Obstetric levator ani muscle injuries: current status

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ABSTRACT

Levator ani muscle (LAM) injuries occur in 13–36% of women who have a vaginal delivery. Although these injuries were first described using magnetic resonance imaging, three-dimensional transperineal and endovaginal ultrasound has emerged as a more readily available and economic alternative to identify LAM morphology. Injury to the LAM is attributed to vaginal delivery resulting in reduced pelvic floor muscle strength, enlargement of the vaginal hiatus and pelvic organ prolapse. There is inconclusive evidence to support an association between LAM injuries and stress urinary incontinence and there seems to be a trend towards the development of fecal incontinence. Longitudinal studies with long-term follow-up assessing the LAM before and after childbirth are lacking. Furthermore, the consequence of LAM injuries on quality of life due to prolapse and/or urinary and fecal incontinence have not been evaluated using validated questionnaires. Direct comparative studies using the above-mentioned imaging modalities are needed to determine the true gold standard for the diagnosis of LAM injuries. This would enable consistency in definition and classification of LAM injuries. Only then could high-risk groups be identified and preventive strategies implemented in obstetric practice. Copyright © 2012 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION

Until recently, the concept of pelvic floor trauma was attributed largely to perineal, vaginal and anal sphincter injuries. Over the past two decades much attention has been focused on obstetric anal sphincter injuries. However, in recent years, with advances in magnetic resonance imaging (MRI) and 3-dimensional (3D) ultrasound, it has become evident that levator ani muscle (LAM) injuries form an important component of pelvic floor trauma.

The aims of this review article were to critically appraise the diagnosis of obstetric LAM injuries, to establish the relationship between LAM injuries and pelvic floor dysfunction and to identify risk factors and preventive strategies to minimize such injuries.

METHODS

• PubMed literature search was conducted between July 2010 and September 2011 using the terms ‘LAM avulsion’, ‘levator ani muscle injury’, ‘levator ani muscle trauma’, ‘pelvic organ prolapse’, ‘stress urinary incontinence’, ‘faecal incontinence’, ‘pelvic floor trauma and childbirth’, ‘prevention of LAM injury’ and ‘LAM palpation’. In addition, these documents were hand searched for additional citations.

ANATOMY AND PHYSIOLOGY OF THE LEVATOR ANI MUSCLE

The pelvic floor is a musculotendinous sheet that spans the pelvic outlet and consists mainly of the symmetrically paired LAM, which is a broad muscular sheet of variable thickness attached to the internal surface of the true pelvis. Although there is controversy regarding the subdivisions of the muscle, it is broadly accepted that it is subdivided into parts according to their attachments, namely the pubovisceral, puboanal and iliococcygeus. The pubovisceral part is further subdivided according to its relationship to the visera, i.e. puboperinealis, pubovaginalis and puboanalis. The puborectalis muscle is located lateral to the pubovisceral muscle, cephalad to the deep component of the external anal sphincter, from which it is inseparable posteriorly (Figure 1). The pubovisceral muscle, collagen and elastin fibers of the vaginal wall and paraurethral tissues directly interdigitate with the muscle fibers of the most medial portion of the LAM.

The pelvic floor supports the urogenital organs and the anorectum, exiting the pelvis through their respective foramina. The LAM differs from most other skeletal muscles in that it maintains a constant tone, except...
during voiding, defecation and the Valsalva maneuver\(^1\)\(^2\). It has the ability to contract quickly with a sudden increase in abdominal pressure, e.g. during a cough, sneeze or physical activity\(^9\)\(^\text{--}\)\(^11\), thereby minimizing the risk of incontinence and pelvic organ prolapse (POP)\(^4\)\(^\text{--}\)\(^6\). Paradoxically, it has to stretch during parturition even beyond its limits\(^1\)\(^2\)\(^\text{--}\)\(^12\) in order to allow the passage of the term infant, but it contracts after delivery to resume normal function\(^9\).

### Pathophysiology

Prospective studies have shown that LAM injuries occur in 13–36% of women who deliver vaginally\(^13\)\(^\text{--}\)\(^17\). It appears that the degree of muscle stretch varies widely in the population and in some women there can be as much as a three-fold increase in muscle stretch\(^3\)\(^\text{--}\)\(^12\)\(^18\). Given that skeletal muscle will not stretch to more than twice its length without tearing\(^19\), it is surprising that more women do not sustain LAM injuries.\(^\text{--}\) Brooks et al.\(^19\) have shown that in passive muscles, single stretches of 50% are necessary to produce significant injury, whereas in maximally activated muscles exposure to 30% stretch results in injury. This may explain the suggested protective effect of epidural anesthesia in developing LAM injuries\(^17\).

The degree of distension as well as the point of maximum tissue strain vary in MRI-based models\(^3\)\(^\text{--}\)\(^12\). Lien et al.\(^3\) demonstrated that the largest tissue strain ratio of 3.26 occurs in the most medial component of the pubococcygeus muscle as a result of its short initial length and its original location near the midline. However, Hoyte et al.\(^12\) claimed that the postero medial puborectalis muscle experiences the maximum stretch, with a ratio of 3.5. These differences in stretch ratios could be due to the variation (between 25 and 245%) in the dimensions of the LAM on maximal Valsalva maneuver and the biochemical properties of the muscle\(^4\)\(^\text{--}\)\(^\text{--}\)\(^20\)\(^\text{--}\)\(^24\). It has been suggested that the hormonal effects of pregnancy may have an effect on LAM properties\(^25\). Balmforth\(^26\) explored the hypothesis that the inherent constitutional quality of women’s connective tissue may influence the likelihood of normal progress in labor and the development of POP and stress incontinence. He/she found that women with a higher distensibility of the pelvic floor in the antenatal period were more likely to deliver vaginally and concluded that this was the result of fundamental differences in tissue quality.

It has been well established that pelvic floor muscle denervation and reinnervation occur after childbirth\(^27\)\(^\text{--}\)\(^32\). Electromyographical changes to the pelvic floor muscles are frequently found in women complaining of defecation disorders\(^31\)\(^\text{--}\)\(^33\), stress urinary incontinence (SUI)\(^36\)\(^\text{--}\)\(^38\) or prolapse\(^35\)\(^\text{--}\)\(^36\)\(^\text{--}\)\(^38\). Abnormalities are more frequently found in multiparae\(^28\)\(^\text{--}\)\(^29\)\(^\text{--}\)\(^33\) and correlate with a prolonged second stage of labor\(^28\)\(^\text{--}\)\(^30\)\(^\text{--}\)\(^34\), forceps delivery\(^28\)\(^\text{--}\)\(^29\)\(^\text{--}\)\(^\text{--}\)\(^34\) and high birth weight\(^28\)\(^\text{--}\)\(^30\). Neuropathy appears to be cumulative in multiparae\(^29\)\(^\text{--}\)\(^33\). There is conflicting evidence regarding the effect of epidurals, as one study did not find a lower incidence of neuropathy\(^28\), while another study found that a shorter duration of epidural anesthesia was an independent predictor of levator injury\(^32\).

### DEFINITION OF LAM INJURY

There are numerous definitions of LAM injury depending on the mode of assessment, namely clinical palpation (Table 1), ultrasonography (Table 2) or MRI (Table 3). Although it is widely believed that nulliparous women do not suffer from LAM injuries\(^39\), a study comparing MRI of nulliparous and primiparous women found LAM abnormalities in 18% of nulliparous women\(^40\). This is supported by another study that found that the origin of the LAM from the pubic bone was not visible bilaterally in 10% and was absent unilaterally in 10% of nulliparous women\(^41\). This could be the result of technical limitations (slice thickness and gap, huge vessels, chemical shift artifacts) or a reflection of the anatomic variation in LAM insertion.

### Prevalence of LAM injury

In recent years studies have focused on birth-related injuries to evaluate the prevalence and consequences of LAM injuries. To detect these injuries, modern imaging techniques like MRI\(^39\)\(^\text{--}\)\(^40\)\(^\text{--}\)\(^42\)\(^\text{--}\)\(^50\), transperineal ultrasound\(^13\)\(^\text{--}\)\(^16\)\(^\text{--}\)\(^18\)\(^\text{--}\)\(^44\)\(^\text{--}\)\(^51\)\(^\text{--}\)\(^71\) and endovaginal sonography can be used\(^72\).
Table 1 Definitions used for levator ani muscle avulsion on palpation

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<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Definition</th>
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<tbody>
<tr>
<td>2006</td>
<td>Dietz et al.66</td>
<td>Palpable detachment of the most anterior and intermedial fibers of the pubovisceral muscle from the inferior pubic ramus and/or as a gap in the continuity of the pubovisceral muscle between the pubic rami and the anorectum</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz et al.60</td>
<td>Interior aspects of the muscle were detached from the pelvic sidewall with no muscle remaining on the inferior pubic ramus (either uni- or bilaterally)</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz &amp; Shek57</td>
<td>Insertion of the pubovisceral muscle on the inferior pubic ramus not palpable and/or whenever a discontinuity between bone and muscle was detected on ultrasound</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz &amp; Shek61</td>
<td>Detachment of the puborectalis muscle from its insertion on the inferior pubic ramus</td>
</tr>
<tr>
<td>2009</td>
<td>Dietz &amp; Shek52</td>
<td>With the urethra medially, the insertion of the puborectalis muscle palpated immediately lateral to the palpating finger, about 2 cm cranial to the introitus on the os pubis. If no muscle palpated on the os pubis and if the inferior pubic ramus is felt to be free of muscle while moving the finger laterally, then an avulsion is diagnosed</td>
</tr>
<tr>
<td>2010</td>
<td>Kruger et al.33</td>
<td>1) Direct palpation of discontinuity of puborectalis where the muscle attaches to the bone 2) Palpation of distance between the two sides of muscle insertion (&gt; 3.5 finger widths)</td>
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Table 2 Definitions used on ultrasound as diagnostic tool to identify levator ani muscle (LAM) injury

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<th>Year</th>
<th>Author</th>
<th>Definition</th>
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<tbody>
<tr>
<td>2006</td>
<td>Dietz &amp; Steensma67</td>
<td>Avulsion diagnosed on rendered volumes if there was an obvious detachment of the muscle from the pelvic sidewall and if an abnormality was detected in all three or more volumes (i.e. at rest, Valsalva, levator contraction). Each side was rated separately</td>
</tr>
<tr>
<td>2007</td>
<td>Dietz65</td>
<td>Diagnosis made on tomographic ultrasound imaging using a scoring system from 0 = no abnormality to 16 = bilateral complete avulsion</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz &amp; Simpson58</td>
<td>Avulsion injury was diagnosed when there was a discontinuity between the inferior pubic rami and the puborectalis muscle. Complete defect if the reference slice and slices 2.5 mm and 5 mm cranial to it showed avulsion</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz &amp; Shek61</td>
<td>Avulsion diagnosed if there was evidence of discontinuity between the puborectalis muscle and the pelvic sidewall at the level of levator hiatus and for at least 5 mm above this level</td>
</tr>
<tr>
<td>2008</td>
<td>Dietz et al.60</td>
<td>Cut-off of LUG &gt; 25 mm at reference slice, 2.5 mm cranial and 5 mm cranial in doubtful cases</td>
</tr>
<tr>
<td>2009</td>
<td>Dietz &amp; Shek91</td>
<td>Slices were scored as positive or negative for levator avulsion using a combination of direct visualization of the insertion of the puborectalis muscle on the pelvic sidewall and measurements of the LUG &gt; 2.5 cm being regarded as abnormal</td>
</tr>
<tr>
<td>2009</td>
<td>Krofta et al.74</td>
<td>Avulsion diagnosed if there was loss of continuity between muscle and pelvic sidewall in all volume datasets</td>
</tr>
<tr>
<td>2009</td>
<td>Valsky et al.13</td>
<td>LAM trauma whenever discontinuity and distortion were visible in the anteromedial part of the pubovisceral muscle in the coronal C-plane or rendered image</td>
</tr>
<tr>
<td>2009</td>
<td>Weinstein et al.54</td>
<td>Two hemislings of puborectalis scored independently: 0 = normal; 1, &lt; 50% abnormal; 2, ≥ 50% abnormal. Then bilateral scores added for a total maximum of 4. Grade 0, normal; Grade 1, minor abnormality (scores 1 or 2); Grade 2, major abnormality (scores 3 or 4)</td>
</tr>
<tr>
<td>2010</td>
<td>Dietz et al.90</td>
<td>Full avulsion: All three central slices show abnormal insertion Partial avulsion: any of the three central slices being abnormal</td>
</tr>
<tr>
<td>2010</td>
<td>Erdmann et al.201</td>
<td>Full avulsion diagnosed if all three central slices showed abnormal insertion with a LUG over 25 mm</td>
</tr>
<tr>
<td>2010</td>
<td>Shek &amp; Dietz32</td>
<td>Macrotum: avulsion if the reference slice and slices 2.5 mm and 5 mm cranial to it showed avulsion</td>
</tr>
<tr>
<td>2011</td>
<td>Zhuang et al.99</td>
<td>Full avulsion diagnosed if the puborectalis-to-ipsilateral sidewall attachment is not seen on any of the three central slices. Partial avulsion diagnosed when the puborectalis attachment to the ipsilateral sidewall is not seen on at least one slice</td>
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LUG, levator–urethra gap.

The prevalence of levator trauma uncovered depends on the technique: transperineal ultrasonography, 13–36%13–17,73; needle electromyography, 30%27; and MRI, 20%39. In high-risk groups such as women delivered by forceps, LAM injuries can be detected in 64% using 3D transperineal ultrasound74 and 66% using MRI52.

Comparison between these studies is difficult for a number of reasons including patient selection, differences in demographics and variations in obstetric practice.

Women delivered by forceps are considered to be at high risk for LAM injury and hence are not representative of the normal primiparous population. Women in tertiary urogynaecological clinics are referred with symptoms of pelvic-floor disorders and are therefore more likely to sustain LAM injuries than asymptomatic women.

However, a more fundamental issue that hinders direct comparison between these studies is difficult for a number of reasons including patient selection, differences in demographics and variations in obstetric practice.
comparison is a lack of consistency in the definition and classification of LAM injuries.

Risk factors

One of the risk factors for LAM injuries is forceps delivery. While DeLancey et al. showed that women delivered by forceps have an adjusted odds ratio of 3.4 for LAM injury compared to those delivered without, Kearney et al. found an odds ratio of 14.7. Using transperineal ultrasound, LAM injuries have been demonstrated in 35–64% of women after forceps delivery. Although an association between LAM injuries and forceps delivery has been demonstrated, it remains to be established whether it is caused by the indication for its assignment or by the procedure itself. Furthermore, it is unclear whether it depends on the speed of delivery of the fetal head or the different types of forceps used.

Vacuum extraction does not seem to be a risk factor. There is evidence that a prolonged second stage of labor is associated with damage to the LAM. One study reported that women with LAM injuries have a 78-min longer second stage of labor, and another study reported an odds ratio of 2.27 for LAM injuries when the second stage was >110 min. Furthermore, fetal head circumference appears to be an independent risk factor. When the head circumference was greater than 33.5 cm, the odds ratio for LAM injury increased to 3.34, while a combination of both risk factors augmented the odds ratio to 5.32. In contrast, another study found no association between fetal head circumference and LAM injury. Epidural analgesia has been shown to provide a protective effect against LAM injury. There is evidence that increased maternal age at first delivery contributes to LAM injuries, although no association was found by others. The role of maternal body mass index (BMI) remains unclear. Shek and Dietz found that women with a lower BMI were at a higher risk of sustaining LAM injury, but the clinical significance is questionable, as the BMI was 27.85 vs. 30.01 kg/m².

Hoyte et al. found a significantly greater levator ani volume among African–American than in White American women. Moreover, the puborectalis attachment was closer to the symphysis in African–American than in white American women, and they concluded that this may protect against pelvic-floor dysfunction in the former. However, this study had small sample sizes of 12 and 10, respectively. In a larger study (n = 234), Handa et al. found no racial differences in LAM thickness, but found that African–American women who delivered without sustaining a sphincter tear had more pelvic floor mobility.

RELATIONSHIP BETWEEN OBSTETRIC LAM INJURIES AND PELVIC FLOOR DYSFUNCTION

Pelvic floor muscle strength

Pelvic floor muscle strength can be measured by, for example using the Oxford grading system, transperineal ultrasound imaging, and perineometry. Steensma et al. found that underactive pelvic floor muscle (defined as absent or weak pelvic floor muscle contraction on ultrasonography resulting in no or only minimal changes in the reduction of the levator hiatus) occurred more often in patients with an avulsion injury. LAM injuries were present in 53.8% with underactive pelvic floor muscle compared to 16.1% with normal pelvic floor muscle contraction. This finding is consistent with another study in which women with LAM avulsion had lower Oxford grading scores.

Stress urinary incontinence

The relationship between LAM injuries and SUI is controversial. Women suffering from SUI have been shown to be twice as likely to have a LAM injury, and the SUI of those with LAM injuries worsened postpartum. DeLancey et al. reported an odds ratio of 2.27 for LAM injuries when others were present. Table 3 Definitions used on magnetic resonance imaging to diagnose levator ani muscle (LAM) injury

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<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Definition</th>
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<tr>
<td>2003</td>
<td>DeLancey et al.</td>
<td>LAM defined as abnormal when this morphology was found in both the axial and coronal planes and had agreement by two examiners</td>
</tr>
<tr>
<td>2007</td>
<td>Branham et al.</td>
<td>Muscle belly thinning, disruption of continuity of the muscle, detachment from the insertion as well as for puborectalis injury the presence of protrusion of the vagina into the paravaginal space</td>
</tr>
<tr>
<td>2007</td>
<td>DeLancey et al.</td>
<td>Left and right muscles scored separately. A score of 0 assigned if no damage visible, 1 if less than half of the muscle is missing, 2 if more than half, and 3 if the complete muscle bulk is lost Total score is sum of both sides, ranging from 0 to 6 and categorized as follows: 0, normal or no defect; 1–3, minor defect; 4–6 major defect</td>
</tr>
<tr>
<td>2009</td>
<td>Adekanmi et al.</td>
<td>Loss of muscle attachment was recorded for the corresponding image number on the structured analysis grid if there was failure of continuity of the muscle between its normal attachment points</td>
</tr>
<tr>
<td>2010</td>
<td>Miller et al.</td>
<td>Muscle tear if fibers were absent in at least one 4-mm section or two or more adjacent 2-mm sections in both the axial and coronal planes, rated for both sides separately. They also distinguished between subtle (equivocal muscle fiber loss), low-grade (muscle fiber loss of &lt; 50%) and high-grade tears (muscle fiber loss of &gt; 50%)</td>
</tr>
<tr>
<td>2010</td>
<td>Novellas et al.</td>
<td>Puborectalis abnormality: hypersignal of muscle, thinning or thickening, a rupture of the muscular insertion. Iliococcygeus abnormality: flat or concave aspect either uni- or bilateral</td>
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et al.\textsuperscript{82} found no relationship with LAM injuries while others have found a negative association\textsuperscript{55,56}.

Morgan et al.\textsuperscript{83} found that women with major LAM defects were less likely to experience SUI, whereas the risk increased in those with minor LAM defects (odds ratio (OR) 0.27 vs. 3.1). Furthermore, they found an increased risk of urge urinary incontinence in the minor LAM defects group (OR 4.0).

Fecal incontinence

There appears to be a relationship between LAM defects and fecal incontinence in older women, highlighting the importance of an adequately functioning external anal sphincter as well as LAM\textsuperscript{47,48}. This concurs with another case–control study in which more puborectalis muscle abnormalities (as identified by transperineal 3D ultrasonography) were seen in fecally incontinent cases than in controls\textsuperscript{84}. In contrast to this Chantarasorn et al.\textsuperscript{85} did not find an association between LAM defects and fecal incontinence. However, data on anal sphincter injury were not available in their study, which might explain this surprising result.

Pelvic organ prolapse

It has been established that LAM injury increases the risk of POP\textsuperscript{53}. Levator avulsion appears to double the risk of significant anterior and central compartment prolapse, with less effect on posterior compartment prolapse\textsuperscript{58}. There is a direct correlation between the size of the defect and the symptoms and/or signs of prolapse\textsuperscript{56}, and women with bilateral avulsion are more likely to suffer from uterine prolapse\textsuperscript{58}. It is unclear why all women with LAM injuries do not develop prolapse – or is it just a matter of time?

In a case–control study of 151 women with POP, DeLancey et al.\textsuperscript{75} found an adjusted odds ratio of 7.3 (95% CI, 3.9–13.6) (P < 0.001) for major LAM defects but an equal number of minor defects. Not only do short-term operative results seem to deteriorate with major levator defects\textsuperscript{86}, but also the risk of recurrence of POP (cystocele) after an operation in women with LAM injuries has been demonstrated\textsuperscript{58,88}. This is further supported by another study reporting an odds ratio of 5.99 for greater than stage two POP (International Continence Society POP quantification system) after hysterectomy, 4.35 after incontinence or POP surgery, 3.37 after anterior repair and 4.33 after colposuspension\textsuperscript{89}. Furthermore, POP symptoms appear to correlate with LAM avulsion if at least three central slices on tomographic ultrasound imaging (TUI) show LAM abnormality\textsuperscript{90}, but surprisingly this has not been confirmed by others subsequently\textsuperscript{87}.

There is an association between vaginal delivery and increased hiatal area, especially in women with altered LAM integrity like microtrauma or LAM avulsion\textsuperscript{33,91}.

**DIAGNOSIS OF LAM INJURY**

Clinical examination

Acute LAM injuries can be diagnosed clinically by visualization and digital examination when levator avulsion is associated with a large vaginal tear\textsuperscript{44}. Chronic detachment of the LAM from the inferior ramus of the pubic bone can be evaluated by palpation\textsuperscript{52,57,61,63,66,79,89,92–94}. To diagnose LAM injury, the index finger should be inserted into the vagina to a maximum depth of 4 cm (as the insertion of the puborectalis muscle on the inferior ramus of the pubic bone is only 2–4 cm proximal to the perineum). The finger should be placed lateral and parallel to the urethra with the finger tip on the bladder neck. Hence the insertion of the puborectalis muscle to the pubic bone can be palpated immediately lateral to the index finger about 2 cm proximal to the introitus\textsuperscript{52}. According to Laycock\textsuperscript{80} the strong pubococcygeus of a young woman will feel as a 1–2 cm firm band. An avulsion defect is diagnosed if the inferior ramus feels free of muscle while moving the finger laterally\textsuperscript{52}. Palpation should be performed at rest and during contraction to identify the presence of small muscle amounts\textsuperscript{92}.

A recognized contraction of the bulbospongiosus muscle outside the hymen and the iliococcygeal muscle more than 3 cm proximal to the hymen can easily be distinguished from the targeted pubovisceral muscle contraction\textsuperscript{93}.

Table 1 shows different definitions that have been used to diagnose LAM injury and Figure 2 shows a ‘template’ that can be used to document it. Even though operators were blinded against each others’ findings, correlation...
of palpation and transperineal ultrasound assessment ranged between good, moderate and poor. Palpation between different assessors revealed moderate correlation. It has been established that the assessment of LAM injuries with transperineal two-dimensional (2D)/3D ultrasound between assessors reveals highly reproducible findings.

Ultrasonography

According to the recommendations on ultrasonography images should depict cranial parts on top and ventral parts on the right side of the screen to allow for comparison between investigators. However, this recommendation has not been followed universally. Although strictly speaking, the notations transperineal, interlabial and translabial are not interchangeable, they are often used as such. The term transperineal is often adopted for intravaginal ultrasound as well, even though the latter implies the placement of a transvaginal probe within the introitus. Furthermore, endovaginal ultrasound can be used to assess the pelvic floor.

2D Transperineal ultrasound

Dietz and Shek showed that detection of LAM injuries via 2D transperineal ultrasound is possible and reproducible and correlates with palpation and 3D transperineal ultrasound. A mid-sagittal view is obtained by placing a transducer (usually a 3.5–7-MHz curved array) on the perineum after covering the transducer with a glove. Dorsal lithotomy with the hips flexed and the legs slightly abducted or upright are common imaging positions. Patients should be advised to empty the bladder prior to scanning.

An oblique parasagittal approach is used to line up the main transducer axis with the fiber direction of the puborectalis muscle. Starting from the midsagittal plane the curved array transducer is rotated by 10–20° and tilted from the inferomedial to the superolateral aspect. Avulsion is diagnosed if there is a discontinuity between the hyperechogenic fibers of the puborectalis muscle and the pelvic sidewall, with the insertion replaced by a hypoechogenic zone representing the vaginal wall.

3D/4D Transperineal ultrasound

3D/4D Transperineal ultrasound using the GE Voluson 730 system (GE Kretztechnik, Zipf, Austria) with an 8–4-MHz curved array volume transducer (with an acquisition angle of up to 85°) is popular for diagnosing LAM injuries. Women are examined in the supine position after emptying the bladder. Volume acquisition is performed at rest, on maximal Valsalva and on maximal pelvic floor contraction. Hiatal anteroposterior and coronal diameters, circumference and areas are measured at the plane of minimal hiatal dimensions as defined in the midsagittal plane.

evident as the minimal distance between the hyperechogenic posterior aspect of the symphysis pubis and the hyperechogenic anterior boarder of the LAM just posterior to the anorectal angle. TUI with slices obtained in the axial plane at 2.5-mm slice intervals, from 5 mm below the plane of minimal hiatal dimensions to 12.5 mm above the plane of minimal hiatal dimensions to 12.5 mm above (Figure 3), and rendered volumes (Figure 4) are used to diagnose levator avulsion.

Figure 3 Tomographic ultrasound images obtained using transperineal ultrasound of (a) a typical intact levator ani muscle (LAM) in a nulliparous woman and (b) a bilateral LAM avulsion in a multiparous woman. White asterisks in (b), LAM defects. L, levator ani muscle; R, rectum; U, urethra; V, vagina.

Figure 4 Three-dimensional rendered volumes obtained on transperineal ultrasound showing (a) an intact levator ani muscle (LAM) displayed as oblique axial plane in a nulliparous woman and (b) a bilateral avulsion injury. White asterisks in (b), LAM defects. IR, inferior ramus os pubis; L, levator ani muscle; R, rectum; U, urethra; V, vagina.
The various definitions used to define LAM injury demonstrate the scientific process in action and are shown in Table 2.

**Endovaginal 3D ultrasound**

Images obtained on endovaginal ultrasound have good to very good correlation with the muscle parts in cadaveric sections. In order to standardize endovaginal examination of, for example, the levator ani muscle, Santoro et al. inserted an endoanal ultrasound probe (9–16-MHz rotational 360° transducer (type 2050, B-K Medical)) into the vagina of 20 nulliparous women, who were in the dorsal lithotomy position with a comfortable bladder volume. Three hundred axial images over a distance of 6 cm were taken in 60 s and four standard levels of assessment (from proximal to distal) were defined. The 1st level includes the bladder base and rectum, the 2nd the bladder base, the intramural urethra and the anorectal angle. At the 3rd level the entire pubovisceral muscle can be visualized as a hyperechoic sling lying posterior to the anorectum and attaching to the pubic bone, which resembles a ‘gothic arch’ (Figure 5a). Tilting of the axial plane that includes the symphysis pubis anteriorly to the ischiopubic rami laterally demonstrates the structures more clearly. On the 4th level the transverse and sagittal diameters of levator hiatus are performed on transverse sections at the level of the middle urethra. The width of the levator hiatus is measured between the medial margin of the right and left LA• attachment to the two pubic rami and Cronbach’s \( \alpha = 0.970 \) for levator hiatus length, width and area.

**Magnetic resonance imaging**

Pelvic floor MRI uses proton density T-2-weighted scans, 2-D fast-spin proton density MR with an echo time of 15 ms and a repetition time of 4000 ms, performed at 5-mm intervals in the axial, sagittal, and coronal planes in the supine position using a 1.5 Tesla superconducting magnet (Signa, General Electric Medical Systems, Milwaukee, WI, USA). The settings most often used have a slice thickness of 4 mm with a gap of 1 mm. The transverse imaging acquisition plane is perpendicular to the body axis and deviates from the sacrococcygeal inferior pubic point line by approximately 32° degrees. LAM thickness is measured in axial planes at the level of the mid urethra, proximal urethra and bladder base (Figure 6). In the coronal planes LAM thickness and cross-sectional area are measured at the level of the urethral lumen (level 1), the posterior urethral wall and the lateral anterior vaginal wall (level 2), the rectovaginal space/rectal pillar (level 3), 1.5 cm dorsally (level 4) and at the level of the ischial spine/sacrospinous ligament (level 5), and the LAM volume is calculated. Measurements of the transverse and sagittal diameters of levator hiatus are performed on transverse sections at the level of the middle urethra. The width of the levator hiatus is measured between the medial margin of the right and left LA• at the level of the lateral vaginal wall. The length (sagittal diameter) of levator hiatus is the distance from the pubic bone to the posterior rectal wall.

Figure 5 Images obtained on endovaginal scan in (a) a nulliparous woman with intact levator ani muscle (LAM) at level 3 and (b) a primiparous woman after forceps delivery, right mediolateral episiotomy and a third-degree tear with unilateral avulsion injury (axial plane at level 3). In (a) the LAM attachment is indicated by arrows. In (b) arrows indicate missing LAM muscle on patient’s right side. IR, inferior rami os pubis; L, levator ani muscle; P, probe; R, rectum; U, urethra; V, vagina (with endovaginal probe).
iliococcygeus part of the LAM. Furthermore, those who were older than 30 years had a better recovery at 6 months than those who were younger than 30 years. However, larger sample sizes are needed to confirm these findings.

One of the advantages of MRI over ultrasound is the visualization of concomitant pelvic fractures. Miller et al. identified fracture lines involving the subcortical regions of the pubis in 46% of subjects after high-risk childbirth. All the fractures had resolved at the follow-up appointment. It seems that a combination of injury patterns, including LAM fibers tearing from their origin and tendinous fascia pelvis (white open arrowhead) on the left side (black arrowhead) and loss of hammock-like shaped vagina on the avulsed side (white arrowhead).

Figure 6 (a) Axial proton-density-weighted magnetic resonance (MR) image at the level of the middle urethra in a nulliparous woman, showing levator ani muscle (LAM) (outlined in white), hammock-shaped anterior vaginal wall (white arrowhead) and LAM thickness at lateral vaginal wall (area between T-brackets). Low signal intensity shows the smooth muscle layer of intact anterior vaginal wall and insertion of the LAM into the pubic bone. (b) MR image showing LAM (white filled arrowhead), intact LAM attachment to lateral vaginal wall (black arrowhead) and arcus tendineus fascia pelvis (white open arrowhead) on the left side.

Including...

Using MRI 16% of patients complaining of SUI and/or prolapse were shown to have defects in the pubovisceral portion of the LAM (Figure 7). In addition a missing connection of LAM at the symphysis pubis has been demonstrated in 20% of asymptomatic nullipara. There is a 2–3-fold inter-individual difference in LAM morphometry. On the first postpartum day in addition to altered thickness of the LAM altered signal intensities have been demonstrated. A constant tissue composition is seen in nulliparae whereas birth-related changes are found in primiparae.

Novellas et al. found that the effort of labor itself inflicts a deleterious effect on the pelvic floor muscle independently of fetal head crowning, as they found a 2.7-fold increase in abnormalities among women delivered by Cesarean section during labor compared to those scheduled prior to the onset of labor. These abnormalities were detected as hypersignal of the puborectalis more often than hypersignal of the iliococcygeus and a change in the orientation of the iliococcygeus from convex to flat or concave in the early postpartum period. This agrees with another study in which most of the trauma was identified in the pubovisceral portion rather than the iliococcygeus part of the LAM. Furthermore, those who sustained injuries of the puborectalis and iliococcygeus had not recovered by 6 months after delivery whereas those with isolated damage to the puborectalis had. Moreover, white primiparous women who were younger than 30 years had a better recovery at 6 months than those who were older than 30 years. However, larger sample sizes are needed to confirm these findings.

One of the advantages of MRI over ultrasound is the visualization of concomitant pelvic fractures. Miller et al. identified fracture lines involving the subcortical regions of the pubis in 46% of subjects after high-risk childbirth. All the fractures had resolved at the follow-up appointment. It seems that a combination of injury patterns, including LAM fibers tearing from their origin and tendinous fascia pelvis (white open arrowhead) on the left side (black arrowhead) and loss of hammock-like shaped vagina on the avulsed side (white arrowhead).

Figure 7 Axial proton-density-weighted magnetic resonance image at the level of the middle urethra of a parous patient, showing missing levator ani muscle attachment on the right side (black arrowhead) and loss of hammock-like shaped vagina on the avulsed side (white arrowhead).

COMPARISON OF MRI AND ULTRASOUND

Very few comparative studies exist that utilize MRI and 3D-transperineal ultrasound to detect levator injuries. Majida et al. used 18 female volunteers to compare biometric measurements of the pubovisceral muscle at rest. They found very good agreement, with interclass correlation coefficients of 0.80–0.97, and concluded that 3D transperineal ultrasound scans could be used instead of MRI for the evaluation of static pelvic floor anatomy in women without prolapse at rest.

Kruger et al. conducted a study in 27 asymptomatic nulliparous women to compare biometric measurements of the pelvic floor using 3D transperineal ultrasound and MRI. They defined the plane of minimal hiatal dimensions on ultrasound according to Dietz et al. with a comparable definition used for MRI. Moderate to substantial agreement between the two methods for all parameters except for hiatal area on Valsalva maneuver was found. They concluded that this was the result of difficulties in identifying the plane of minimal hiatal dimensions on MRI owing to poorer temporal resolution compared with ultrasound imaging, and reasoned that 3D ultrasonography is an interchangeable modality with MRI. In a recent study transperineal ultrasound and MRI were compared in 69 women with prolapse. Interobserver repeatability was moderate to excellent.
for levator–urethra gap, levator symphysis gap and puborectalis attachment width with both methods, as was agreement between methods in diagnosing levator avulsion.

In a case report Dietz et al. demonstrated pubovisceral avulsion associated with a large vaginal tear with both MRI and translabial 4D ultrasound. In the axial MRI sections they were able to illustrate muscle thinning on the right side with a focal defect as well as the lateral edge of the vagina, reaching the lateral pelvic wall without any intervening tissue. 4D ultrasound showed a complete absence of the right pubovisceral muscle insertion on the inferior pubic ramus.

Although it is possible to detect LAM injuries with both imaging modalities, there is a substantial learning curve in performing the techniques and interpreting the images. More comparative studies in which MRI and 3D ultrasound are performed in the same patients are awaited.

PREVENTION OF LAM INJURY

The strong association between POP and obstetric LAM injuries suggests that risk factors need to be identified in order to institute preventive strategies. POP is a common condition that is found in 41% of women between 50 and 79 years of age and is one of the most common indications for gynecological surgery. Forceps is a known risk factor for LAM injuries. As forceps is a known risk factor for LAM injuries, it is possible to detect LAM injuries with MRI and fecal and urinary incontinence is less clear. Although it is possible to detect LAM injuries with MRI and 3D ultrasound are performed in the same patients are awaited.

CONCLUSIONS

Prospective studies have shown that LAM injuries occur in 13 to 36% of women who deliver vaginally. LAM injuries increase the risk of cystocele and uterine prolapse but their relationship to posterior wall prolapse and fecal and urinary incontinence is less clear. Although it is possible to detect LAM injuries with MRI and 3D ultrasound, there is a substantial learning curve in carrying out the procedures and interpreting images. Furthermore, the numerous definitions of LAM injury make it difficult to perform comparisons and draw conclusions. More studies are awaited where both imaging modalities are performed on the same subjects. It may be prudent to determine standards for LAM diagnosis so that comparisons between studies can be made. Further research should focus on risk factors and preventive measures.

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AQ2 NOTE TO COPY EDITOR: Please keep changes to the text, beyond formatting and stylistic corrections, to a minimum. Thanks (OS)

AQ3 Author query: I've interpreted ‘3.5 fingers’ as ‘3.5 finger widths’; is that OK?

AQ4 Author query: Here again LUG has been expanded as levator–urethra gap; OK? And I've added cm after LUG in the 2009 Dietz & Shek entry; OK?

AQ5 Au: Please check that you are happy with the new Figure 5 legend.

AQ6 Au: “A Pubmed literature search was conducted between July 2010 and September 2011 using the terms…” just to clarify, I assume that there was no publication date restriction on studies considered. Would it make sense to add this here? (OS)

AQ7 Au: “‘faecal incontinence’, was the American spelling ‘fecal incontinence’ also considered? (OS)

AQ8 Author query: injuries added after LAM; OK?

AQ9 Author query: In the refs list, ref. 26 is a single-author work, so I have deleted ‘et al.’ after ‘Balmforth’; but should ‘They’ be changed to ‘He’ or ‘She’?

AQ10 Author query: ‘and those with LAM injuries that worsened postpartum’ changed to: ‘and the SUI of those with LAM injuries worsened postpartum’; does that convey the correct sense?

AQ11 Author query: ‘ICS POP-Q’ changed to ‘International Continence Society POP quantification system’; OK?

AQ12 Author query: I’m not quite sure what is meant by ‘small muscle amounts’; would you mind checking? Is it ‘small amounts of detached muscle’?

AQ13 Author query: I don’t see the significance of the shaded ‘Defect’ and ‘Thinning’ in Fig. 2; would you mind checking?

AQ14 Author query: Is the address correct for GE Voluson?

AQ15 Au: Please note that Figures 3 and 4 (now 3a&b), Figures 5 and 6 (now 4a&b) and Figures 7 and 8 (now 5a&b) have been paired up. Are you happy with this? (OS)

AQ16 Au: Figure 3: “Slices are obtained at 2.5 mm intervals below and above the level of minimal hiatal dimension (green star)” I have used the wording from the second image for both here, is that correct? (OS)

AQ17 Au: “U, urethra; V, vagina; R, rectum; L, LAM.” These are not shown in the images. Should this be removed or should the labels be added? (OS)

AQ18 Author query: I wasn’t quite sure what was meant by ‘The various definitions used to define LAM injury demonstrate a scientific process in motion’; I’ve changed it to: ‘The various definitions used to define LAM injury demonstrate the scientific process in action’; is that OK?

AQ19 Author query: Would it be possible to provide an address for B-K Medical?

AQ20 Author query: Should LA here be LAM?

AQ21 Author query: Have the arrows been identified correctly? And are the changes made OK?

AQ22 Author query: Here again should LA be LAM?

AQ23 Author query: Could you please check: ‘The length (sagittal diameter) of levator hiatus is the distance from the pubic bone to the posterior rectal wall. Including,’ and amend as appropriate?

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