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Comparison of the main body of the external anal sphincter muscle cross-sectional area between women with and without prolapse

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Abstract

The aim of the study was to compare the main body of the external anal sphincter (EAS) cross-sectional area (CSA) of women with and without pelvic organ prolapse. Pelvic magnetic resonance imaging (MRI) scans of 40 women were selected for analysis. Of these women, 20 had pelvic organ prolapse and 20 had normal support. Of the women with normal support, 10 had known major levator ani (LA) muscle defects and 10 had normal LA muscles. The same was true for the women with pelvic prolapse: half had major LA defects and half had no LA defects. All patients had previously completed pelvic MRI in the supine position. 3-D models of the EAS were made and CSA of the EAS perpendicular to the fiber direction were measured circumferentially at 30° intervals. Univariable and multivariable analyses were performed. The mean CSA did not significantly differ between women with prolapse and normal support regardless of LA defect status (normal/−LA defect=1.13 cm², prolapse/−LA defect=0.86 cm², $p=0.065$; normal/+LA defect=1.08 cm², prolapse/+LA defect=1.28 cm², $p=0.28$). Women with prolapse and LA defects had a 49% larger mean muscle CSA compared to prolapse patients without LA defects ($p=0.01$). This difference associated with defect status in prolapse patients was not seen in women with normal support. Women with prolapse alone had external anal sphincter CSAs that were comparable to women with normal support. However, women with both prolapse and a major levator ani defect had larger external anal sphincter CSAs compared to prolapse patients without levator ani defects.

Keywords

Anal sphincter; Cross-sectional area; Pelvic organ prolapse; Levator ani; Magnetic resonance imaging

Introduction

The development of magnetic resonance imaging (MRI)-based 3-D reconstruction has provided new insight into the complex 3-D shape and orientation of the external anal sphincter in living women [1]. When examined undistorted by an endoanal probe, the external anal sphincter is not a simple circular structure, but has a wing-like configuration laterally and a tail-like arrangement where the posterior fibers decussate to join the anococcygeal raphe. Recent studies have shown that women with stage II pelvic organ prolapse and/or urinary incontinence are five times more likely to have anal incontinence and have a higher rate of sphincter defects on endoanal ultrasonography (52% vs 30%) compared to women with normal pelvic support [2]. However, there is a limited number of quantitative comparisons of the different patient populations.

The ability to produce MRI-based 3-D models of the external anal sphincter has allowed us to move on to a quantitative structural analysis. Cross-sectional area perpendicular to the fiber direction is the most appropriate quantitative technique for muscle measurements because it most directly correlates with the force that a muscle can generate [3,4]. Its complex shape makes obtaining external anal sphincter cross-sectional areas perpendicular to the fiber direction technically difficult. This study was undertaken to develop a method of cross-sectional area measurement that took the complex shape into account. Previous work from our group showed no significant difference in levator ani cross-sectional area measurements between women with prolapse and normal support [5]. This suggested that prolapse alone was not associated with altered muscle function. However, we did find that the severity of levator ani injury was directly related to muscle cross-sectional area. These observations and previous observations linking prolapse and fecal incontinence led us to ask the following clinically relevant questions: (1) How does the external anal sphincter differ between women with and without prolapse? (2) What is the relationship of levator ani injury to the external anal sphincter?

Materials and methods

To perform this analysis, 40 parous women recruited between November 2000 and April 2005 were selected for analysis from an ongoing IRB-approved case-control study comparing findings in women with normal support to women with pelvic organ prolapse. Of these, 20 women were selected who had pelvic organ prolapse as demonstrated by a vaginal wall or the cervix being at least 1 cm beyond the introitus upon supine examination during maximal Valsalva. Subjects were deemed continent of stool if the answer “never” on two questions querying subjects for control of stool modified from the PFDI (Pelvic Floor Distress Inventory). None of the patients from the parent study complained of bothersome incontinence of liquid or solid stool. Twenty women with normal support where the vaginal wall and cervix were 1 cm or more above the hymen were selected for analysis as the control group. Patients were selected such that the mean age of each group would be similar. For the parent study, women with prolapse had been recruited from the University of Michigan Urogynecology Clinic, while the controls were women recruited through advertisements and through the Women's Health Registry, a database of women who expressed interest in participating in women's health projects. Women were excluded if they had previous surgery for prolapse or incontinence, had genital anomalies, or had delivered in the past year.

To avoid potential confounding effects of concomitant levator ani defects, the groups were also matched for levator defect status whereby half of the patients in each group had levator defects and half had no levator defects. Therefore, each of the 4 subgroups had 10 patients (Table 1).

All patients had a pelvic MR scan performed in the supine position. Multiplanar, two-dimensional, fast spin, proton density MR images (echo time 15 ms, repetition time 4,000 ms) were obtained using a 1.5 T superconducting magnet (General Electric Signa Horizon LX GE Medical System, Milwaukee, WI) with version 9.1 software. The field of view was 16×16 cm with slice thickness of 4 mm and a 1 mm gap between slices.

Axial MR images (Fig. 1) were imported into a 3-D imaging program (3-D Slicer, version 2.1b1, Brigham and Women's Hospital, Boston, MA). 3-D volume-rendering models were generated from axial images by tracing the main body of the external anal sphincter. Because the subcutaneous division of the external anal sphincter is not thought to have as much of a role in anal continence, it was not included. To perform measurements, the 3-D models were imported into I-DEAS® version 9.0 (UGS, Plano, TX), an engineering graphics program (Fig. 2). For each external anal sphincter model, a best-fit ellipse was created. Each ellipse was segmented at 30° intervals, creating 12 intersecting points similar to the face of a clock with 12 o'clock at the ventral portion of the sphincter. The cross-sectional area perpendicular to the fitted ellipse was measured at the intersecting points. Means ± standard error of the mean (SEM) of the cross-sectional areas were obtained for each of the four patient subgroups (Table 1). In the supine position, the external anal sphincter has a folded appearance. After preliminary review, it was found that folding of the sphincter produced irregular areas at 11 and 1 o'clock and so these were excluded from analysis due to concerns about the accuracy of the measurements at these locations (see Fig. 2 and the "Discussion" section). In addition, the cross-sectional area at region 6 o'clock where the anococcygeal ligament connects the sphincter to the coccyx could not be evaluated. Analysis was therefore performed by dividing the external anal sphincter into four quadrants: anterior, left, right, and posterior to detect regional variations. Ratios of cross-sectional area means were calculated to characterize the magnitude of group differences. Univariable and multivariable analyses were performed.

Three-way repeated measures analysis of variance and one-way ANOVA were performed; $p < 0.05$ was considered significant.

Results

The demographics of the patient subgroups are shown in Table 1. There were no statistically significant differences ($p > 0.5$) in mean age, BMI, or parity between groups. The women were Caucasian with the exception of one African American.

The mean cross-sectional areas of the subgroups are shown in Table 2. Mean cross-sectional areas did not significantly differ between women with prolapse and those with normal support regardless of levator ani defect status. However, women with prolapse and levator defects had a 49% larger mean muscle cross-sectional area compared to prolapse patients without levator defects ($p = 0.01$). This difference associated with the defect status in prolapse patients was not seen in women with normal support. The post hoc power calculations are also shown in Table 2.

The cross-sectional area results of the four subgroups were further analyzed according to the four quadrants: anterior, posterior, left, and right (Fig. 3). In all quadrants, patients with prolapse and levator ani defects had the largest cross-sectional area, while those with normal support and defects had the smallest cross-sectional area. In patients with normal support, there were small cross-sectional area differences between those with levator defects compared to those without. However, in patients with prolapse, the difference between those with defects and without defects was much larger. This pattern was true for all locations. The larger cross-sectional area of patients with prolapse and defects was most noticeable in the anterior and

posterior quadrants. In all four subgroups, the left and right quadrants had similar cross-sectional areas.

Three-way repeated measures analysis of variance was performed analyzing differences between prolapse and normal support, presence or absence of levator defects and quadrant location. Defects status ($p=0.03$) and location ($p<0.001$) are the significant main effects, while group status (i.e., prolapse or normal support) was not significant ($p=0.549$). We also found significant interaction effects between defect status and the group ($p<0.001$) and a three-way interaction between defect, group, and location ($p=0.02$).

Discussion

Women with prolapse without levator ani injury had a mean external anal sphincter cross-sectional area that was comparable to women with normal support. However, women with both prolapse and levator ani defects had larger external anal sphincter cross-sectional areas compared to prolapse patients without levator ani defects. Because cross-sectional area perpendicular to muscle fiber direction directly correlates to maximum muscle strength, the results suggest that women with prolapse alone do not have altered function of the external anal sphincter mechanism compared to women with normal support. The maintenance of fecal continence is accomplished by a complex sphincter system involving three anatomical elements: the smooth muscle internal anal sphincter (IAS), the striated external anal sphincter (EAS), and the puborectalis muscle (PRM) portion of the levator ani. The neurologically coordinated action of these sphincters must resist remarkable variation in stool consistency and volume, colonic transit time, and rectal compliance. Impairment of one or more of these sphincter elements can lead to fecal incontinence due to loss of normal function. We hypothesize that in these women with normal bowel control, the combination of prolapse and levator ani defect may place increased demand on sphincter closure forces leading to compensatory external anal sphincter hypertrophy.

The thickness of the external anal sphincter has been measured at the 9 o'clock position using 2-D axial MR images with and without the use of an endoanal coil and found to correlate with squeeze on manometric testing [6]. External anal sphincter thickness and volume has also been quantified using 3-D endoanal ultrasonography [7,8]. Other researchers have used 3-D models of the external anal sphincter for morphologic study and quantification. Fritsch et al. constructed 3-D models using plastinated sectional anatomical specimens of cadavers to correlate observations from histology and MRI [9]. Cornella et al. used the 3-D Slicer program to create MRI-based models of the external anal sphincters of 10 nulliparous women [10]. In these normal women, volumes of the external anal sphincter were not found to correlate with manometric pressures.

The current study extends existing research by comparing cross-sectional area measurements using 3-D models. The use of reconstructed models avoids the errors and variations of quantification using 2-D images [11]. Although volume and muscle thickness do approximate muscle function, cross-sectional area perpendicular to fiber direction is the most direct correlate of muscle force [3,4]. Because of the higher rate of anal incontinence reported for patients with pelvic floor dysfunction such as prolapse, we would have expected to see an attenuated anal sphincter. The finding that the mean cross-sectional area was the same between women with prolapse and normal support was unexpected. The absence of sphincter defects in this study is intriguing and calls into question whether sphincter disruptions are overestimated using endoanal ultrasonography. Other authors using 3-D reconstruction techniques have also found unexpectedly low rates of sphincter disruptions [8]. Alternatively, other factors that were not measured in this study such as the internal anal sphincter function could correlate with the altered anal continence reported in women with pelvic floor dysfunction.

There is a difference between the 3-D MRI reconstructions and our preconceived notion of sphincter anatomy from endoanal ultrasonography. This is partly because with ultrasonography, the anal canal is distended by the probe and the patient is in lithotomy, while for MRI, the patients are supine with their legs together. The advantage of the supine posture results in less distortion of the external anal sphincter. The disadvantage is that the sphincter has a folded appearance, which makes analysis more challenging. While our strategy was able to account for some of the complexities of the 3-D shape, cross-sectional area measurements were limited in certain regions. For example, because the sphincter is folded, it was not possible to obtain a cross-section perpendicular at 1 or 11 o'clock. Therefore, these locations were excluded from analysis. Another limitation of this method is that the technique for model generation traces around the external anal sphincter envelope and not the muscle fascicles. The region posteriorly at 6 o'clock where the anal sphincter fascicles decussate to join the anococcygeal raphe has a feathery appearance where muscle fascicles are intermingled with fat and connective tissue. Our strategy of tracing the muscle envelope does not account for fatty infiltration of the muscle and likely overestimates the amount of muscle in this area. For this reason, the 6 o'clock location was not analyzed. In addition, the dramatically larger cross-sectional area (64%) in the anterior region of patients with prolapse and levator defects forced us to question the validity of our data because we could not explain why this quadrant would be so affected. However, the same trend of increased cross-sectional area in women with prolapse and levator defects is present in the other quadrants. This supports the validity of the result.

Despite these limitations, this technique does allow for cross-sectional area measurements perpendicular to the muscle to be obtained on the external anal sphincters of living women. This approximation of muscle function found that women with prolapse do not have reduced external anal sphincter cross-sectional areas compared to women with normal support, and women with levator injuries and prolapse actually have larger cross-sectional areas.

These observations suggest that the injury mechanism leading to levator injury and prolapse may differ from the one that causes external anal sphincter damage. Birth injuries to the levator ani muscles likely occur from mechanical stretching of the muscle [12], while damage to the anal sphincter may result from a stretch injury to the nerve [12]. However, the finding of larger anal sphincter muscles would suggest that the nerve supply was intact. Further research to test this hypothesis is needed and could significantly impact clinical management of anal incontinence.

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Fig. 1. Static MR images of the external anal sphincter complex. Images are 0.5 mm apart; *image 0* at level of the arcuate pubic ligament, *negative images* cephalad and *positive images* caudal. *U* urethra, *V* vagina, *R* rectum. *Double arrowheads*: anococcygeal raphe, *solid black arrowheads*: main body of the external anal sphincter, *solid white arrowheads*: subcutaneous external anal sphincter

Fig. 2.

Cross-sectional area quantification strategy. **a** Inferior lateral view of a 3-D model of the main body of the external anal sphincter segmented at 30° intervals creating 12 intersecting points similar to the face of a clock with 12 o'clock at the ventral portion of the sphincter. **b** Model has been cut away at cross-section locations 9 and 12 o'clock. Cross-section locations were organized into quadrants: *anterior* location 12 o'clock, *right* locations 8–10 o'clock, *left* locations 2–4 o'clock, *posterior* locations 5 and 7 o'clock

Fig. 3. Mean cross-sectional area $\pm$ SEM results for patient subgroups analyzed by quadrants. *LA* levator ani. Percentage differences were calculated using the “Normal support, No LA defects” group as reference

Table 1

Demographics, means (SD)

	Normal (n=10)			Prolapse (n=10)		
	Age (years)	BMI (kg/m ²)	Vaginal parity ^a	Age (years)	BMI (kg/m ²)	Vaginal parity ^a
No LA defect	63.0 (11.3)	24.5 (3.9)	4 (1–11)	61.1 (12.4)	29.2 (6.8)	2 (2–3)
Major LA defect	62.5 (10.0)	27.7 (4.0)	2 (2–7)	62.2 (13.3)	25.6 (4.6)	3 (2–7)

^aParity is shown as the median (range).

Table 2Mean cross-sectional area $\pm$ SEM

	Normal support (cm ²)	Prolapse (cm ²)	<i>p</i>
No LA defect	1.12 $\pm$ 0.07	0.84 $\pm$ 0.12	0.062
Major LA defect	1.07 $\pm$ 0.14	1.25 $\pm$ 0.08	0.296
<i>p</i>	0.784	0.010	