	29	90.63	30	100.00	
Hemorrhoid							
Yes	10	16.13	10	31.25	0	0.00	**0.0008**
No	52	83.87	22	68.75	30	100.00	
Spine surgery							
Yes	6	10.00	3	9.38	3	10.71	0.8630
No	54	90.00	29	90.63	25	89.29	
TAH							
Yes	11	17.74	7	21.88	4	13.33	0.3790
No	51	82.26	25	78.13	26	86.67	
Urogynecology surgery							
Yes	18	29.51	16	51.61	2	6.67	**0.0001**
No	43	70.49	15	48.39	28	93.33	
Sling procedure							
Yes	9	14.52	8	25.00	1	3.33	**0.0155**
No	53	85.48	24	75.00	29	96.67	
Stool type							
Too hard (1,2)	5	8.33	5	15.63	0	0.00	**0.0320**
Normal (3,4,5)	50	83.33	23	71.88	27	96.43	
Loose (6,7)	5	8.33	4	12.5	1	3.57	
BM frequency per week, mean ± SD	8.85 ± 6.15		9.81 ± 7.75		7.83 ± 3.63		0.2000
POP-Q exam (mean ± SD)							
Ba	−0.87 ± 1.79		−0.91 ± 1.37		−0.83 ± 2.18		0.8764
C	−3.97 ± 3.11		−3.53 ± 3.01		−4.43 ± 3.20		0.2574
GH	3.52 ± 0.74		3.73 ± 0.61		3.30 ± 0.81		**0.0192**
PB	2.61 ± 0.56		2.61 ± 0.45		2.62 ± 0.67		0.9602
Bp	−0.98 ± 1.68		−1.02 ± 1.51		−0.95 ± 1.87		0.8791
Rectocele stage							
0	12	19.35	7	21.88	5	16.67	0.9161
1	23	37.10	11	34.38	12	40.00	
2	22	35.48	11	34.38	11	36.67	
3	5	8.06	3	9.38	2	6.67	

Significant P values are shown in bold

These rectal mobility findings were extremely consistent among women reporting ODS and not seen among asymptomatic controls.

Interestingly, with the positive correlation observed between ODS symptoms and rectal hypermobility, this study also showed a lack of correlation between ODS symptoms and the presence of rectocele as diagnosed via a pelvic examination. Our study supports the notion that while posterior vaginal compartment prolapse (i.e., rectoceles) may underlie an array of bothersome symptoms such as vaginal bulging and laxity, rectoceles appear to have essentially no relationship with obstructive defecation. Because ODS appear to be related to excessive mobility of the rectum and cul de sac and have no correlation with rectocele defects, it should be unsurprising that historically rectocele repairs have performed poorly as a means to resolve obstructive defecation symptoms [7, 8].

A novel measurement developed and utilized for this study was the "compression ratio," utilized to quantify rectal sliding/hypermobility. The compression ratio in our study proved to represent a strong and independent predictor of ODS symptoms. As measured via dynamic ultrasound, the risk of ODS symptoms was 32 times greater among those with a high compression ratio (≥ 14) compared with those with a low compression ratio (< 14) after controlling for age, BMI, parity,

Table 2 Obstructed defecation symptom distribution in case group

ODS symptoms	Case	
	n	%
Straining		
Yes	17	53.13
No	15	46.88
Incomplete emptying (%) of bowel movements, mean ± SD	66.56 ± 27.66	
< 50%	5	15.63
≥ 50%	27	84.37
Splinting around rectum		
Yes	6	18.75
No	26	81.25
Splinting inside rectum		
Yes	8	25.00
No	24	75.00
Splinting on perineum		
Yes	6	18.75
No	26	81.25
Splinting inside vagina		
Yes	3	9.68
No	28	90.32

stool type and BM frequency per week. The term "compression" was initially utilized because during dynamic ultrasound the rectum appeared to behave like an empty aluminum beverage can being compressed from its ends. As the cul de sac descended toward the anorectal junction with increased intraabdominal pressure, the rigid support of the probe anteriorly caused the descent of the cul de sac to be linear, making it appear as if it was sliding and folding on itself relative to the posterior vaginal wall. In subjects without ODS symptoms, little to no sliding was observed. A similar compression ratio was also calculated using measurements obtained by MR defecography, and while MR measurements added meaningfully to our conclusions, the absence of a probe anteriorly resulted in a less vivid "crushed can" appearance compared with dynamic ultrasonography.

One potential mechanism underlying the significant downward/sliding movement of the rectum may involve defects in its lateral and/or anterior support structures. Indeed, Puvviani et al. (1996) suggested that rectoceles associated with more frequent manual evacuation of stool, lower anal pressure and greater mucosal intussusception were more likely to represent a "displacement" rectocele resulting from downward descent of the rectum as opposed to the "distension" type or rectoceles resulting from weak or torn rectovaginal fascia [19]. These pathophysiological concepts were previously described by Graham in 1942 [20] and Moschowitz in 1912 [21]. In the present study, our ability to precisely visualize and quantify sliding rectocele defects, and to quantitatively correlate these key anatomic changes with ODS symptoms, provides new and expanded insight into these concepts.

Interestingly, our findings may be consistent with the etiology of obstructed defecation symptoms in males as described by previous authors [22, 23]. Although the mechanisms of defecation dysfunction may not be identical between males and females, it is interesting to note that Piloni et al. observed a "sliding" relative motion of the rectal wall in male subjects with ODS and further hypothesized that this hypermobility could result from detachment of the rectal wall from the Denonvilliers' and mesorectal fascia due to repetitive overloading [22]. These homologous observations relating to a "sliding rectum" pathophysiology underlying ODS in males, combined with our observation of female ODS being entirely unrelated to the presence or stage of rectocele, further suggest that conventional rectocele repairs, without addressing support to the rectum, may be ineffective in treating ODS [24, 25].

The unique implementation of dynamic ultrasound for the evaluation of rectal mobility is the strength of our work. However, it is acknowledged that this study is limited by a low subject number. In addition, both ultrasound and MRI imaging modalities are associated with their own limitations. Both observers (GR, SA) felt that identification of landmarks was less reliable via MR defecography compared with dynamic endovaginal posterior compartment ultrasound, and this was supported by intra- and interobserver repeatability analyses. In particular, the location of the cul de sac was not as clear and could become obscured as the vagina was pushed toward the rectum during increased intraabdominal pressure. While

Table 3 Ultrasound and MRI measurements among groups

	Total		Case (total), $N = 32$		Case with outlet obstruction, $N = 21$		Control, $N = 30$		P value[a]	P value[b]
Pelvic floor 3D findings										
PR, median (range)	2 (0–6)		3 (0–6)		4 (0–6)		2 (0–4)		**0.0120**	**0.0182**
Right	1 (0–3)		1 (0–3)		2 (0–3)		1 (0–2)		**0.0416**	**0.0454**
Left	1 (0–3)		1.5 (0–3)		2 (0–3)		1 (0–2)		**0.0090**	**0.0110**
IC, median (range)	4 (0–6)		4 (2–6)		4 (2–6)		4 (0–6)		**0.0401**	**0.0338**
Right	2 (0–3)		2 (1–3)		2 (1–3)		2 (0–3)		**0.0179**	**0.0125**
Left	2 (0–3)		2 (0–3)		2 (0–3)		2 (0–3)		0.0584	0.0545
	n	%	*n*	%	*n*	%	*n*	%		
Avulsion (bilateral)	9	14.75	7	21.88	5	23.81	2	6.90	0.0893	0.0800
Avulsion (unilateral)	33	53.23	19	59.38	13	61.90	14	46.67	0.3162	0.2833
Right										
Yes	28	45.16	15	46.88	11	52.38	13	43.33	0.7794	0.5241
No	34	54.84	17	53.13	10	47.62	17	56.67		
Left										
Yes	14	22.95	11	34.38	7	33.33	3	10.34	**0.0258**	**0.0389**
No	47	77.05	21	65.63	14	66.67	26	89.66		
LAD	6.13 ± 3.04		7.09 ± 2.52		7.38 ± 2.75		5.07 ± 3.24		**0.0081**	**0.0070**
MLH area (cm^2)	14.79 ± 3.96		15.41 ± 3.83		15.33 ± 4.37		14.11 ± 4.06		0.2031	0.2619
LPDA (°), median (range)	11 (−16–33)		8.5 (−16–25)		10 (−16–22)		15 (−7–33)		**0.0301**	**0.0351**
Rectal area (cm^2)	1.72 ± 0.69		1.91 ± 0.76		1.95 ± 0.83		1.51 ± 0.55		**0.0253**	**0.0357**
Dynamic ultrasound findings										
RVS length at rest (cm)	3.96 ± 1.06		3.38 ± 1.01		2.96 ± 0.87		4.60 ± 0.67		**< 0.0001**	**< 0.0001**
RVS length at strain (cm)	3.35 ± 1.45		2.47 ± 1.34		1.83 ± 0.91		4.33 ± 0.80		**< 0.0001**	**< 0.0001**
Compression ratio (%)	18.87 ± 24.35		31.01 ± 25.00		40.50 ± 27.33		5.92 ± 8.84		**< 0.0001**	**< 0.0001**
Enterocele	*n*	%	*n*	%	*n*	%	*n*	%		
Yes	6	10.53	6	21.43	6	35.29	0	0	**0.0084**	**0.0005**
No	51	89.47	22	78.57	11	64.71	29	100		
CDS from PB (cm)	5.75 ± 0.27		5.75 ± 0.29		6.00		5.75 ± 0.35		1.0000	–
MRI measurements			$N = 10$		$N = 8$		$N = 6$			
At rest										
Cul de sac to ARJ (cm)	5.77 ± 1.53		5.55 ± 1.63		5.34 ± 1.72		6.13 ± 1.41		0.4791	0.3750
Cul de sac to PC line (cm)	3.03 ± 2.35		2.40 ± 2.65		1.91 ± 2.77		4.07 ± 1.35		0.1782	0.1074
ARJ to PC line (cm)	2.05 ± 1.17		2.38 ± 1.05		2.54 ± 1.05		1.50 ± 1.24		0.1505	0.1163
At maximal evacuation										
Cul de sac to ARJ (cm)	3.97 ± 1.93		2.98 ± 1.31		2.63 ± 1.18		5.96 ± 1.32		**0.0011**	**0.0006**
Cul de sac to PC line (cm)	2.14 ± 2.22		2.96 ± 2.25		3.64 ± 1.93		0.50 ± 0.94		**0.0378**	**0.0064**
ARJ to PC line (cm)	5.00 ± 1.50		5.30 ± 1.64		5.59 ± 1.72		4.40 ± 1.10		0.2907	0.1993
From rest to maximal evacuation										
Cul de sac to ARJ										
Compression Ratio (%)	33.24 ± 28.70		45.75 ± 26.00		49.78 ± 25.96		8.21 ± 13.73		**0.0104**	**0.0075**

All data are reported as mean ± SD unless indicated otherwise

ARJ anorectal junction, *IC* illiococcygeus, *LAD* levator ani deficiency, *LP* levator plate, *LPDA* levator plate descent angel, *MLH* minimal levator hiatus, *PR* puborectalis, *PC* pubococcygeal, *RVS* rectovaginal septum

[a] Comparison of case vs. control

[b] Comparison of case with outlet obstruction vs. control

Significant P values are shown in bold

the cul de sac was more easily visualized via ultrasound, shadowing resulting from stool in the rectum would occasionally hide the levator plate from view, although this limitation in almost all cases could be overcome by performing 1–2 additional scans. Ultrasound was also associated with some distinct advantages over MR defecography including the

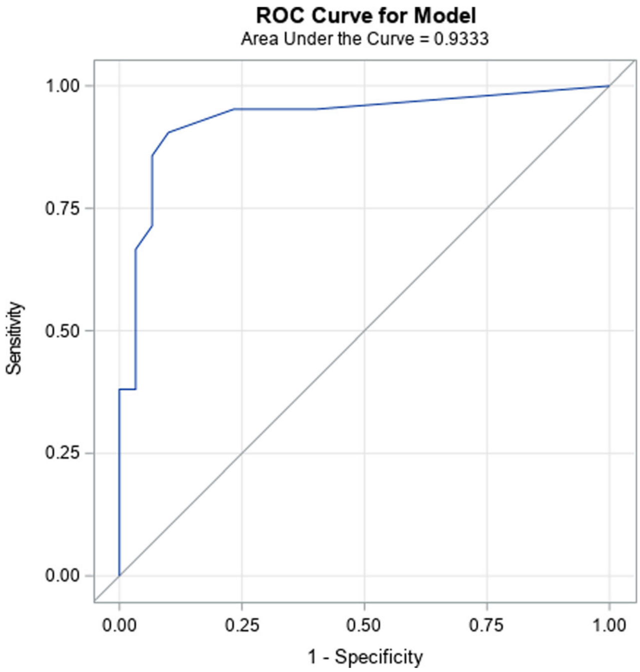

Fig. 4 ROC curve for the compression ratio as a predictor for the presence of symptoms

ability to perform the study in the office setting, reduced cost (roughly 10× less), less invasiveness and generally better patient tolerance.

Table 4 Multivariable analysis to predict the presence of symptoms

	OR	95% CI		*p* value
Demographics				
Age (years)	0.992	0.936	1.052	0.7912
BMI (kg/m^2)	1.025	0.911	1.153	0.6871
Parity	1.01	0.71	1.437	0.9543
Stool type				
Too hard (1,2) (ref)	–	–	–	–
Normal (3,4,5)	0.005	< 0.001	9.495	0.1678
Loose (6,7)	0.006	< 0.001	19.613	0.2128
BM frequency per week	1.123	0.943	1.338	0.1913
Pelvic floor 3D findings				
LPDA	1.019	0.936	1.109	0.6607
POP-Q exam				
Rectocele stage				
0 (ref)	–	–	–	–
1	2.236	0.121	41.452	0.5890
2	1.618	0.093	28.098	0.7412
3	1.384	0.032	59.228	0.8653
Dynamic ultrasound findings				
Compression ratio (%)				
< 14.29 (ref)	–	–	–	–
≥ 14.29	32.516	4.87	217.108	**0.0003**

Significant P values are shown in bold

While the relationship between functional abnormalities and anatomic defects is likely complex and requires further investigation, we believe these study findings may help to challenge assumptions and perhaps clarify misconceptions, relating to obstructed defecation symptoms in women. Rectoceles, for instance, appear to have no correlation with obstructed defecation symptoms; as such, conventional rectocele/posterior vaginal compartment repairs most likely will remain an unreliable surgical strategy for addressing ODS symptoms. 'Sliding' rectal support defects appear to be a predictable and quantifiable anatomic defect associated with ODS in women. We anticipate that future work at our center, stemming from the current study, will be focused on improved surgical techniques that more effectively target the rectal hypermobility defects underlying ODS. Certainly, further investigation will be needed to determine the ways in which the anatomic findings of this study, which provide insight into the origins of ODS, can be translated into more effective clinical pathways and/or improved surgical methods to offer women suffering from this commonly overlooked clinical condition.

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Compliance with ethical standards

Conflicts of interest None.

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