Anal Sphincter Length as Determined by 3-Dimensional Endoanal Ultrasound and Anal Manometry

A Study in Healthy Nulliparous Women

Stig Norderval, MD, PhD , Torunn K. Pedersen, BSN, Rowan J. Collinson, MD, PhD

Objectives—The normal female external anal sphincter (EAS) is shorter anteriorly than laterally and posteriorly. Furthermore, the thickness of the very proximal part of the circular EAS is thinner than 50% of the lateral and posterior EAS thickness. The extent of these features is not fully explored. The aim of this prospective study was to assess the normal anal sphincter with 3-dimensional (3D) endoanal ultrasound (EAUS) and to relate 3D EAUS length measurements to sphincter length determined by anal manometry.

Methods—Healthy premenopausal nulliparous women underwent anal manometry and 3D EAUS examinations. Two experienced colorectal surgeons independently assessed all scans, blinded to any patient data.

Results—A total of 43 women were included. Four scans were incomplete and excluded from the analysis. Interobserver agreement was fair to very good for the various length measurements. The mean length from the distal border of the puborectal muscle to the very proximal border of the anterior EAS (the anterior gap) was 4.4 (95% confidence interval, 3.9–4.9) mm, whereas the length to the level where the anterior EAS thickness was at least 50% of the lateral and posterior EAS thickness was 7.2 (95% confidence interval, 6.5–7.9) mm. Manometric sphincter length at rest did not correlate with any 3D EAUS length measurements.

Conclusions—In the normal anterior female anal canal, the EAS is not present or appears with less than 50% of the thickness of the lateral and posterior EAS for the first 7.2 mm below the distal border of the puborectal muscle.

Key Words—anal manometry; anal sphincter; anal ultrasound

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Address correspondence to Stig Norderval, MD, PhD, Department of Gastrointestinal Surgery, University Hospital of North Norway, Sykehusveien 38, N-9019 Tromsø, Norway.

E-mail: stig.norderval@unn.no

Abbreviations
3D, 3-dimensional; BMI, body mass index; CI, confidence interval; EAS, external anal sphincter; EAUS, endoanal ultrasound; HPZ, high-pressure zone; IAS, internal anal sphincter; PRM, puborectal muscle; US, ultrasound

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Endoanal ultrasound (EAUS) is a recognized method for assessment of the anal sphincter complex. The development of high-frequency transducers and scanners enabling 3-dimensional (3D) reconstruction has further increased its use, and an EAUS examination is regarded as an essential investigation in the workup of patients with fecal incontinence.[1,2] Defects in the smooth internal anal sphincter (IAS) muscle and the striated external anal sphincter (EAS) muscle can be identified with a moderate to substantial degree of intra- and inter-rater agreement[3,4] also for the inexperienced user.[4] Furthermore, defects diagnosed by EAUS correlate with findings at reconstructive sphincter surgery.[5] Two different scoring systems have been developed to classify the 3D extent of sphincter defects,[3,6] and studies have shown that larger defects with higher scores are associated with more severe incontinence than smaller defects with lower scores.[7–9] Both scoring systems include partial EAS defects, defined as ultrasound (US) defects involving greater than 50% but less than 100% of the EAS thickness. However, the very proximal part of the normal female anterior EAS at the level where it forms a complete muscular ring is thinner than 50% of the lateral and posterior EAS thickness. This implies that the EAUS finding of an EAS thinner than 50% of the lateral and posterior EAS thickness in the proximal part of the anterior sphincter complex may represent a true partial defect or a normal finding. The longitudinal extent over which the anterior EAS in women is complete but thinner than 50% of the lateral and posterior EAS thickness has not previously been explored.

The primary aim of this study was, therefore, to assess the length of the normal female anal sphincters with 3D EAUS, with a special focus on the distance between the distal border of the puborectal muscle (PRM) and the proximal border of the anterior EAS, where it first appears as a complete muscular ring, and the length over which the anterior EAS thickness is less than 50% of the lateral and posterior EAS thickness. The secondary aim was to relate the EAUS sphincter length measures to the body mass index (BMI) and to length measurements obtained by anal manometry.

Materials and Methods

Nulliparous women older than 18 years who had not reached menopause were invited to participate in this prospective cross-sectional study by wall posters at the University Hospital of North Norway. Women willing to participate contacted the outpatient clinic for assessment of eligibility according to inclusion and exclusion criteria. Exclusion criteria were the presence of neuromuscular disease or inflammatory bowel disease or previous surgery for hemorrhoids, anal abscesses, or anal fistulas. After eligibility was confirmed, signed informed consent was obtained. Included women were seen in the outpatient clinic by a specialist nurse (T.K.P.) who performed an interview including the St Mark's incontinence score and measurement of height and weight before anal manometry and 3D EAUS examinations were undertaken by the same nurse. Included women were offered compensation of NOK1000 (about US$100) for participation. The study was funded by the Health Authorities of North Norway and approved by the Norwegian Social Science Data Service and the Regional Committee for Medical and Health Research Ethics of North Norway (approval number 682006).

Endoanal US

Endoanal US examinations were performed with the women in the lithotomy position using a ProFocus 2202 US scanner with a 16.0-MHz rotating 2050 endoanal transducer of 12 mm in external diameter (BK Medical, Gentofte, Denmark). The transducer had a built-in 3D mover providing 360° high-resolution images with no movement between the outer plastic cone and the anal mucosa during 3D EAUS acquisition. The scan should have included the complete anal canal from above the proximal border of the PRM to the distal border of the EAS. The nurse who performed the EAUS investigation performed a second scan if she regarded the first to be incomplete or otherwise inadequate. Only a single volume acquisition was stored for each woman. The complete acquired 3D EAUS volumes from each participant were assessed independently by 2 authors (S.N. and R.J.C.), both colorectal surgeons having performed more than 500 EAUS assessments each before the study. The EAUS data sets were viewed on a personal computer with a 22-inch full high-definition LED monitor using BK 3D Viewer version 7.0 software (BK Medical). Both investigators were blinded to other patient data. The assessment of the acquired 3D EAUS volumes was standardized, as 6 distinct anatomic landmarks were identified and marked in the transverse view:

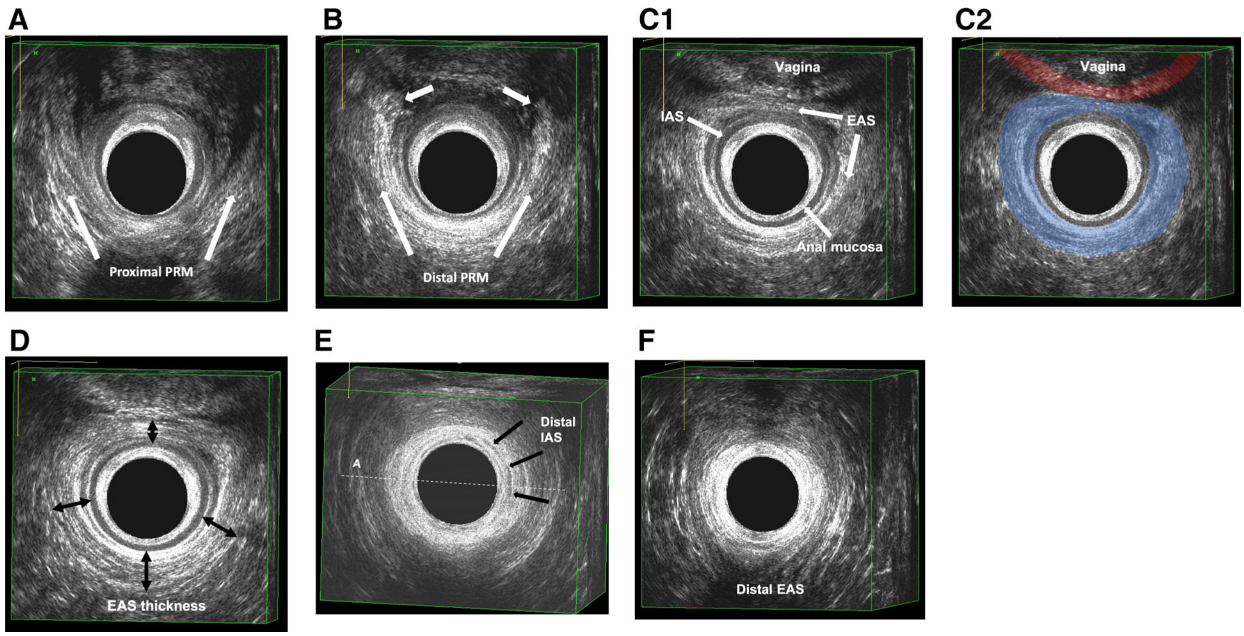
1. The proximal border of the PRM, defined as the level at which the posterior muscular sling became evident (Figure 1A);
2. The distal border of the PRM just before curving to form the EAS (Figure 1B);
3. The proximal border of the anterior EAS, defined as the level at which a complete muscular ring was first seen (Figure 1, C1 and C2); the longitudinal muscle was included in the assessments of the

EAS, as it frequently is indistinguishable from the latter by US;

4. The proximal limit at which the anterior EAS thickness was at least 50% of the mean EAS thickness measured at the 3-, 6-, and 9-o'clock positions in the midanal canal (Figure 1D);
5. The distal border of the IAS, defined as the level at which less than 25% of the IAS ring was visible (Figure 1E); and
6. The distal border of the EAS, defined as the distal level at which a complete muscular ring still was seen (Figure 1F).

The proximal border of the IAS was determined on the basis of its appearance in the midcoronal view according to a study by Williams et al[10] to minimize the impact on the tissue thickness anteriorly or posteriorly in the proximal anal canal caused by an inadvertent oblique transducer position. The most distal onset of the proximal border of the IAS was chosen as the proximal IAS limitation in cases in which the onset varied from one side to the other (Figure 2). Based on the markings in the coronal and transverse views, length measurements of the PRM, IAS, anterior EAS, and lateral/posterior EAS were undertaken in the sagittal view, as well as the distance from the distal border of the PRM to the first sign of a complete EAS ring (the anterior gap) and the longitudinal extent over which the anterior EAS thickness was less than 50% of the lateral and posterior EAS thickness (Figure 3). All length measurements were performed in a plane parallel to the endoanal transducer. The anterior gap and the length of the anterior and lateral EAS are further illustrated in the coronal view in Figure 4. To ensure standardization of the various steps of the EAUS assessment, the investigators assessed several external EAUS data sets together before the study assessment.

Figure 1. A, Axial view of the proximal border of the PRM at the level where the posterior muscular sling is first visible. **B**, Axial view from the distal border of the PRM (long arrows) just at the level where the anterior parts start to bend medially (short arrows) to form the EAS. **C1**, Axial view at the level where a complete muscular ring of the EAS first is seen. The IAS is seen as a hypoechoic circular structure completely surrounded by the EAS at this level. The inner hyperechoic ring represents the anal mucosa. **C2**, Identical scan as **C1**. The EAS has been highlighted transparent blue and the dorsal vaginal wall transparent red. The inner hyperechoic (white) ring represents the anal mucosa. The IAS is seen as a hypoechoic ring between the EAS and the anal mucosa. **D**, Axial view at the level where the anterior EAS has gained 50% of the average lateral and posterior EAS thickness. In this case, the average thickness is 8 mm laterally and posteriorly and 4 mm anteriorly. **E**, Axial view from the distal border of the IAS at the level where less than 25% of the muscular ring (arrows) is seen. A marker (dotted line; A) is placed at this level for later identification of the level in the coronal plan (see Figure 2). **F**, Axial view from the distal border of the EAS.



Anal Manometry

Anal manometry (Polygraf ID; Medtronic, Minneapolis MN) was undertaken in the left lateral position before the EAUS examination. A water-perfused, 8-channel catheter was introduced into the anal canal at the level above the PRM, and with a continuous

Figure 2. Midcoronal view. The IAS is clearly seen at both sides (arrows). Dotted line A represents the very distal border of the IAS, marked in the axial plane (Figure 1F), and dotted line B represents the proximal IAS border. The length of the IAS is then measured (double arrow).

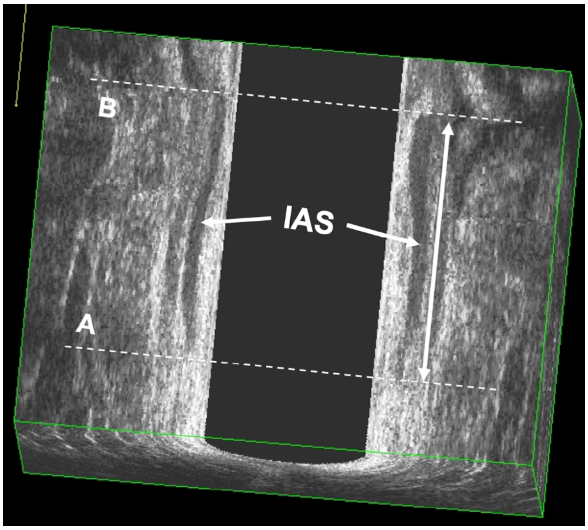


Figure 4. Coronal view from the ventral part of the anal sphincter complex, showing the length of the PRM (dotted short double arrow), the lateral part of the EAS (continuous long double arrow), the anterior gap (continuous short double arrow), and the anterior EAS (dotted long double arrow). The IAS is seen as it emerges beyond the proximal border of the anterior EAS, illustrating the anterior gap where no striated muscles are covering the IAS anteriorly.

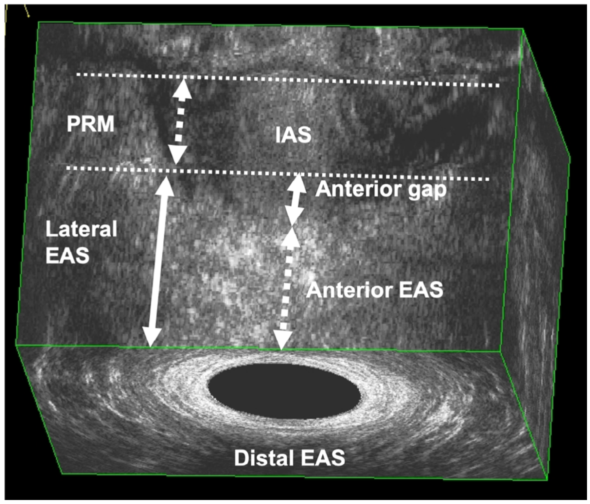
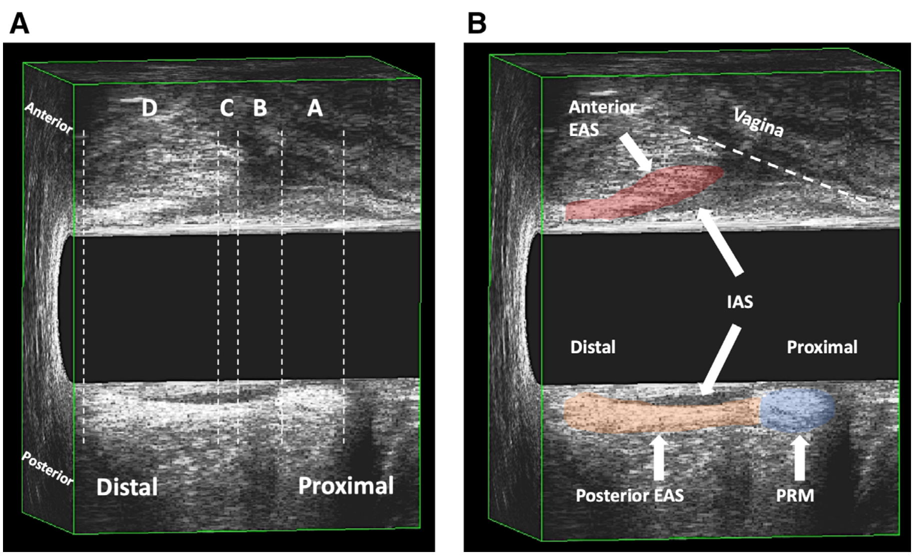


Figure 3. A, Sagittal view. Dotted lines indicate levels based on the markings marked in the axial view (Figure 1, A–E). The extents between dotted lines represent the different length measures: A, PRM length; B, length of the anterior gap; C, length over which the anterior EAS thickness is less than 50% of the lateral and posterior EAS thickness; and D, length over which the entire EAS thickness is 50% or more of the lateral and posterior EAS thickness. C + D = anterior EAS length; and B + C + D = lateral and posterior EAS lengths. **B**, Same view as **A**, but with the anatomic structures highlighted.



pull-through technique during rest and squeeze, a pressure profile was obtained. The mean value of 3 measurements was calculated, including calculation of the total sphincter length and length of the high-pressure zone (HPZ). The total sphincter length was defined as the distance over which the mean resting pressure exceeded the rectal pressure by 5 mm Hg and HPZ as the distance over which the pressure was at least 50% of the mean maximal resting pressure.[11]

Statistics

Data were analyzed using SPSS Statistics version 25 software for Mac (IBM Corporation, Armonk, NY). Continuous variables were presented as mean values with 95% confidence interval (CIs). The level of inter-rater agreement between the 2 EAUS investigators was assessed by the intraclass correlation coefficient. Mean values of the various length measurements were calculated from the measurements of the 2 assessors. Comparisons of continuous variables were performed with the Student *t* test. Correlations between various sphincter length measurements by EAUS and anal manometry were assessed with the Pearson correlation coefficient. Two-sided $P < .05$ was considered statistically significant. On the basis of previous studies,[3,10,12–14] we intended to include about 40 women to establish fairly robust reference material in this subgroup of women.

Results

A total of 43 women were included in the study. Four EAUS acquisitions were classified as incomplete by both assessors, as the very distal part of the EAS was not included in 2 cases, and the proximal border of the IAS was not included in another 2 cases. Hence, the data from 39 women were eligible for analysis. The mean age was 25.7 (95% CI, 23.8–27.6) years. The mean height was 169.1 (95% CI, 167.0–171.2) cm; the mean weight was 66.4 (95% CI, 62.9–79.8) kg; and the mean BMI was 23.2 (95% CI, 21.8–24.7) kg/m^2. One woman reported a St Mark's score of 8 due to urgency with daily alteration of her lifestyle, whereas the remaining 38 women had no anal incontinence symptoms.

Three-Dimensional EAUS

The various mean EAUS length measurements are presented in Table 1. The anterior gap was 4.4 (95% CI, 3.9–4.9) mm, and the length over which the anterior EAS thickness was less than 50% of the lateral and posterior EAS thickness was 2.8 (95% CI, 2.4–3.2) mm. The length over which the anterior EAS was either not present or with a thickness of less

Table 1. Mean Length Measures of Various Parts of the Anal Sphincter Complex by 3D EAUS in 39 Nulliparous Women

Measurement	Value
Anatomic anal canal length, mm	34.8 (33.6–36.0)
Total sphincter length (EAS + IAS), mm	38.6 (37.4–39.8)
PRM length, mm	14.6 (13.3–15.9)
Lateral EAS length, mm	20.2 (19.3–21.1)
Anterior EAS length, mm	15.8 (14.9–16.7)
Anterior gap length, mm	4.4 (3.9–4.9)
Anterior EAS length with <50% of mean EAS thickness, mm	2.8 (2.4–3.2)
IAS length, mm	31.9 (30.5–33.3)

Data are presented as mean (95% CI). Anatomic anal canal length was the distance from the proximal border of the PRM to the distal border of the external sphincter; total sphincter length, distance from the proximal border of the IAS to the distal border of the EAS; gap length, distance from the distal border of the PRM to the level at which a complete muscular ring of the EAS was first seen; and anterior EAS with <50% of mean EAS thickness, longitudinal extension over which the anterior EAS thickness was less than 50% of the lateral and posterior EAS thickness.

Table 2. Interclass Correlation Coefficients (ICCs) Between the Assessors for Various Length Measurements of the Anal Sphincter Complex by 3D EAUS in 39 Nulliparous Women

Measurement	ICC	95% CI
Anatomic anal canal length	0.40	0.10–0.63
Total sphincter length (EAS + IAS)	0.56	0.31–0.74
PRM length	0.56	0.31–0.75
Lateral EAS length	0.65	0.43–0.80
Anterior EAS length	0.64	0.41–0.79
Anterior gap length	0.64	0.41–0.79
Anterior EAS length with <50% of mean EAS thickness	0.35	0.04–0.60
IAS length	0.83	0.69–0.91

Notations are as in Table 1.

than 50% of the lateral and posterior EAS thickness was 7.2 (95% CI, 6.5–7.9) mm. The mean proximal onset of the IAS was 3.8 (95% CI, 3.0–4.6) mm proximal to the proximal border of the PRM and within the level of the PRM in 4 women (10%) only. There was no correlation between any EAUS length measurements and height, weight, or BMI. The level of interobserver agreement was fair to very good for the various length measurements (Table 2).

Anal Manometry

The various manometric findings are shown in Table 3. A fair correlation was seen between the anal sphincter length at squeeze and weight (Pearson $r = 0.35$; $P = .031$), and a moderate correlation was seen between the anal sphincter length at squeeze and BMI (Pearson $r = 0.41$; $P = .009$). There were no further correlations between manometric findings and height, weight, or BMI. Although the mean manometric sphincter length at rest (Table 1) did not differ significantly from the US length of the anatomic anal canal ($P = .11$) or the total US sphincter length ($P = .09$), there were no correlations between the various manometric sphincter lengths and any of the EAUS sphincter length measurements (Table 4). A total of 15 of the 39 women (38%) were unable to generate a mean squeeze pressure exceeding 10% of the mean resting pressure in the HPZ. When these women were excluded from analysis, there was a moderate correlation between the anal sphincter length at squeeze and the EAUS anal canal length (Pearson $r = 0.46$; $P = .023$) and EAUS total sphincter length (Pearson $r = 0.43$; $P = .036$).

Table 3. Findings by Anal Manometry in 39 Nulliparous Women

Variable	Value
Resting pressures	
Mean resting pressure HPZ, mm Hg	67.2 (60.9–73.5)
Maximal resting pressure, mm Hg	108.5 (97.5–119.5)
Anal sphincter length, mm	36.7 (34.7–38.7)
Anal sphincter length HPZ, mm	22.2 (20.5–23.9)
Squeeze pressures	
Mean squeeze pressure HPZ, mm Hg	85.7 (75.3–95.9)
Maximal squeeze pressure, mm Hg	128.4 (114.5–142.3)
Anal sphincter length, mm	40.1 (37.8–42.4)
Anal sphincter length HPZ, mm	26.6 (24.7–28.85)

Data are presented as mean (95% CI).

Discussion

The presence of the anterior gap has been documented previously,[5,15,16] but this study is, to our knowledge, the first to also explore the length over which the anterior EAS thickness is less than 50% of the lateral and posterior EAS thickness in nulliparous women and to correlate the various length measurements by 3D EAUS with length measurements

Table 4. Assessment of the Pearson Correlation Between Various Length Measurements by 3D EAUS and Anal Sphincter Lengths by Anal Manometry in 39 Nulliparous Women

	Anal Manometry at Rest	Anal Manometry at Squeeze		
EAUS Measurement	Sphincter Length	Sphincter Length (HPZ)	Sphincter Length	Sphincter Length (HPZ)
Anatomic anal canal length	$r = 0.09$, $P = .60$	$r = -0.08$, $P = .65$	$r = 0.25$, $P = .12$	$r = 0.04$, $P = .80$
Total sphincter length (EAS + IAS)	$r = 0.19$, $P = .29$	$r = 0.17$, $P = .31$	$r = 0.17$, $P = .32$	$r = 0.17$, $P = .31$
PRM length	$r = -0.08$, $P = .63$	$r = -0.19$, $P = .25$	$r = 0.06$, $P = .70$	$r = -0.16$, $P = .34$
Lateral EAS length	$r = 0.22$, $P = .18$	$r = 0.16$, $P = .32$	$r = 0.23$, $P = .15$	$r = 0.26$, $P = .09$
Anterior EAS length	$r = 0.18$, $P = .29$	$r = 0.21$, $P = .20$	$r = 0.13$, $P = .45$	$r = 0.21$, $P = .19$
IAS length	$r = -0.02$, $P = .91$	$r = -0.06$, $P = .72$	$r = 0.14$, $P = .38$	$r = 0.16$, $P = .33$

obtained by anal manometry. Our findings show that immediately distal to the PRM, the EAS is not present anteriorly for the first 4 mm on average (Figures 3 and 4) and thereafter has a thickness of less than 50% of the lateral and posterior EAS thickness for another 3 mm before it gains the same thickness as the rest of the EAS.

Several previous studies on anal sphincter length in nulliparous women had 10 or fewer participants and were performed with a first-generation 3D EAUS transducer, in which the entire transducer was moving outward along the anal canal during EAUS acquisition.[10,13,17] That may explain why the reported mean length of the anal canal in nullipara differed from 3.3 to 4.2 cm and the anterior EAS length from 1.4 to 1.8 cm between the studies.[10,17] In a recent study by Wickramasinghe et al[18] including 101 primigravid Asian women in the early third trimester, normal material was established for sphincter thickness but not for sphincter length. In a study by Murad-Regadas et al[19] using a similar US endoanal transducer as in this study, the mean anterior EAS length was 1.8 cm in 35 nulliparous women. The anterior gap was 2.2 cm but was defined as the distance from the proximal border of the PRM to the proximal border of the EAS. According to the definition of Murad-Regadas et al,[19] the gap would be 1.9 cm in this study (anterior gap length plus PRM length), indicating good agreement on the extent of the phenomenon. This normal finding is important to take into consideration when assessing EAUS findings of women with fecal incontinence, as a proximal lack of the EAS anteriorly or a thin EAS in the same area may represent normal anatomy rather than a proximal defect.

The difficulties associated with US assessments of sphincter defects in the proximal part of the anterior sphincter complex was explored by Sentovich et al.[14] Sphincter defects were initially noted in 55% to 75% of nulliparous women, but when the assessment was restricted to the distal 1.5 cm of the anal canal, the rate of falsely classified defects fell to 5% to 25%. In a study by Starck et al,[3] EAS defects were described in 15% of asymptomatic nulliparous women. On the basis of the results from our study, we argue that the finding of proximal EAS defects anteriorly in asymptomatic nulliparous women without any history of sphincter injuries represents a misinterpretation of the normal anatomy. Furthermore, studies have shown that the anterior gap increases by 1 to 3 mm after uncomplicated vaginal delivery.[12,19] To minimize overrating of sphincter defects, the assessment of the EAS should therefore be restricted to the anal canal at least 4 mm distal to the distal border of the PRM. If partial US EAS defects are to be included in the assessment, as in the two 3D EAUS defect scoring systems,[3,4] the proximal limit for EAS assessment should be at least 7 mm distal to the distal PRM border.

As the IAS contributes to 50% to 70% of the anal pressure at rest,[20] we would expect a strong correlation between the length of the IAS measured by EAUS and the manometric sphincter length at rest in this cohort of asymptomatic nulliparous women. Unexpectedly, there was no correlation between any of the EAUS length measurements and the manometric length measurements (Table 4). When women unable to produce a substantial squeeze were excluded from the analyses, there was a moderate correlation between the anal canal length by EAUS and the manometric sphincter length at squeeze. We have no definite explanations for why more than one-third of the women were unable to squeeze at command. It might be that this cohort of young women with no known sphincter injuries or impaired pelvic floor function were less aware of how to voluntarily contract the pelvic floor and anal sphincter than parous women, or that they were more embarrassed and less comfortable during such an investigation and therefore not fully able to comply with the instructions given. Anyway, this factor highlights one limitation of anal manometry, as an inability to squeeze when instructed does not necessarily imply impaired sphincter function.

Only a few previous publications have presented sphincter length measurements obtained by both EAUS and manometry in nulliparous women. In the study by Williams et al,[10] the length of the anatomic anal canal by EAUS was 42 mm, and the manometric sphincter length was 38 mm, whereas Starck et al[3] reported a 30-mm mean length of the anatomic anal canal by EAUS compared to 52 mm by manometry. In a more recent study by Raizada et al,[21] length measurements of the anal sphincters were undertaken by 3D transperineal US and high-definition anorectal manometry, and lengths of the anterior, lateral, and posterior parts of the anal canal differed only slightly between the methods. Unfortunately, tests for the correlation between EAUS and manometric length measurements were not presented in any of these studies. We were therefore unable to show whether the lack of a correlation between length measurements by EAUS and manometry at rest in this study was a normal finding. One possible explanation could be that the substantial asymmetric sphincter pressure profile revealed in nulliparous women[21] was independent from the anatomic sphincter, but further studies are needed to demonstrate this relationship.

This study had some limitations. Anal manometry was performed with a water-perfused, 8-channel catheter with motorized, continuous pull-through system. Although this technique provides accurate longitudinal pressure profiles, high-definition anorectal manometry enables more detailed circumferential pressure mapping of the anal canal.[22] It is possible, therefore, that the longitudinal extent of specific pressure areas at rest correlates with the sphincter length by 3D EAUS, but further studies with high-definition anorectal manometry are needed to explore this issue. Furthermore, more than one-third of the women were unable to produce a substantial squeeze at manometry when instructed, although the investigation was conducted by an experienced continence nurse.

Only nulliparous women were included in this study to document normal findings, especially in the anterior and proximal parts of the sphincter complex. It has been shown that 10% to 33% of women sustain unrecognized anal sphincter tears during their first vaginal delivery.[23–26] As these tears typically affect the anterior parts of the sphincters, it was necessary to avoid this possible bias by only assessing women in whom preexisting sphincter defects were highly unlikely. Future studies may explore the extent of the anterior gap and the length of the anterior EAS in both continent and incontinent parous women, as the relative length of the anterior EAS seems to be inversely associated with incontinence at least in women who have sustained obstetric sphincter tears.[7] Finally, the study was undertaken in white women only, and the findings will not necessarily apply to other ethnic groups.

In conclusion, the anterior EAS is missing or appears with less than 50% of the thickness of the lateral and posterior EAS on average for the first 7.2 mm below the distal border of the PRM in nulliparous white women. This normal phenomenon must be taken into consideration when assessing EAUS findings in women. The manometric sphincter length at rest does not correlate with the sphincter length measured by 3D EAUS.

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