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Research Article
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Injury-associated levator ani muscle and anal sphincter ooedema following vaginal birth: a secondary analysis of the EMRLD study

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Objective To determine whether all three components of the levator ani muscle (pubovisceral [= pubococcygeal], puborectal and iliococcygeal) and the external anal sphincter are equally affected by oedema associated with muscle injury after vaginal birth.

Design Observational cross-sectional study.

Setting Michigan Medicine, University of Michigan.

Population Primiparous women classified as high risk for levator ani muscle injury during childbirth.

Method MRI scans obtained 6–8 weeks postpartum were analysed. Muscle oedema was assessed on axial and coronal fluid-sensitive magnetic resonance (MRI) scans. Presence of oedema was separately determined in each levator ani muscle component and in the external anal sphincter for all subjects. Descriptive statistics and correlation with obstetric variables were obtained.

Main outcome measures Oedema score on fluid-sensitive MRI scans.

Results Of the 78 women included in this cohort, 51.3% (n = 40/78) showed muscle oedema in the pubovisceral (one bilateral avulsion excluded), 5.1% (n = 4/78) in the puborectal and 5.1% (n = 4/78) in the iliococcygeal muscle. No subject showed definite oedema on external anal sphincter. Incidence of oedema on the pubovisceral muscle was seven times higher than on any of the other analysed muscles (all paired comparisons, $P < 0.001$).

Conclusions Even in the absence of muscle tearing, the pubovisceral muscle shows by far the highest incidence of injury, establishing that levator components are not equally affected by childbirth. External anal sphincter did not show oedema—even in women with sphincter laceration— suggesting a different injury mechanism. Developing a databased map of injured areas helps understand injury mechanisms that can guide us in honing research on treatment and prevention.

Keywords Levator ani, magnetic resonance imaging, musculoskeletal injuries, pelvic floor, vaginal birth.

Tweetable abstract Injury-associated levator ani muscle and anal sphincter oedema mapping on MRI reveals vulnerable muscle components after childbirth.

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Introduction

Women with childbirth-related pelvic floor trauma are present in the everyday practice of obstetricians and midwives. It is, therefore, incumbent on us to know the scientific foundation of these injuries; what type of injury has occurred, how it happened, how different types of injury are best treated, and how they could be prevented. Although progress is being made in this science, our knowledge of injury mechanisms remains incomplete.

Levator ani muscle tearing or avulsion from its pubic origin occurs in 10–15% of women[1,2] so a unit that does 10 births daily will have, on average, one injured woman each day. Definitive studies have shown that this gross muscle disruption (a 'defect' seen on imaging) results in prolapse in 25% of women followed longitudinally.[3] However, gross disruption, the focus of most research so far, is only one form of muscle injury.[4] Injury within the muscle, known in lay terms as 'pulled muscle', can occur in the absence of a torn muscle, yet anyone who has pulled a muscle knows how painful and disabling this can be, and how long it takes to recover fully.

In previous work, we documented levator oedema following childbirth.[5] We subsequently realised it did not equally involve all three components of the muscle (pubovisceral,[1] puborectal and iliococcygeal[6]) (Figure 1). As biomechanical modelling studies predict that different parts of the muscle experience different degrees of stretch,[7] the oedema pattern may give us insight into injury mechanisms and yield a databased map of vulnerable muscles. This could help build a more complete foundation on which to base injury treatment or prevention.

Based on anatomical and functional differences between each levator component and the external anal sphincter,[8] it is plausible to think that injury to one muscle may have a different mechanical effect than injury to another. Therefore, we sought to test the null hypothesis that all three components of levator ani muscle and external anal sphincter are equally affected by oedema related to vaginal childbirth. In addition, we sought to establish the consequences on hiatal dimensions at 6–8 months after healing was complete.

Methods

This report is a secondary analysis of data from the *Evaluating Maternal Recovery from Labor and Delivery* (EMRLD) project,[9] an institutional review board-approved longitudinal study conducted at the University of Michigan (IRB HUM00051193). EMRLD was designed to study patterns of childbirth-related muscle injury, short- and longer-term, as

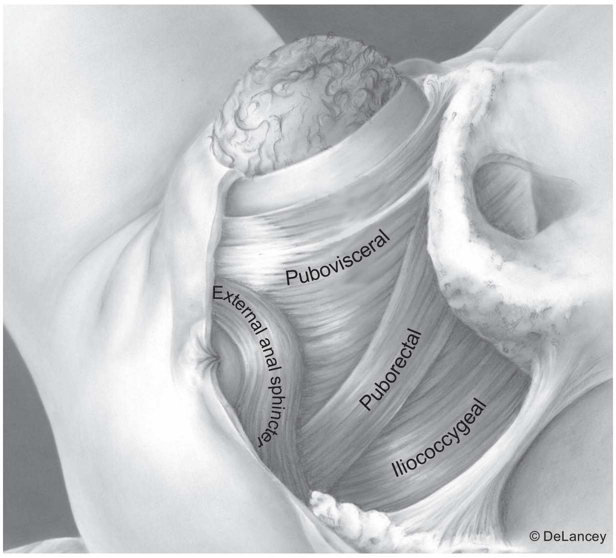

Figure 1. Illustration of pelvic floor muscles at crowning where all three components of the levator ani muscle (pubovisceral, puborectal and iliococcygeal) as well as the external anal sphincter can be seen. Note different fibre directions between different muscles (© DeLancey).

evaluated by magnetic resonance imaging (MRI) at 6–8 weeks and again at 6–8 months after delivery. Pertinent demographic and obstetric data were obtained by chart review early postpartum. Ninety primiparous women were recruited for risk of levator ani injury during childbirth. Screening factors were: length of second stage of labour >150 or <30 minutes, anal sphincter laceration, forceps use, maternal age >35 years and newborn birthweight >4000 g, as established in the original study.[10]

In the present report, additional inclusion criteria were the availability of an MRI done at the early time point (6–8 weeks postpartum) using fluid-sensitive sequences. The scoring of this report differs from prior EMRLD reports in its focus on identifying variance in distribution of oedema by discrete muscle subdivisions, some of which have not been scored previously.

Details of the imaging protocol have been described previously.[11] To summarise briefly, MRI was performed using a 3 Tesla Philips Achieva scanner (Philips Medical Systems, Eindhoven, The Netherlands), with an 8-channel cardiac coil positioned over the pelvis, and included coronal, axial and sagittal proton density-weighted sequences. Additional fluid-sensitive sequences in axial and coronal planes were obtained with either proton density-weighted fat saturation or short tau inversion recovery (STIR) sequences.

High-intensity signal on fluid-sensitive scans was used as a marker for muscle injury, as it is a well-established technique for other parts of the body to assess stretch injuries that did not result in gross muscle tearing. In brief, musculotendinous strains are a type of muscle injury particularly suitable for MRI assessment with fluid-sensitive sequences because the microscopic fibre disruption present in stretch injuries leads to interstitial oedema and sometimes haemorrhage. These altered fluid states are easily identified on fluid-sensitive imaging.[12]

Assessment of each levator ani muscle component (pubovisceral, puborectal and iliococcygeal) and the external anal sphincter was performed on axial fluid-sensitive scans based on muscle subdivision identification previously established.[13] It should be noted that the custom in pelvic floor ultrasound is to use the term 'puborectal' for the injured muscle.

To assess oedema, signal was compared with the immediately adjacent obturator internus muscle—known not to be involved in childbirth-related injuries—[14] on fluid-sensitive axial scans. Anatomical landmarks were confirmed on T2 proton density-weighted sequences, and presence of muscle oedema was confirmed on the coronal plane. Each of the three levator muscle subdivisions and the external anal sphincter were individually analysed on every subject for presence or absence of oedema as a dichotomous variable (Figure 2). Whenever presence of oedema was uncertain during this review, window and level settings were adjusted until the obturator internus muscle could no longer be identified. If the signal in the levator ani muscle was still not visible, oedema was judged to be absent but if it was still possible to see some degree of signal, oedema was determined to be present. If a discrepancy between sides occurred (left-right), the side with the higher score was chosen for comparisons.

Subjects were excluded from the cohort if complete bilateral levator ani avulsion was present. Although the muscle is likely still present after detachment from the pubic symphysis, we have not been able accurately to identify where it has retracted to. Therefore, muscle oedema could not reliably be quantified in the pubovisceral component in these instances. In this report, classification of levator ani tears (as observed muscle 'defect' on MRI) was done according to the method previously validated and published by the group.[15] Briefly, tears were categorised as none (bilaterally intact muscles), minor (bilateral scores 1–3) or major (bilateral scores 4–6 or score 3 unilaterally). All scans were reviewed independently by two authors (FP and JOLD), who reviewed and discussed all instances when muscle oedema score or levator status differed, to arrive at consensus.

The difference in fibre direction between pubovisceral and puborectal muscle becomes clearer as they diverge dorsally.[8] For this reason, this was the area chosen for oedema assessment. Near the pubic symphysis, their anatomy overlaps and therefore impairs precise identification of structures.

The measurements of urogenital and levator hiatuses were made on mid-sagittal 8-month scans at rest. Rather than 6- to 8-week scans, 6- to 8-month scans were chosen to reflect hiatus status after completion of the healing process to provide a better long-term assessment of the effect of injury. The levator hiatus was defined as the shortest distance in centimetres from the inferior pubic point to the ventral surface of the levator ani on rest scans. The urogenital hiatus was defined as the shortest distance from the pubic bone to the ventral aspect of the perineal body.[16]

In our obstetrical unit, some providers delay pushing after complete cervical dilation till the head is lower in the pelvis to conserve maternal energy reserves. For this reason,

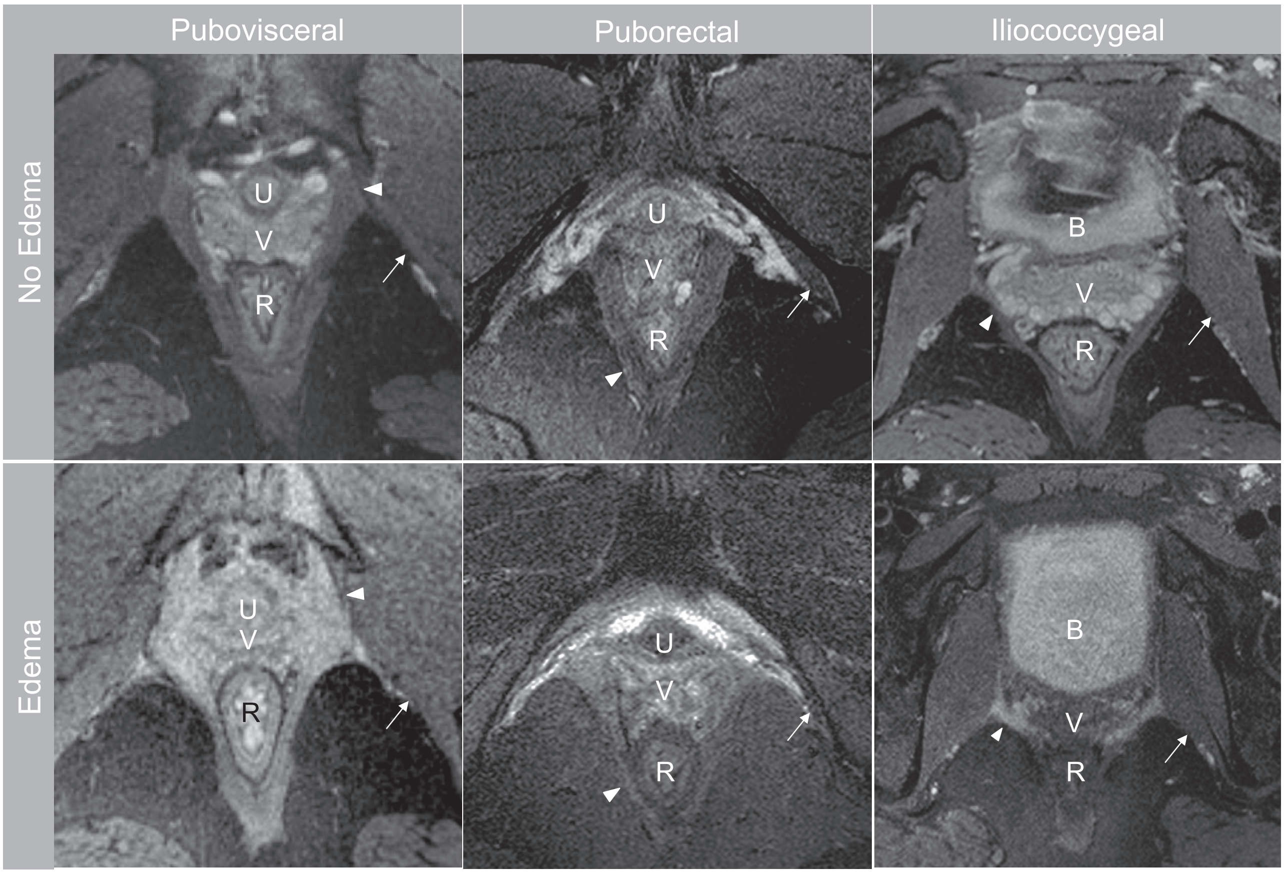

Figure 2. Fluid-sensitive MRI axial scan illustrating muscle oedema scoring. Top and bottom rows display subjects without muscle oedema and with muscle oedema, respectively. Each column, as labelled, corresponds to one levator ani component, indicated by closed arrowheads. The external anal sphincter is not illustrated here, as oedema was not demonstrated in this muscle for any woman. Obturator internus muscle (closed arrow) is the reference for signal intensity. (B) Bladder; (U) urethra; (V) vagina; (R) rectum.

length of second stage of labour is presented here as two different continuous variables: total second stage, defined as the period of time from total cervical dilation to birth; and active second stage, defined as the length of time during which women were actively pushing.

Statistical analysis

Descriptive statistics stratified by oedema status were obtained for demographic, obstetric data, levator tear status and hiatus status. Independent samples *t*-tests and Fisher's exact tests, where appropriate, were used to assess the distributions by oedema status of these characteristics. McNemar tests were used to compare oedema status for the pubovisceral, puborectal and iliococcygeal muscles. SPSS (IBM® SPSS® Statistics 26.0) and a 95% confidence level were used for all analyses.

Results

Seventy-nine postpartum primiparous women met inclusion criteria. One woman was excluded for bilateral levator muscle avulsion, leaving 78 women for analysis.

Sample characteristics are shown in Table 1. Women were of childbearing age with an average BMI of 26.4 ± 5.3 kg/m^2 per postpartum status. Six had a discrepancy between the right and left sides, and in five of these it was the right side that showed a greater degree of oedema. Among the 78 scans, there were nine in which there was a difference of opinion between authors; consensus was achieved after discussion.

For the urogenital hiatus and levator hiatus dimensions observed at 6–8 months postpartum, mean (SD) distance was 32.2 (8.1) cm and 52.4 (10.3) cm, respectively, with no difference between groups by muscle oedema status at 6–8 weeks postpartum (Table 1).

Muscle oedema in the pubovisceral muscle was found in 51.3% of women (n = 40/78), puborectal muscle in 5.1% (n = 4/78), iliococcygeal muscle in 5.1% (n = 4/78) and the external anal sphincter in none of the cases (n = 0/78). The incidence of oedema in the pubovisceral muscle was significantly higher than in any of the other analysed muscles (all paired comparisons yielded a P-value < 0.001).[2] Figure 3 details injury-score distribution per muscle. Notably, puborectal and iliococcygeal oedema was only present when there was pubovisceral oedema, never in its absence.

In women with pubovisceral oedema a clear transition between the oedematous area and other portions of the

Table 1. Demographic, obstetric and MRI characteristics of the study population

	All subjects	By oedema status		
	N = 78	Edema *n* = 40	No oedema *n* = 38	*P*-value
Demograhic data	Mean ± SD			
Age (y)	28.9 ± 5.9	29.3 ± 5.3	28.5 ± 6.5	0.60
BMI (kg/m^2)	26.4 ± 5.3	25.9 ± 5.0	27.0 ± 5.8	0.49
Obstetric data	Subjects (%)			
Forceps	2 (2.6)	2	0	
Instrumented	7 (9.0)	5	2	0.18
Total 2nd stage >150 min	38 (48.7)	25 (62.5)	13 (35)	0.01
OASI*	19 (33.3)	11 (34.4)	8 (32.0)	0.22
NB weight >4000 g	7 (9.0)	1 (3)	6 (15)	0.06
Episiotomy	15 (19.2)	10 (27)	5 (13.5)	0.10
	Mean ± SD			
Total 2nd stage length (min)	151 ± 131	171 ± 125	134 ± 137	0.20
Active 2nd stage length (min)	104 ± 88	136 ± 90	77 ± 76	0.01
Newborn weight (g)	3372 ± 506	3532 ± 509	3214 ± 470	0.00
MRI data				
Levator ani tears	Subjects (%)			
None	41 (52.6)	18 (23.1)	23 (29.5)	0.12
Minor	28 (35.9)	14 (17.9)	14 (17.9)	
Major	9 (11.5)	8 (10.3)	1 (1.3)	0.02▲
Hiatuses on 2nd scan**	Mean ± SD			
Urogenital hiatus (mm)	32.2 ± 8.1	31.3 ± 9.5	33.4 ± 5.8	0.39
Levator hiatus (mm)	52.4 ± 10.3	50.5 ± 11.9	55.2 ± 7.2	0.11

Continuous variables were analysed with unpaired *t*-test. Categorical variables were analysed with Fisher's exact test.
**n* = 57; ***n* = 55; ▲levator tears were dichotomised into 'major' and 'not major' for statistical analysis.

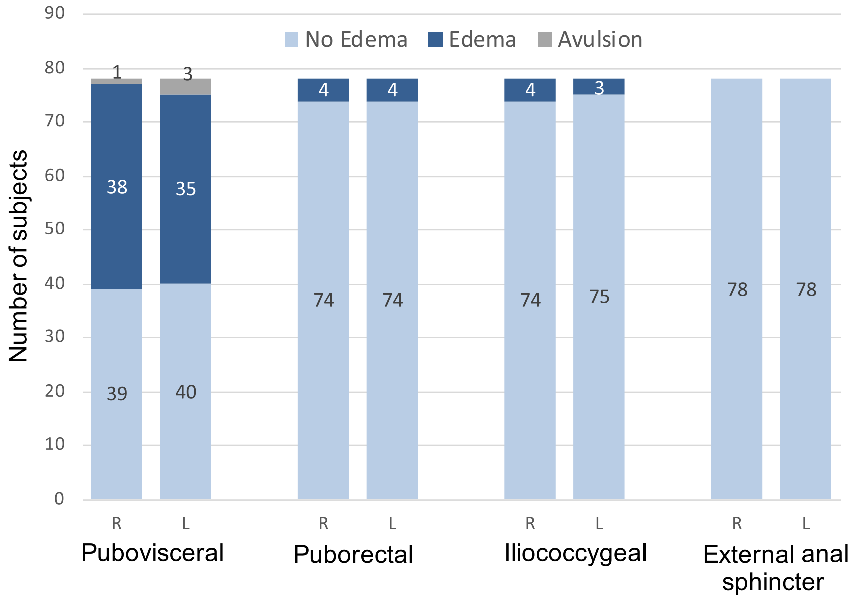

Figure 3. Edema distribution per levator ani muscle component on the right (R) and on the left (L) sides.

levator was often evident. Figure 4 shows examples of subjects in which this transition can be easily seen on fluid-sensitive sequences. It occurred at the junction between the pubovisceral and iliococcygeal muscles.

Oedema groups differed significantly in the continuous measures of newborn birthweight and active second stage of labour length (Table 1). Mean newborn weight was 9% greater in subjects with muscle oedema. Mean active second stage length was 75% longer in patients with oedema. We chose also to analyse total second stage as a dichotomised variable (> or <150 min), per the inclusion criteria cut point of 150 minutes, as one of the risk factors for levator injury considered when recruiting this cohort. When this variable was dichotomised, the oedema group showed a 27% higher incidence of total length of second stage >150 min ($P = 0.01$).

Discussion

Main findings

These data provide a map of muscle oedema in women at high risk for levator tear during vaginal birth. Oedema is seven times more common in the pubovisceral muscle than puborectal or iliococcygeal muscles and occurs in about half the cases. Muscle oedema was only found in the two latter muscles when it was also present in the pubovisceral component. This suggests an injury pattern that most often affects pubovisceral muscle but can in some cases extend to adjacent muscles. It is consistent with the stretch-induced injury premise from biomechanical modelling[7] that reveals that the pubovisceral muscle undergoes the greatest degree of elongation during birth. It also supports the hypothesis that this injury is caused by stretching rather than

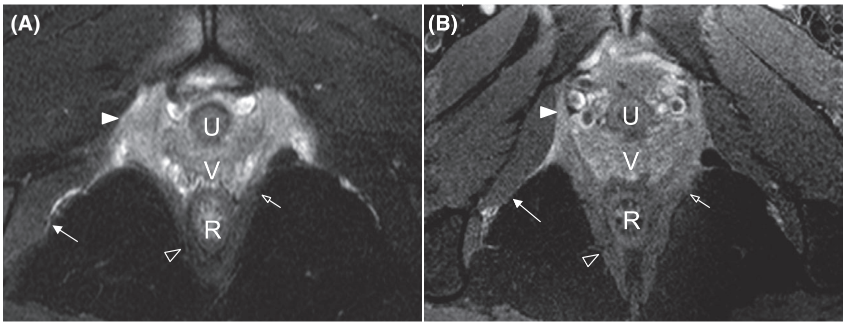

Figure 4. Fluid-sensitive axial MRI scans at the level where the pubovisceral (closed arrowhead) and the puborectal (open arrowhead) fibres diverge. (A,B) Two different women. Open arrow indicates transition between oedema in the pubococcygeal and lack of oedema in the puborectal muscles. Obturator internus muscle is indicated (closed arrow). (U) Urethra; (V) vagina; (R) rectum.

compression, as the iliococcygeal muscle, being higher in the birth canal, would be subjected to compressive forces for longer than the pubovisceral muscle. The anal sphincter, in turn, moves dorsally during birth but is not subjected to similar degrees of stretching (Figure 1). In this report, the external anal sphincter did not demonstrate clear oedema in any woman, even though many of them—selected to be at high risk for injury—had sphincter tears. We, therefore, reject the null hypothesis that all three levator ani muscle components and the external anal sphincter are equally affected by oedema, a marker of tissue injury. Although the association of obstetric variables with muscle oedema was not our primary objective and is limited by sample size, it parallels, as expected, what is known about levator tears.[10,17]

As hiatus size and closure mechanism failure are now an established link between childbirth injuries and the consequent pelvic floor disorders,[3,16,18] we decided to include in the analysis the measurement for both urogenital and levator hiatuses. A choice was made to use hiatal anteroposterior diameter and not hiatal area, as it captures the majority of the variation[18] and the software we had available for window and level adjustment did not allow for plane tipping needed to capture the plane parallel to the puborectal muscle for area calculation[19] at the time of this analysis. On average, smaller hiatal measurements were observed for women with oedema. Although this study failed to find statistical differences in hiatal measures between women with and without oedema, it is possible that individuals with overall smaller pelvises are at greater risk for pelvic floor trauma. Further research is needed to elucidate these findings.

Interpretation

Why is it important to know about these injuries? Many women have significant pain and disability after vaginal birth. For centuries, no tests were available to document the cause. Ultrasound and MRI have allowed us to determine whether the muscle is visibly torn, but this is only the most severe aspect of the muscle injury spectrum. Muscle strain (‘pulled muscle’) can be very painful despite not involving gross muscle disruption and may be the reason for pain and dysfunction after birth. Specific treatment regimens are well established for other muscles in the body and should be considered for these injuries. We emphasise that we are not suggesting that women require MRI clinically, but rather that this can help inform us about definite injuries and their mechanisms. Ultrasound is used in other parts of the body for oedema assessment[20] and we believe that with proper study it can be applied to the levator oedema after birth.

The specific oedema pattern can yield insight into injury mechanisms by providing a map of areas under greater risk. Each levator component has its own origin and insertion points,[21] and MRI studies in living women have confirmed that they also have different fibre directions and, consequently, different lines of action.[8] The pubovisceral muscle, for instance, attaches to the vagina, perineal body and anus, generating both a lifting force on these structures and a closure force on the urogenital hiatus. The puborectal muscle passes behind the ano-rectal junction, affecting levator hiatus closure but with no significant lifting action. The iliococcygeal muscle has similar line of action to the pubovisceral, although inserted differently, and might mitigate major pubovisceral tears. The external anal sphincter, although not part of the levator, is attached to the anococcygeal ligament and may participate in those actions, aside from its constriction role. Based on these anatomical and functional differences, it is plausible to think that injury to one muscle—and the consequent loss of its specific force vector—may have different mechanical effects than injury to another muscle. In addition, the external anal sphincter is known to undergo laceration and denervation,[22–25] but it is unknown whether these are associated with visible oedema.

From our new analysis of data within the EMRLD study, it seems likely that the mechanism of injury in anal sphincter differs from that in pubovisceral muscle. For the 33% of women who came into the EMRLD study with 3rd or 4th degree perineal laceration documented in the delivery room (as it was an inclusion criterion to this high-risk cohort for levator ani injury), oedema was nevertheless rarely seen in the external anal sphincter. This suggests that anal sphincter tearing is associated with tearing of the perineal body rather than stretching of the sphincter fibres themselves. This finding raises the important issue of different injury mechanisms having different consequences, and hence should elicit different preventive measures.

As a striated muscle, the levator ani is more likely to be injured if forcibly lengthened.[26] Biomechanical studies simulating childbirth have shown a 3.3 stretch ratio for the pubovisceral muscle, which is 217% greater than the stretch limit established as non-injurious for striated muscles.[7] Therefore, even in the absence of grossly visible muscle tearing, it is logical that at a finer level there is muscle disruption.

Broadening the spectrum of possible injuries and further detailing the mechanisms through which they happen is key in developing effective prevention measures. Women who present muscle oedema but not muscle tears, for instance, might benefit from early postpartum physical therapy. In addition, if we learn how to identify the subset of women who are at higher risk for extensive pelvic floor micro trauma, prenatal counselling on mode of delivery might be conducted differently.

Strengths and limitations

Our report adds important new information to the growing knowledge about the several different muscle injury mechanisms that affect the levator muscle and provides additional evidence that pubovisceral injury is stretch-induced.

Our findings regarding oedema are in parallel with previously reported literature about grossly visible muscle tearing[27] and intact puborectal muscle in subjects with major levator ani tear.[28] Analysis was done on MRI scans with high spatial resolution by individuals experienced with levator anatomy—including identification of the different subdivisions[13] – which provide detailed pelvic anatomy and a powerful tool for oedema assessment with fluid-sensitive sequences.

Several limitations must be considered in interpreting the results. This is not a population-based sample. Rather, the sample was purposely enriched to recruit women at high risk for levator injury and so the frequency with which oedema is seen is higher than one would expect with normal birth. In addition, our sample size and design limit interpretation of factors associated with muscle injury. Subsequent studies should be performed to confirm the observed associations we have highlighted in this manuscript.

Conclusion

Even in the absence of gross muscle tearing, the pubovisceral muscle shows by far the highest incidence of childbirth-related muscle injury. Adjacent muscles only show signs of oedema in the presence of oedema on the pubovisceral component. External anal sphincter did not show oedema, even in the presence of tears, suggesting a different injury mechanism for sphincter laceration. Future studies are necessary to understand what it is that leads to these subclinical injuries, whether they result in symptom variances across women, and delayed or inadequate return to normal function.

Disclosure of interests

The University of Michigan has received partial salary support from Materna Medical for Dr. DeLancey for research related to preventing birth-related injuries. Completed disclosure of interests forms are available to view online as supporting information.

Contribution to authorship

FP: study design, acquisition of data, analysis of data, manuscript draft. JMM: acquisition of data, manuscript revision. JOLD: study design, acquisition of data, analysis of data, manuscript revision.

Details of ethics approval

University of Michigan, Institutional Review Board approved on 30 August 2011 (HUM00051193).

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None.

Data availability statement

Data sharing is available on request from the corresponding author.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article. ■

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