Original article

The influence of age on the sonographic visualization of structures within the anterior and posterior pelvic floor compartments

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Abstract: The aim of study was to evaluate the inter-observer reliability in assessing anterior and posterior pelvic floor compartments in nulliparous women using 3-dimensional endovaginal ultrasound, and to evaluate the association of age with the visualization or measurement of these structures. 3D EVUS images were obtained in community-dwelling nulliparous women ages 21-80. Two observers independently read all images, looking anteriorly for the vesical trigone (VT), trigonal ring (TR), trigonal plate (TP), striated urogenital sphincter (SUG), compressor urethra (CU), longitudinal and circular smooth muscle (LCM); posterior structures included the superficial external anal sphincter (EAS-sq), main external anal sphincter (EAS-m), internal anal sphincter (IAS), and rectovaginal septum (RVS). Urethral, RVS, and anal sphincter measurements were recorded. Inter-observer reliability was determined with Cohen's kappa. Spearman's rank correlation was used to evaluate the association between these measurements and age. Ultrasound images of 77 volunteers, including anterior and posterior compartment 3D volumes (total of 154), were analyzed for this study. The median measurements were: urethral length 3.68 cm (range 1.67, 6.84), IAS length 2.60 cm (range 1.74, 4.12), IAS width 0.32 cm (range 0.17, 0.63), RVS length 3.02 cm (range 2.15, 3.98), anorectal angle 157° (range 142, 168). Inter-observer agreement for the visualization of structures was substantial to almost perfect. There was no correlation between age and variations in urethral length, IAS length or width, RVS length or anorectal angle. 3D EVUS can reliably identify anterior and posterior compartment structures. Age is not associated with the visualization or measurement of these structures.

Key words: Age; 3D EVUS; Anterior and posterior compartment.

INTRODUCTION

Pelvic floor disorders represent an important part of women's healthcare throughout the world. POP, voiding disorders, and defecatory dysfunction are estimated to affect millions of women worldwide. 41% of women aged 50-79 have some degree of POP[1, 2] resulting in an estimated annual cost of more than $1 billion dollars per year in the United States alone.[3] It is estimated that the number of American women with at least one pelvic floor disorder will exceed 40 million by 2050. Despite the high prevalence and financial burden of these disorders, they continue to be poorly understood. A major contributor to our poor understanding of these disorders is our inability to reliably and accurately characterize key pelvic floor structures in women using conventional techniques.

Currently, MRI is the primary means of imaging many of the structures of the female pelvic floor. As such, MRI has revealed both anterior and posterior compartment anatomy in great detail, and correlative studies using MRI in patients with and without incontinence, and pelvic organ prolapse have shown a number of structural abnormalities.[5-10] However, MRI has a number of limitations that limit its use on a broad scale. 3D Transperineal ultrasound techniques have been widely used to evaluate pelvic floor dysfunction and have been shown to be reliable and valid for detecting abnormalities.[11, 12] 3D endovaginal ultrasound (3D EVUS) imaging of the pelvic floor has emerged as a promising technology for use in patient evaluation. The ease of use and availability of 3D EVUS currently makes it feasible to screen large numbers of subjects with minimal cost. 3D EVUS techniques have been demonstrated to visualize with great detail and reliability the structures of the pelvic floor in young nulliparous women.[13]

While 3D EVUS has been shown to be useful in the evaluation of a "normal" young female pelvic floor, no studies to date have established its use in an older population. Age is a well-established risk factor for the development of most pelvic floor disorders.[1, 14-18] Although it has not consistently been associated with clinical evidence of deterioration in pelvic organ support, urethral support, or levator function,[17] age-related changes in histologic aspects of support structures, such as muscle and collagen composition are well documented.[19-21] It is not known if changes related to age will have an effect on the appearance of pelvic floor anatomy in nulliparous subjects.

In this study, we aim to assess anterior and posterior compartment pelvic floor anatomy in a community-based cohort of nulliparous women with 3D EVUS. The main goals of this study are to assess for inter-observer reliability in measuring these structures, and to determine the effect of age in the visualization of these structures.

METHODS

This study was approved by the Institutional Review Board at the University of Oklahoma Health Sciences Center. Informed consent was obtained by all participants. It is a sub-analysis of a study aimed at assessing age-related changes of the levator ani in nulliparous women using 3D EVUS. Imaging of the anterior and posterior compartments was obtained at the time of the primary study using the BK Medical Ultrafocus (Peabody, MA) and an 8848 12 MHz transducer by one of the authors (LHQ). The transducer is the size of an average index finger and rotates on a timed mechanical arm at a constant speed in a standardized way to obtain reproducible data cubes. For each patient, a length of 6 cm was scanned every 0.25 degrees for a total of 180 degrees starting at the 0300 position and ending at 0900 position with 720 cumulative radial scans from which 3D rendered cube of each compartment was calculated.

All ultrasounds were performed in the office setting, with the patient in dorsal lithotomy position, with hips flexed and abducted. No preparation was required and the patient was recommended to have a comfortable volume of urine in the bladder. No rectal or vaginal contrast was used. To avoid excessive pressure on surrounding structures that might distort the anatomy, the probe was inserted into the vagina in a neutral position. It has been shown that an endovaginal probe does not have an adverse effect on anatomy compared to transperineal ultrasound.[22] The 3D cube for each compartment was digitally catalogued for future analysis.

Two observers (DW and GR) independently evaluated all images of the anterior compartment structures and confirmed the visibility of the following structures in the anterior compartment: vesical trigone (VT), trigonal ring (TR), trigonal plate (TP), striated urogenital sphincter (SUG), compressor urethra (CU), and the longitudinal and circular smooth muscle (LCM) (Figure 1 a/b). Several investigators are working to show correlation of these structures with clinical symptoms.[20, 21] The same two observers evaluated the posterior compartment 3D data cubes (Figure 2 a/b). Posterior structures visualized included the superficial external anal sphincter (EAS-sq), main external anal sphincter (EAS-m), internal anal sphincter (IAS), and the rectovaginal septum (RVS). Structures were rated as "seen" or "not seen". Urethral length, RVS length, and internal and external anal sphincter measurements were recorded.

Ultrasound protocol

In reviewed images, we used the mid-sagittal view for our measurements.

Anterior Compartment: The trigonal ring was seen as a mixed echoic structure around the urethral opening to the bladder, the vesical trigone was seen as a hypoechoic structure in the inferior border of the bladder, and the trigonal plate was identified as a hypoechoic line that continued from the vesical trigone to the mid-urethra. Longitudinal and circular muscles were seen as an olive-shaped density encompassing the mid-urethra. The striated urogenital sphincter was a hyperechoic stripe anterior to the longitudinal and circular layer. The compressor urethra and the urethrovaginal sphincter complex were seen at the distal 1/3 of the urethra. The length of the urethra was defined as the distance from the opening into the bladder to the opening at the external urethral meatus. If a structure was architecturally unidentifiable, it was coded as a defect.

Posterior compartment: In the mid-sagittal view, the rectovaginal septum was seen as a hypoechoic line that superficially starts from external anal sphincter and continues cephalad; this length was measured as the RVS length. The external anal sphincter was seen as two parts - the superficial part and he main part, both as hypoechoic structures starting at the same level of the perineal body and continuing to the rectovaginal septum. The internal anal sphincter was a hyperechoic structure starting at the level of main part of external anal sphincter and the length was measured from the beginning to the end part that narrows and is finished. The anorectal angle in the midsagittal plane was measured as the angle between the axis of rectum with the axis of anal canal.

Statistical Analysis

Statistical analyses were performed using SAS v9.2 (SAS Institute, Cary, NC). Summary statistics were calculated for the patient population. Spearman's rank correlation (rs) was used to evaluate the association between urethral and anal sphincter measurements and age. Logistic regression was used to evaluate the association between age and the visualization of anterior or posterior compartment structures. Two-sided p-values of < 0.05 were considered significant. Exact agreement was calculated as the total number of each structure identified by both readers and dividing it by the total number of cases. Inter-observer reliability was determined with Cohen's kappa statistics. Landis

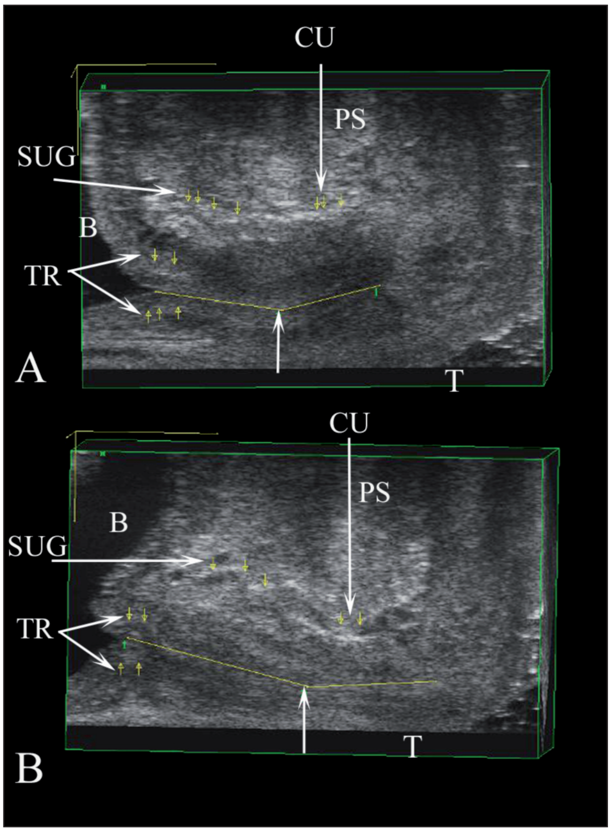

Figure 1. - 3D EVUS image of the anterior compartment in A) 27 year old nulliparous woman, and B) 64 year old nulliparous woman.
B: Bladder, CU: Compressor Urethra, PS: Pubic Symphysis, SUG: Striated urogenital sphincter, TR: Trigonal ring, U: Urethra.

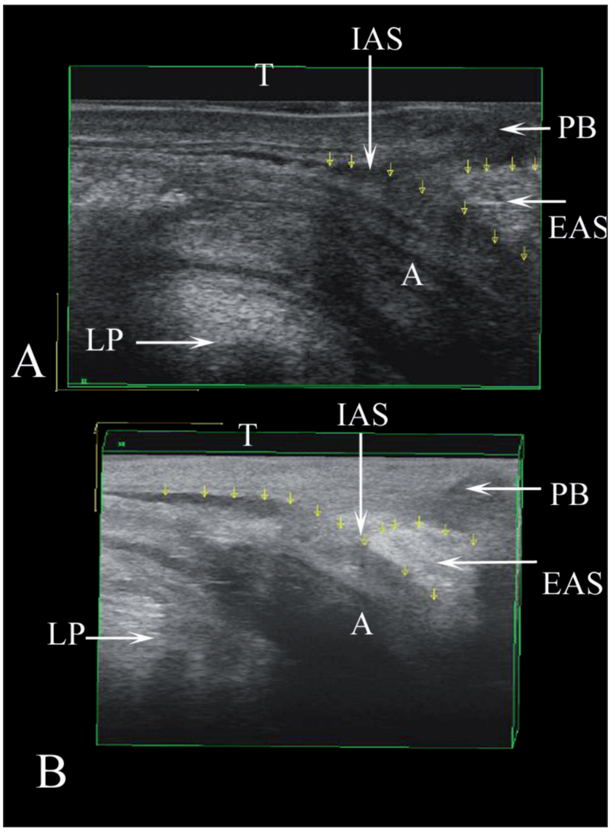

Figure 2. - 3D EVUS image of the posterior compartment in A) 27 year old nulliparous woman, and B) 64 year old nulliparous woman.
A: Anus, EAS: External Anal Sphincter, IAS: Internal Anal Sphincter, LP: Levator Plate, PB: Perineal Body.

and Koch's benchmarks for the evaluation of observed Kappa values were used: 0.81-1.00 was considered almost perfect agreement, 0.61-0.80 substantial agreement, 0.41-0.60 moderate agreement, 0.21-0.40 fair agreement, 0.01-0.20 slight agreement, and 0.00 poor agreement.[23]

RESULTS

Eighty participants were enrolled in the primary study and included in this sub analysis. The ultrasound images of 3 participants were excluded due to corruption of the image files. The median age of the participants was 47 (range 22, 70). The average body mass index (BMI) was 28.3 (± 7.2 SD). The majority of the participants were Caucasian (81.25%). Demographic information is shown in Table 1. Thirty percent of the participants were postmenopausal, and 10% were on hormone replacement therapy (HRT), with only one participant having evidence of vaginal atrophy on examination. 52.5% considered themselves healthy; hypertension was the most common medical comorbidity (17.5%). 35% of participants reported having a prior abdomino-pelvic surgery, with hysterectomy being the most common (12.5%). None of patients had surgeries for urinary incontinence, pelvic organ prolapse or anal incontinence.

The median urethral length was 3.68 cm (range 1.67, 6.84). The median IAS length was 2.60 cm (range 1.74, 4.12) and width was 0.32 cm (range 0.17, 0.63). The median RVS length was 3.02 cm (range 2.15, 3.98). When evaluating the association between age and each measurement, none of the individual measurements showed a significant correlation with advancing age. When grouping age by decade, there continued to be no correlation between age and the measurement of any structure (Table 2). Additionally, no association was found between age or age group and the visualization of any structure in the anterior or posterior compartment (Table 3). Menopausal status was evaluated as part of the logistic regression model but was excluded due to non-significance in the model.

Table 4 shows the percent agreement for the visualization of each structure (seen/not seen). Cohen's kappa demonstrated almost perfect agreement for the visualization of VT, TP, RVS, IAS, and EAS-m. Substantial agreement was noted for the visualization of TR, LCM, SUG, CU, and EAS-sq (Table 4).

TABLE 1. – Characteristics of the study population.

Variable	Summary Statistic
Age (median, range)	47 (22, 70)
Race (n, %)	
Caucasian	65 (81.25)
African American	10 (12.5)
Native American	3 (3.75)
Asian	1 (1.25)
Hispanic	1 (1.25)
BMI (kg/m2) (mean, SD)	28.3 ± 7.2
Menopausal Status (n, %)	
Pre-	56 (70)
Post-	24 (30)
Use of HRT (n, %)	
Yes	8 (33)
No	16 (66)
Vaginal atrophy (n, %)	
Yes	1 (1.25)
No	70 (98.75)
Current Tobacco Use (n, %)	8 (10)
Medical Co morbidities (n, %)	
None	42 (52.5)
Hypertension	14 (17.5)
Diabetes	3 (3.75)
Steroid use	1 (1.25)
Autoimmune disease	1 (1.25)
No response	19 (23.75)

TABLE 2. – Spearman's rank correlation for age with the measurement of anterior and posterior compartment structures.

Structure	Measurement (median, range)*	rs (p-value)**
Urethral length	3.68 (1.67, 6.38)	0.05 (0.69
RVS	3.02 (2.15, 3.98)	-0.18 (0.12)
IAS length	2.60 (1.74, 4.12)	-0.15 (0.26)
IAS width	0.32 (0.17, 0.63)	-0.001 (0.99)
ARA	157.00 (142.00, 168.00)	-0.07 (0.57)

TABLE 3. – Association between age and the visualization of anterior and posterior compartment structures.

Structure	OR (95% CI)
Anterior compartment	
TP	0.959 (0.923, 0.997)
TR	0.959 (0.923, 0.995)
VT	0.978 (0.940, 1.017)
SUG	1.099 (0.967, 1.248)
LCM	1.099 (0.967, 1.248)
CU	0.997 (0.954, 1.042)
Posterior compartment	
RVS	0.966 (0.929, 1.005)
IAS	0.962 (0.919, 1.006)
EAS-m	0.959 (0.915, 1.005)
EAS-sq	0.963 (0.927, 1.001)

DISCUSSION

In order for 3D EVUS to become a suitable option for imaging the female pelvic floor, its use must be validated in the patient population that it will be clinically useful for. However, due to the novel nature of this technology, it is important to first prove its ability to identify normal key structures in clinically normal patients. We have previously shown that 3D EVUS can reliably provide a detailed anatomic depiction of the anterior and posterior pelvic floor compartments in young, asymptomatic, nulliparous women by correlating the rendered images with histologic specimens.[13] However, a limitation of that study was the generalizability of our findings to a broader population, given

TABLE 4. – Inter-observer analysis of the visualization of key structures within the anterior and posterior compartments.

Structure	Agreement (n, %)	k	95% CI	p-value
VT	70/75 (93.33)	0.806	0.643, 0.969	<0.0001
TR	67/77 (87.01)	0.696	0.537, 0.854	<0.0001
TP	73/75 (97.33)	0.937	0.852, 1.000	<0.0001
LCM	76/77 (98.70)	0.794	0.400, 1.000	0.0010
SUG	76/77 (98.70)	0.794	0.400, 1.000	0.0010
CU	72/77 (93.51)	0.724	0.496, 0.953	<0.0001
RVS	70/74 (94.59)	0.854	0.716, 0.992	<0.0001
IAS	74/75 (98.67)	0.957	0.874, 1.000	<0.0001
EAS-sq	67/75 (89.33)	0.718	0.536, 0.901	<0.0001
EAS-m	72/75 (94.67)	0.878	0.743, 1.000	<0.0001

that many patients seeking care for pelvic floor disorders are neither young, nulliparous, nor asymptomatic.

The incidence and prevalence of pelvic floor disorders is known to increase with age.[19] There is evidence suggesting that pelvic organ support, urethral function, and levator function are not affected by age.[17] Quiroz et al. showed that age had no significant effect on the visualization of levator ani muscles by 3D EVUS in nulliparous women.[24] Using transperineal ultrasound, Dietz et al. showed that age seems to have a limited effect on contractility and distensibility of the pelvic floor muscle. The small effect of aging results in reduced contraction strength and increased hiatal diameter.[25] Our group has published on the association between the visualization of anterior compartment structures by 3D EVUS and urinary incontinence symptoms;[26] however, to our knowledge, the influence of age on the visualization of anterior and posterior compartment structures seen on 3D EVUS has not been previously studied . Several age-related changes in pelvic floor tissues, such as muscle atrophy and collagen degradation have been noted in several studies.[19-21] With such structural changes, it is possible that the ability to visualize pelvic floor structures changes with age, thus affecting the usefulness of 3D EVUS in an older population. In the current study, we demonstrated that age was not related to urethral, rectovaginal septum, or anal sphincter measurements. In this study, the ability to visualize important structures in the anterior and posterior pelvic floor compartments was not affected by increasing age, and there is good agreement between observers when viewing 3D EVUS images across all age groups.

This study does have some limitations that must be acknowledged. Since the majority of our patients were Caucasian, our findings may not apply to other ethnic groups. Additionally, these findings have limited generalizability because, as previously mentioned, the majority of patients in whom 3D EVUS would be indicated are parous and have symptoms of pelvic floor disorders. However, the aim of this study was not to evaluate the use of 3D EVUS in symptomatic patients. Rather, it is the next step in establishing the reliable visibility of pelvic floor structures of interest using this novel technology, as a baseline for future studies in a more generalizable urogynecologic patient population.

We acknowledge that this technology is still in the early stages of development. Age alone did not significantly impact the visualization of anterior and posterior compartment structures. Future studies are needed to address the clinical implications of 3D EVUS in the clinical assessment of women with symptomatic pelvic floor disorders.

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INVITED COMMENT. The modern transperineal sonography of the pelvic floor

High-resolution three-dimensional endovaginal ultrasound (3D-EVUS) has recently come into the clinical practice to evaluate the complex anatomy of the female pelvic floor including the bladder base, urethral and paraurethral structures (anteriorly) and anal sphincter complex, rectovaginal septum and postanal space (posteriorly). Compared to 3D- transperineal ultrasound (TPUS), in face of the disadvantage of not allowing a dynamic evaluation[1] of the pelvic floor under the effect of useful provocative maneuvers (i.e., Valsalva and Kegel maneuvers), 3D- EVUS avoids the adverse effect of excessive variability when accurately measuring distances, areas, angles and volumes in any plane. Common to both techniques, a series of advanced post-processing techniques including digital enhancing of individual voxels for better representation of transparency (volume render mode), selection and display on the screen of the brightest value found along the ultrasound beam (maximum intensity projection) and marking and/or subtraction from the neighbor anatomy of selected volume voxels (sculpting) can also been applied for better interpretation of the pertinent anatomy[2]. Although not adding new relevant information to knowledge, the elegant study by White et al. confirms that 3D-EVUS is a highly reproducible diagnostic tool[3] for the measurements of the most common biometric indices used in the clinical practice and, even more important, that ageing has no (adverse) effect on the visualization of pelvic floor structures, thus indicating that the technique is feasible for becoming the baseline investigation in the general female population. Moreover, given the good-to-excellent interobserver and interdisciplinary reproducibility of the technique demonstrated by Santoro et al. with the exception of the anorectal angle (ARA) measurement[4], 3D-EVUS seems ideal as an objective site-specific diagnostic tool for describing, quantitating, and staging pelvic support defects in women, ultimately enhancing both clinical and academic communication among urologists, gynecologists, coloproctologists and radiologists. This is a primary issue in Perineology, as confirmed by the fact that, although patients may present with symptoms which involve only one compartment, a multicompartment defect is usually revealed at imaging[5], highlighting the role of a simple, cheap and tolerable tool, such as 3D-TVUS, for assessing the presence of associated defects and the severity of singular abnormalities so as to reach a more accurate diagnosis than during physical examination alone, regardless of the specialization of the examiner. Further improvement with the technique may be anticipated when considering the possibility of simultaneous capturing and subsequent merging of images obtained during the assessment of urethral vascularity[6] based on selected Doppler parameters such as velocity (V), resistive index (RI) and pulsatility index (PI), for better comprehension of urinary continence mechanism. Unfortunately, the application of similar principles to the investigation of the posterior compartment has received little attention in the literature. Conversely, using 3D- TVUS to depict the cushioning effect of blood vessel within the anal submucosa (Figure 1) can disclose new interesting scenaries for the diagnosis and treatment of the hemorrhoidal disease, one of the most common clinical problem in proctology. Finally, a space for implementation of comparative studies that apply 3D - TVUS and magnetic resonance (MR) imaging using an endovaginal coil does exist and is highly desirable. In fact, while 3D-ultrasonography can be considered an unsurpassed technique for visualizing and measuring the most important structures of lower urinary tract anatomy, such as the vesical trigone, trigonal ring, striated urogenital sphincter, compressor urethra and longitudinal or circular smooth muscle, as shown in the present article, it is worth mentioning that MRI using an endovaginal coil has even been reported by Kim JK et al.[7] to allow discrimination between continent and incontinent subjects on the basis of a score of the risk of stress urinary incontinence (scale of 0-5). All of this taking into account established MR diagnostic criteria, including the degree of asymmetry of the puborectalis muscle, and frequency of distortion in the periurethral, paraurethral and pubourethral ligaments, which are not visible at sonography. Hopefully, data obtained using both methods of investigation (fusion imaging) will help physicians in the future reaching a more accurate diagnosis and treatment.

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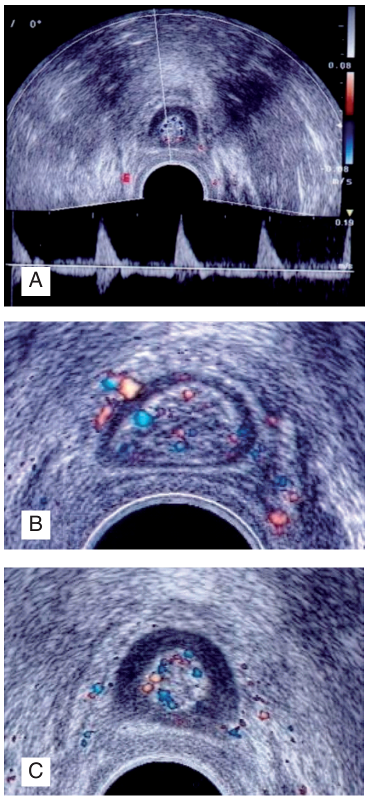

Figure 1. – Analysis of flow parameters (A) from a region of interest of the anal canal by biplane endovaginal probe in a case on normal vascular pattern (B) and one with 2nd degree hemorrhoidal varices (C): note the shift of the flow from the submucosal space toward the intersphincteric space (arrow).