DR JENNIFER KRUGER (Orcid ID : 0000-0003-4609-8966)

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Characterising levator-ani muscle stiffness pre- and post-childbirth in European and Polynesian women in New Zealand: a pilot study.

Running headline: Characterising levator-ani muscle stiffness.

Jennifer A Kruger[1] , Stephanie C Budgett [1] , Vivien Wong[2] , Poul M.F. Nielsen[1,3], Martyn P Nash[1,3] , Jackie Smalldridge[1] , Lynsey M Hayward[1] , Tania Yu TIAN[1] & Andrew J. Taberner[1]

[1]Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand

[2] Sydney Medical School Nepean, University of Sydney, Sydney, Australia

[3]Department of Engineering Science, University of Auckland, Auckland, New Zealand

Corresponding author

Jennifer A Kruger

Auckland Bioengineering Institute, University of Auckland, 70 Symonds Street, Auckland, New Zealand

Email: j.kruger@auckland.ac.nz

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Abstract

Introduction: The influence of levator-ani muscles on second stage labour is poorly understood. The ability of these muscles to stretch without damage may affect birth outcomes, but little is known about material properties, effects of pregnancy and/or ethnicity on levator-ani stiffness. There are strong associations between muscle damage and subsequent pelvic floor disorders. This study aimed to quantify levator-ani muscle stiffness during the third trimester of pregnancy and postpartum in European and Polynesian women. Associations between stiffness, obstetric variables, and the risk of intrapartum levator-ani injury (avulsion) were investigated. *Materials and methods:* This was a prospective observational pilot study. 167 nulliparous women were recruited antenatally; 106 European and 61 Polynesian, 129 returned postnatally. Participants were assessed between 36 and 38 weeks gestation and 3 to 5 months postpartum. Assessments included pelvic floor ultrasound, elastometry testing, and validated questionnaires on pelvic floor function. Logistic regression, Student *t*, Chi-squared and Mann-Whitney tests were used as appropriate. *Results:* There are significant differences between antenatal and postnatal muscle stiffness measurements ($p < 0.01$). Stiffness was significantly higher in the European cohort ($p = 0.03$). There were more avulsion injuries in European (20 %) compared to Polynesian (9 %) women. There were no significant differences in antenatal stiffness between women with and without avulsion, but change in stiffness (antenatal to postnatal) was significantly less in the avulsion group. There were no associations between stiffness, and other obstetric variables, epidural anaesthesia seemed protective ($p = 0.03$). *Conclusions:* Quantification of levator-ani muscle stiffness is feasible. Muscle stiffness is significantly different before and after birth.

Key words:

Avulsion injury, levator-ani muscle, muscle stiffness, pelvic floor, birth.

Abbreviations

LAM levator-ani muscles

PFDs pelvic floor disorders

BMI body mass index

ICIQ International Consultation on Incontinence Questionnaires

Key message

Quantification of levator-ani muscle stiffness before and after birth is feasible. This study demonstrated that stiffness was influenced by pregnancy, body mass index, ethnicity and the presence of levator-ani muscle damage. Further work will determine if this metric is predictive for levator-ani muscle damage prior to birth.

Introduction

The biomechanics of birth are poorly understood. The clinically accepted mechanism of second stage labour describes the change in attitude and position of the fetal head, relative to bony boundaries, as it negotiates its way through the birth canal. It is well established that the bony constraints of the fetal head and maternal pelvis influence the second stage of labour, but the contribution of the soft tissues, in particular the levator-ani muscles (LAM), is not well quantified (1).

The LAM have a high resting tone to support the organs of the pelvis, are able to relax during elimination of urine and faeces and, in women, are capable of a large degree of stretch to allow for passage of the fetal head during vaginal birth (2, 3). Computational modelling estimates that this stretch can be approximately three times the resting length of the muscle (4, 5). Quantifying the ability of the LAM (and surrounding tissue) to elastically stretch may be a useful metric for assessing risk for a non-complicated vaginal delivery, or assessing damage post-delivery. This is particularly relevant since studies using advances in imaging techniques, such as magnetic resonance imaging and ultrasound, have shown that 10 % to 39.5 % of primiparous women who birth spontaneously have subsequent LAM damage (6-8).

Recent literature has linked this damage to the development of pelvic floor disorders (PFDs), which predominately include pelvic organ prolapse and faecal incontinence (9-11).

The ability to measure the mechanical properties of skeletal muscle in vivo remains challenging, with no single accepted method proven to be able to provide a comprehensive characterisation of muscle properties (12). A variety of techniques have been used, including hand-held instrumentation such as dynamometers and myotometers to measure the length-tension curves and thus estimate the mechanical properties of muscle in vivo(13, 14)

Population-based studies investigating the association of ethnicity with the prevalence of PFDs have shown that African-American and Hispanic women have half the prevalence of PFDs compared to European women, even after adjusting for age, parity, and body mass index (BMI) (15). The 2013 census in New Zealand identified that people of European and Polynesian descent form New Zealand's predominant ethnic groups. Very little is known about the prevalence of PFDs in Polynesian women, but anecdotal evidence from urogynaecologists in South Auckland suggests that Polynesian women have lower rates than European women of attending urogynaecology clinics. There may be several reasons for this, but a plausible hypothesis is that this population group is less susceptible to LAM damage during vaginal delivery, due to a more compliant (less stiff) LAM.

Our research group has previously developed a hand-held automated elastometer, specifically designed to measure LAM stiffness in vivo (16). Elastometry measurements have been shown to be reliable and repeatable in a cohort of pregnant women (16). Characterising LAM stiffness during late stage pregnancy and postnatally in different ethnicities will add to our understanding of the significance of the relationship between stiffness, other obstetric variables, subjective symptoms of PFDs, and the potential for LAM stiffness to be a predictor for birth injury.

The primary aim of this pilot study was to use the automated elastometer to characterise antenatal and postnatal stiffness of the LAM in European and Polynesian women. Secondary outcomes included investigating associations between muscle stiffness, LAM damage (avulsion), obstetric variables, and postpartum subjective symptoms of PFDs, determined using validated questionnaires.

Material and methods

This paper presents data from an observational prospective pilot study investigating associations between a novel method for measuring pelvic floor muscle stiffness, and variables such as pregnancy, ethnicity, delivery outcomes, and postnatal changes.

Primiparous women were invited to participate via advertisement or direct referral from their lead maternity carer. Inclusion criteria included a primiparous, low risk pregnancy, over 18 years of age, of Polynesian or European descent, and the intention to have a vaginal delivery. Ethnicity was classified according to the ethnic group with which the participant most closely identified.

The study participants were assessed twice, once at 36 weeks to 38 weeks gestation and again 3 months to 5 months postpartum. The assessments included: completion of validated questionnaires on PFDs using the International Consultation on Incontinence Questionnaires (ICIQ) for urinary, vaginal, and bowel symptoms (ICIQ-UI Short Form, ICIQ-VS and ICIQ-BS respectively); digital palpation for muscle tone and strength using the 'Dietz scale' for tone (17) and the modified Oxford grading scale for strength (18); a transperineal ultrasound scan of their pelvic floor muscles using Philips IU22 ultrasound system (Philips Ultrasound, Bothwell, WA, USA) (19); and elastometry quantification (16).

Assessments were performed after voiding, with the participant semi-reclined with knees bent, and the trunk slightly elevated. Transperineal ultrasound imaging was conducted using previously defined protocols (19). The ultrasound transducer was covered and placed on the perineum in the mid-sagittal orientation. Off-line analysis of muscle integrity pre- and post-delivery was performed using proprietary software QLAB® (Philips, Amsterdam, Netherlands) by an independent expert in pelvic floor muscle ultrasound imaging, blinded to delivery mode. The presence or absence of avulsion injury was determined using multi-slice imaging, as previously published (20).

Muscle stiffness estimates were determined using the elastometer and a predefined protocol (16). In short, the elastometer is a hand-held automated instrumented speculum (Figure 1). The speculum tips of the elastometer were inserted into the vagina in the closed position in the coronal orientation to the level of the LAM. The speculum was opened in ten incremental steps to a maximum aperture of 50 mm, comprising one measurement cycle. At each step,

within a cycle, force measurements were acquired over one second after a three second relaxation time. The measured force and displacement data sets were recorded at a frequency of 100 samples per second.

The first of three measurement cycles was included to allow for tissue preconditioning and to familiarise the participant with the procedure. The two subsequent cycles were conducted within two minutes. The force/displacement curve was used to calculate passive tangent stiffness (*k*) from approximately the most linear portion of the force-displacement curve (Figure 2), which was between an aperture of 40 mm and 50 mm for all women. Averaged force and displacement measurements from cycle 2 were used in the analysis. Elastometry measurements have already been demonstrated to be repeatable and reproducible in a test/re-test series (16) but, due to the novelty of this measurement, a questionnaire on acceptability of the device and procedure was acquired in the first fifty women.

Demographic data, including performance and knowledge of pelvic floor muscle exercise, in addition to the PFD questionnaires were collected at both assessment times. Delivery outcomes were obtained from electronic health records.

Statistical analyses

Statistical analysis was performed using IBM SPSS v 22 where a p value of < 0.05 indicated statistical significance. After visually inspecting the data for normality, exploratory analysis was conducted using univariate or bivariate methods. Mean, median, standard deviation, range, and percentages are presented for background and obstetrical characteristics. Independent Student's *t*-, Chi-squared, and Mann-Whitney tests for comparisons were used where appropriate. Logistic regression was used to determine if antenatal LAM stiffness was associated with avulsion injury, or other intrapartum variables, and to explore the relationship between antenatal/postnatal incontinence, BMI, and ethnicity.

Ethical approval

The study was conducted at Counties Manukau District Health, South Auckland, New Zealand. Ethical approval was granted from the Lower South Ethics Committee (LRS /10/07/029, November 2010).

Results

167 participants enrolled in the study. 61 participants identified as being of Polynesian origin, and 106 as European. 129 returned for their postnatal follow-up, of which 34 were Polynesian, and 95 European. The overall drop-out rate was 23 % (n = 38).

Elastometry testing was possible in 114 antenatal and 91 postnatal participants. Women were excluded from the elastometry testing if there was a vaginal infection, the fetal head was too low, or because of other issues (such as low battery power of the elastometer), leaving datasets from 80 participants with both antenatal and postnatal elastometry measurements. Results from the questionnaire on acceptability of the device and procedure (n = 50) showed that all but one of the participants felt it would be an acceptable procedure to use in an antenatal clinic, and all felt the procedure was more acceptable compared to other gynaecological procedures. 6 % (n = 3) found the device threatening. The questionnaire has been included as supplementary material.

Table 1 presents the demographic characteristics and delivery outcomes for each ethnic group. The European cohort were older, with a significantly lower antenatal and postnatal BMI, had significantly longer second stage labours, used more pain relief, and were more inclined to perform antenatal pelvic floor muscle exercises than the Polynesian cohort. On average, antenatal LAM stiffness was significantly higher in the European women compared to Polynesian women (344 N/m ± 160 N/m vs 291 N/m ± 98 N/m, 95 % CI [5, 100] N/m, p = 0.03).

For all women, postnatal stiffness was significantly higher, on average, than antenatal stiffness (436 N/m ± 198 N/m vs 325 N/m ± 14 N/m) with a mean difference of 111 N/m (95 % CI [62.14, 160.04] N/m, $p < 0.01$). In a sub-analysis defined by presence or absence of avulsion injury, postnatal stiffness was significantly lower for those with muscle injury (Table 2).

There was no evidence of a statistically significant difference in antenatal stiffness measurements for women who sustained an avulsion (n = 11) compared to those who did not (n = 69) (390 N/m ± 207 N/m vs 316 N/m ± 142 N/m).

For those who had an acute Caesarean section (C/S) (n = 27) there were no statistically significant differences in antenatal stiffness measurements compared to those who did not have a C/S (n = 87) 345 N/m ± 159 N/m vs 317 N/m ± 137 N/m, respectively. Postnatal

stiffness measures, however, were significantly higher post C/S (n = 19) compared to non-C/S (n = 72) 523 N/m ± 268 N/m vs 421 N/m ± 164 N/m p = 0.04, respectively.

After controlling for BMI, there was no statistically significant association between ethnicity and antenatal LAM stiffness. After controlling for ethnicity there was a 7.8 N/m decrease in stiffness for every 1 kgm^2 increase in BMI ($p < 0.01$).

Univariate analysis showed that there were no statistically significant associations of ethnicity, BMI, gestation, mode of delivery, or head circumference with the risk of avulsion, however the use of epidural anaesthesia was significantly protective p = 0.03 (Table 3).

BMI was significantly associated with antenatal (p = 0.046) and postnatal urinary incontinence (p = 0.004). However, having controlled for BMI, the effects of ethnicity on both antenatal and postnatal incontinence were not statistically significant (p = 0.534 and p = 0.11 respectively). The prevalence of antenatal and postnatal incontinence was similar in both ethnic groups; 69 % European, 67 % Polynesian; 53 % European, 70 % Polynesian, respectively.

There were also no statistically significant associations between symptoms of PFDs and measured stiffness values, although for the whole cohort, sexual symptom change scores tended to be negative (sexual matters got worse) for 36 % of postpartum women (Figure 3). For most women with an avulsion, sexual symptoms worsened, irrespective of changes in LAM stiffness (Figure 3).

Discussion

The main finding of this study is that postnatal stiffness of the LAM was significantly greater than the antenatal stiffness, except in those women who sustained an avulsion injury. There are also statistically significant differences in stiffness according to ethnicity and BMI, with the Polynesian cohort having lower stiffness measurements at both time points.

This is the first study, to the authors' knowledge, that has attempted to assess objectively the in vivo stiffness of the LAM and surrounding tissue in the late third stage of pregnancy and three to five months postpartum. We initially hypothesised that the non-attendance of Polynesian women at urogynaecology outpatients was because they had a lower LAM stiffness, and were therefore less likely to sustain pelvic floor muscle damage during vaginal

delivery. Although our numbers are small, the lower LAM stiffness in the Polynesian group and the relatively lower incidence of avulsion injury (9 % Polynesian vs 20 % European) would suggest that muscle stiffness may be a factor. There are known maternal adaptations that occur in the vagina during pregnancy, presumably in preparation for delivery. Decreasing stiffness of the muscles and tissues of the birth canal is likely one of those adaptations. Oliphant et al (2014) measured elastase, a biological marker of elastin, at 12 weeks and 36 weeks of pregnancy to determine if this biomarker was associated with an uncomplicated vaginal delivery (21). The authors found a strong association between higher levels of elastase at 12 weeks, and an increased descent of the pelvic organs, according to the pelvic organ prolapse quantification system (21). These findings were positively associated with the likelihood of a spontaneous vaginal delivery. They are also consistent with maternal adaptations during pregnancy involving an overall relaxation of the vaginal tissue and supporting structures of the pelvic organs, such as the LAM. Our elastometry measures, quantifying a difference in stiffness during pregnancy, are consistent with these findings.

The levels of oestrogen and progesterone are known to rise substantially during pregnancy and are likely to have an effect on the biomechanical properties of the pelvic floor structures (1). It is known that progesterone is a relaxant of smooth muscle, with levels peaking at approximately 36 weeks gestation (1). Receptors for these hormones have been found in the connective tissue and smooth muscle components of the LAM (22). It is plausible therefore that hormonal factors may affect the stiffness characteristics of the LAM. Research, using animal models, has shown that the stiffness characteristics of rat vaginal tissue demonstrate marked changes during the course of pregnancy and post-delivery (23). These authors reported a significant decrease (up to 43 %) in the stiffness of vaginal tissue from Long-Evans rats by mid-pregnancy, and an increase in the ultimate tensile strain of the tissue. It is not possible to replicate these ex vivo studies using human tissue, but the measurements of tissue stiffness using the elastometer are broadly consistent with those demonstrated in the animal models.

Imaging studies using transperineal ultrasound, have shown changes in the dimensions of the levator hiatus before and after pregnancy (24-26). Significant increases in all hiatal dimensions were most evident between 21 weeks and 38 weeks gestation, with most reporting smaller hiatal dimensions by approximately six months postpartum (25, 27).

Although not directly comparable (as this type of imaging does not provide direct information on the material properties), our finding that antenatal stiffness is lower than postnatal stiffness is in accordance with the observations using ultrasound. Although we did not observe any statistically significant differences in antenatal stiffness between women who experienced an uncomplicated vaginal delivery and women who sustained an avulsion injury, the postnatal stiffness for the avulsion group, was significantly lower. Currently, diagnosis of avulsion injury post-delivery is dependent on skilled palpation or ultrasound imaging (28). Elastometry measurement could be another means of determining muscle damage provided the antenatal stiffness measurements were known.

The association between BMI and stiffness raises some interesting questions. There is very little literature on the effect of BMI on tissue mechanics, but recent research using ultrasound imaging, in a predominantly European cohort of women, demonstrated a positive association between BMI and hiatal area (3). Furthermore, cultured human dermal fibroblast cells exposed to cyclic stretch have been shown to produce additional elastin within two weeks, while similar 'non-exercised' cells cultures do not (29). It is possible that the increase in levator hiatal area observed from ultrasound images, and the lower stiffness values in women with higher BMI, may be a result of increased loading on the LAM. Or more simply, women with higher BMI's are likely to have more fat deposits around the vaginal canal and ischio-rectal fossa, thus possibly limiting the resistance of the tissue to the elastometer opening.

Large epidemiological studies have shown strong associations between BMI and increased prevalence of stress urinary incontinence (15). Several of these studies have shown consistently lower prevalence of incontinence among black women compared to white, even after adjusting for BMI, parity, and age, suggesting ethnicity itself is an important consideration in the mechanism of incontinence (15). A survey to assess the prevalence of urinary incontinence in women in New Zealand found a higher incidence of incontinence among Maori women (46.8 %) compared to European (31.2 %) (30). However, in our pilot study, there was no statistically significant difference in the prevalence of urinary incontinence (ante- or postnatally) in Polynesian compared to European women, or any association with LAM stiffness. This is may be due to the confounding effect of the pregnancy itself, or simply the higher BMI values, which were significantly associated with the presence of antenatal and postnatal incontinence.

We found only epidural anaesthesia to be protective for muscle damage in this cohort of women. This is consistent with some studies (31), but others have not reported this effect (6, 32). This may be related to the dosage and use of bupivacaine, which would provide a motor block to the pelvic floor muscles (33). Potentially this could affect the ability of the muscles to respond to the downward pressure from uterine contractions and the advancing head.

It is widely recognised that forceps delivery is strongly associated with pelvic floor trauma (34, 35), however the lack of association between delivery mode and avulsion injury, in this pilot, may be due to the very low (2 %) incidence of instrumental deliveries using forceps. Nevertheless this is consistent with the rate of instrumental deliveries of 6.9 % reported for Counties Manukau for 2014 to 2015 (36).

We found no association between age and stiffness, which might have been due the relatively young age of our participants.

A strength of this study is its prospective design, capturing subjective and objective measurement parameters in both the antenatal and postnatal period. The unique measurement of muscle stiffness in two distinct ethnic groups has, for the first time, provided quantitative information on the effect of pregnancy and ethnicity on this metric. This research has demonstrated that measuring the stiffness of the LAM complex is feasible and clinically acceptable.

A limitation of the study is that it was statistically underpowered to determine if antenatal elastometry is predictive of avulsion injury. However, the presence of an avulsion does have a significant effect on postnatal stiffness. Although prediction of avulsion was not one of the primary aims of this pilot study, the known physiological changes that occur during pregnancy, which are likely to affect the muscle properties, make this question worthy of further investigation. We also acknowledge that the dropout rates between the two ethnicities was different (~40 % for the Polynesian compared to ~20 % for the European women) which may influence the accuracy of the results. Notwithstanding, this pilot study was still able to capture elastometry data pre- and post-delivery for 80 women, which is a novel finding. It is well recognised that there is often disparity between dropout rates of women from different cultural backgrounds (37, 38). This is likely multifactorial, but challenges in health literacy, different cultural views of health and illness, and practical issues such as lack of transportation and childcare may have influenced follow up attendance. Future studies should emphasize retention of indigenous participants, perhaps by employing assessors of similar

background, providing additional resources for transportation and education, and/or the ability to provide follow up assessments in the participant's home.

Conclusion

Antenatal and postnatal measurement of the stiffness characteristics of the LAM is feasible and clinically acceptable. This study has demonstrated that there are significant differences in the stiffness characteristics of the LAM during pregnancy and three to five months postpartum, and that ethnicity, avulsion injury and/or BMI are likely to influence these measurements. Further work, with larger cohorts is needed to determine the evolution of LAM stiffness from pre-pregnancy onwards, and if this metric is predictable of avulsion in a larger population.

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Supporting Information legend

Appendix S1. Survey document.

Legends figures and tables

Table 1: Demographic characteristics for Polynesian and European women. BMI, body mass index; PFM, pelvic floor muscle; NVD, normal vaginal delivery; GA, gestational age; IQR, inter-quartile range.

Table 2: Mean subject stiffness differences (postnatal (PN) minus antenatal (AN)) according to avulsion status, ethnicity and mode of delivery. (ł includes one forceps delivery). PFM, pelvic floor muscle; NVD,normal vaginal delivery.

Table 3: Estimated odds ratio's for associations between obstetric variables and avulsion injury.

Figure 1. Elastometer system (A) Hand-piece (B) controller and, (C) laptop user interface.

Figure 2. Representative plot of force to displacement during cycle two and three for the one procedure. Linear trend lines are fitted to measurements spanning apertures from 40 to 50 mm.

Figure 3. Association between stiffness characteristics and Change Score for sexual function for all women. Blue circle represents those without an avulsion, green circle represents those with an avulsion.

Table 1: Demographic characteristics for Polynesian and European women.

	Polynesian		European		*p*-value
Age, years; mean (SD)	23.67	(4.20)	29.27	(5.86)	<0.01*
Antenatal, BMI kg/m^2; mean (SD)	33.18	(6.55)	30.01	(5.63)	<0.01*
Postnatal BMI, kg/m^2; mean (SD)	30.61	(6.97)	26.92	(5.50)	0.04*
Antenatal smoking; frequency (%)	12	(0.20)	2	(0.02)	<0.01#
Antenatal alcohol; frequency (%)	1	(0.02)	1	(0.01)	1#
Antenatal PFM exercise; frequency (%)	17	(0.28)	70	(0.69)	<0.01^
Antenatal Stiffness, N/m; mean (SD)	291.4	(97.9)	343.98	(160.59)	0.03*
Gestation, weeks; mean (SD)	39.84	(1.01)	40.12	(1.18)	0.11*
Mode of Delivery; frequency (%)					0.12#
NVD	43	(70%)	62	(59%)	
Vacuum	4	(7%)	19	(18%)	
Forceps	0	(0%)	2	(2%)	
Caesarean section	14	(23%)	22	(21%)	
Pain Relief; frequency (%)					0.01#
None	37	(61%)	50	(48%)	
Other	2	(3%)	1	(1%)	
Epidural	16	(26%)	49	(47%)	
Pudendal	2	(3%)	1	(1%)	
Spinal	4	(7%)	1	(1%)	
GA	0	(0%)	2	(2%)	
Perineal Tear; frequency (%)					0.22#
none	29	(50%)	61	(62%)	

1st	13	(22%)	11	(11%)		
2nd	15	(26%)	22	(22%)		
3rd/4th	1	(2%)	5	(5%)		
Avulsion injury	3	(9%)	19	(20.4%)		
Episiotomy	7	(0.11)	17	(0.16)	0.55^	
Length of second stage of labour, minutes; median (IQR)	42	(19-70)	58	(30-110)	0.03†	
Head circumference, cm; mean (SD)	35.08	(1.34)	34.84	(1.45)	0.29*	
Birth weight, grams; mean (SD)	3481.80	(436.63)	3523.62	(505.33)	0.58*	

†Mann-Whitney U Test, * Two sample t-test, # Fisher's exact test, ^ Pearson's Chi-squared test with Yates' continuity correction

Table 2: Mean subject stiffness differences (postnatal minus antenatal) according to avulsion status, ethnicity and mode of delivery. (ǂ includes one forceps delivery)

	Mean of Subject Differences (PN - AN), N/m	95% Confidence Interval	*p*-value
PFM injury			
Avulsion (*n*=11)	-47.9	[-200.5,104.6]	0.5
No Avulsion (*n*=69)	133.8	[82.1,185.6]	<0.01
Ethnicity			
European (*n*=56)	110.8	[50.7,171.0]	<0.01
Polynesian (*n*=24)	111.7	[21.6,201.7]	0.02
Mode of Delivery‡			
NVD (*n*=52)	93	[38.4,147.7]	<0.01
Caesarean Section (*n*=17)	169.7	[24.6,314.8]	0.02
Ventouse (*n*=10)	139.6	[-8.6,287.8]	0.06

Table 3: Estimated odds ratio's for associations between obstetric variables and avulsion injury.

Variable	Estimated Odds Ratio	95 % Confidence Interval	*p*
Maternal Age (years)	1.08	[0.99,1.18]	0.09
Maternal Ethnicity (European vs. Polynesian)	2.65	[0.80,12.04]	0.15
Antenatal BMI (kg/m^2)	0.90	[0.80,1.00]	0.08
Length of pregnancy (weeks)	1.28	[0.82,2.07]	0.30
Mode of delivery (ventouse vs. svd)	1.18	[0.78,1.71]	0.41
Foetal head circumference (cm)	1.17	[0.80,1.70]	0.42
Epidural use (yes vs. no)	0.16	[0.02,0.60]	0.02*