Do Ultrasound Findings of Levator Ani "Avulsion" Correlate With Anatomical Findings: A Multicenter Cadaveric Study

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Aims: This study aimed to validate the levator "avulsion" injury as seen on ultrasound against anatomical dissection in the same cadaver. **Methods:** Puboviseral muscle (PVM) anatomy of female cadavers was studied using 3D-translabial ultrasonography and an "avulsion" confirmed per standard recommendations [Dietz HP. Aust N Z J Obstet Gynaecol 53:220–230, 2013]. Cadavers were then dissected to determine the macroscopic attachment or detachment of the PVM and the dimensions including the PVM symphysis gap and PVM attachment depth. Intra and inter-observer reliability of USS findings and anatomical measurements were assessed using the Cohen's κ and Bland & Altman plots respectively. McNemar's and Mann–Whitney *U* tests were used to compare imaging and cadaveric dissection findings. **Results:** "Avulsions" were seen on imaging in 11/30 (36.7%) cadavers; the defect was bilateral in 1/30 (3.3%) and unilateral in 10/30 (33.3%). No "avulsion" was found at dissection (McNemar's $\chi^2 = 60.0$, $P < 0.001$). An additional thirty-nine cadavers were dissected with no "avulsion" identified. A narrower PVM insertion depth was strongly associated with "avulsion" on ultrasound (mean: 4.79 mm vs. 6.32 mm, $Z = -3.191$, $P = 0.001$). Intra- and inter-observer agreement was perfect ($K = 1.0 \pm 0.0$) and good ($K = 0.85 \pm 0.142$) for anatomical "avulsions" and USS, respectively. **Conclusions:** There is a clear difference between anatomical and USS findings. The imaged appearance of an "avulsion" does not represent a true anatomical "avulsion" as confirmed on dissection. The term "avulsion" is misrepresentative and should not be used to describe this imaging finding. Moreover, further attempts at surgically repairing this defect should be avoided, at least until there is a better understanding of its pathophysiology. *Neurourol. Urodynam.* © 2015 Wiley Periodicals, Inc.

Key words: avulsion; cadaver; pelvic floor muscle; prolapse; puborectalis; puboviseral muscle; three-dimensional ultrasound

INTRODUCTION

In an era where medical diagnosis is becoming increasingly reliant on imaging, the presumed authenticity of the images obtained using ultrasonography (USS), computed tomography (CT), magnetic resonance imaging (MRI), and other imaging modalities, can heavily influence clinical practice. The only true place to visualize the 3D structure of the human body, thus validate imaging findings, are on cadaveric or live tissue dissections. Unfortunately, very few imaging modalities have been the subject of basic anatomical studies to assess the validity and reliability of the images obtained. This begs the question; does the assumed reliability of radiology and the omission of anatomical validation studies adversely affect clinical practice and research?

A region of hypoechogenicity adjacent to the pelvic sidewall, as detected using 3D-translabial USS and other imaging modalities, has been denoted as an "avulsion" by some authors.[2] The term, "avulsion", has been used as imaging appears to show the literal detachment of the pubovisceral (puborectalis/pubococcygeus) muscle (PVM) from its insertion following childbirth.[1] This ultrasound finding has been associated with pelvic organ prolapse (POP)[3] and poor outcome/failure following POP surgery.[4] Other studies have found the risk of urinary incontinence decreased, a highly counterintuitive finding.[5] The prevalence of "avulsion" varies significantly, ranging from 6% to 50%, depending on the imaging technique used.[6–8]

Since 2005, over 90 papers from 16 countries have been published relating to this imaging finding; however, the imaging appearance of the levator ani "avulsion" has never been validated against anatomical dissection findings, which would be gold standard. Therefore, the existence of a levator ani "avulsions", as seen during imaging is still unproven. This study aims to compare anatomical dissection and USS findings in the same cadaver to determine the structure associated with the imaging finding of a levator ani "avulsion" injury.

MATERIALS AND METHODS

Female cadaveric material was ethically obtained and utilized according to the Human Tissue Act of 2004. Twenty-five cadavers had been fixed using a modified solution of 7% phenol, 7% formalin, 25% isopropyl alcohol, and 61% water. Further, six bodies were "soft fixed" with Thiel. The study was then divided into two phases. The purpose of the first phase was

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to quantify the number of ultrasonographic-identified levator ani "avulsion" injuries. The second phase consisted of the anatomical dissection of the cadavers to visualize and quantify the number of anatomical "avulsion" injuries. Throughout the study, strict protocols were followed to ensure assessor agreement. Skilled specialist anatomist performed all cadaveric dissections.

The pelvic floor was imaged using a Voluson I portable ultrasound machine (GE Healthcare, UK), with a RAB 4–8 MHz transducer. Due to the stiffness of the cadaveric tissue and the size and shape of the probe good contact between the tissue and the transducer did not occur, as such, the RIC 5–9 MHz transvaginal probe was employed due to its smaller head and superior contact with the cadaveric tissue; the probe was not advanced into the vagina. If the image quality was found to be poor then gel was injected into the vagina to ensure that there was an excellent acoustic window to allow good imaging of the pelvic structures. Images were obtained according to standard methodology.[9] If the image quality was poor then the USS was repeated until the experienced sonographers were happy with the image quality in all planes. Particular care was taken to assess the constructed image in the axial plane to ensure no artefacts were present due to poor contact or technique.

Tomographic ultrasound images (TUI) were then constructed. Slices were taken at 2.5 mm intervals, from 12.5 mm above to 5 mm below the plane of minimal hiatal dimensions. A total of eight slices were taken per subject. The two lowermost TUI slices were excluded from analysis as studies have found the appearance of an "avulsion" in those slices to often be false positives.[10] An "avulsion" injury was confirmed if discontinuity was identified between the PVM and the pelvic sidewall in at least two slices. Volume datasets were analyzed on two occasions. Only complete "avulsions" were considered to ensure a definitive finding was being assessed. Slices were scored as normal or abnormal, separately for the left and right insertion sites.

In the second phase, the imaged cadavers were meticulously dissected to reveal the PVM attachment sites on the pubic bone. Access was obtained via the retropubic space. An "avulsion" was determined as present if there was visual detachment or discontinuity between the PVM muscle and the pelvic sidewall. The PVM-symphysis gap was measured on both sides as the distance from the closest point of the symphysis pubis to the most medial border of the PVM insertion. The high precision dial calliper was used to take measurements. Fifteen cadavers were then hemi dissected to give a longitudinal section of the female pelvis. Measures of the PVM attachment depth (cranial-caudal diameter), the urogenital hiatus width (transverse diameter), and length (anterior-posterior diameter) were obtained. Figure 1 is the diagrammatic representation of the measurements obtained. An additional thirty-nine cadavers, making a total of seventy cadavers, from three countries were dissected for the presence or absence of an anatomical "avulsion" injury.

To ensure assessor agreement and validity of the study, assessments were conducted twice in at least 10 cadavers by two separate investigators whom were blinded to each other's assessment and ultrasound findings. Measurements of agreement were then calculated using Bland and Altman plots and Cohan's κ for gross anatomical measurements and presence/absence of "avulsion," respectively. The non-parametric McNemar's test was used to compare the proportion of levator ani "avulsion" injuries between translabial 3D-USS and cadaveric dissection. The differences between the measured anatomical sites were assessed against the presence of an "avulsion" using the Mann–Whitney *U*-test. Each pubovisceral insertion site was studied as individual variables.

RESULTS

Correlation Between Ultrasonographic and Anatomical Levator "Avulsion" Injuries

A 3D-translabial USS was performed on thirty-one female cadavers (mean age at time of death 85.8; range 72–103 years). One donor was withdrawn from analysis due to incomplete datasets leaving thirty subjects. Levator ani muscle "avulsion" injury was detected in 11/30 (36.7%) cadavers; the defect was bilateral in 1/30 (3.3%) and unilateral in 10/30 (30.0%). "Avulsion" had a left-sided preponderance with left-sided defects seen in 8/10 (80.0%) of the unilateral cases (Table I). Detachment of the levator ani from the pelvic sidewall was not identified in any of the cadaveric dissections with a 0% incidence on both left and right sides. The likelihood of an "avulsion," as seen on ultrasound, to represent detachment of the PVM from the pelvic sidewall is improbable (McNemar's $\chi^2 = 60.0$, $P < 0.001$). There was no anatomical "avulsion" seen in the additional thirty-nine cadavers dissected internationally. In total, 0/70 cadavers had anatomical levator "avulsion" injury.

Levator Ani Muscle Measurements

The mean values, standard deviation and ranges of the PVM-symphysis gap, PVM-insertion depth, and the urogenital hiatus width and length are shown in Table II. A narrower PVM insertion depth (mean 4.79 mm vs. 6.32 mm) is strongly associated with an "avulsion" on ultrasound $Z = -3.191$, $P = 0.001$. The variations between urogenital hiatus measurement and imaged "avulsion" are not proven to be significant. Table III summarizes these results.

Intraobserver and Interobserver Measurement Reproducibility

The Cohen's κ and standard error for intra- and inter-observer agreement between ultrasound was 1.0 ± 0.0 and 0.85 ± 0.142, respectively, representing perfect and good agreement. Agreement on anatomical findings was perfect for both intra- and interobserver ($K = 1.0$). Intra- and inter-observer agreement using the Bland and Altman Plots for the assessment of PVM symphysis gap, PVM attachment depth, and urogenital hiatus measurements displayed good agreement with 95% of readings being within ± 2 standard deviations from the paired difference of the mean.

DISCUSSION

This is the first study to validate the appearance of the pubovisceral "avulsion" as identified on translabial ultrasound with the anatomical dissection findings on the same cadaver. The prevalence of USS "avulsions" in our cohort was 36.7%, with unilateral abnormalities seen in 30.0% and bilateral defects in 3.3% of cases. The prevalence of "avulsions" as identified on USS in this study is comparable with those seen in living subjects, although a relatively smaller proportion of bilateral defects were identified.[8,11–13] The absence of parity history limits the interpretation of these results, but considering the average age of donors was 85.8 years, it is likely that the majority of the cohort was parous; according to the UK parliament population aging statistics women born in the mid 1930s had an average of 2.45 children.[14]

The most significant finding of this study was the observation that an "avulsion" as seen on 3D ultrasound does not seem to be a literal detachment of the PVM from its insertion. In fact,

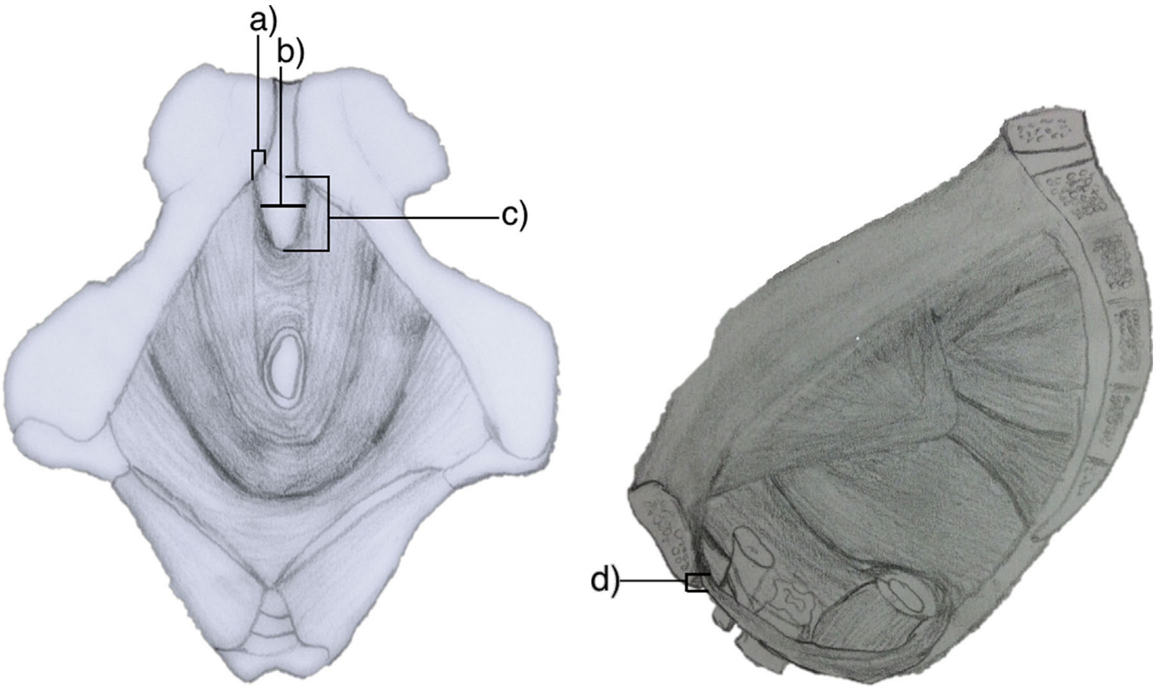

Fig. 1. Diagrammatic demonstration of the measurements obtained. a) Distance from the insertion of the pubovisceralis muscle (PVM) and the symphysis pubis (PVM-symphysis gap). b) Urogenital hiatus width. c) Urogenital hiatus length.

all seventy cadavers had intact PVM enthesis. Notably, it was observed that the PVM insertion depth was significantly narrower on the "avulsion" side. This observation may help to explain the disparity with regards to the clinical consequences of this apparent lesion and why it appears as a detachment on imaging.

The apparent observation of an "avulsion" is most likely an imaging artefact due to the inability of the ultrasound machine to resolve the smaller insertion sites or a slice thickness artefact. A CT scan study that imaged the pelvic floor using 1 mm slices without a gap found the prevalence of an "avulsion" to be 6.4%.[7] Previous MRI imaging on young nulliparous women found the thickness of the PVM to average 4.9 mm (SD 2.3).[15] This study found narrowing of the PVM in the suspected "avulsion" cases thus it is probable that the standard imaging recommendations of 2.5 mm slices, including the omissions of the lowest two slices, is likely to miss the smaller insertion sites. It is possible that the combination of slice thickness and axial resolution artefacts in conjunction with speed-of-sound errors explain why the smaller insertion sites are not being resolved and appear as a detachment.[16] That said the sample size used for the anatomical measurements was small which lessons the significance of this finding. Additional studies are required to validate this point.

It is recognized that depending on the tissue composition, ultrasound waves are reflected differently. It has previously been noted that the proportion of connective tissue gradually increases and the number of muscle fibers gradually decreases as they veer towards the bone, with an equilibrium reached at around 8 mm from the insertion site.[17] It is known that the acoustic impendence of muscle and connective tissue vary substantially to appear hypoechoic and hyperechoic, respectively.[18–20] If the proportion of muscle fibers were greater in these smaller insertion sites, then they would be more difficult to differentiate from the retro-pubic space and may be interpreted as a gap.[21] This is another possible explanation for this imaging artefact and would hold weight with the concept that muscle has half the strength of connective tissue and is less resilient to stretch-related injuries thus more susceptible to prolapse.[3,22] A study by Singh et al., found the iliococcygeus insertion angle increased from the mean 14.6° to 23° from stage 0 to stage I, POP-Q defined prolapse.[23] This observation in conjunction with the knowledge that striated muscle appears hypoechoic when the ultrasound waves pass along the long axis of the muscle could provide a further explanation for this imaging artefact. Additional research needs to be undertaken to demonstrate these findings, but if they were to be proven, it would explain why this hypoechoic region on imaging is strongly associated with anterior compartment prolapse and may in fact represent the early decent of the anterior compartment.

The strict methodology of this study was a key strength. Cadavers have previously proven to be an effective medium for validating imaging studies as the morphological findings are generally transferable to the living subject.[24–28] The method used to image the pelvic floor followed the most common practice, with previous studies yielding a moderate to fair inter-observer reproducibility agreement.[30] The clearly defined measurement parameters and use of the highly accurate and precise dial calliper, along with the assessment of reproducibility using the Bland and Altman statistical methods, further strengthened the validity of the measurements.[31] Moreover, assessment bias was minimized as assessors were blinded to the outcome of the ultrasound and anatomical measurement findings.

We acknowledge several limitations in this research. Most tests were carried out on a subset of the cohort. The smaller samples and the use of non-parametric statistical tests, may predispose to type I or II errors, where a finding that is thought to be significant is indeed not, or where a significant finding is not identified due to insufficient power, this limitation relates to the anatomical measurements acquired. The generally very

TABLE I. Location and Site of Levator "Avulsion" Injury According to Method of Analysis

Cadaver no.	"Avulsuion" identified on USS (LEFT)	"Avulsion" identified on dissection (LEFT)	"Avulsuion" identified on USS (RIGHT)	"Avulsion" identified on dissection (RIGHT)
1	Y	N	N	N
2	N	N	N	N
3	N	N	N	N
4	N	N	N	N
5	N	N	N	N
6	Y	N	N	N
7	Y	N	N	N
8	N	N	N	N
9	N	N	N	N
10	Y	N	Y	N
11	Y	N	N	N
12	N	N	N	N
13	N	N	N	N
14	N	N	N	N
15	N	N	N	N
16	-	N	N	N
17	N	N	N	N
18	Y	N	N	N
19	N	N	N	N
20	N	N	Y	N
21	Y	N	N	N
22	N	N	N	N
23	N	N	Y	N
24	N	N	N	N
25	N	N	N	N
26	N	N	N	N
27	N	N	N	N
28	Y	N	N	N
29	N	N	N	N
30	Y	N	N	N
31	N	N	N	N
No. avulsions	9	0	3	0
% avulsions	30.0	0	10.0	0

Y, "avulsion" present, N, "avulsion" absent, LEFT, left pubovisceral insertion site, RIGHT, right pubovisceral insertion site.

TABLE II. Pubovisceral and the Urogenital Hiatus Measurements Mean, Range, and Std. Deviation

	PVM symphysis gap	PVM attachment width	Urogenital hiatus width	Urogenital hiatus length
Mean	15.95	5.98	33.41	63.01
Median	16.00	6.35	32.90	65.00
Std. Deviation	2.71	1.01	3.64	4.58
Minimum	9.20	4.40	30.00	55.00
Maximum	23.40	7.50	44.60	71.50

TABLE III. Mean Measures According to Presence or Absence of Levator "Avulsion" Injury on Ultrasound (Mann–Whitney U-Test, $P < 0.05$)

	Mean			
	Avulsion present	Avulsion absent	Z-score	*P*-value
PVM symphysis gap (mm)	15.08	16.16	−1.683	.141
PVM attachment depth (mm)	4.79	6.32	−3.191	.001
Urogenital hiatus width	34.20	33.15	−0.266	.796
Urogenital hiatus length	63.07	63.00	−0.435	.678

elderly cohort, in addition to the lack of parity and previous pelvic surgical history limited the extrapolation of these results to younger women. Moreover, due to the difficulty of obtaining a young nulliparous cadaver, this study lacked a control. All studies using fixed cadavers are at risk of altered tissue dimensions due to the fixation method,[29] thus there is a potential that this may have affected the accuracy and validity of the measurements. However, as the principle aim of the study was to compare differences within the same fixed tissue the true impact is considered to be minor. It is known that poor hydration of tissue can affect image quality and due to the nature of our subjects the ability to accurately interpret an image may have been affected. That said, the display of perfect and good agreement between intra- and inter-observer analyses validates the findings.

CONCLUSIONS

The findings from this study have questioned the definition of the "avulsion" injury and enhanced our understanding into the pathological significance of this ultrasound defect. At present great consideration needs to be taken when assessing this imaging finding. Firstly, the term "avulsion" should not be used to refer to this imaging appearance; the generic term of "levator ani defect or damage" should be adopted. Secondly, further attempts at surgically repairing this defect should be avoided at least until there is a better understanding of this lesion. In addition, alternative methodology for imaging should be considered to include the adoption of higher frequency transducers and 1 mm slice thickness without a slice gap. Nevertheless, although it is clear that an "avulsion" does not literally represent the detachment of the PVM insertion, the abundance of evidence that supports the link of this ultrasound finding as a complication of labor and an independent risk factor for anterior compartment prolapse cannot be ignored. Thus, it is essential that further research is conducted to determine the true pathophysiology of the imaging defect.

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