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Vaginal Anatomy on MRI: New Information Obtained Using Distention

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Objectives: To demonstrate and confirm the presence of three anatomic zones of the vagina (a superficial sphincteric zone; a central wedge shaped transition zone; and a deep, expanded forniceal zone) using pelvic magnetic resonance imaging with contrast distention of the vagina.

Methods: A total of 107 consecutive female pelvic magnetic resonance imaging scans using vaginal contrast distention were retrospectively reviewed. The images were observed for the three-zone configuration. Anteroposterior and transverse diameter measurements were taken in the proximal, mid, and distal sphincteric, transition, and forniceal zones. Means and standard deviations were calculated at each site. Adjacent sites were compared using paired *t* tests.

Results: The three-zone configuration was observed in all of the cases but one. Statistically significant increases and decreases of mean anteroposterior diameters occurred at all levels expected by visual observation.

Conclusions: The three-zone configuration of the distended vagina was confirmed by this study. The configuration of the vagina is more complex than has been reported previously. This configuration may facilitate parturition and may be useful in the design of intravaginal devices.

Key Words: anatomy, obstetric delivery, urogynecology, vagina, women's health issues

M ost anatomic studies of the vagina are of its nondistended state. The anatomic literature describes the configuration of the vagina as a tube with a slight dilation at the cervix.^{1,2} The only previous references to the anatomy of the distended vagina that we have found are casting studies^{3–5} and an ultrasound

This article discusses the use of Chester Laboratories' lubricating gel as an intraluminal contrast gel in the vagina. This is currently an off-label use of this drug. Accepted May 2, 2018.

0038-4348/0-2000/111-691 DOI: 10.14423/SMJ.000000000000889 study.⁶ The casting studies show less detail than can be demonstrated on magnetic resonance imaging (MRI) and give no information on surrounding soft tissue structures. The ultrasound study included only the lower vagina and imaged only in the sagittal plane. Previous studies of the anatomic appearance of the vagina on MRI have focused on the MRI appearance of the nondistended vagina,⁷ the layers of the vaginal wall,⁸ and the support structures of the vagina.^{9–12} To the best of our knowledge, there has been no previous study of the anatomy of the distended vagina as displayed by MRI.

In pelvic MRI examinations performed with vaginal distention by endoluminal contrast for clinical purposes, we noticed that the vagina appears to show a more complex configuration than has been described previously. Specifically, the distended vagina appears to demonstrate three consistent zones; a narrow tubular zone at the introitus, followed by a wedge-shaped zone, and then an expanded zone around the fornices. We termed these zones the sphincteric zone, the transition zone, and the forniceal zone, respectively (Fig. 1). In our opinion, the casting studies demonstrated the three-zone configuration, but this concept was not discussed by the studies' authors.^{3–5} The ultrasound study demonstrated an anatomic and a physiologic sphincteric zone in the lower vagina,⁶ but it did not examine the upper vagina. The purpose of the present study was to determine whether the three-zone configuration is a constant finding.

Methods

After approval was obtained from the institutional review board of the Memphis Veterans Affairs Medical Center, 107 consecutive female pelvic MRI scans performed with vaginal distention by contrast gel at our institution for clinical purposes were

Key Points

- The configuration of the vagina is more complex than has been reported previously.
- This configuration may facilitate childbirth.
- This configuration may be useful in the design of intravaginal devices.

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Fig. 1. Sagittal T2 fast relaxation fast spin echo section of the pelvis performed with vaginal distension by endoluminal contrast. This image shows a more complex contour of the vagina than has been described previously. The distended vagina demonstrates three zones: a narrow tubular sphincteric zone at the introitus, a wedge-shaped transition zone, and an expanded forniceal zone.

reviewed. Each case was assessed visually for the presence of the three hypothesized zones. Diameter measurements of the zones were taken to provide objective assessment of these observations.

Exclusions

Cases were excluded from both the qualitative and quantitative portions of the study for inadequate distention, if they were repeat examinations of patients who had already been entered into the study or if the scan was technically inadequate. Cases were excluded from the quantitative portion of the study if measurements could not be obtained.

Patient Characteristics

Ages, number of pregnancies, and number of live births were recorded for all patients for whom the information was available; means and standard deviations were calculated. Indications for the studies were tallied.

Patient Preparation

To place contrast in the vagina, a 20-cm³ syringe was filled with Chester Laboratories' (Hong Kong) sterile, water-soluble lubricating gel. The syringe was attached to a Yankauer suction device (Covidien, Dublin, Ireland) that was attached to a short section of Argyle suction tubing (Covidien, Dublin, Ireland). The gel was pushed to the tip of the tubing using care to remove air bubbles. In the supine position on the scan table, the patients passed the device into their vaginas and injected the gel under the supervision of two female MRI technologists. A technologist would confirm that the entire 20 cm³ of gel had been injected and was primarily intravaginal.

MRI Protocols

Scans were performed on a GE Signa LX 1.5T or a GE Signa HDxt 1.5T scanner (GE Healthcare, Waukesha, WI). Axial proton density, axial T2 fast relaxation fast spin echo (FRFSE), sagittal T2 FRFSE, coronal T2 FRFSE, sagittal three-dimensional respiratory-triggered T2 FRFSE, axial liver acquisition with volume acquisition multiphase breath hold contrast, postcontrast axial, and coronal and sagittal proton density sequences were obtained for all of the scans performed on the Signa HDxt scanner. Maximum-intensity projection images were generated at the scanner using the interactive vascular imaging tool. The same sequences were performed on the Signa LX apart from the three-dimensional respiratory-triggered T2 FRFSE and maximum-intensity projection images, which were not done on that scanner.

Vaginal Measurement and Image Analysis

The images were observed for the three-zone configuration and for the relations of adjacent anatomic structures to the vagina. Using these observations and anatomic landmarks, sagittal diameter measurements were taken of the proximal, mid, and distal levels of the postulated sphincteric (S1-S3) transition (T1-T3), and forniceal (F1-F3) zones with the distance measurement tool of the GE PACS 4.0 Radiology 1000 Workstation (GE Healthcare). In the sphincteric zone, the introitus was designated S1, the transition point between the sphincteric and transition zones was designated S3, and the midpoint between S1 and S3 was designated S2. In the transition zone, 1 cm above S3 was designated T1, the origin of the urethra was designated T2, and the midpoint between T2 and the anterior fornix was designated T3. In the forniceal zone, the level of the anterior fornix was designated F1, the level of the cervical os was designated F2, and the level of the posterior fornix was designated F3 (Fig. 2). Transverse diameters were taken at the same positions using the navigator function and the distance measurement tool of the GE PACS 4.0 Radiology 1000 Workstation.

Length measurements were taken of the sphincteric, transition, and forniceal zones and from the introitus to the anterior fornix and the introitus to the posterior fornix. All of the measurements were taken by the principal investigator (A.H.A.).

Statistical Analysis of the Vaginal Measurements

Means and standard deviations (SDs) of the sagittal and transverse diameters were calculated at each site. The mean diameter at each site was compared with its adjacent levels by paired t tests. Means and SDs of length measurements were calculated.



Fig. 2. Sagittal T2 fast relaxation fast spin echo section of the pelvis performed with vaginal distension by endoluminal contrast. Measurements of the proximal, mid, and distal sphincteric transition and forniceal zones were taken as illustrated above. S1, introitus; S2, midpoint between S1 and S3; S3, transition between sphincteric and transition zones; T1, 1 cm above S3; T2, origin of the urethra; T3, midpoint between T2 and F1; F1, anterior fornix; F2, cervical os; F3, posterior fornix.

Results

Exclusions

A total of 107 scans were reviewed. Seven scans were excluded from both the qualitative and quantitative portions of the study. Of those, four scans were excluded for inadequate vaginal distention, two scans were excluded because they were repeat examinations of the same patient, and one scan was excluded for excessive motion artifact.

Eleven scans were excluded from the quantitative portion of the study only. Of those, seven posthysterectomy scans were excluded because multiple measurements for this study could not be obtained posthysterectomy. Three scans were excluded where the fornices were oriented parallel to the vagina. Measurements extending from the fornices in these cases run parallel to the long axis of the vagina and do not correspond to measurements in all of the other cases that run roughly perpendicular to the long axis. One scan was excluded because transverse measurements could not be obtained as a result of poor positioning of the axial and coronal series.

Patient Characteristics and Study Indications

The mean age of the subjects was 46.1 years (SD 8.7), with a range of 23 to 63 years. Fifteen patients were scanned on the GE Signa LX 1.5T between January 2007 and December 2009; 85 patients were scanned on the GE Signa HDxt 1.5T between December 2009 and January 2015. Indications for imaging and obstetric history of the study population are provided in Table 1.

Length Measurements

The mean length of the sphincteric zone was 2.2 cm (SD 0.6). The mean length of the transition zone was 3.3 cm (SD 1.0). The mean length of the forniceal zone was 3.5 cm (SD 0.8). The mean lengths of the vagina from the introitus to the anterior fornix and the introitus to the posterior fornix were 6.4 cm (SD 1.1) and 8.6 cm (SD 1.3), respectively.

Three-Zone Configuration

The three-zone configuration was observed in all cases but one. There is a narrow sphincteric zone extending from the introitus (S1) to the transition point between the sphincteric and transition zones (S3), a wedge-shaped transition zone extending from the sphincteric zone (S3) to the anterior fornix (F1), and an expanded forniceal zone extending from the anterior fornix (F1) to the posterior fornix (F3; Fig. 1 and 2). In three-dimensional reconstructions the vagina has the appearance of a flattened, curved, asymmetrical funnel (Fig. 3). The forniceal zone and the transition zone were markedly compressed by an enlarged uterus in the one case that did not show a three-zone configuration.

In the sphincteric zone the anterior wall of the vagina follows the urethra, the posterior wall follows the perineal body and anus (Figs. 2 and 4A), and the lateral walls follow the puborectalis muscle (Fig. 4B). The sagittal diameter usually is greatest at

Table 1. Patient characteristics (N = 100)

	Moon \pm SD or n (%)	Dongo	
	Weat \pm SD of II (78)	Kange	
Age, y	46.1 ± 8.7	23-63	
No. pregnancies	2.0 ± 1.6	0–6	
No. live births	1.4 ± 1.2	0–4	
Indication for MRI			
Ovarian cyst/mass	46 (46)		
Uterine mass	25 (25)		
Endometrial polyp	6 (6)		
Pelvic pain	6 (6)		
Hydrosalpinx	5 (5)		
Abnormal uterine bleeding	5 (5)		
Bartholin gland cyst	3 (3)		
Rectovaginal fistula	1 (1)		
Cervical mass	1 (1)		
Polycystic ovaries	1 (1)		
Mesenteric cyst	1 (1)		

Obstetric history was available for 68 subjects. MRI, magnetic resonance imaging; SD, standard deviation.



Fig. 3. Compressed reconstruction image of the pelvis performed with vaginal distension by endoluminal contrast. This image better demonstrates the overall funnel-like configuration of the vagina and again shows the three-zone configuration. Free intraabdominal fluid and the urinary bladder also are visible.

the introitus, decreases, and then remains unchanged, creating a narrow wedge shape followed by a parallel configuration (Fig. 1). In some cases, the introitus is equal in sagittal diameter to the deeper portions of the sphincteric zone (Fig. 2). Transverse diameters in the sphincteric zone usually are smallest at the introitus, then show a slight continuous increase (Fig. 4B, Table 2). The transverse diameters are much greater than the sagittal diameters in the sphincteric zone (Fig. 4A, Table 2).

In the transition zone, the sagittal diameters increase as the anterior wall of the vagina curves anteriorly as it follows the urethra, and the posterior wall of the vagina curves posteriorly as it follows the rectum and rectovaginal fascia. The sagittal diameters then increase more slowly as the anterior vaginal wall curves posteriorly along the urinary bladder while the posterior vaginal wall continues to follow the rectum (Figs. 1 and 2). The lateral walls of the vagina follow the pubococcygeus muscles. The paracolpium is visible as it attaches the lateral wall of the vagina to the pubococcygeus muscle (Fig. 4B). The pubococcygeus muscles rise at a mild angle, so transverse diameters increase slowly. Above the pubococcygeus muscles the vaginal walls become more vertical, so transverse diameters increase more slowly (Fig. 4B). The transverse diameters are much greater than the sagittal diameters in the transition zone (Table 2).

The cervix and the fornices define the superior margin of the vagina in the forniceal zone. The inferoposterior wall of the vagina continues to follow the rectum in the forniceal zone (Figs. 1 and 2). Anteroposterior diameters increase at the level of the anterior fornix, decrease at the cervix, and decrease at the level of the posterior fornix. Transverse diameters decrease at the anterior fornix, increase at the level of the cervix, and then decrease at the level of the posterior fornix. The transverse diameters are greater than the sagittal diameters in the forniceal zone (Table 2).

Statistically significant measurement increases of mean sagittal diameters occurred at all levels expected from image review (S3–T1, P < 0.001; T1–T2, P < 0.001; T2–T3, P < 0.001; T3–F1, P = 0.008; Table 3). Statistically significant decreases in mean sagittal diameter occurred at two expected levels (S1–S2, P < 0.001; F1–F2, P < 0.001). There was a 1-mm increase in mean diameter between the mid and distal sphincteric zone (P = 0.021); this minimal change is consistent with expectations; thus, all findings on image review were confirmed by measurements in the sagittal projection.

Statistically significant measurement increases of transverse mean diameters occurred at all levels from S1 to T3 (P < 0.001 at all levels) as expected (Table 3). A 3-mm decrease in mean diameter occurred at the T3–F1 level (P = 0.009), which was not expected. An increase in mean diameter occurred at the F1–F2 level, and a decrease occurred at the F2–F3 level (P < 0.001 for both) as expected. As such, the findings on image review were generally confirmed by measurements in the transverse projection.

Discussion

In the sagittal plane, which defines the three-zone configuration, paired t tests showed statistically significant mean diameter increases or decreases at all of the levels where change was expected. In the transverse plane, statistically significant mean diameter increases or decreases occurred at all of the levels where change was expected, except between T3 and F1, where a minimal decrease occurred when an increase was expected. As such, there was excellent overall correspondence between visual observations and measurements, which confirms the three-zone configuration.

The three-zone configuration of the distended vagina corresponds to the potential spaces created by surrounding organs and/or supporting structures of the vagina at all of the levels of the Delancey classification system. The sphincteric zone is formed by the potential space between the structures that are fused to the vaginal wall at Delancey's level 3. The anterior wall of the vagina follows the urethra to which it is fused, and the posterior wall follows the perineal body to which it is fused. The vagina is bounded laterally by the puborectalis to which it is fused.¹³

The contours of the transition zone are determined by both the supporting structures of Delancey's level 2 and the potential space created by structures surrounding the vagina at this level. The distended vagina increases in anteroposterior diameter as the anterior vaginal wall is pulled anteriorly along the urethra to which it is fused and anteriorly along the bladder by the pubocervical fascia, while the posterior wall curves posteriorly along the rectovaginal fascia and rectum.¹⁴ The vagina increases



Fig. 4. *A*, Axial T2 fast relaxation fast spin echo section of the pelvis performed with vaginal distension by endoluminal contrast. In the sphincteric zone the puborectalis muscle forms a sling around the urethra, vagina, and rectum. The lateral walls of the vagina are fused with the puborectalis, the anterior wall is fused with the urethra, and the posterior wall is fused with the perineal body. *B*, Coronal T2 fast relaxation fast spin echo section of the pelvis performed with vaginal distension by endoluminal contrast. Coronal images demonstrate the paracolpium connecting the lateral walls of the vagina to the pubococcygeus muscles. This determines the contour of the lateral walls of the vagina in the transition zone. Note the large endometrioma visible superior and to the left of the uterus.

in transverse diameter as the lateral walls of the vagina follow the pubococcygeus muscles to which they are attached by the paracolpium.¹³

The main determinants of the contours of the forniceal zone are the fascial supports of level 1 of the Delancey classification system. The vagina extends above the true pelvis to the more spacious false pelvis in this zone, so surrounding structures have a diminished role. The transverse diameter of the anterior fornix is maintained by the pubocervical fascia.¹⁴ The transverse diameter of the vagina reaches its maximum at the level of the cervix correlating with the strong attachments of the laterally positioned cardinal (transverse cervical) ligaments.¹³ The transverse diameter of the posterior fornix decreases correlating with the strong attachments of the uterosacral ligaments located posteriorly and centrally.¹³

Table 2. Vaginal diameters ($N = 89$)				
Level of measurement	Sagittal, mean ± SD	Transverse, mean ± SD		
S1	0.8 ± 0.6	1.5 ± 0.6		
S2	0.3 ± 0.3	1.9 ± 0.6		
S3	0.4 ± 0.3	2.1 ± 0.6		
T1	0.8 ± 0.4	2.7 ± 0.6		
T2	1.3 ± 0.6	3.5 ± 0.6		
T3	2.0 ± 0.8	4.2 ± 0.8		
F1	2.2 ± 0.8	3.9 ± 0.9		
F2	1.3 ± 0.6	5.1 ± 0.8		
F3	1.2 ± 0.6	4.1 ± 1.1		

Table 2. Vaginal diameters (N = 89)

Measurements are in centimeters. SD, standard deviation; S1, introitus; S2, midpoint between S1 and S3; S3, transition between sphincteric and transition zones; T1, 1 cm above S3; T2, origin of the urethra; T3, midpoint between T2 and F1; F1, anterior fornix; F2, cervical os; F3, posterior fornix.

Table 3. Comparisons of vagina diameter levels (N = 89)

Sagitt		Transverse	
Difference, mean ± SD	Р	Difference, mean ± SD	Р
0.5 ± 0.5	< 0.001	-0.3 ± 0.5	< 0.001
-0.1 ± 0.2	0.021	-0.3 ± 0.4	< 0.001
-0.4 ± 0.3	< 0.001	-0.6 ± 0.5	< 0.001
-0.5 ± 0.3	< 0.001	-0.8 ± 0.5	< 0.001
-0.7 ± 0.5	< 0.001	-0.7 ± 0.5	< 0.001
-0.2 ± 0.7	0.008	0.3 ± 0.9	0.009
1.0 ± 0.8	< 0.001	-1.2 ± 0.8	< 0.001
$<\!\!0.1 \pm 0.7$	0.509	1.0 ± 1.0	< 0.001
	$\begin{tabular}{ c c c c c } \hline Sagitta \\ \hline Difference, \\mean \pm SD \\ \hline 0.5 \pm 0.5 \\ -0.1 \pm 0.2 \\ -0.4 \pm 0.3 \\ -0.5 \pm 0.3 \\ -0.5 \pm 0.3 \\ -0.7 \pm 0.5 \\ -0.2 \pm 0.7 \\ 1.0 \pm 0.8 \\ < 0.1 \pm 0.7 \end{tabular}$	SagittalDifference, mean \pm SDP 0.5 ± 0.5 <0.001	$\begin{tabular}{ c c c c } \hline Sagittal & Transver \\ \hline \hline Difference, mean \pm SD & P & \hline Difference, mean \pm SD \\ \hline 0.5 \pm 0.5 & <0.001 & -0.3 \pm 0.5 \\ \hline -0.1 \pm 0.2 & 0.021 & -0.3 \pm 0.4 \\ \hline -0.4 \pm 0.3 & <0.001 & -0.6 \pm 0.5 \\ \hline -0.5 \pm 0.3 & <0.001 & -0.8 \pm 0.5 \\ \hline -0.7 \pm 0.5 & <0.001 & -0.7 \pm 0.5 \\ \hline -0.2 \pm 0.7 & 0.008 & 0.3 \pm 0.9 \\ \hline 1.0 \pm 0.8 & <0.001 & -1.2 \pm 0.8 \\ \hline <0.1 \pm 0.7 & 0.509 & 1.0 \pm 1.0 \\ \hline \end{tabular}$

Measurements are in centimeters. P values are from paired t tests. SD, standard deviation; S1, introitus; S2, midpoint between S1 and S3; S3, transition between sphincteric and transition zones; T1, 1 cm above S3; T2, origin of the urethra; T3, midpoint between T2 and F1; F1, anterior fornix; F2, cervical os; F3, posterior fornix.

The inferior wall of the vagina curves posteriorly as it follows the rectum and rectovaginal fascia as it is pulled posteriorly by the uterosacral ligaments.¹³

Our review of photographs from the casting studies^{3–5} shows that the vaginal casts demonstrated the three-zone configuration and the overall funnel shape of the vagina. The authors of those studies did not comment on the concept of vaginal zones, however. The images from the ultrasound study were obtained with balloons filled with 45 and 60 cm³ of fluid placed in the lower vagina.⁶ These images correspond well with MRI images showing similar vaginal configurations in the sphincteric zone, lower transition zone, and the transition point between these zones in the sagittal plane at both degrees of distention. Pressure measurements performed in the Jung et al study show that the puborectalis muscle functions as an external sphincter at the sphincteric zone.⁶

The widely held concept that parturition takes place through a massively dilated tubular vagina¹⁵ is incomplete because the expanded configuration of the vagina is more complex. Cinematic MRI images of a human birth with the vagina filled with amniotic fluid, retained by intact amniotic membranes, have been obtained.¹⁶ In an image from the study by Bamberg et al, when the fetal head is engaged, the forniceal zone and fornices are preserved but flattened, creating a receptacle for the fetal head. The transition zone retains its wedge shape, although it is increased in anteroposterior diameter, shortened, and rounded. The sphincteric zone is not visualized, presumably because fluid was blocked by the amniotic membranes. The fetus passes through the wedge-shaped transition zone (rather than a tubular structure) on later images. The configuration of the vagina during parturition in this case corresponds to its baseline distended contour. Aspects of this configuration appear to facilitate parturition. Also, in its baseline state the volume of the vagina is greater than previously thought, so the amount of expansion of the vagina required for parturition to take place is less than previously believed.

The configuration of an open duckbill (Graves) speculum corresponds well to the distended configuration of the vagina. The smaller ovoid base corresponds to the sphincteric zone and the blades correspond to the wedge shape of the transition zone. Opening the speculum brings the vaginal walls to their normal distended configuration, explaining why examination with a duckbill speculum is well tolerated by most women. It may be possible to use knowledge of the three-zone configuration in the design of other intravaginal devices.

The measurements of vaginal length and diameter probably would vary with the volume of material instilled into the vagina; a constant volume of 20 cm^3 of intraluminal contrast was used in this study. Vaginal length and diameter measurements also may vary with parity and age; the influence of these factors on vaginal size was not assessed by our study. The purpose of the measurements in this study was to compare the relative length of the diameters of the vagina. Establishing normal values for vaginal length and diameter for different ages, parity, and degree of distention of the vagina is outside the scope of our study. Conceivably, vaginal configuration could vary at higher volumes; however, review of MRI images from other institutions performed with higher volumes of endovaginal contrast show persistence of the three-zone configuration. The three-zone configuration was demonstrated in casting studies^{3–5} that were performed with 50 cm³ of casting material. The configuration of the lower portion of the vagina visualized in the ultrasound study, performed with a maximum of 60 cm³ fluid, corresponded well to MRI findings at this location.⁶ The three-zone configuration appeared altered but persistent during parturition.¹⁶

The vagina can be occluded, allowing greater distention of the vagina by fluid. Hence, this study could be repeated with higher volumes of contrast gel to remove this limitation. Such a study would need to be performed cautiously because fluid can be driven into the peritoneal cavity when fluid is injected into the vagina under pressure.^{17,18} For example, imaging at 5-cm³ increments while checking fluid position may prevent this complication.

The diameter and length measurements were taken a single time by a single investigator; therefore, intraobserver and interobserver variability cannot be assessed. The measurements, however, are objective because they were taken using landmarks. Also, assessing the variability of the data is not essential to compare the relative diameter measurements.

Conclusions

The three-zone configuration of the distended vagina, which results from potential spaces between surrounding organs and supporting structures of the vagina, was confirmed by our study. The configuration of the vagina is more complex than has been assumed previously.^{1,2,15} This configuration may facilitate childbirth and may be useful in the future design of intravaginal devices.

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