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Evaluating Maternal Recovery from Labor and Delivery: Bone and Levator Ani Injuries

Janis M. Miller, PhD, APRN, FAAN^{1,2}, Lisa Kane Low, PhD, CNM, FACNM, FAAN^{1,2,3}, Ruth Zielinski, PhD, CNM, FACNM¹, Ms. Abigail R. Smith, MS⁴, John O.L. DeLancey, MD², and Catherine Brandon, MD, MS⁵

¹School of Nursing, University of Michigan, Ann Arbor MI

²Department of Obstetrics and Gynecology, Medical School, University of Michigan, Ann Arbor MI

³Women's Studies Department, University of Michigan, Ann Arbor MI

⁴Arbor Research Collaborative for Health, Ann Arbor MI

⁵Department of Radiology, Medical School, University of Michigan, Ann Arbor MI

Abstract

Objective—To describe occurrence, recovery, and consequences of musculoskeletal injuries in women at-risk for childbirth-related pelvic floor injury at first vaginal birth.

Study Design—Evaluating Maternal Recovery from Labor and Delivery (EMRLD) is a longitudinal cohort design study of women recruited early post-birth and followed over time. We report here on 68 women who had birth-related risk factors for levator ani muscle injury, including long second stage, anal tears, and/or older maternal age, and who were evaluated by musculoskeletal magnetic resonance imaging at both 7-weeks and 8-months postpartum. We categorized magnitude of injury by extent of bone marrow edema, pubic bone fracture, levator ani muscle edema, and levator ani muscle tear. We also measured the force of levator ani muscle contraction, urethral pressure, pelvic organ prolapse, and incontinence.

Results—In this higher-risk sample, 66% (39/59) had pubic bone marrow edema, 29% (17/59) had subcortical fracture, 90% (53/59) levator ani muscle edema, and 41% (28/68) low-grade or greater levator ani tear 7-weeks postpartum. The magnitude of levator ani muscle tear did not substantially change by 8-months postpartum ($p=0.86$), but levator ani muscle edema and bone injuries showed total or near total resolution ($p<.05$). The magnitude of unresolved musculoskeletal injuries correlated with magnitude of reduced levator ani muscle strength and posterior vaginal wall descent ($p<.05$) but not with urethral pressure, volume of demonstrable stress incontinence, nor self-report of incontinence severity ($p>.05$).

Corresponding Author: Janis M. MILLER; School of Nursing/Department of Obstetrics and Gynecology, Medical School; University of Michigan; 400 N. Ingalls, Ann Arbor, MI 48109; Work Phone: 734-764-4545; janismm@umich.edu.

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Conclusion—Pubic bone edema and subcortical fracture and levator ani muscle injury are common when studied in women with certain risk factors. The bony abnormalities resolve, but levator tear does not, and is associated with levator weakness and posterior-vaginal wall descent.

Keywords

levator ani; magnetic resonance imaging; musculoskeletal injuries; pelvic floor; vaginal birth

Introduction

Childbirth is arguably one of the most dramatic musculoskeletal events the human body undergoes. Passage of the newborn through the pelvis and its muscles requires an exceptional degree of soft-tissue stretch.¹ Childbirth exerts remarkable stresses on maternal pelvic bones from the pressures of the fetal head and the forces of abdominal muscles used during maternal pushing that originate from the pelvic bones. Such stretch and stress may produce injury in some women.

In the last decade, new imaging techniques have brought important new insights into understanding the mechanisms of soft tissue and bony injury.² Special sequences in musculoskeletal magnetic resonance imaging (MSK-MRI) offer advantages over other imaging techniques for studying deep bony and soft tissue changes. Fluid-sensitive sequences have the best combined specificity and sensitivity for revealing areas of injury and edema. Hence, they are the recommended diagnostic imaging test for stress injuries.^{3,4} These sequences are commonly applied in evaluation of sports-related injury to allow for detection of injuries not seen with other MRI sequences or imaging modalities.^{2,3,5-7} However, MSK-MRI fluid-sensitive sequences have only recently been applied to reveal the scope of childbirth-related pelvic injuries.⁸⁻¹¹

Soon after beginning a study of levator ani (LA) muscle injury following vaginal birth, it became evident we should add these standard MSK-MRI fluid-sensitive sequences to our existing protocol of anatomical MRI sequences to better characterize the full scope of possible injuries and pattern of recovery.

The purpose of this study is to report on the occurrence and severity of bony and LA muscle injuries observed and how magnitude of tissue trauma relates to clinical consequences in the first 8-months postpartum. Fluid-sensitive sequences are necessary for three of four indicators of bone and muscle injury evaluated in our study. The sequences show: 1) increased signal that indicates edema (extracellular fluid) in bone; 2) matched linear signal changes in bone that indicate a fracture; or 3) increased signal that indicates edema in muscle. The fourth indicator of injury, visual discontinuity of muscle seen with muscle tear, does not require fluid-sensitive sequences. However, use of fluid-sensitive sequences makes detection of tears and their magnitude much easier. The precision of these measures offered opportunity to assess more precisely the relationship between injury magnitude and relative consequences seen clinically in the first 8-months postpartum.

Materials and Methods

Study Design

The parent study Evaluating Maternal Recovery from Labor and Delivery (EMRLD) is an Institutional Review Board-approved (University of Michigan MED IRB HUM00051193) longitudinal cohort study following primiparous women with recent history of childbirth. In this paper, we report on those with higher-risk factors for LA injury. The first published reports from this work included: a) details on EMRLD's sampling strategies and a STROBE diagram; b) specifics of using MSK-MRI methods; c) ensuing anatomical detail of pelvic floor structures at rest, during dynamic activity, and by LA muscle subdivision and line-of-action; and d) predominant demographic or obstetric variables associated with LA tear when evaluated early postpartum.⁸⁻¹² EMRLD data collection occurred between 06/13/2005-03/14/2012, collecting data at approximately 7-weeks after a first vaginal birth (hereafter "7-wks-pp") and again at about 8-months post-first vaginal birth (hereafter "8-mos-pp"). In this manuscript, we report the 7-wks-pp to 8-mos-pp longitudinal findings.

Sample

The enriched sampling relied on inclusion criteria of heuristically-determined risk factors for LA tear (e.g., prolonged second stage, anal sphincter tear, higher maternal age, forceps delivery) suggestive in 2005, the time of the study's start.¹³ Women were excluded from EMRLD if <18 years, spoke a primary health care language other than English, delivered at <36 weeks gestation, birthed more than one infant, or if the infant was admitted to neonatal intensive care.

Of the 90 women originally recruited into EMRLD, 22 women did not have a second MRI at 8-mos-pp. Our analysis was based on the 68 women with MRI data at both 7-wks-pp and 8-mos-pp.⁹

MRI

MRIs were completed on a 3 Tesla, Philips Achieva (Philips Medical System, Eindhoven, Netherlands) with an 8-channel cardiac coil positioned over the pelvis. The lower pelvis was imaged in the coronal, axial, and sagittal planes with proton density-weighted (PD) sequences; repeat time (TR)=2107ms; echo time (TE)=30ms; number sequence averages (NSA)=2; slice thickness=4mm, gap=1mm; field of view (FOV)=20cm, matrix=256 × 256. For better definition of the anterior pelvic floor anatomy, additional tailored imaging (slice thickness=2mm, gap=0.2mm; FOV=18cm, matrix=256 × 256) included three planes of PD sequences and axial and coronal planes, either proton density-weighted fat saturation (PDFS) (TR=2355ms; TE=30ms) or short tau inversion recovery (STIR) (TR=5987ms; TE=60ms; NSA=2) sequences. A single sacral PDFS sequence was obtained in the axial plane (slice thickness=4mm, gap=1mm; FOV=20cm, matrix=256 × 256).

The complete MRI protocol has been discussed in previously-published reports.^{8,9} MRIs were reviewed by two board-certified, fellowship-trained musculoskeletal radiologists who were blinded to details of an individual woman's birth data and risk category. They were

aware if the woman was having her initial 7-wks-pp or 8-mos-pp since the postpartum uterus was obvious in the pelvic MRI study.

We used standard MSK-MRI radiology grading categories to evaluate edema and fractures in bone and muscle injuries so our data could be compared across time and studies in the radiology literature.^{3,7,14} When there was a difference in scoring between the two radiologists, the scans were reviewed together and graded by consensus, consistent with standard procedures in radiology. The radiologists measured and scored four sites of likely musculoskeletal injury.

1) Pubic Bone Marrow Evaluation for Edema—Bone marrow edema was assessed by grading signal intensity (none, mild, moderate, or intense) within the bone marrow of each pubic bone (right, left) as compared with the ischial tuberosity and other bones in the field of view.^{3,4,7,15} The spectrum of bone stress injuries has been correlated with clinical findings in athletes and military recruits and is graded 0 to 4, based on the degree of bone marrow edema according to the MSK-MRI scale with STIR or fat-suppressed sequences.^{3,4,7,16-18} Grade 0 is no abnormal signal. Grades 1 to 3 are mild, moderate, and intense bone marrow edema. Grade 4 is a true stress fracture with a line of increased signal (STIR or fat-suppressed sequences) with matching linear decreased signal on T1.

2) Pubic Bone Evaluation for Fracture—Evidence of pubic bone fractures in the cortical or trabecular bone was assessed as matching lines of increased and decreased signal on the fluid-sensitive and standard T1 sequences visible in two imaging planes.^{3,7} Fractures were recorded as none, subcortical, or cortical fractures for both pubic bones.

3) LA Evaluation for Edema—The LA was evaluated for the presence and location of increased signal, indicating edema consistent with stress or injury, as compared with other pelvic muscles, including the obturator internus. Grading classification categories were none, mild, moderate, or intense for each side.

4) LA Evaluation for Tear—The LA was evaluated for discontinuity of muscle observed as loss of visible muscle in an area where it is known to occur, indicating muscle tear. Grading classifications were: 0% to <20% (none-to-subtle), 20% to <50% (low-grade), or 50% (high-grade) for each side. Based on previous pelvic floor imaging experience, it was assumed that normal muscles should be symmetrical and that each should have the same morphological configuration as muscles seen in nulliparous controls reported in other studies.^{19,20}

Clinical Symptoms and Pelvic Floor Function Evaluation

Participants completed standardized questionnaires on symptoms of urinary and fecal incontinence at 7-wks-pp and 8-mos-pp.^{21,23} Strength of the LA was evaluated at both timepoints by measuring the vagina closure force at rest and during maximal pelvic muscle contraction (average of three attempts) using an instrumented speculum modified to not be influenced by changes in abdominal pressure.²⁴ Pelvic organ support was assessed during Valsalva in the lithotomy position using the pelvic organ prolapse quantification system.²⁵ Demonstrable stress incontinence was documented in the standing position and measures

made of volume of urine loss by the quantified paper towel standing stress test.²⁶ A urethral pressure profile was obtained at 8-mos-pp only, due to its invasive nature. These measures were made by a nurse practitioner with over 5 years of experience in clinical examinations. She was blinded to the MRI findings.

To standardize rehabilitation during the study period, at the examination, the same nurse practitioner instructed each woman in Knack technique and individually prescribed home pelvic muscle exercises per the graduated strength-training protocol.^{27,28}

Statistical Analysis

Of the 68 women with MRIs at 7-wks-pp and 8-mos-pp, 59 had fluid-sensitive sequences, and the remaining nine women had only non-fluid-sensitive sequences. Discovery of the importance of these sequences occurred after study initiation. The missing sequences were due to early enrollment before the MSK-MRI protocol was in use. Since LA tear is readily observable without fluid-sensitive sequences, the full 68 women were retained for that analysis, but the nine were not included in analysis of pubic bone edema, fracture, and LA edema.

A composite score for the degree of injury for each individual was derived by collapsing “left,” “right” sides to yield ordinal-level data: For the LA tears, a composite score of “0” indicated no or subtle tear on both sides, “1” indicated a low-grade unilateral tear, “2” indicated a bilateral low-grade or unilateral high-grade tear, and a score of “3” indicated a bilateral high-grade tear. Similar composite scores were constructed for pubic bone marrow edema, pubic bone fracture, and LA edema (see tables).

Descriptive statistics were conducted only for those who completed both MRIs, comparing magnitude levels on 7-wks-pp and 8-mos-pp in the four musculoskeletal sites. We excluded subjects from analysis when there was missing data due to lack of follow-up or, on select analysis, lack of fluid-sensitive sequences required for a particular variable.

The Stuart-Maxwell test was used to test for homogeneity between the marginal distributions for each of the four sites at the two evaluation times. To calculate the statistic, an inconsequential decimal (0.5) was added to each empty cell in the table.²⁹

We used repeated measures modeling techniques to investigate the association between the four types of musculoskeletal injury and the clinical measures. Weighted Kappa coefficient was used to determine the level of agreement between magnitude of LA tear graded by MRI and magnitude of clinical parameters. Analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC) and R version 2.14.1.

Results

Tables 1 and 2 show the obstetric, demographic, and 8-mos-pp clinical characteristics of the 68 women analyzed with 7-wks-pp and 8-mos-pp MRI scans (including nine who had scans without the fluid-sensitive sequences). When compared with the 22 women without a second MRI, the group with scans at both evaluation times (n=68) was older, more predominately white, and more highly educated. The two groups did not differ in terms of obstetric

characteristics or distribution of musculoskeletal injury severity at 7-wks-pp. The 7-wks-pp MRI scans were obtained on average 47.3 ± 21.0 days postpartum; the late MRI scans were obtained 242.1 ± 60.8 days postpartum.

Figure 1 shows one woman's MRI findings and types of injuries observed and reported by category.

Pubic Bone Marrow Edema

Of the 59 women with complete MSK-MRI studies, 66% (39 of 59) showed increased signal, indicating edema in the pubic bone marrow at 7-wks-pp. At 8-mos-pp, only 14% (eight of 59) still showed increased signal (Table 3). Of the eight women with continued marrow edema, five did not show any improvement, while the other three who all initially had the highest category of signal intensity, improved by one category. For 7-wks-pp to 8-mos-pp, the distribution of women's signal intensity scores across the four magnitude category levels (intense, moderate, mild, no signal intensity) was statistically different ($p < 0.0001$), with a strong shift toward lower severity categories at 8-mos-pp, indicating resolving marrow edema (Figure 2a).

Pubic Bone Fracture

Fractures in the bone marrow of the pubic bone were observed in 17 of 59 women (29%) on the 7-wks-pp scans. By 8-mos-pp, two still showed evidence of healing fractures (Table 3). Both were low-grade. Distributions of women's signal intensity scores across the four magnitude category levels of signal intensity compared 7-wks-pp to 8-mos-pp were significantly different ($p = 0.01$), indicating overall fracture healing (Figure 2b).

LA Edema

LA edema was initially observed in 53 of 59 women (90%) and was still evident in four women (7%) on follow-up (Table 3). Of the four without complete resolution of LA edema, only one did not show any improvement (level II magnitude at both evaluation times), while the other three had incomplete resolution. Similar to pubic bone marrow edema, severity for LA edema, compared 7-wks-pp to 8-mos-pp, was significantly different ($p < 0.000$), indicating progress toward full resolution by 8-mos-pp. However, LA edema was faster to resolve than bone marrow edema, as only four women continued to have some increased signal in the LA at 8-mos-pp (Figure 2c). There was no abnormal signal in the other pelvic muscles (e.g., obturator internus) for any of the women, either 7-wks-pp or 8-mos-pp.

LA Discontinuity

LA discontinuity was seen at 7-wks-pp in 28 out of 68 women (41%). The magnitude of discontinuity for these 28 women was distributed as follows: eight having unilateral low-grade tears, 13 having bilateral low-grade or unilateral high-grade tears, and seven having bilateral high-grade tears. When all 68 women were evaluated at 8-mos-pp, no new tears were identified, and of the 28 who showed tear at 7-wks-pp, all but three showed the same magnitude level at 8-mos-pp (Table 3). Of the three who showed a difference, two dropped one category from unilateral "low-grade tear" to "none-to-subtle tear" and one dropped from "bilateral high-grade tear" to the category labeled as "bilateral low-grade or unilateral high-

grade tear” (Figure 2d). Statistically, there was no difference in the magnitude of the tears 7-wks-pp to 8-mos-pp ($p=0.86$), indicating that tears did not resolve.

Clinical Measures at 8-Months

None of the clinical measures (prolapse, urethral pressure, incontinence, LA strength) obtained were significantly associated with higher magnitude of MRI-documented pubic bone marrow edema, pubic bone fracture, or LA edema injury. Kegel contraction force and the degree of descent of the posterior vaginal wall were significantly associated with higher magnitude of LA tear ($p=0.008$ and $p=0.005$). None of the fecal or urinary incontinence measures were associated with magnitude of LA tear scores (Table 4).

Comment

This study of women with risk factors for LA injury from first childbirth demonstrates that 91% of this selected sample show some form of musculoskeletal injury involving the pubic bone or LA when studied with MSK-MRI 7-wks-pp. Most of the observed injuries resolve by 8-mos-pp. LA muscle tears identified 7-wks-pp after birth in 41% of this selective sample did not resolve. Overall, 9% were high-grade lesions involving >50% of the muscle. Eighty-nine percent had the same magnitude of levator injury 8-mos-pp, and for those with a change, it was by only one severity level.

We speculate that torn muscle edges retract from their origin because of the significant resting tone,³⁰ so that the resulting large gap prohibits healing that would retain muscle volume.³¹⁻³⁴ Severity of LA muscle tear was associated with degree of reduced LA resting force developed during a maximal contraction on instrumented speculum testing and with degree of posterior wall descent. There was not association with anterior wall descent, which differs from case-control studies when women were classified by only two categories (major or none) and were older.^{35,36} Figure 3 shows how various degrees of tear do or do not explain various clinical findings.

Edema within the LA and pubic bone marrow and pubic bone fracture tended to recover. These observations are similar to general MSK-MRI studies where resolution of muscle strains or stress fractures found in athletes (e.g., marathoners) resolve over time.^{3,4,7,31-34} The most likely explanation for persistence of LA muscle edema in four women (7%) at 8-mos-pp is that each had a high-grade LA muscle tear. In MSK-MRI studies, the magnitude of muscle and bone injury is proportional to the intensity of signal abnormalities and length of time to heal.^{3,4,7,31-34}

Urethral pressure, incontinence signs and symptoms, fecal or urinary, were not sensitive indicators of magnitude of injury in any of the musculoskeletal aspects studied in the first few months after birth at this sample size. This differs from data reported in three studies^{38, 35, 39} which showed that postpartum women with “major” LA tear, compared with those “without major” LA tear, experienced lower urethral pressures and more incontinence.

Study limitations include that 22 of the original 90 women evaluated did not return for follow-up visit. Since these women were, on average, older and more frequently white, which are traits commonly associated with more traumatic vaginal delivery, we believe our findings regarding number and type of injuries may be conservative. However, the radiologists could not be completely blinded to study design and timepoints, which may have introduced bias towards maximally-identifying injuries. It is logical to assume from other, better-understood musculoskeletal trauma (e.g., hamstring tear and sacral fractures) that symptoms such as degree of pain (which we did not measure in EMRLD) correlate with injury severity, and time needed for healing will vary accordingly.^{3,7,31-34,40} Establishing the most effective rehabilitation protocol and time when activities, e.g., high-intensity exercise or sexual intercourse, should occur, will require further study.

This study's findings suggest we cannot rely on clinical examination to intuit the full spectrum of musculoskeletal issues associated with higher-risk birth. In select women, MSK-MRI may be warranted clinically and in research, since MSK-MRI can provide the full spectrum of MSK injuries. Consideration should be given to including MSK-MRI for evaluation of high-risk symptomatic patients. The role of MSK-MRI in evaluation of postpartum women could be expanded in situations of unexplained or prolonged pain after delivery, nonrecoverable ability to contract the LA (Kegel), or non-resolving post-partum pelvic organ descent. The differential diagnosis will suggest patient care aspects, i.e., reassurance of no structural lasting injury, expected timeline of resolution, or follow-up considerations (short- or long-term) for more serious findings.

The degree to which women with postpartum levator defects and other musculoskeletal injuries will eventually develop symptomatic urinary incontinence, fecal incontinence, or chronic pelvic organ prolapse is not known. The longitudinal EMRLD study is continuing with long-term follow-up and will help answer these questions over time.

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Figure 1. 31 year-old with high-grade bone marrow edema and bilateral LA tears, right greater than left. By convention, images are presented in anatomic position and axial images as if viewed from the feet. **1A**

Initial MRI with axial *STIR sequence* that demonstrates the right pubic bone marrow edema (horizontal arrow). STIR sequence images, such as this one, always appear coarse because of the poor spatial resolution inherent in the acquisition of these sequences. Although most clinicians will find these images less pleasing to study than the more familiar anatomic images, the STIR sequences have high sensitivity to sites of edema (edema as bright white contrast) compared with anatomic images. Vertical arrows indicate the bilateral LA tears (better seen in 1B). **1B.** Initial MRI with axial *proton density sequence* showing bilateral LA tears. Vertical arrows are pointing to the region where thick LA muscle should be demonstrated between the vagina and the internal obturator muscle, but essentially, the muscle is missing for this person. Proton density sequences such as this one will always appear with better spatial resolution compared with STIR sequence, but the proton density sequences do not reveal the bone marrow edema that was seen in the STIR sequence of 1A. **1C.** Follow-up MRI with axial *proton density fat saturation sequence* that demonstrates almost complete resolution of bone marrow edema. Image sequences of proton density with fat saturation appear less coarse than STIR sequences (in the 1A image) but still allow for better visualization of bone marrow edema than proton density-weighted image without fat

suppression, shown in 1D. **1D.** Follow-up MRI with axial proton density *without fat saturation* sequence showing bilateral LA tears (vertical arrows) unchanged. Arrowheads point to the inner margin of muscle site.

Figure 2. Mean MRI scores at two evaluation times, grouped by 7-weeks postpartum score
 Subjects were grouped by magnitude level at 7-weeks postpartum; magnitude levels were ordered from 0 (none) to 3 (intense/severe). Each group starts at its group magnitude level because all women within a group have the same magnitude level at 7-weeks postpartum. Panels (a), (c), and (d) show improvement over time as the mean scores drop 0 (none). Magnitude level in panel (b) shows little improvement in LA tear, indicating toward grossly stable muscle tear to 8-months postpartum. Edema in the levator muscle or in the pubic bone marrow shows a pattern of resolving over time.

Figure 3. Mean values of clinical and questionnaire findings at 7-weeks postpartum and 8-months postpartum grouped by LA tear severity at 7-weeks postpartum

Each panel shows trends over time for variables relating to incontinence (standing stress test [PTT]; Antonakos, Sandvik, and Wexner), Kegel strength (resting and rep average measured by one-billed speculum), and POP-Q measures. Most measures do not show meaningful differences for different levels of LA tear severity, except in the case of the Kegel rep averages ($p=0.006$) and posterior vaginal wall descent ($p=0.005$).

Table 1
Maternal demographics and birth variables among women with 7-weeks postpartum and 8-months postpartum MRIs

	Total	Mean (SD) or Frequency	Range or %
Demographics			
Maternal age (years)	68	30.38 (5.48)	19-46
Maternal age >31 years		27	40%
Race	66		
Black/African-American		2	3%
White		58	88%
Asian		3	5%
Other race		3	5%
Non-Hispanic/Non-Latino		66	100%
Education	66		
High school graduate or less		6	9%
Some college		13	20%
College/technical school graduate		17	26%
Graduate school		29	44%
Birth Variables			
Infant's weight (grams)	67	3411.90 (507.12)	2100-4550
Infant's head circumference (cm)	66	34.19 (1.62)	30-38
Second stage (minutes)	67	154.91 (126.58)	6-518
Second stage >150 minutes		31	46%
Active pushing (minutes)	56	113.75 (84.65)	6-312
Passive 2 nd stage (minutes)	56	44.45 (72.40)	0-307
Anal tear	68	22	32%
Episiotomy	68	14	21%
Vacuum	68	4	6%
Forceps	68	2	3%

Table 2
Postpartum clinical variables among women with 7-weeks postpartum and 8-months postpartum MRIs

	Total	Mean (SD) or Frequency	Range or %
Clinical Variables ~8-Months Postpartum			
Vaginal resting force on instrumented speculum (Newtons)	62	1.92 (0.48)	1 to 4
Vaginal Kegel force (average of 3 repetitions) on instrumented speculum (Newtons)	62	4.16 (1.93)	1 to 10
POP-Q anterior vaginal wall (cm)	63	-2.13 (0.70)	-3 to 1
POP-Q posterior vaginal wall (cm)	63	-2.28 (0.63)	-3 to 0
POP-Q cervix descent (cm)	62	-7.71 (0.60)	-8 to -6
POP-Q genital hiatus (cm)	63	4.69 (0.91)	2 to 7
POP-Q perineal body measure (cm)	63	2.29 (0.66)	1 to 4
POP-Q total vaginal length (cm)	62	11.98 (1.16)	9 to 14
Maximum urethral pressure (cm H ₂ O)	55	66.95 (19.71)	24 to 128
Quantified standing stress test	63		
No leakage		57	90%
Drops (<10 cm ³)		3	5%
Some leakage (10-11 cm ³)		0	0%
A lot of leakage (>33 cm ³)		3	5%
Antonakos urinary incontinence (points, 0=none, 8=high)	64	3.30 (2.57)	0-8
Antonakos urinary incontinence full 40-point scale (points, 8=none, 40=high)	64	14.11 (5.19)	8-28
Sandvik urinary incontinence (points, 0=none, 8=high, as frequency X amount)	62	1.24 (1.10)	0-3
Wexner fecal incontinence (points, 0=none, 20=high)	64	1.58 (1.54)	0-6

Table 3
Distribution of 7-weeks postpartum (7-wks-pp) and 8-months postpartum (8-mos-pp) MRI scores across four outcomes

	MRI Score	7-wks-pp N (%)	8-mos-pp N (%)	N (%) with Different Score 8-mos-pp	N (%) with Same Score 8-mos-pp	Stuart-Maxwell Statistic (p-value)
(a) Pubic Bone Marrow Edema (n=59)						
	None	20 (34%)	51 (86%)	0 (0%)	20 (100%)	27.2 (<0.0001)
	I = Diffuse mild	6 (10%)	1 (2%)	5 (83%)	1 (17%)	
	II = Focal mild or diffuse intense	21 (36%)	5 (8%)	19 (90%)	2 (10%)	
	III = Focal intense	12 (20%)	2 (3%)	10 (83%)	2 (17%)	
	Total	59 (100%)	59 (100%)	34 (58%)	25 (42%)	
(b) Pubic Bone Fracture (n=59)						
	None	42 (71%)	57 (97%)	0 (0%)	42 (100%)	11.2 (0.011)
	I = <5 mm unilateral or bilateral	5 (8%)	2 (3%)	3 (60%)	2 (40%)	
	II = 5 mm unilateral or bilateral	10 (17%)	0 (0%)	10 (100%)	0 (0%)	
	III = Cortical unilateral or bilateral	2 (3%)	0 (0%)	2 (100%)	0 (0%)	
	Total	59 (100%)	59 (100%)	15 (25%)	44 (75%)	
(c) Levator Ani Edema (n=59)						
	None	6 (10%)	55 (93%)	0 (0%)	6 (100%)	45.1 (<0.0001)
	I = Mild unilateral or bilateral	2 (3%)	1 (2%)	2 (100%)	0 (0%)	
	II = Moderate unilateral or bilateral	40 (68%)	3 (5%)	39 (98%)	1 (3%)	
	III = Intense unilateral or bilateral	11 (19%)	0 (0%)	11 (100%)	0 (0%)	
	Total	59 (100%)	59 (100%)	52 (88%)	7 (12%)	
(d) Levator Ani Tear (n=68)						
	None or subtle	40 (59%)	42 (62%)	0 (0%)	40 (100%)	0.74 (0.86)
	I = Low-grade (<50%) unilateral	8 (12%)	6 (9%)	2 (25%)	6 (75%)	
	II = Low-grade (<50%) bilateral or high-grade (50%) unilateral	13 (19%)	14 (21%)	0 (0%)	13 (100%)	
	III = High-grade (50%) bilateral	7 (10%)	6 (9%)	1 (14%)	6 (86%)	
	Total	68 (100%)	68 (100%)	3 (4%)	65 (96%)	

Table 4
Descriptive statistics and timepoint differences for indicators of pelvic floor disorders by LA tear status at 7-weeks postpartum and 8-months postpartum

	LA Tear Severity	7-Weeks Postpartum		8-Months Postpartum		ANOVA p-value*
		N	Mean (SD)	N	Mean (SD)	
Levator Ani Strength						
Force at rest (Newtons)	None	38	1.75 (0.34)	34	1.93 (0.53)	0.432
	I	8	1.93 (0.26)	8	1.88 (0.21)	
	II	9	1.59 (0.53)	13	1.91 (0.61)	
	III	6	1.81 (0.36)	7	1.98 (0.16)	
Force at volitional contraction (Newtons)	None	38	3.99 (1.68)	34	4.90 (2.04)	0.008
	I	8	3.19 (2.02)	8	3.51 (1.96)	
	II	9	2.46 (0.85)	13	3.09 (1.20)	
	III	6	2.82 (1.21)	7	3.29 (0.78)	
Pelvic Organ Prolapse Quantification						
Anterior vaginal wall descent (cm)	None	39	-2.12 (0.64)	35	-2.19 (0.56)	0.190
	I	8	-2.19 (0.26)	8	-2.25 (0.38)	
	II	12	-2.26 (0.48)	13	-2.08 (0.76)	
	III	7	-1.57 (0.93)	7	-1.86 (1.35)	
Posterior vaginal wall descent (cm)	None	39	-2.37 (0.60)	35	-2.33 (0.54)	0.005
	I	8	-2.56 (0.18)	8	-2.50 (0.38)	
	II	12	-2.29 (0.45)	13	-2.31 (0.69)	
	III	7	-1.57 (1.10)	7	-1.71 (0.95)	
Cervix descent (cm)	None	39	-7.64 (0.79)	35	-7.66 (0.67)	0.369
	I	8	-7.88 (0.35)	8	-7.75 (0.46)	
	II	12	-8.00 (0.00)	12	-7.88 (0.43)	
	III	7	-7.71 (0.49)	7	-7.64 (0.63)	
Genital hiatus (cm)	None	39	4.51 (0.98)	35	4.70 (0.96)	0.706
	I	8	4.50 (0.60)	8	4.63 (0.52)	
	II	12	4.29 (0.84)	13	4.46 (1.05)	
	III	7	4.57 (1.06)	7	5.14 (0.75)	

	LA Tear Severity	7-Weeks Postpartum			8-Months Postpartum			ANOVA p-value*
		N	Mean (SD)		N	Mean (SD)		
Perineal body (cm)	None	39	2.40 (0.65)	35	2.31 (0.69)	0.921		
	I	8	2.56 (0.73)	8	2.13 (0.69)			
	II	12	2.46 (0.66)	13	2.42 (0.61)			
	III	7	2.57 (1.06)	7	2.07 (0.61)			
Total vaginal length (cm)	None	39	11.56 (1.63)	34	11.96 (1.28)	0.900		
	I	8	12.00 (1.16)	8	11.81 (1.46)			
	II	12	11.75 (1.20)	13	12.19 (0.88)			
	III	7	11.36 (0.90)	7	11.93 (0.61)			
Urethral Function/Incontinence								
Maximum urethral pressure (cm H ₂ O)**	None	-	-	32	66.13 (20.89)	0.945		
	I	-	-	6	65.83 (14.91)			
	II	-	-	12	67.67 (16.84)			
	III	-	-	5	71.80 (27.70)			
Wetted area on paper towel standing stress test (cm ²) ^δ	None	39	0.24 (1.51)	36	3.46 (14.76)	0.696		
	I	8	27.52 (64.38)	8	0.00 (0.00)			
	II	12	0.00 (0.00)	13	3.33 (9.47)			
	III	7	7.09 (18.77)	6	0.92 (2.24)			
Antonakos urine leakage (potential 8 points based on “yes=1” “no=0” across 8 items)	None	39	3.08 (2.51)	36	3.06 (2.48)	0.488		
	I	8	4.25 (3.06)	8	4.00 (3.02)			
	II	13	3.85 (3.21)	13	4.00 (2.58)			
	III	7	3.43 (3.74)	7	2.43 (2.57)			
Antonakos urine leakage (potential 40 points based on full 5-point severity likert scale)	None	39	13.23 (5.01)	36	13.64 (4.72)	0.406		
	I	8	16.50 (8.12)	8	15.50 (6.80)			
	II	13	15.85 (7.07)	13	15.54 (5.59)			
	III	7	15.29 (8.58)	7	12.29 (4.92)			
Sandvik urinary incontinence (points)	None	39	1.00 (1.19)	34	1.09 (0.97)	0.276		
	I	8	2.00 (2.56)	8	1.50 (1.20)			
	II	13	2.00 (2.00)	13	1.54 (1.20)			
	III	7	1.14 (1.46)	7	1.14 (1.46)			

LA Tear Severity	7-Weeks Postpartum		8-Months Postpartum		ANOVA p-value *
	Mean (SD)		Mean (SD)		
	N		N		
None	36	1.89 (1.91)	36	1.78 (1.64)	0.599
I	7	2.57 (3.99)	8	1.00 (0.93)	
II	13	2.15 (1.63)	13	1.85 (1.63)	
III	7	3.29 (3.77)	7	0.71 (1.11)	

* Repeated measures analysis of variance (ANOVA) p-value from F-test adjusted for timepoint.
** Only collected at 8-months postpartum due to invasive nature of procedure.
δ Also adjusted for interaction between LA tear severity and evaluation time-point (p=0.02). P-value from F-test including interaction is shown.