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Title Page:

Effects of posture and anatomical location on inter-recti distance measured using ultrasound imaging in parous women

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Ethical approval

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Abstract

Study Design: Cross-sectional repeated measures.

Objectives: To quantify the effects of posture and measurement site on the inter-recti distance (IRD) and investigate the reliability of IRD measurement using ultrasound imaging in different postures.

Background: The linea alba connects the rectus abdominis muscles anteriorly and the width is known as the IRD. The IRD is usually measured in crook-lying and is the primary outcome measure to assess for a divarication of recti abdominis (DRA). The effects of posture and measurement site on the IRD have not been investigated.

Methods: Ultrasound imaging was used to measure IRD in 41 women ≥8 weeks postpartum. The IRD was measured at three sites (superior-umbilicus, umbilicus and inferior-umbilicus), in three postures (crook-lying, sitting and standing), and repeated one-week later. The effects of posture and site were investigated using one-way ANOVAs. Reliability was analysed using Intraclass correlation coefficients (ICCs), Bland Altman analyses, standard error of measurement and minimal detectable change.

Results: The IRD was wider when standing vs. lying at both the superior-umbilicus and umbilicus by 0.30cm (95% CI 0.21 to 0.39) and 0.20cm (0.11 to 0.30) respectively ($p<0.001$). Measurements at the inferior-umbilicus were, on average, 1.6 and 2.1cm narrower than superior-umbilicus and umbilicus sites, respectively ($p<0.001$). There was high intra-rater reliability within-session ($ICC_{3.3}$) and between-session ($ICC_{3.1}$) at all sites measured.

Conclusion: The IRD can be measured reliably at all sites and postures. The IRD is wider at superior-umbilicus and umbilicus when upright compared with lying. There is a difference in IRD between all sites measured.

Key words: Abdominals; Inter-recti distance; Divarication of rectus abdominis; Ultrasound imaging.

1. Introduction

An increase in the width of the linea alba, known as inter-recti distance (IRD) during pregnancy is common [6,14,32] and leads to divarication of the rectus abdominis muscles (DRA) and thinning of the linea alba.[2] Hormonal elastic changes within the connective tissue, prolonged stretch from the growing uterus and displacement of the abdominal organs in the third trimester,[21] causes this widening of IRD and appears to be a natural consequence of pregnancy[6,21,27,32,33] There is a partial natural reduction in the IRD in the eight-weeks post-delivery for some women[6,7,8,12] and for 60% of women by six months postpartum, the IRD naturally reduces towards normal values.[12,14,19,26] However, for up to 40% of parous women the IRD is still wider than normal one year post-delivery[9,12,19,26] and years later[37]. A DRA can affect the integrity of the myofascial system[19], lead to poor posture,[6] abdominal muscle dysfunction,[11] reduced lumbopelvic stability,[20,36] reduced pelvic floor support[5,37] and a less cosmetic appearance of the abdomen.[20,26,29] Rehabilitation using abdominal muscle exercises may reduce these effects in women with a DRA[5].

The linea alba is the central tendon of the combined aponeurosis of the lateral abdominal muscles and the sheath of the rectus abdominis.[2,38] It runs from the xyphoid process to the pubic symphysis and its length is dependent on height and torso length. Cadaver studies report mean linea alba lengths of 26.2cm[2] to 29.1cm[30] with the umbilicus positioned just over half-way down. A DRA is diagnosed when the IRD is wider than normal.[2,30,] While there is no firm agreement on what is the normal IRD, [5,26] it is commonly cited to be within normal range when the IRD is up to 15mm at xyphoid, 22mm at 3cm above and 16mm at 2cm below umbilicus.[4]

Measurement of the IRD is used to assess and monitor the DRA.[5,20,39] Traditionally the IRD is measured in crook-lying during a head lift, while the therapist palpates the medial borders of the rectus muscles and measures in finger-widths the distance between them at different points along the linea alba.[39] Crook-lying enables the IRD to be measured at rest and during a head-lift. The head lift shortens rectus abdominis and approximates the medial rectus borders which reduces the IRD.[26] Research suggests the reliability of palpation to measure the IRD in this position is poor-to-moderate.[8,25]

Abdominal muscle exercises to correct a DRA use the direction and attachment of the abdominal muscle fibres to draw the rectus muscles together and thereby reduce the linea alba width.[5,11,26] There is, however, no evidence that the linea alba width itself can be reduced and current research suggests a head-lift may actually slacken or bulge the linea alba rather than shorten it.[20] Therefore the relevance of measuring the IRD in the non-functional position of crook-lying is questionable. Instead the measurement of the IRD in upright postures such as sitting and standing could more closely reflect the IRD in functional positions and give a more accurate picture of the changes to the IRD during dynamic abdominal muscle exercises.

The width and formation of the linea alba varies down its length from the xyphoid to pubis insertion.[2,4,30] There is no consensus within the literature as to where to measure the IRD.[26] Studies commonly use the umbilicus as the reference point and measure at set distances above and below.[5,26,27] To date there has been no study into the selection of the measurement site on the linea alba, accounting for anatomical differences and individual torso measurements.

The aim of this study was to determine the effect of posture and anatomical measurement site on the IRD using ultrasound imaging and to investigate the reliability of measuring the IRD using ultrasound imaging in different postures.

2. Method

Participants:

This cross-sectional study recruited a convenience sample from a university and a private physiotherapy practice of parous women, ≥8 weeks post-delivery who had a vaginal birth. All provided written informed consent. The sample size was based on a test of ICC; with a type I error rate of 5%, 80% power and 2 repeated measurements, and with a null hypothesis of ICC 0.7 (minimum level of acceptable reliability) and alternative hypothesis of ICC 0.85 (desired level of reliability).[40] Women were excluded if they had previous abdominal surgery including a caesarean section, current pregnancy, back or pelvic pain in the last 6-months, or an allergy to hypoallergenic gel or face paint crayon. The study was approved by the School of Health & Social Care Research Governance and Ethics committee at Teesside University (reference: 005/14).

Ultrasound Imaging:

Rehabilitative ultrasound imaging is used in musculoskeletal rehabilitation for the assessment of muscle morphology and architectural changes in muscles and associated structures.[13,41,43] Ultrasound imaging is a reliable, valid, repeatable, non-invasive tool to measure IRD.[3,10,19,22,24,25,3]

Instrumentation and examiner:

A digital ultrasonic diagnostic imaging unit (Mindray DP50) was used, with a working frequency of 5 MHZ, and a 53-mm (75L53EA) linear transducer. Ultrasound images of the recti abdominis were obtained in B-mode, producing two-dimensional cross-sectional grey-scale images. The lead author (SG), a women's health physiotherapist with 22 years' experience, >12 months scanning experience, and specialist training on a British Medical Ultrasound Society endorsed program, performed all scans.

Procedures:

The site of the transducer was standardised and each measurement location was marked on the skin with face crayon, with the participant in crook-lying. The transducer was placed transversely across the abdomen, along the midline at a perpendicular angle to the muscle length. Care was taken to minimise pressure through the probe so as not to distort the image. The medial borders of the rectus abdominis muscle were identified and the linea alba visualised. Still images were obtained at the end of normal expiration, to control for the influence of respiration and provide consistency.[41] Two images were taken at three specified sites and in three postural positions.

Postural positions

Each of the three postural positions was standardised. In crook-lying, a pillow was placed under the head, legs were hip width apart and knees flexed at 90° (measured with a manual goniometer), with feet facing forward. Mid-pelvic alignment was established by teaching the participant to pelvic tilt. In sitting the participant sat over the edge of the plinth with feet flat on the floor, arms resting on their thighs and mid-pelvic alignment (as above). In standing the participant stood facing forwards with legs hip width apart, arms by their sides and in mid-pelvic alignment (as above). To avoid order effects there was random assignment of the postural positions using Latin squares.

IRD Measurement sites

The measurement sites were located by; palpating the xyphoid and superior pubis bony landmark in line with the umbilicus and then measuring the distance from the umbilicus to the bony landmarks using a flexible measuring tape. An 8cm horizontal line was made with a ridged ruler, to enable alignment of the transducer. The three sites were: a) superior-umbilicus located a third of the distance between the xyphoid and umbilicus; b) just superior to the umbilicus; and c) inferior-umbilicus half-way between the umbilicus and the pubis. All sites were scanned in the three postures detailed above. All scans were repeated twice within-session and repeated on a separate day at the same time of day, to try to minimise differences in activities of daily living and food intake on the separate days.

Data Processing

The ultrasound images were downloaded, converted into JPEG files and measured offline by SG, using bespoke Matlab image-processing software (version 7.1) following a similar procedure to that of Mota et al[24]. The inner borders of the left then right rectus abdominis muscles were traced, a 4th order polynomial regression fit through the traced points was then used to determine the muscle border (Figure 1). The IRD was defined as the transverse linear distance between the most medial points of the borders of the recti muscles. Scan 1 was measured first and then the screen cleared. Then scan 2 was measured.

Statistical Analysis:

Data were analysed using the Statistical package IBM SPSS Statistics version 22 (IBM Corporation, Endicott, NY, USA), and are presented as means, standard deviations and 95% confidence intervals (CIs). IRD for each anatomical site was calculated by the mean of the two images. A repeated measure analysis of variance (ANOVA) was used to examine differences between the postures and sites. Statistical significance was set at 0.05. Where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Where the ANOVA showed a significant difference, post hoc comparisons were carried out. Reliability was tested using ICCs for within-session ($ICC_{3.3}$) and between-days ($ICC_{3.1}$). The standard error of the measurement (SEM) was calculated to determine the typical error. The minimal detectable change (MDC) was calculated: MDC=SEM × 1.96x√2. Bland Altman analysis was used to calculate the mean difference ($\bar{d}$) and 95% limits of agreement (LOA).

2 Results:

Demographics

Forty-one parous women were recruited from May-December 2014. The IRD was measured on 1,476 scans in total. One participant was unable to attend the second session. The characteristics of the participants are presented in **Table 1.** Twelve participants were primiparous and 29 were multiparous. Post hoc independent t-tests indicated no significant difference between mean BMI (p=0.623) and mean age (p=0.096) for primiparous and multiparous women. A mixed factorial ANOVA was performed to determine whether the IRD was significantly different between primiparous and multiparous women in all postural positions. The Wilks' Lambda was analysed for significant interaction. There was no significant difference in the IRD at SU (p=0.742), U (p=0.607) or IU (p=0.523), so the data were not separated for the statistical analyses.

Reliability

Intraclass correlation coefficients (ICCs) for repeated scans within-session were between 0.93 and 0.99 (Table 2). The mean and standard deviation of within-session ICCs were 0.97±0.03 and between-days were 0.97±0.025 when all sites measured were analysis demonstrating excellent intra-rater reliability.[1] The ICC's for each site can be seen in **Table 2**. The SEM was between 0.03 and 0.14cm, with the larger SEM at the umbilicus in standing. The MDCs were 0.09 to 0.38cm, with the largest MDC at the umbilicus in standing. The lowest SEM (0.03cm) and MDC (0.09cm) was at the inferior-umbilicus site. The systematic difference (bias) between repeated sessions was small and not statistically significant (p=0.76) and the SD of the differences between all scans in all positions and anatomical sites was 0.16cm giving 95% LOA of 0.30cm between days. The SD of session differences for sites and postures can be seen in **Table 2**.

Postural effects

The IRD was statistically ($p<0.01$) wider at the superior-umbilicus for standing versus lying, and sitting versus lying by a mean difference of 0.3cm (95% CI 0.14 to 0.49cm) and 0.2cm (0.07 to 0.36), respectively (Figure 2 & Table 3). The IRD was statistically ($p<0.01$) wider at the umbilicus for standing versus lying and sitting versus lying by 0.18cm (0.03 to 0.32) and 0.20cm (0.07 to 0.34), respectively. At the inferior-umbilicus the differences were not statistically significant ($p=0.44$) between standing and lying -0.02cm (-0.09 to 0.02) or sitting and lying -0.03cm (-0.06 to 0.22). Differences between sitting and standing at all measurement points were small and not statistically significant; the superior-umbilicus IRD was wider by 0.10cm, (-0.5 to 0.25), the umbilicus and inferior-umbilicus IRD was smaller by -0.03cm (-0.16 to 0.1) and -0.01cm (-0.07 to 0.05) respectively.

Anatomical site measured on the linea alba

The IRD (Figure 2 & Table 3) at the superior-umbilicus was statistically ($p<0.01$) wider than inferior-umbilicus in all postures by 1.49cm (1.26 to 1.73). The IRD at the umbilicus was statistically ($p<0.01$) wider than superior-umbilicus in all postures by 0.6cm (0.41 to 0.78). The IRD at the umbilicus was statistically ($p<0.01$) wider than inferior-umbilicus in all postures by 2.08cm (1.85 to 2.33).

The IRD at inferior-umbilicus was statistically ($p<0.01$) narrower compared to umbilicus and superior-umbilicus in all positions. Overall the IRD at the inferior umbilicus were, 1.60 and 2.10 cm lower than superior-umbilicus and umbilicus sites, respectively ($p<0.01$). The 95%CI for the mean difference between superior-umbilicus and umbilicus was 0.51 to 0.61 cm ($p<0.01$).

3 Discussion

This study found that both posture and measurement site effect the IRD. The IRD was significantly wider in standing and sitting at the superior-umbilicus and umbilicus measurement sites compared to crook-lying, the differences being larger than the SEM (≤0.15cm). There was no difference between standing and sitting. The inferior-umbilicus site was significantly narrower than both the umbilicus and superior-umbilicus sites.

The high test-retest ICCs demonstrate that ultrasound imaging is a reliable technique for measuring IRD in parous women at all sites in all postures investigated. In lying the superior-umbilicus ICC of 0.98 (95%CI 0.96-0.99) was in line with previous studies.[17,24] The slightly lower ICC of 0.92 (95%CI 0.85-0.96) at the inferior-umbilicus is difficult to compare due to being a lower anatomical site than in other studies. However, in all previous studies[17,19,24] the inferior-umbilicus site had lower ICC than those superior to the umbilicus, consistent with the present findings. The MDCs were 0.09 to 0.38cm, with the highest at the umbilicus in standing and the 95% limits of agreements for all sites and postures (Table 2) within-session was ≤0.3cm meaning that changes in the IRD above these in clinical practice would likely be attributable to an intervention.

Beer et al[4] proposed that the IRD is pathological if it is ≥ 2.2cm at 3cm above the umbilicus. Using these criteria 63% (n=26) of the participants had a DRA, at the umbilicus site in crook-lying. The high number of participants with a DRA in this study could be due to several factors: the mean age (43±9 years); 70% of participants being multiparous[33]; 20 of these participants being over a year since delivery (9.8±8.9); and the average BMI being within the overweight category (25.5±4.1). The present results are in line with current research that suggests the IRD remains widened over a year post-delivery, into older age.[6,7,12,14,16,19,37], and increased prevalence with multiparty and maternal age >34[9,12,32] The inclusion of women with and without a DRA makes the results more generalisable to parous women with both a normal IRD and a DRA.

Posture

The traditional use of finger palpation to assess the IRD limits clinical positioning to crook-lying to enable the rectus borders to be palpated and the distance to be measured[27] but this position is not functional, is non-weight bearing and has poor-to-moderate reliability.[8,25] The IRD is statistically wider at the superior-umbilicus and umbilicus sites in sitting and standing compared to lying. This suggests that the wider IRD in sitting and standing is the actual width of the linea alba in functional, weight bearing positions and therefore provides a more relevant baseline measurement from which to compare the effect of exercises instead of a sit-up that only demonstrates whether the rectus abdominis muscles can shorten and approximate in the non-functional lying position.[5,11,26,]

The increased IRD in sitting and standing may be attributable to the increased activation of the lateral abdominal muscles to maintain postural stability in these weight-bearing functional positions.[23,28,31] As opposed to lying, where the transverse abdominis (TrA) would be inactive, in the postural positions of sitting and standing the TrA works sub-maximally to maintain the posture and intra-abdominal pressure. The transverse nature of the TrA muscle could therefore have a lateral pull on the linea alba and increase the IRD. This theory is supported by a recent study,[20] which suggests that TrA may not reduce the IRD and may actually tension and widen the IRD in line with the transverse orientation of the fibres.[2,15,26]

The increased IRD may alternatively be the result of the change in the centre of gravity in the weight-bearing positions of sitting and standing, when the effect of gravity moves the abdominal contents anteriorly, pressing onto the abdominal muscular wall and potentially stretching the linea alba and widening the IRD. This pressure on an already stretched aponeurosis and linea alba, combined with weaker abdominal muscles[12,14,] may result in the abdomen protruding more anteriorly postpartum. This bulging anteriorly of the abdomen can affect the women's figure and is a common reason for women seeking treatment for a DRA.[20,26,29]

Measurement site

The IRD is the primary outcome measure used to examine effectiveness when treating a DRA. Noble[27] first suggested measuring the IRD three finger breadths (4.5cm) above and below the umbilicus to diagnose a DRA but there remains no consensus as to the optimum site as evident on examination of the 11 postnatal studies[10,12,17,18,19,20,22,24,26,29,34,] which have used ultrasound imaging to measure IRD. In these studies, 17 different anatomical linea alba sites were measured ranging from 12cm superior to the umbilicus to 4.50cm below the umbilicus. The mean site on the linea alba measured above the umbilicus was 5.50±3.45cm and below the umbilicus was 3.20±1.03cm. In the present study the exact superior-umbilicus and inferior-umbilicus site was standardised by calculating it from the participant's linea alba length, as a proportion, to take into account the height of the person, linea alba length and the anatomical changes down the length of the linea alba.

We hypothesise that the differences in the IRD at different sites on the linea alba may be due to anatomical structural variations in the formation of the linea alba and the alignment of the rectus muscle alters as its draws together at its attachment to the pubis as previously proposed[2, 15, 38].

The umbilicus IRD was the widest point in all positions, this coincides with previous research indicating that the umbilicus is the widest and weakest point on the linea alba[2] with over 50% of DRA occurring at this point.[6]

The smallest IRD was at inferior-umbilicus which on average was 1.6 and 2.1cm narrower than the superior-umbilicus and umbilicus sites respectively. This inferior umbilical region is the thickest site on the linea alba and thought to be able to withstand prolonged stretch[2,15] due to the change in formation of the rectus sheath below the accurate transition zone.[2,38] The aponeurosis of internal oblique inferior layer and TrA move anteriorly increasing the support and thickness of the rectus sheath and linea alba,[2,38]

A comparison of the IRD in sitting and standing with other studies is not possible as the current study is the first to provide such data. The IRD in crook-lying broadly agrees with all previous publications in this field in that the widest IRD was at the umbilicus, then the superior-umbilicus and narrowest at the inferior-umbilicus.[10,12,17,18,19,20,,22,24,26,29,34] However a comparison of the IRD between studies is difficult due to the wide variety of sites measured and the known anatomical differences cited. In the present study the superior-umbilicus mean location site was 5.2±0.43cm above the umbilicus and the IRD at this site in crook lying measured 1.86±0.66cm. This IRD compares closely with that reported by Mendes et al[22] at 6cm superior to the umbilicus, measuring 1.85cm and Mota et al[26] 5cm superior umbilicus at 1.87±8.40cm. These values are lower than that reported by Chairello et al[10] who measured 4.50cm superior umbilicus and measured 2.03±1.05cm. These IRD differences could be due to the anatomical structural variations within the linea alba as it widens at the umbilicus.

The inferior umbilicus mean location was 7.14±0.80cm below the umbilicus; this is 2.64cm lower than the inferior umbilicus sites measured in other studies. The inferior umbilicus IRD of 0.49±0.19 is 0.56cm narrower than Chairello et al[10] who measured 4.50cm below the umbilicus. The difference in IRD seen between these studies reflects the known anatomical variants below the umbilicus, closer alignment of the rectus muscle, and altered formation of the rectus sheath below the accurate transition zone[2].

Clinical Relevance

In clinical practice IRD is traditionally measured in crook-lying, a non-functional position. The present data show that measurement of IRD in functional positions produces larger IRD values questioning the clinical usefulness of measurements in lying. The clinical use of loaded functional positions in the rehabilitation of the DRA is in line with the stages of tendon rehabilitation which aim to gradually build up the load and develop tensile strength.[35] It is proposed that in these functional loaded, dynamic positions, the increased abdominal muscle activity will pull through the linea alba to improve both abdominal strength and the ability of the linea alba to transfer the muscular force from each side of the abdominal muscles. The effect of increased abdominal muscle activity on the IRD can be measured with ultrasound in functional postures to monitor the effect of rehabilitation.

In this study 2% (28 out of 1,476) of the ultrasound images in 14 of the 41 participants were of poor quality and unmeasurable in the sitting or standing postures at the umbilicus or inferior-umbilicus sites. This seemed to be predominantly related to higher BMI participants and/or due to poor visibility of the rectus muscle. The clinical relevance is that for women with a high BMI and poorly defined rectus muscles, ultrasound imaging of the IRD in sitting and standing may not always be achievable. This may present a challenge when imaging for some women postpartum, who tend to present with a larger layer of subcutaneous fat.

The anatomical site to measure the IRD and diagnose a DRA should be decided on the anatomical structural differences down the length of the linea alba. This study has demonstrated that the IRD varies depending on the site measured and therefore any studies examining the effect of abdominal muscle exercises on correcting a DRA need to measure at the same site. The effect of directional pull of the abdominal muscles on the IRD could vary depending on the site measured due to the anatomical structure of the linea alba. This suggests that the effectiveness of abdominal muscle exercises may vary along the length of the linea alba. It is therefore proposed that standardisation of the exact location superior-umbilicus,

umbilicus and inferior-umbilicus of the linea alba measured based on the anatomical structure and linea alba length is a central factor in moving forward research into the effectiveness of abdominal muscle exercises to treat a DRA.

Limitations of the study

The limitations of this study are the lack of age-matched nulliparous controls to compare the effects of posture and measurement site on the IRD. In reliability studies, it is important that the phenomenon of interest remains constant from measurement time 1 to measurement time 2. Natural reductions in IRD occur in the early weeks postpartum but plateau for approximately 40% of women. Thus, to minimise the risk of change in IRD between times 1 and 2, women under eight weeks post-delivery were excluded from this study. However, in some cases a plateau does not occur until six months or more [12,14,19,26], which may have influenced the results. However, no systematic difference in IRD was identified between time 1 and 2.

The participants with a greater BMI negatively impacted the researcher's ability to gain measurable scans in sitting and standing at the umbilicus and inferior umbilicus due to a larger layer of sub-cutaneous fat, poor visibility of the rectus muscle and the size of the transducer. The potential effect on IRD from the high number of multiparous women (70%) included in this study needs further investigation. *Physical activity levels may also effect IRD, however as habitual activity was not recorded it is difficult to assess the generalisability of our finding to women of different activity levels.*

5. Conclusion

The present study found that the IRD is wider at superior-umbilicus and umbilicus in sitting and standing compared with lying, and that there is a difference in IRD between differing anatomical sites measured along the linea alba.

Conflict of Interest:

No author received or will receive any financial benefits from this work. The authors have no conflict of interest to declare.

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Reference:

1. Atkinson G, Nevill A M. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998; 26 (4):217-238.
2. Axer H, Keyserlingk D G, Prescher, A. Collagen Fibers in Linea Alba and Rectus sheath. 1. General scheme and morphological aspects. *J of Surgical Research,* 2001; 96: pp. 127-134.
3. Barbosa S, Moreira de Sá R A, Coca Velarde L G. Diastasis of rectus abdominis in the immediate puerperium: correlation between imaging diagnosis and clinical examination. *Arch Gynecol Obstet* 2013; 288: 299-303.

4. Beer G M, Schuster A, Seifert B, Manestar, M, Mihic-probst D, Weber S.A. The normal width of the Linea Alba in Nulliparous Women. *Clinical Anatomy.* 2009; 22: pp. 706-711.
5. Benjamin D R, Van DE Water A TM, Peiris C L. Effects of exercise on diastasis of the rectus abdominis muscle in the antenatal and postnatal periods: a systematic review. *Physiotherapy.* 2014; 100(1): 1-8.
6. Boissonnault JS, Blaschak M J. Incidence of Diastasis Recti Abdominis during the childbearing year. *Physical Therapy.* 1988; 68: pp.1082-1086.
7. Boxer S, Jones S. Intra-rater reliability of rectus abdominis diastasis measurement using dial calipers. *Australian Physiotherapy* 1997; 43: 109-114.
8. Bursch S G. Interrater reliability of diastasis recti abdominis measurement. *Physical Therapy* 1987; 67:1077-1079.
9. Candido G Lo, T Janssen, P.A. Risk factors for diastasis of the recti abdominis. *Journal of the Chartered Physiotherapists in Women's Health.* 2005; 97: 49-54.
10. Chiarello C M, Mcauley J A. Concurrent validity of calipers and ultrasound imaging to measure interrecti distance. *Journal of Orthopaedic & Sports Physical Therapy.* 2013; 43:495-503.
11. Chiarello C M, Mcauley J A, Hartigan E H. Immediate effect of active abdominal contraction on inter-recti distance. *Journal of Orthopaedic & Sports Physical Therapy.* 2016; Vol 46 No 3: 177-183.
12. Coldron Y, Stokes M J, Newham, D J, Cook K. Postpartum characteristics of rectus abdominis on ultrasound imaging. *Manual Therapy.* 2008; 13: 112-121.
13. Costa L O P, Maher C G, Latimer J, Smeets R J E M. Reproducibility of rehabilitative ultrasound imaging for the measurement of abdominal muscle activity: A systematic review. *Physical Therapy* 2009; 89: 756-769.

14. Gilleard W L, Brown J M M. Structure and Function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. *Physical Therapy.* 1996; 76(7): 750-762.
15. Gräβel D, Prescher A, Fitzek S, Keyserlingk D G, Axer H. Anisotropy of human linea alba: A biomechanical study. *Journal of Surgical Research* 2005; 124: 118-125
16. Hsia M, Jones S. Natural resolution of rectus abdominis diastasis. Two single case studies. *Australian Journal of Physiotherapy.* 2000; 46: 301-307.
17. Iwan T, Garton B, Ellis R. The reliability of measuring the inter-recti distance using high-resolution ultrasound imaging comparing a novice to an experienced sonographer. *New Zealand Journal of Physiotherapy.* 2014; 42(2):154-163.
18. Keshwani N, Mclean L. Ultrasound imaging in postpartum women with diastasis recti: Intrarater between-session reliability. *Journal of Orthopaedic & Sports Physical Therapy* 2015; 45:713-718.
19. Liaw L M, Hsu C, Liao M, Hsu L, Hsu A. The relationships between inter-recti distance measured by ultrasound imaging and abdomina muscle function in postpartum women: a 6-month follow-up study. *Journal of Orthopaedic & Sports Physical Therapy* 2011: 41: pp. 435-443.
20. Lee D, Hodges P. Behavior of the Linea Alba During a Curl-up Task in Diastasis Rectus Abdominis: an Observational Study. *Journal of Orthopaedic & Sports Physical Therapy.* 2016; vol: 46 (7): 580-589
21. Mantle J, Haslam J, Barton S. *Physiotherapy in Obstetrics and Gynaecology.* 2nd edn. 2004 Edingburgh: Butterworth-Heinemann.
22. Mendes D A, Nahas F X, Veiga D F et al. Ultrasonography for measuring rectus abdominis muscle diastasis. *Acta Cirurgica Brasileria.* 2007; 22: 182-186.

23. Mew R. Comparioson of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. *Manual Therapy.* 2009; 14: 690-695.
24. Mota P, Pascoal A G, Sancho F, Bø K. Test-retest and intrarater reliability of 2-dimensional ultrasound measurements of distance between rectus abdominis in women. *Journal of Orthopaedic & Sports Physical Therapy.* 2012; 42:940-946.
25. Mota P, Pascoal A G, Sancho F, Carita A I, Bø K. Reliability of the inter-rectus distance measured by palpation. Comparison of palpation and ultrasound measurements. *Manual Therapy.* 2013; 18: 294-298.
26. Mota P, Pascoal A ,Carita A, Bø K. The Immediate Effects on Inter-rectus Distance of Abdominal Crunch and Drawing-in Exercises During Pregnancy and the Postpartum Period. *Journal of Orthopaedic & Sports Physical Therapy.* 2015; vol: 45 (10): 781-788.
27. Noble E. *Essential exercises for the childbearing year. A guide to health and comfort before and after the birth of your baby.* 1985. London: John Murray (Publishers) Ltd.
28. O'Sullivan P B, Grahamslaw K M, Kendell A, Lapenskie S C, Möller N E, Richards K V. The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. *Spine* 2002; 11:1238-1244.
29. Pascol A G, Dionisio S, Cordeiro F, Mota P Inter-rectus distance in postpartum women can be reduced by isometric contraction of the abdominal muscles: a preliiminary case-control study. Physiotherapy, 2014; 100: 344-348. http://dx.doi.org/10.1016/j.physio.2013.11.006.

30. Rath A M, Attali P, Dumas J L, Goldlust D, Zhang J, Chevrel J P. The abdominal linea alba: an anatomo-radilogic and biomechanical study. *Surg Radio Anatomy.* 1996; 18: 281-288.
31. Rasouli O, Arab A M, Amiri M, Jaberzadeh S. Ultrasound measurement of deep abdominal muscles activity in sitting positions with different stability levels in subjects with and without chronic low back pain. *Manual Therapy* 2011; 16: 388-393.
32. Rett M T, Braga M D, Bernardes N O, Andrade S C. Prevalence of diastasis of the rectus abdominis muscles immediately postpartum: comparison between primiparae and multiparae. *Rev Bras Fisioter,* 2009; 13(4): 275-280.
33. Rett M T, De Araujo R, Rocha I, Da Silva A. 2012. Diastasis of rectus abdominis muscle immediately postpartum of primiparous and multiparous after vaginal delivery. *Fisioteraputa pela.* 2012; 19(3):236-241.
34. Sancho M F, Pascoal A G, Mota P, Bø K. Abdominal exercises affect inter-rectus distance in postpartum women: a two-dimensional ultrasound study. *Physiotherapy* 2015; 101:286-291.
35. Sharma P, Maffulli N. Biology of tendon injury: healing, modeling and remodeling. *Journal of Musculosketal Neuronal Interactions* 2006; 6:181-190.
36. Sperstad J B, Tennfjord M K, Hilde G, Ellstrom-Engh M, Bø K. Diastasis recti abdominis during pregnancy and 12 months after childbirth: prevalence, risk factors and report of lumbopelvic pain. Br J sports Med 2016; 0:1-6. Doi:10.1136/bjsports-2016-096065
37. Spitznagle T M, Leong F C, Van Dillen L R. Prevalence of diastasis recti abdominis in a urogynecological patient population. *Int Urogynecol J* . 2007; 18: 321-328

38. Standing S. *Grays's Anatomy. The anatomical basis of clinical practice.* 40th edn. 2008. Edinburgh: Churchill Livingstone Elsevier.
39. Van de Water A T M, Benjamin D R. Measurement methods to assess diastasis of the rectus abdominis muscle (DRAM): A systematic review of their measurement properties and meta-analytic reliability generalisation. *Manual Therapy* 2016; 21:41-53.
40. Walter S D, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. *Statistics in Medicine.* 1998; Vol 17: 101-110.
41. Whittaker J L, Teyhen D S, Elliott J M et al. Rehabilitative ultrasound imaging: understanding the technology and its applications. *Journal of Orthopaedic & Sports Physical Therapy.* 2007; Vol 37 No 8: 434-449.
42. Whittaker J, Stokes M. Ultrasound imaging and muscle function. *Journal of Orthopaedic & Sports Physical Therapy* 2011; 41:572-580.
43. Whittaker J L, Warner M, Stokes M. Comparison of the sonographic features of the abdominal wall muscles and connective tissues in individuals with and without lumbopelvic pain. *Journal of Orthopaedic & Sports Physical Therapy.* 2013; 43:11-19.

Tables:

TABLE 1	Demographics Variables (n=41) *
Characteristic	**Value**
Age (years)	43 ± 9
Weight (kg)	69.8 ± 12.5
Height (cm)	166 ± 6
BMI	25.2 ± 4
Para	1.8 ± 0.6
Multiparous number of births	2.2 ± 0.41 (56% P2 / 14.6% P3)
Primiparous, n (%)	12 (29.3)
Multiparous, n (%)	29 (70.7)
Baby birth weight, g	3543.4 ± 545.1
Years post delivery	9.8 ± 8.9
Range of time since delivery	2 months to 28 years

Abbreviations: BMI, body mass index
*Data are mean ±SD
Para = number of births
P2= two births and P3 = three births

TABLE 2: Within and Between Session Intra-rater Reliability *								
Within session (mean of 2 scans)								
Posture	**Point**	**n**	**ICC (95% CI)**	**SEM (cm)**	**MDC (cm)**	**95%LOA (cm)**		
						Mean diff	**SD**	**LOA**
Lying	SU	41	0.98 (0.98 to 0.99)	0.07	0.20	-0.001	0.09	0.18
	U	41	0.99 (0.99 to 0.99)	0.05	0.15	-0.015	0.91	0.18
	IU	41	0.93 (0.87 to 0.96)	0.05	0.15	-0.004	0.07	0.13
Sitting	SU	41	0.98 (0.97 to 0.99)	0.08	0.23	-0.004	0.11	0.21
	U	33	0.98 (0.97 to 0.99)	0.08	0.22	0.003	0.12	0.23
	IU	41	0.90 (0.83 to 0.95)	0.05	0.15	0.009	0.08	0.15
Standing	SU	41	0.99 (0.98 to 0.99)	0.06	0.18	0.003	0.09	0.18
	U	35	0.99 (0.98 to 0.99)	0.06	0.18	-0.026	0.14	0.26
	IU	40	0.96 (0.94 to 0.98)	0.04	0.12	0.008	0.06	0.12
Between session: (Mean of 2 scans at session 1 & 2)								
Lying	SU	40	0.98 (0.96 to 0.99)	0.13	0.36	-0.029	0.19	0.37
	U	40	0.99 (0.98 to 0.99)	0.09	0.26	-0.003	0.15	0.29
	IU	40	0.92 (0.85 to 0.96)	0.08	0.23	-0.014	0.13	0.25
Sitting	SU	40	0.98 (0.97 to 0.99)	0.11	0.32	-0.036	0.18	0.34
	U	34	0.98 (0.96 to 0.99)	0.13	0.36	0.056	0.20	0.39
	IU	40	0.94 (0.89 to 0.97)	0.06	0.18	0.006	0.1	0.20
Standing	SU	40	0.99 (0.98 to 0.99)	0.09	0.25	-0.003	0.14	0.27
	U	35	0.98 (0.96 to 0.99)	0.14	0.38	-0.19	0.22	0.43
	IU	40	0.98 (0.97 to 0.99)	0.03	0.09	0.021	0.07	0.13

Abbreviations: SU=superior umbilicus U=umbilicus IU=inferior umbilicus
ICC = intraclass correlation coefficient; SEM = standard error measurement, MDC= minimal detectable difference, LOA=95% limits of agreement.
* Derived from Linear regression model

Table 3: Posture and site effect (Mean ±SD (cm)			
Site	**Lying**	**Sitting**	**Standing**
SU (n=41)	**1.86±0.66**	**2.08±0.72**	**2.18±0.84**
U (n=31)	**2.40±0.70**	**2.60±0.69**	**2.57±0.76**
IU (n=39)	**0.49±0.19**	**0.47±0.18**	**0.46±0.25**
Abbreviations: SU=superior umbilicus U=umbilicus IU=inferior umbilicus			

Figures:

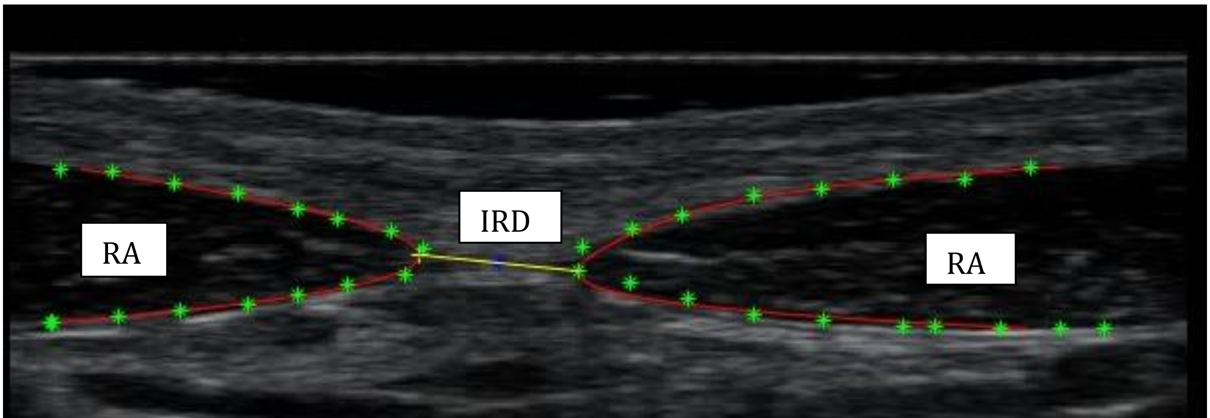

Figure 1: Ultrasound image measured offline using bespoke Matlab image-processing software. Abbreviations: RA, rectus Abdominis and IRD, inter-recti distance.

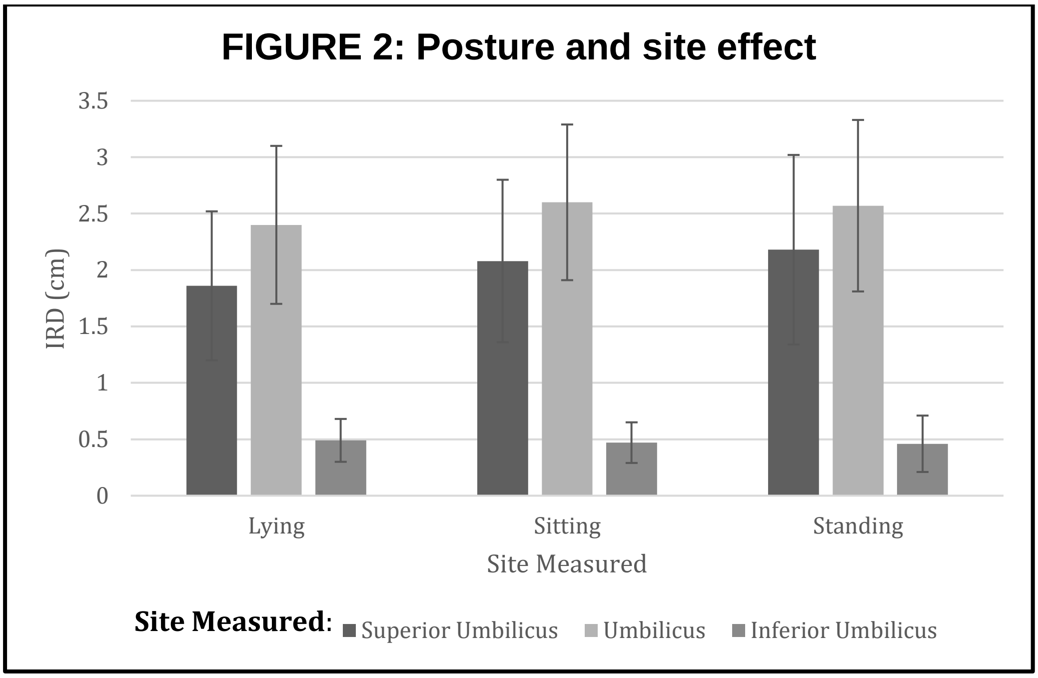
FIGURE 2: Posture and site effect
3.5
3
2.5
2
1.5
1
0.5
0
IRD (cm)
Lying
Sitting
Standing
Site Measured
Site Measured:
Superior Umbilicus
Umbilicus
Inferior Umbilicus