How much does the levator hiatus have to stretch during childbirth?

K Svabik,a KL Shek,b HP Dietzb

a Department of Obstetrics and Gynecology, First Faculty of Medicine, Charles University in Prague, General University Hospital in Prague, Prague, Czech Republic b Nepean Clinical School, University of Sydney, Nepean Hospital, Penrith, NSW, Australia

Correspondence: K Svabik, Department of Obstetrics and Gynecology, First Faculty of Medicine, Charles University in Prague, General University Hospital in Prague, Apolinarska 18, Prague 2, 128 00, Czech Republic. Email kamil@svabik.cz

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Objective This study was designed to define the degree of stretch/strain required of the levator hiatus in childbirth. There have been attempts at defining the distension required for vaginal childbirth with the help of individual data sets, but from previous work it is clear that hiatal dimensions and distensibility are likely to vary greatly between individuals.

Design Retrospective observational study.

Setting Nepean Hospital, University of Sydney.

Population Nulliparous women at 36–38 week’s gestation.

Methods The ultrasound data sets of 227 nulliparous women examined at 36–38 week’s gestation were investigated using post-processing software. Minimal hiatal diameters, subpubic arch, circumference and area were measured at rest, on Valsalva and pelvic floor muscle contraction. To estimate required hiatal distension at vaginal birth we used neonatal biometric data obtained in a Caucasian population. The muscle ‘strain’ or ‘stretch ratio’ required to allow delivery of a Caucasian baby of average size was calculated from dimensions at rest and on maximal Valsalva.

Main outcome measures Degree of stretch/strain required of the levator hiatus in childbirth.

Results The mean strain (stretch ratio) required for vaginal delivery was calculated as 1.47 (range 0.62–2.76; SD 0.39) from resting length, and 1.07 (range 0.25–2.45; SD 0.44) when calculated from dimensions at maximal Valsalva. This implies that, from dimensions at maximal Valsalva, some women will have to distend only 25%, others by 245%.

Conclusions We have obtained normative data for the required distension of the levator hiatus in a largely Caucasian population.

Keywords Avulsion, birth trauma, levator ani, levator hiatus, translabial ultrasound.

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Introduction

Biometry and function of the levator ani muscle in the human female is likely to be of importance for successful vaginal childbirth. The birth canal is defined not only by the rigid bony pelvis but also by the puborectalis component of the levator ani muscle. The main purpose of this muscle in the human female is to close off the abdominal cavity caudally while allowing for elimination of faeces and urine as well as for intercourse, requiring limited dimensions and distensibility and high resting tone. Vaginal childbirth implies an entirely different set of requirements. The levator hiatus has to distend to a much greater degree, preferably without reaching its elastic limit. The crucial moment in testing muscle properties is the late second stage of labour and crowning of the fetal head,1 a process that frequently results in substantial trauma.2–4 There have been attempts at defining the distension required for vaginal childbirth with the help of individual data sets acquired with magnetic resonance imaging,5,6 but from previous work it is clear that hiatal dimensions and distensibility are likely to vary greatly between individuals.7 Both the unit of the first author8 as well as others9 have shown a potential association between hiatal dimensions and delivery outcome. This study was designed to define the degree of stretch/strain required of the levator hiatus (defined by the puborectalis muscle) in childbirth in a large nulliparous cohort.

Methods

In a retrospective observational study, we analysed the 4D ultrasound data sets of 227 nulliparous women seen at 36–38 week’s gestation as part of an continuing perinatal inter-
vention trial. The antenatal assessment consisted of a history, a clinical examination with Bishop Score, and 4D ultrasound imaging using a GE Kretz Voluson 730 Expert system (GE Kretztechnik GmbH, Zipf, Austria) with RAB 8–4 MHz curved array volume transducer. Volume data sets were acquired with the patient supine with empty bladder at rest, on maximal Valsalva and during pelvic floor muscle contraction. The stored volumes of 224 women were processed using proprietary software by KS; three data sets were missing. Minimal hiatal diameters (coronal and sagittal), circumference and area were determined as previously described,10 see Figure 1 for a representation of axial plane imaging on Valsalva.

To determine muscle strain, we also measured the bony part of the hiatus, i.e., part of the subpubic arch, and this was subtracted from the hiatal circumference to obtain the muscular component of the levator hiatus. To estimate the required hiatal distension at vaginal birth we used neonatal biometric data obtained in a Caucasian population.11 We assumed an ellipsoid shape of the fetal head and a best case scenario where the baby is going to be delivered from the occipito-anterior position. As the minimal head circumference is determined by the biparietal (BPD = 9.15 cm) and sub-occipito-bregmatic diameters (SOBD = 9.6 cm) we calculated a mean circumference of 29.38 cm using Ramanujan’s equation12 for ellipse circumference, i.e.,

\[
C = \frac{1}{2} \pi \left(\frac{3}{\pi} (3 \times 0.5 \text{SOBD} + 0.5 \text{BPD}) \times (0.5 \text{SOBD} + 3 \times 0.5 \text{BPD})\right).
\]

we re-calculated the postnatal biometric data to account for the effect of moulding of the head using the modified moulding index. (SOBD—decrease by 2.84% and BPD decrease by 0.92% as published by Lapper and Prager).13 Subtraction of the individual bony arc measurement (\(h_b\)) from the calculated circumference of an average Caucasian baby provided the required muscular length (RML) for individual women, to allow us to answer the research question: ‘How much does the levator hiatus have to distend to allow delivery of an average Caucasian baby?’ The required ‘strain’ or ‘stretch ratio’ was calculated as previously described,14 dividing the required length of this muscle to allow delivery of the baby (RML) by the observed length of the puborectalis muscle defining the hiatus at rest or on maximal Valsalva. (Formula 1). A strain of 25% implies elongation of fibres to 125% of their initial length. The data were analysed with descriptive statistics.

\[
\varepsilon_{\text{req}} = \frac{(C_{\text{rest/valsalva}} - C_{\text{rest/valsalva}})}{(C_{\text{rest/valsalva}} - h_b)}
\]

\(\varepsilon_{\text{req}}\) = strain to reach the required muscular length; \(C_{\text{req}}\) = required hiatal circumference for delivery of average Caucasian baby; \(C_{\text{rest/valsalva}}\) = hiatal circumference at rest or on Valsalva; \(h_b\) = bony arc length.

In a series of 10 data sets analysed by KS and KLS all parameters used in this paper were tested for repeatability, using intraclass correlation coefficients (single measurements, absolute agreement definition) and Bland-Altman analysis.

This study is a sub-analysis of a project that was approved by the Institutional Human Research Ethics Committee (reference SWAHS 05-004). Statistical analysis was undertaken using SAS Version 9 (SAS Institute Inc., Cary, NC, USA) and Minitab V. 13 (Minitab Inc., State College, PA, USA). All parameters used for analysis were found to be normally distributed on Kolmogorov–Smirnov testing.

**Results**

We examined the 4D ultrasound volume data sets of 227 women. Three volumes proved unavailable for analysis, leaving 224. Mean gestational age was 37.1 weeks (range 35.6–39.1), mean BMI before pregnancy 24.96 (15.3–46.33), BMI at examination 30.61 (19.37–50.29) mean age 25.4 years. Both height (Pearson correlation \(r = 0.211\); \(P\)-value 0.0015) and weight (\(r = 0.220\); \(P\)-value 0.0009) were weakly associated with hiatal area, as well as BMI (\(r = 0.167\); \(P\)-value 0.0121).
Table 1. Descriptive statistics for hiatal dimensions at rest and on Valsalva

<table>
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<th></th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
<th>SD</th>
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<tbody>
<tr>
<td>Sagittal diameter at rest</td>
<td>5.51</td>
<td>7.42</td>
<td>3.62</td>
<td>0.75</td>
</tr>
<tr>
<td>Coronal diameter at rest</td>
<td>3.82</td>
<td>5.48</td>
<td>2.48</td>
<td>0.45</td>
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<tr>
<td>Hiatal circumference at rest</td>
<td>14.74</td>
<td>20.35</td>
<td>10.81</td>
<td>1.67</td>
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<tr>
<td>Hiatal area at rest (cm²)</td>
<td>14.13</td>
<td>24.37</td>
<td>8.33</td>
<td>3.05</td>
</tr>
<tr>
<td>Sagittal diameter on Valsalva</td>
<td>6.28</td>
<td>9.31</td>
<td>3.78</td>
<td>1.09</td>
</tr>
<tr>
<td>Coronal diameter on Valsalva</td>
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<td>6.26</td>
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<tr>
<td>Hiatal circumference on Valsalva</td>
<td>16.98</td>
<td>24.36</td>
<td>11.47</td>
<td>2.61</td>
</tr>
<tr>
<td>Hiatal area on Valsalva (cm²)</td>
<td>20.17</td>
<td>42.39</td>
<td>9.74</td>
<td>6.47</td>
</tr>
<tr>
<td>Bony arc length</td>
<td>4.37</td>
<td>5.87</td>
<td>2.96</td>
<td>0.59</td>
</tr>
</tbody>
</table>

All measurements given in cm unless otherwise indicated (n = 224).

Over 91% of women were of Caucasian background (6% part Caucasian, 3% Asian, Polynesian or Indian). The reliability of measurements was tested in a test–retest series on ten patients, with intraclass correlations (absolute agreement definition, single measurements) all above 0.8, indicating excellent repeatability, except for bony arc (data not shown).

Table 1 gives descriptive statistics for hiatal dimensions at rest and on Valsalva. The mean strain (stretch ratio) required for vaginal delivery (assuming an average Caucasian baby delivered in the occipito-anterior position) was calculated as 1.47 (range 0.62–2.76; SD 0.39) from resting length, and 1.07 (range 0.25–2.45; SD 0.44) when calculated from dimensions at maximal Valsalva. This implies that, from dimensions at maximal Valsalva, some women will have to distend only 25%; others by 245% (Figures 1 and 2); that is, in individuals fibres may have to stretch to 1.25 times or to 3.45 times the fibre length on Valsalva (Figure 3). For comparison with MR data, the respective figures for resting dimensions imply a range for required distension of 62–276% over resting length. This implies that in some individuals fibres have to stretch to 1.62 times their resting length, and in others to 3.78 times resting length.

Taking into account the potential effect of moulding changes figures only slightly. The mean strain from dimensions at rest decreases from 1.47 to 1.42 (range 0.59–2.69; SD 0.38) and on maximal Valsalva from 1.07 to 1.03 (range 0.23–2.38; SD 0.43).

Discussion

There is no doubt that the levator hiatus, in particular the puborectalis muscle, has to distend markedly to allow vaginal childbirth. Several authors have used computer modelling of individual data set of non-pregnant nulliparae to estimate the degree of distension required for successful vaginal delivery and obtained stretch ratios of 2.26 (226%) and 2.5 (250%) for this muscle. Our results demonstrate that the population distribution for this parameter is likely to be very wide, with a mean of 1.47. Both quoted studies show required distension in the upper part of the range demonstrated by us. A direct comparison should be possible, since 4D ultrasound and MR pelvic floor imaging have been shown to correlate well.\(^1\)^

Figure 2. Histogram of required strain from dimensions at rest to deliver an average Caucasian baby.
Apart from chance, there may be another potential explanation for the fact that the mean required distension obtained in our study is below the quoted MR data on individuals. We analysed data of women in late pregnancy, and while we are not aware of any longitudinal studies examining the effect of pregnancy on hiatal dimensions, our descriptive data (Table 1) are substantially higher than our previously published normative data in nulligravid women (area at rest, 14.13 versus 11.25; area on Valsalva, 20.17 versus 14.05). Clearly, late pregnancy is a more appropriate time to assess required distension in childbirth compared to the non-pregnant state.

In this study, we have obtained normative data for required distension of the levator hiatus on childbirth in a largely Caucasian population. We were able to calculate required strain not only from the resting state, but also from maximal Valsalva. While, this may be regarded as a more realistic measure, it has to be acknowledged that hiatal dimensions on Valsalva are frequently confounded by involuntary co-activation of the levator ani, even after substantial teaching by operators well aware of this confounder. The strain required for vaginal delivery of an average sized Caucasian baby, on top of the distension obtained by maximal Valsalva, varied from 25% to 245%, that is, by a factor of 10. When considering dimensions at rest, the respective figures are from 62% to 276%, i.e., by a factor of 4.5.

This enormous variability might explain why the muscle reaches its elastic limit in a substantial number of women, suffering an avulsion injury. This is not uncommon, with a prevalence of 20–36% after first vaginal delivery. Avulsion is permanent and has late sequelae because it is associated with pelvic organ prolapse, mainly cystocele and uterine prolapse. Contrary to expectations, however, levator trauma is not associated with urodynamic stress incontinence or fecal incontinence.

It is not surprising that in some women the levator ani is not able to withstand the force causing its elongation. Skeletal muscle fibres in the uncontracted state are injured when single sarcomeres are stretched so much that thick and thin filaments no longer overlap which in mice starts to occur at 30% fibre elongation. Disruption is complete at a strain of 60%. Some overstretched thin filaments are able to re-enter the thick filament array, but the extent of this effect is difficult to predict. There is a strong relationship between the work performed to lengthen the muscle and the magnitude of damage. It seems apparent that there will be several mechanisms of trauma affecting components of the levator ani muscle during childbirth. Trauma may occur within the muscle or at its insertion, and it may be partial or complete.

Since childbirth-related trauma to the levator ani, in particular to the puborectalis muscle, is common and clinically important, one should consider potential preventative measures. One approach would be to avoid vaginal delivery by performing elective Caesarean Section. This may become feasible if it was possible to identify women at high risk of levator trauma, and the authors are currently investigating this possibility. Modification of obstetric practice, e.g. Vacuum instead of Forceps delivery, may also hold some
promise. Furthermore, it may be possible to modify the biomechanical properties of the muscle, i.e., to increase its distensibility, and the authors are currently undertaking an intervention trial testing this hypothesis.

There are a number of limitations to this study. It is acknowledged that the variable direction of levator ani fibres and the non-euclidean shape of the levator plane make it virtually impossible to describe the hiatus and its distension in anything other than global terms. For this reason, we use the term ‘puborectalis muscle’ for the muscular structure defining the levator hiatus at rest and on Valsalva, even though it is currently technically impossible to define the relative contribution of other minor aspects of the levator ani, i.e., of the pubovaginalis, puboperinealis or puboanalis components of the levator ani.

In addition, the size of the hiatus is only one factor influencing events. It is conceivable that in some women the shape of the subpubic arch will affect required distension. A narrow subpubic arch may displace the fetal head posteriorly and increase the necessary hiatal distension beyond the degree assumed by us. Different degrees of moulding and malpresentation will also exert an influence, and this implies that our methodology is likely to underestimate required distension in many clinical scenarios.

Conclusion

There are substantial inter-individual variations in the distension required of the levator hiatus in Caucasian women at term, even assuming an optimal fetal position. It is entirely plausible that in some women the required distension will result in the muscle reaching its elastic limit, causing permanent injury, either in the form of avulsion, or in the form of permanent overdistension. The wide population spread for required muscle strain documented in this study questions the appropriateness of using individual imaging data sets for modelling pelvic floor function in childbirth, and may explain some of the variation in obstetric outcomes observed in nulliparous women. We are in the process of testing the parameters described here for their value as surrogate measures of pelvic floor muscle compliance, analysing their predictive value for obstetric performance and delivery-related pelvic floor trauma.

Disclosure of interests

K Svabik and KL Shek have no conflict of interest; HP Dietz has acted as a consultant for AMS and CCS, received speaker’s fees from Astellas, GE and AMS and has obtained equipment loans from Toshiba, GE and Bruel&Kjaer.

Contribution to authorship

K Svabik contributed in data analysis, data entry and manuscript preparation. KL Shek accessed reliability series, data acquisition, analysis and proofreading of manuscript. HP Dietz contributed to the study design, supervision of data entry and analysis, manuscript preparation.

Details of ethics approval

Institutional Human Research Ethics Committee SWAHS 05-004.

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References


