Int Urogynecol J (2015) 26:1191–1199
DOI 10.1007/s00192-015-2676-y

ORIGINAL ARTICLE

The relationship of 3-D translabial ultrasound anal sphincter complex measurements to postpartum anal and fecal incontinence

Kate V. Meriwether · Rebecca J. Hall · Lawrence M. Leeman · Laura Migliaccio · Clifford Qualls · Rebecca G. Rogers

Received: 9 January 2015 / Accepted: 24 February 2015 / Published online: 18 June 2015

Abstract
Introduction and hypothesis We aimed to determine whether anal sphincter complex (ASC) measurements on translabial ultrasound (TL-US) were related to anal incontinence (AI) or fecal incontinence (FI) symptoms 6 months postpartum.
Methods A prospective cohort of primiparous women underwent TL-US 6 months after a vaginal birth (VB) or cesarean delivery (CD). Muscle thickness was measured at 3, 6, 9, and 12 o'clock positions of the external anal sphincter (EAS), the same four quadrants of the internal anal sphincter (IAS) at proximal, mid, and distal levels, and at the bilateral pubovisceralis muscle (PVM). Measurements were correlated to AI and FI on the Wexner Fecal Incontinence Scale, with sub-analyses by mode of delivery. The odds ratio (OR) of symptoms was calculated for every 1 mm increase in muscle thickness (E1MIT).
Results A total of 423 women (299 VB, 124 CD) had TL-US 6 months postpartum. Decreased AI risk was associated with thicker measurements at the 6 o'clock (OR 0.74 E1MIT) and 9 o'clock proximal IAS (OR 0.71 E1MIT) in the entire cohort. For CD women, thicker measurements of the 9 o'clock proximal IAS were associated with decreased risk of AI (OR 0.56 E1MIT) and thicker distal 6 o'clock IAS measurements were related to a decreased risk of FI (OR 0.37 E1MIT). For VB women, no sphincter measurements were significantly related to symptoms, but thicker PVM measurements were associated with increased risk of AI (right side OR 1.32 E1MIT; left side OR 1.21 E1MIT).
Conclusions ASC anatomy is associated with AI and FI in certain locations; these locations vary based on the patient's mode of delivery.

Keywords Anal sphincter · Ultrasound · Postpartum · Fecal incontinence · Anal incontinence

Introduction

Disruption of the anal sphincter complex (ASC) with childbirth can lead to increased anal incontinence (AI), an embarrassing and disabling disorder that involves the involuntary loss of stool or gas from the anus. Epidemiological studies have found that up to 10 % of women in the US population have fecal incontinence (FI) but that this disorder is underreported [1, 2], and the probability of FI following a repaired sphincter injury is 7–16 % [3]. Although it is known that women with FI symptoms have an increased chance of having sphincter interruption on ultrasound (US) imaging of the ASC [4–6], sonographic defects are frequently seen in asymptomatic women as well [7, 8].

We have previously reported that translabial ultrasound (TL-US) reliably evaluates the ASC [9, 10]. Unfortunately, it is unknown if sphincter measurements (length, size, or volume) can reliably predict AI or FI. Magnetic resonance imaging studies have not demonstrated a correlation between anal sphincter size and incontinence symptoms [11, 12], and a past US imaging study on sphincter volume found that women with incontinence had longer sphincters than continent women [13]. Given these data, it is unknown if the risk for

K. V. Meriwether · R. J. Hall · L. M. Leeman · L. Migliaccio · C. Qualls · R. G. Rogers
University of New Mexico, Albuquerque, NM, USA

K. V. Meriwether (✉)
Department of Obstetrics and Gynecology, University of New Mexico Health Sciences Center, University of New Mexico, Albuquerque, NM, USA
e-mail: meriwet2@salud.unm.edu

symptoms can be predicted by certain anatomical findings on ASC imaging.

The aim of this study was to investigate the relationship between 3-D TL-US anal sphincter measurements and the presence of AI or FI symptoms at 6 months following the delivery of a first child by either vaginal birth (VB) or cesarean delivery (CD).

Methods

This study is a planned secondary analysis of data collected for a large, prospective cohort study on pelvic floor changes after the delivery of a first child. Healthy women in their first pregnancy who had antepartum care with a University of New Mexico midwifery service were recruited prenatally, and another group of women who delivered their first child by CD without entering the second stage of labor were recruited immediately after their delivery. Only full term deliveries were included in the study. This study was approved by the University of New Mexico Health Sciences Center Internal Review Board (IRB). Informed written consent was given by all participants. Methods of the parent study and US findings have been reported in prior publications [10, 14]. One expert sonologist (RH), three female pelvic medicine fellows, and one female pelvic medicine attending (RG) performed and interpreted all the imaging, with a previous publication reporting on the inter-rater reliability of this group [9]. Patients underwent both TL-US and endoanal ultrasound (EA-US) at the same time point as part of the parent study, with comparison between these imaging modalities published previously [15], but this manuscript concerns itself with the TL-US imaging.

Labor and delivery information and patient characteristics were gathered, including data on spontaneous lacerations to the perineum. If there was a second-degree or greater laceration, women were evaluated by a second examiner, and all third- and fourth-degree lacerations were repaired at delivery using standard methods. All patients in the study underwent 2-D and 3-D TL-US imaging examinations 6 months after their delivery, and the sonologist was unaware of the patient's mode of delivery.

We have described our TL-US, which has been shown to have high inter-rater reliability, in prior publications [9, 10]. The ASC was imaged in multiple planes, including the proximal, mid, and distal levels of the ASC as described by DeLancey et al. [16]. The proximal level was just distal to the anal angle, the mid-level was the plane at which the pubovisceralis muscle group (PVM) was visualized passing posteriorly to the IAS, and the distal level was the level at which the internal anal sphincter (IAS) and external anal sphincter (EAS) were best seen together. In this article, the PVM refers to the medial portion of the levator ani complex seen adjacent to the anal canal.

We acquired all 2-D and 3-D measurements and 3-D volume sets with a GE E8 US system with the 5–9 MHz endovaginal transducer (Milwaukee, WI, USA) or a Philips IU22 with the 4–8 MHz endovaginal transducer (Bothell, WA, USA). The transducer was placed at the posterior introitus in a transverse plane with minimal pressure, angling nearly perpendicularly to the horizontal, and the transducer was altered to image the ASC superior to inferior in multiple planes. All TL-US volume sets were stored in our imaging center's picture archiving and communication system (PACS).

A full survey of the IAS and EAS complex was performed, including imaging of the PVM. The 2-D TL-US transducer was rotated 90° from the axial plane to a midsagittal plane to acquire 3-D volume sets of the entire ASC. A 75° volume sweep was taken with high quality resolution (slow sweep). We describe 3-D planes relative to the anatomy being imaged, as is consistent with usual practice in this imaging [17]. Acquisition of 3-D volume sets were taken in the midline sagittal plane (A plane), and 3-D ASC measurements were performed in the plane perpendicular to this (B plane). We manipulated the coronal plane (C plane) and the B plane to optimally align the overall volume. The 3-D volume set was then manipulated by X, Y, and Z axis rotations in order to optimize the planes in which to take the most precise measurements of the IAS/EAS complex at 12, 3, 6 and 9 o'clock positions in the transverse plane at proximal, mid and distal anal ASC levels. We produced a subset of short field of view (FOV) 2-D and manipulated 3-D planes in order to optimize the thickest transverse PVM cut, typically best measured at the 4 and 8 o'clock locations at the mid IAS level [17, 18]. As noted in our previous publications [9, 10], this protocol did not include visualization of the insertion of the PVM on the pubic bone (Figs. 1 and 2).

Women completed the Wexner Fecal Incontinence Scale (W) 6 months postpartum; this questionnaire has been validated as a reliable measure of AI and FI symptoms [19]. AI was defined as the presence of any Wexner score>0 (which can include leakage of gas), and fFI was defined as the presence of accidental leakage of fecal matter as determined by responses to the Wexner questionnaire.

Sphincter interruption on US was defined as complete discontinuity in the sphincter at a specific location on US, with complete discontinuity in the lucent diameter of the muscle considered to be sphincter interruption regardless of the extent of the discontinuity (11–12 o'clock complete discontinuity considered a sphincter interruption equally to a 9–3 o'clock complete discontinuity). Recognized sphincter injury (RSI) was defined as women who had a third- or fourth-degree laceration diagnosed at the time of their delivery or had a sphincter interruption on US. Logistical regression was used to evaluate the relationship between the sphincter measurements at all levels and in all quadrants, the PVM measurements on the

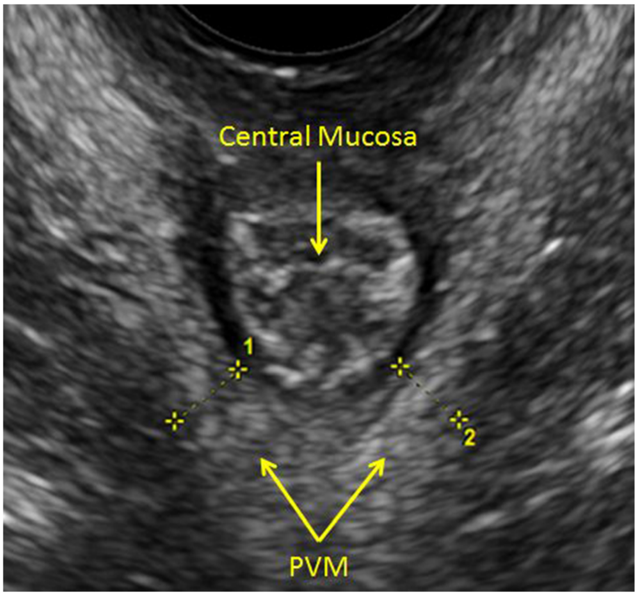

Fig. 1 A TL-US image of the mid-level ASC demonstrates the central mucosa (*arrow*), the axial view of the IAS, and the PVM (*two arrows*). The PVM thickness is measured at 4 and 8 o'clock

left and right side, and the probability of postpartum AI or FI. We calculated the odds ratio (OR) and 95 % confidence intervals (CI) for every 1 mm increase in muscle thickness (from here forward designated as E1MIT). Analysis was performed and ORs were generated both including and excluding women who had an RSI to allow data to be available both for a population without RSI and for a general population. Continuous variables were compared using *t* tests. Categorical variables were compared with chi-square analysis or Fisher's exact test. All statistical analysis was performed using SAS programming.

Results

From July 2006 to December 2011, 782 women consented to participate in the study, and 696 of these patients had their delivery at the study institution (448 VB and 246 CD). As reported previously [10, 14], there was a low rate of vacuum deliveries (25 women, 6 %), forceps delivery (1 woman, 0.2 %), episiotomy (8 women, 2 %), and third- or fourth-degree lacerations (22 women, 5 %) among the women who had a VB, and only 24 women entered the second stage of labor before delivering by a CD. There were 433 women (62 %) who presented for US imaging 6 months postpartum, with 423 (299 VB and 124 CD) having full imaging of the sphincters [15]. Sphincter disruption in this population was uncommon, with 38/423 women (33 VB and 5 CD), or 11 % of VB and 4 % of CD women, having a sphincter interruption 6 months postpartum on US.

Excluding women who had an RSI, few TL-US measurements were related to postpartum AI. The relationship of TL-US measurements to AI and FI symptoms in the entire cohort (VB and CD women) is shown in Table 1. A thicker 6 o'clock proximal IAS was related to less odds of AI in the entire cohort (OR 0.72, 95 % CI 0.54–0.97 E1MIT), but no other measurements were significantly related to AI symptoms in the entire cohort. In contrast to AI, no TL-US sphincter measurements were significantly related to FI. Also, the 12 o'clock position of the IAS at any level was not significantly correlated with symptoms. No EAS measurements were significantly related to AI or FI in the entire cohort with RSI excluded.

Fig. 2 A TL-US 3-D volume at the proximal level ASC demonstrates the center reference point (*arrows*) on the sagittal and axial views of the ASC, and the circumferentially intact IAS is well seen on the axial view

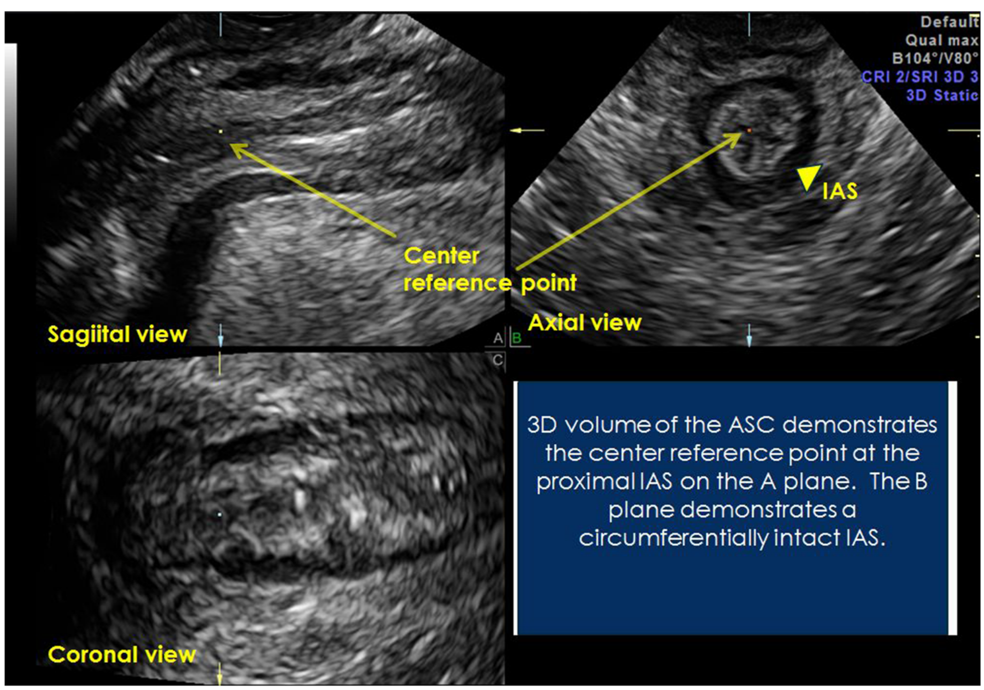

Table 1 The relationship of ASC measurements to AI and FI symptoms, excluding women with an RSI[a]

Measurements	OR AI (95 % CI)	*P* value AI	OR FI (95 % CI)	*P* value FI
IAS prox				
12	1.05 (0.81–1.35)	0.72	1.17 (0.75–1.81)	0.50
3	0.86 (0.63–1.19)	0.37	0.86 (0.49–1.51)	0.60
6	0.72 (0.54–0.97)	0.03	0.71 (0.41–1.23)	0.22
9	0.75 (0.55–1.03)	0.07	0.93 (0.54–1.59)	0.78
IAS mid				
12	1.11 (0.83–1.48)	0.48	1.46 (0.90–2.37)	0.12
3	1.06 (0.76–1.48)	0.74	1.04 (0.59–1.86)	0.89
6	0.86 (0.63–1.19)	0.38	1.37 (0.86–2.19)	0.19
9	1.28 (0.92–1.78)	0.15	1.23 (0.69–2.17)	0.49
IAS dist				
12	1.12 (0.81–1.54)	0.49	1.09 (0.63–1.89)	0.75
3	1.18 (0.82–1.68)	0.38	0.62 (0.32–1.20)	0.15
6	1.10 (0.81–1.49)	0.55	0.70 (0.40–1.22)	0.21
9	1.00 (0.71–1.41)	0.99	0.76 (0.41–1.40)	0.38
EAS				
12	1.03 (0.80–1.32)	0.81	1.11 (0.73–1.69)	0.62
3	1.00 (0.88–1.13)	0.96	1.08 (0.87–1.34)	0.49
6	0.92 (0.86–1.04)	0.22	1.06 (0.90–1.24)	0.49
9	1.01 (0.90–1.14)	0.85	1.08 (0.87–1.33)	0.48
PVM				
Right	1.18 (1.03–1.35)	0.02	1.24 (0.99–1.56)	0.07
Left	1.11 (0.98–1.26)	0.10	1.22 (0.98–1.52)	0.07

[a] Recognized sphincter injury (RSI) is defined as a history of a third- or fourth-degree perineal laceration at the time of the patient's delivery or a sphincter interruption at any location on postpartum US imaging

The relationship of TL-US measurements to AI and FI symptoms for the entire cohort of women, including those with RSI, is shown in Table 2. In these women with RSI included, proximal IAS measurements were again related to AI symptoms. A thicker 6 o'clock (OR 0.74, 95 % CI 0.57–0.98 E1MIT) and a thicker 9 o'clock proximal IAS (OR 0.71, 95 % CI 0.53–0.96 E1MIT) were associated with less risk of AI. Again, the 12 o'clock IAS at any level was not related to any AI or FI symptoms, and no EAS measurements were significantly related to AI or FI. With RSI included, no IAS sphincter measurements were significantly related to FI symptoms.

Analyzing only those women who had a CD, a thicker 9 o'clock proximal IAS was associated with less odds of AI (OR 0.56, 95 % CI 0.33–0.94 E1MIT) when women with RSI were excluded (Table 3). This relationship was not seen in women who had a VB. For CD women with RSI included (Table 4), a thicker distal IAS at 6 o'clock was also associated with less risk of FI (OR 0.37, 95 % CI 0.14–0.96 E1MIT). Again, this relationship was not seen in women who had a VB. In fact, the analysis of women having a VB revealed that no sphincter measurements were significantly related to AI or FI in this cohort, whether or not RSI were included (all $P>0.05$) (Tables 3 and 4).

In the entire cohort with RSI excluded, thicker right-sided PVM measurements were significantly associated with increased odds of AI (OR 1.18, 95 % CI 1.03–1.35 E1MIT). When this relationship was analyzed by mode of delivery, the PVM was significantly related to FI and AI symptoms in VB women with RSI excluded. Thicker PVM measurements were associated with increased odds of AI on both the right (OR 1.32, 95 % CI 1.12–1.57 E1MIT) and left side (OR 1.21, 95 % CI 1.03–1.42 E1MIT); thicker PVM measurements were similarly associated with increased odds of FI on both the right (OR 1.52, 95 % CI 1.12–2.06 E1MIT) and left side (OR 1.36, 95 % CI 1.02–1.82 E1MIT). In VB women with RSI included, thicker right PVM measurements were again associated with more odds of AI (OR 1.19, 95 % CI 1.03–1.39 E1MIT) and FI (OR 1.36, 95 % CI 1.06–1.76 E1MIT). In contrast, PVM measurements in CD women were not significantly associated with AI and FI whether or not RSI were included.

Discussion

We found that most TL-US measurements of the ASC are not related to AI or FI symptoms 6 months after delivery. However, in women with a CD, a thicker lateral and posterior proximal IAS was related to a decreased risk of AI (not FI), indicating that anatomy may be protective only to gaseous incontinence when no vaginal birth has taken place. We did not find a relationship between EAS measurements or distal

Table 2 The relationship of ASC measurements to AI and FI symptoms, including women with an RSI[a]

Measurements	OR AI (95 % CI)	*P* value AI	OR FI (95 % CI)	*P* value FI
IAS prox				
12	1.08 (0.85–1.37)	0.54	1.30 (0.88–1.93)	0.18
3	0.80 (0.59–1.08)	0.15	0.85 (0.51–1.41)	0.52
6	0.74 (0.57–0.98)	0.03	0.92 (0.59–1.45)	0.72
9	0.71 (0.53–0.96)	0.03	0.87 (0.53–1.42)	0.57
IAS mid				
12	1.10 (0.86–1.42)	0.45	1.25 (0.83–1.86)	0.29
3	1.04 (0.77–1.42)	0.80	1.0 (0.60–1.67)	1.00
6	0.91 (0.69–1.21)	0.53	1.42 (0.96–2.08)	0.08
9	1.11 (0.82–1.52)	0.50	1.04 (0.62–1.74)	0.88
IAS dist				
12	1.12 (0.83–1.51)	0.46	1.10 (0.66–1.84)	0.72
3	1.05 (0.76–1.44)	0.77	0.59 (0.33–1.05)	0.07
6	1.02 (0.78–1.32)	0.91	0.93 (0.59–1.46)	0.75
9	0.90 (0.66–1.24)	0.53	0.73 (0.43–1.25)	0.25
EAS				
12	1.06 (0.84–1.34)	0.62	1.05 (0.72–1.53)	0.81
3	0.99 (0.88–1.11)	0.81	1.02 (0.85–1.24)	0.82
6	0.94 (0.86–1.03)	0.21	1.01 (0.87–1.17)	0.87
9	0.99 (0.89–1.11)	0.91	0.99 (0.82–1.20)	0.92
PVM				
Right	1.11 (0.98–1.26)	0.11	1.22 (1.00–1.50)	0.06
Left	1.05 (0.93–1.18)	0.46	1.15 (0.95–1.40)	0.15

[a] Recognized sphincter injury (RSI) is defined as a history of a third- or fourth-degree perineal laceration at the time of the patient's delivery or a sphincter interruption at any location on postpartum US imaging

IAS measurements and symptoms, regardless of whether or not RSI were included in the analysis. This may suggest that distal anal injury and distal anal sphincter bulk may be less important than other continence mechanisms in postpartum women. Our finding of an association between a thicker PVM and an increased risk of AI and FI may indicate that other muscles may be compensating for compromise of continence mechanisms elsewhere.

Association of the lateral and posterior portions of the internal sphincter with incontinence symptoms is an unexpected finding. Most past studies relate FI and AI to sphincter disruptions [4–7], which traditionally occur in the anterior portions of the sphincter. However, our data found that the 12 o'clock positions of the IAS and EAS were not significantly related to symptoms in this cohort with low levels of sphincter laceration. However, a thicker posterior (6 o'clock) IAS at the proximal level on TL-US was associated with a 28 % decrease in the risk of AI for E1MIT. This relationship was not significant for women having a VB alone, indicating CD women were the primary contributor to this association. When CD women were considered in isolation, it was found that a thicker right-sided (9 o'clock) IAS was also protective against AI. One hypothesis for these findings may be that stronger anatomy may be protective in cases where no trauma to the pelvic floor has been experienced (e.g., after CD), but after VB the damage to nerves and non-anatomical continence mechanisms may overcome this protective effect. This indicates that the pathophysiology of postpartum AI and FI is mechanistically different between the two modes of delivery.

External anal sphincter disruption or attenuation is thought to have a negative impact on sphincter function. Our data indicate that EAS measurements are unrelated to symptoms in women with intact sphincters, but a thicker lateral EAS is related to increased symptoms when women with an RSI are included. We have previously found and reported from this data set that women with a repaired third- or fourth-degree laceration tended to have a thicker sphincter anteriorly [10, 15]. In the analysis including women with RSI, the formation of scar tissue in these women with known sphincter trauma may be more anatomically thick but less functional, leading to an association between a thicker EAS and an increased prevalence of symptoms. When the women with RSI were excluded, the relationship of EAS thickness to symptoms was no longer found. These data indicate that a bulkier postpartum sphincter is not protective against AI or FI symptoms, and attenuation or thinning of the EAS from obstetrical trauma does not itself confer an increased risk of incontinence.

A thicker PVM increased the risk of incontinence in this study population. It is possible that a thicker PVM correlates to, or is compensating for, injury to another continence

Table 3 The relationship of ASC measurements to AI and FI symptoms, separated by mode of delivery, excluding women with an RSI[a]

	AI symptoms				FI symptoms			
	VB		CD		VB		CD	
Measurement	OR AI (95 % CI)	*P* value	OR AI (95 % CI)	*P* value	OR FI (95 % CI)	*P* value	OR FI (95 % CI)	*P* value
IAS proximal								
12	1.05 (0.76–1.46)	0.77	0.95 (0.63–1.45)	0.83	0.97 (0.50–1.89)	0.94	1.17 (0.64–2.15)	0.60
3	0.91 (0.61–1.36)	0.64	0.78 (0.46–1.31)	0.35	1.02 (0.45–2.30)	0.96	0.72 (0.33–1.55)	0.40
6	0.69 (0.47–1.03)	0.07	0.73 (0.46–1.15)	0.18	0.94 (0.44–2.02)	0.88	0.50 (0.22–1.16)	0.11
9	0.86 (0.58–1.29)	0.47	0.57 (0.34–0.97)	0.04	0.96 (0.43–2.13)	0.91	0.85 (0.41–1.75)	0.65
IAS mid								
12	1.03 (0.72–1.48)	0.86	1.19 (0.73–1.92)	0.49	0.87 (0.92–3.79)	0.08	1.07 (0.54–2.12)	0.84
3	1.26 (0.83–1.92)	0.27	0.78 (0.45–1.37)	0.40	1.50 (0.67–3.36)	0.32	0.73 (0.32–1.71)	0.48
6	0.84 (0.56–1.27)	0.42	0.88 (0.53–1.46)	0.62	1.20 (0.56–2.58)	0.64	1.45 (0.79–2.66)	0.23
9	1.50 (0.99–2.28)	0.06	0.94 (0.53–1.67)	0.84	1.75 (0.79–3.91)	0.17	0.85 (0.37–1.96)	0.69
IAS distal								
12	1.04 (0.69–1.55)	0.87	1.18 (0.69–2.01)	0.55	1.69 (0.80–3.57)	0.17	0.60 (0.25–1.41)	0.24
3	1.45 (0.91–2.31)	0.12	0.81 (0.45–1.46)	0.48	0.75 (0.30–1.93)	0.56	0.47 (0.18–1.24)	0.13
6	1.05 (0.73–1.49)	0.80	1.31 (0.72–2.40)	0.38	0.98 (0.48–2.01)	0.96	0.41 (0.15–1.09)	0.07
9	1.21 (0.79–1.85)	0.37	0.69 (0.38–1.24)	0.22	1.12 (0.49–2.60)	0.79	0.47 (0.18–1.23)	0.12
EAS								
12	1.06 (0.79–1.43)	0.70	1.00 (0.62–1.59)	0.99	1.50 (0.90–2.50)	0.12	0.71 (0.32–1.56)	0.40
3	0.98 (0.84–1.15)	0.82	1.03 (0.83–1.28)	0.78	1.19 (0.88–1.61)	0.26	0.99 (0.73–1.35)	0.97
6	0.94 (0.83–1.06)	0.28	0.95 (0.81–1.12)	0.57	1.13 (0.90–1.41)	0.30	1.00 (0.79–1.27)	0.98
9	1.00 (0.87–1.16)	0.97	1.05 (0.84–1.32)	0.68	1.20 (0.91–1.59)	0.20	0.96 (0.69–1.34)	0.82
PVM								
Right	1.32 (1.12–1.57)	<0.01	0.91 (0.71–1.16)	0.45	1.52 (1.12–2.06)	<0.01	0.92 (0.65–1.30)	0.62
Left	1.21 (1.03–1.42)	0.02	0.94 (0.74–1.18)	0.59	1.36 (1.02–1.82)	0.04	1.06 (0.76–1.46)	0.75

[a] Recognized sphincter injury (RSI) is defined as a history of a third- or fourth-degree perineal laceration at the time of the patient's delivery or a sphincter interruption at any location on postpartum US imaging

mechanism in the pelvic floor. This relationship was not significant for women having a CD, indicating that women experiencing VB may have some sort of pelvic floor trauma that both thickens the levator and compromises continence. The mechanism for this may be levator avulsion, which has been found in past studies to be associated with more traumatic vaginal births [20] and is associated with an increased risk of pelvic organ prolapse and pelvic descent [21, 22]. The thicker PVM measured here may also be an indicator of compensatory hypertrophy as the result of an injury to continence mechanisms elsewhere in the pelvic floor that were not measured by this study. PVM anatomy changes may serve as marker for AI risk and risk of pelvic support defects [23]. This study was not designed to investigate the entirety levator anatomy or study levator avulsion, but these results indicate the import of considering levator anatomy in studies that investigate FI and AI symptoms.

Table 4 The relationship of ASC measurements to AI and FI symptoms, separated by mode of delivery, including women with an RSI[a]

	AI				FI			
	VB		CD		VB		CD	
Measurement	OR AI (95 % CI)	*P* value	OR AI (95 % CI)	*P* value	OR FI (95 % CI)	*P* value	OR FI (95 % CI)	*P* value
IAS prox								
12	1.08 (0.80–1.48)	0.59	1.00 (0.67–1.51)	0.99	1.26 (0.74–2.16)	0.39	1.22 (0.68–2.21)	0.51
3	0.82 (0.56–1.20)	0.31	0.74 (0.44–1.24)	0.25	0.97 (0.49–1.94)	0.94	0.69 (0.32–0.49)	0.35
6	0.75 (0.54–1.06)	0.10	0.71 (0.45–1.12)	0.14	1.28 (0.73–2.45)	0.39	0.53 (0.24–1.19)	0.12
9	0.79 (0.54–1.14)	0.21	0.56 (0.33–0.94)	0.03	0.87 (0.44–1.71)	0.69	0.82 (0.40–1.68)	0.58
IAS mid								
12	1.04 (0.75–1.43)	0.83	1.16 (0.76–1.78)	0.49	1.46 (0.83–2.57)	0.19	0.96 (0.52–1.78)	0.90
3	1.19 (0.81–1.75)	0.37	0.81 (0.48–1.37)	0.42	1.34 (0.69–2.58)	0.39	0.67 (0.30–1.52)	0.34
6	0.91 (0.64–1.28)	0.58	0.91 (0.56–1.47)	0.70	1.50 (0.90–2.49)	0.12	1.29 (0.71–2.34)	0.41
9	1.28 (0.87–1.88)	0.22	0.85 (0.50–1.45)	0.55	1.36 (0.69–2.71)	0.37	0.71 (0.32–1.59)	0.41
IAS dist								
12	1.03 (0.71–1.50)	0.87	1.23 (0.73–2.06)	0.44	1.63 (0.83–3.23)	0.16	0.58 (0.25–1.36)	0.21
3	1.26 (0.85–1.86)	0.26	0.72 (0.41–1.25)	0.24	0.71 (0.34–0.48)	0.36	0.43 (0.17–1.11)	0.08
6	1.00 (0.74–1.36)	0.98	1.09 (0.62–1.93)	0.76	1.30 (0.80–2.11)	0.29	0.37 (0.14–0.96)	0.04
9	1.06 (0.73–1.55)	0.76	0.63 (0.35–1.11)	0.11	1.01 (0.51–1.99)	0.97	0.41 (0.16–1.07)	0.07
EAS								
12	1.12 (0.86–1.47)	0.40	0.95 (0.60–1.51)	0.82	1.29 (0.82–2.03)	0.27	0.71 (0.33–1.54)	0.39
3	0.97 (0.85–1.12)	0.70	1.02 (0.83–1.26)	0.82	1.08 (0.85–1.38)	0.55	0.96 (0.71–1.30)	0.79
6	0.94 (0.85–1.05)	0.31	0.95 (0.81–1.11)	0.50	1.05 (0.87–1.27)	0.61	0.97 (0.77–1.22)	0.79
9	0.99 (0.87–1.13)	0.85	1.03 (0.82–1.28)	0.83	1.05 (0.83–1.32)	0.70	0.92 (0.66–1.27)	0.59
PVM								
Right	1.19 (1.03–1.39)	0.02	0.92 (0.72–1.16)	0.46	1.36 (1.06–1.76)	0.02	0.98 (0.70–1.37)	0.89
Left	1.11 (0.96–1.28)	0.17	0.92 (0.74–1.14)	0.44	1.20 (0.93–1.53)	0.16	1.08 (0.79–1.48)	0.63

[a] Recognized sphincter injury (RSI) is defined as a history of a third- or fourth-degree perineal laceration at the time of the patient's delivery or a sphincter interruption at any location on postpartum US imaging

This study has several limitations. First, there was no antepartum US imaging performed in this cohort, so direct comparisons to women's anatomy prior to delivery cannot be made. However, if women who had a VB had preexisting anatomical compromise, that would only lessen the suspicion for a relationship between anatomical measurements and symptoms. Since few measurements were significantly related to symptoms in VB women even without preexisting anatomy taken into account, it increases the confidence that ASC thickness postpartum is usually unrelated to AI or FI after a vaginal delivery and furthers the hypothesis that sphincter bulk does not infer sphincter function.

Second, this study was conducted at one institution in a low-risk, mostly midwifery care population with a low rate of operative delivery and episiotomy. The sphincter interruption rate in this population was only 9 % at 6 months on US imaging, much lower than past studies that have reported [24, 25], and reflects that this population may have experienced less sphincter trauma. Past studies have indicated a higher rate of occult sphincter injury after a vaginal birth. These studies were conducted in populations where the rate of forceps use was >10 % and conducted during a time period when episiotomy was more commonly performed [23, 24]. This may limit the populations to which these data can be applied. As the authors wished data to be available both for a population without RSI and for a general population of women, ORs were generated separately for populations both including and excluding RSI rather than reporting corrected ORs. This would allow these data to be applied either to a patient with an unknown obstetrical laceration history or who is certain that she did not sustain an RSI.

The strengths of the study include the large number of patients and the applicability to more modern obstetrical practice as noted above. This study also followed a detailed protocol for TL-US that allowed for imaging of the sphincter anatomy in great detail. We were able to elicit the relationships between function and anatomy by level of the sphincter complex (proximal, mid, or distal) and by specific quadrant of the anal sphincter at that level (left, right, anterior, and posterior). A further strength of the study lies in the ability to distinctly analyze the VB and CD cohorts, particularly as the vast majority of the CD cohort did not enter the second stage of labor. This allowed these data to reflect how anatomy may affect function in cases without classic obstetrical injury (as in the CD cohort) and when only occult or subtle injury may have taken place (as in the VB cohort without sphincter interruption). The varying role of anatomy based on delivery mode and the presence of sphincter disruption could not be fully appreciated without this type of analysis.

In conclusion, we found that the majority of ASC measurements do not correlate to symptoms of AI or FI in postpartum women, but a thicker IAS laterally and posterior is protective against AI in primiparous women who have had a CD. In women who had a VB and in the entire cohort, thicker PVM measurements indicated an increased risk of AI and FI, while other ASC measurements did not correlate to symptoms. These data suggest that incontinence mechanisms are likely very different based on mode of delivery and the presence or absence of sphincter interruption.

Conflicts of interest K.V. Meriwether, R.J. Hall, L.M. Leeman, L. Migliaccio, and C. Qualls have no conflicts of interest to disclose. R.G. Rogers is Chair DSMB for the Transform trial sponsored by American Medical Systems.

Authors' contributions K.V. Meriwether: data analysis, manuscript writing; R.J. Hall: study development, data collection/management, manuscript editing; L.M. Leeman: protocol/project development, data collection/management, manuscript editing; L. Migliaccio: protocol/project development, manuscript editing; C. Qualls: data analysis, manuscript editing; R.G. Rogers: protocol/project development, data collection/management, manuscript editing.

References

1. Boreham M, Richter H, Kenton K, Nager C, Gregory WT, Aronson MP, Vogt V, Mcintire D, Schaffer J (2005) Anal incontinence in women presenting for gynecologic care: prevalence, risk factors and impact upon quality of life. Am J Obstet Gynecol 192(5): 1637–1642
2. Cichowski SB, Komesu YM, Dunivan GC, Qualls C, Rogers RG (2014) Written versus oral disclosure of fecal and urinary incontinence in women with dual incontinence. Int Urogynecol J 25(9): 1257–1262
3. Farrell SA, Flowerdew G, Gilmour D, Turnbull GK, Schmidt MH, Baskett TF, Fanning CA (2012) Overlapping compared with end-to-end repair of complete third-degree or fourth-degree obstetric tears: three-year follow-up of a randomized controlled trial. Obstet Gynecol 120(4):803–808
4. Roos AM, Thakar R, Sultan AH (2010) Outcome of primary repair of obstetric anal sphincter injuries (OASIS): does the grade of tear matter? Ultrasound Obstet Gynecol 36(3):368–374
5. Mahony R, Behan M, Daly L et al (2007) Internal anal sphincter defect influences continence outcome following obstetric anal sphincter injury. Am J Obstet Gynecol 196(3):217.e1–217.e5
6. Norderval S, Marskog A, Røssaak K, Vonen B (2008) Correlation between anal sphincter defects and anal incontinence following obstetric sphincter tears: assessment using scoring systems for sonographic classification of defects. Ultrasound Obstet Gynecol 31(1):78–84
7. Weinstein MM, Pretorius DH, Jung SA et al (2009) Transperineal three-dimensional ultrasound imaging for detection of anatomic defects in the anal sphincter complex muscles. Clin Gastroenterol Hepatol 7(2):205–211
8. Oude Lohuis EJ, Everhardt E (2014) Outcome of obstetric anal sphincter injuries in terms of persisting endoanal ultrasonographic defects and defecatory symptoms. Int J Gynaecol Obstet 126(1): 70–73
9. Hall RJ, Rogers RG, Saiz L, Qualls C (2007) Translabial ultrasound assessment of the anal sphincter complex: normal measurements of the internal and external anal sphincters at the proximal, mid-, and distal levels. Int Urogynecol J Pelvic Floor Dysfunct 18(8):881–888
10. Meriwether KV, Hall RJ, Leeman LM, Migliaccio L, Qualls C, Rogers RG (2014) Postpartum translabial 2D and 3D ultrasound measurements of the anal sphincter complex in primiparous women delivering by vaginal birth versus Cesarean delivery. Int Urogynecol J 25(3):329–336
11. Handa VL, Nygaard I, Kenton K et al (2009) Pelvic organ support among primiparous women in the first year after childbirth. Int Urogynecol J Pelvic Floor Dysfunct 20(12):1407–1411
12. How P, Evans J, Moran B et al (2012) Preoperative MRI sphincter morphology and anal manometry: can they be markers of functional outcome following anterior resection for rectal cancer? Colorectal Dis 14(6):e339–e345
13. West RL, Felt-Bersma RJ, Hansen BE et al (2005) Volume measurements of the anal sphincter complex in healthy controls and fecal-incontinent patients with a three-dimensional reconstruction of endoanal ultrasonography images. Dis Colon Rectum 48(3):540–548
14. Rogers R, Leeman L, Borders N, Qualls C, Fullilove A, Teaf D, Hall R, Bedrick E, Albers L (2014) Contribution of the second stage of labour to pelvic floor dysfunction: a prospective cohort comparison of nulliparous women. BJOG 121(9):1145–1153
15. Meriwether KV, Hall RJ, Leeman LM, Migliaccio L, Qualls C, Rogers RG (2014) Anal sphincter complex: 2D and 3D endoanal and translabial ultrasound measurement variation in normal postpartum measurements. Int Urogynecol J
16. Delancey JO, Toglia MR, Perucchini D (1997) Internal and external anal sphincter anatomy as it relates to midline obstetric lacerations. Obstet Gynecol 90(6):924–927

17. Valsky DV, Yagel S (2007) Three-dimensional transperineal ultrasonography of the pelvic floor: improving visualization for new clinical applications and better functional assessment. J Ultrasound Med 26(10):1373–1387
18. Lee JH, Pretorius DH, Weinstein M, Guaderrama NM, Nager CW, Mittal RK (2007) Transperineal three-dimensional ultrasound in evaluating anal sphincter muscles. Ultrasound Obstet Gynecol 30(2):201–209
19. Jorge J, Wexner S (1993) Etiology and management of fecal incontinence. Dis Colon Rectum 36:77–97
20. Shek KL, Dietz HP (2010) Intrapartum risk factors for levator trauma. BJOG 117(12):1485–1492
21. DeLancey JO, Morgan DM, Fenner DE, Kearney R, Guire K, Miller JM, Hussain H, Umek W, Hsu Y, Ashton-Miller JA (2007) Comparison of levator ani muscle defects and function in women with and without pelvic organ prolapse. Obstet Gynecol 109(2 Pt 1):295–302
22. Dietz HP, Simpson JM (2008) Levator trauma is associated with pelvic organ prolapse. BJOG 115(8):979–984
23. Lammers K, Fütterer JJ, Prokop M, Vierhout ME, Kluivers KB (2012) Diagnosing pubovisceral avulsions: as systematic review of the clinical relevance of a prevalent anatomic defect. Int Urogynecol J 23(12):1653–1664
24. Sultan AH, Kamm MA, Hudson CN et al (1993) Anal-sphincter disruption during vaginal delivery. N Engl J Med 329(26):1905–1911
25. Faridi A, Willis S, Schelzig P, Siggelkow W, Schumpelick V, Rath W (2002) Anal sphincter injury during vaginal delivery–an argument for cesarean section on request? J Perinat Med 30(5):379–387