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REVIEW ARTICLE

Diastasis Recti Abdominis-diagnosis, Risk Factors, Effect on Musculoskeletal Function, Framework for Treatment and Implications for the Pelvic Floor

Laura Anne Werner[a,*] and Marcy Dayan[b]

[a]Shelbourne Physiotherapy 100B-3200 Shelbourne V8P 5G8, Victoria, BC, Canada; [b]Dayan Physiotherapy and Pelvic Floor Clinic 909-750 W Broadway V5Z 1H8 Vancouver, BC, Canada

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Abstract: ***Background:*** Diastasis Recti Abdominis (DRA) can occur during pregnancy and postpartum. It is defined as an increase of the inter-recti distance (IRD) beyond normal values. The diagnosis of DRA is inconsistent within the literature and varies depending on measurement instrument and activity during measurement (rest *versus* active curl-up). DRA is characterized by the stretching of linea alba (LA) and contributes to a protrusion of the anterior abdominal wall due to increased laxity in the myofascial system that supports abdominal viscera. DRA has been postulated to affect lumbopelvic support and function due to laxity of the LA and altered angle of muscle insertion, but recent studies have not confirmed this. Risk factors for the development of DRA have been investigated in pregnancy to 12-months postpartum.

Objective: Rehabilitation for DRA has been traditionally focused on reducing the IRD, but recent research has proposed that a sole focus on closing the DRA is suboptimal.

Results: It is important alongside the rehabilitation of the abdominal wall that there is the consideration of the pelvic floor (PF). In healthy individuals, with the activation of the transversus abdominis, there is a sub-maximal co-contraction of the PF muscles. This co-contraction can be lost or altered in women with urinary incontinence. An increase in intra-abdominal pressure without simultaneous co-contraction of the PF may cause caudal displacement of the PF.

Conclusion: The aim of this review is to bring the reader up to date on the evidence on DRA and to propose a rehabilitation framework for the whole abdominal wall in DRA with consideration of the impact on the PF.

Keywords: Physiotherapy, inter-recti distance, diastasis recti abdominis, rehabilitation, abdominal exercise, pelvic floor exercise, pregnancy, postpartum.

1. INTRODUCTION

In a woman's life, pregnancy is a time of tremendous change on many different levels. It is remarkable how in the span of nine months a human life is gestated. There are many adjustments that occur in a women's body to accommodate the growing fetus including hormonal and musculoskeletal adaptations. One of the most common adaptations is for the (IRD) between the left and right rectus abdominis (RA) to increase in size to accommodate the growing fetus and uterus. After delivery, the abdominal walls of some women seem to rebound back to their original state, while many do not.

A quick internet or Pinterest search will reveal many online programs aimed at treating DRA, with most promising to close the gap and to get rid of "mommy tummy". Women are often referred to physiotherapy during pregnancy or in the postpartum period for DRA or the increased IRD. Unfortunately, there is currently no consensus on what exercise strategies should be employed in the rehabilitation of DRA. Little is known about the effect and safety of abdominal rehabilitation. The PF can be adversely affected by abdominal rehabilitation and is at risk of developing or worsening support-related pelvic floor dysfunction (SPFD) if the abdominal rehabilitation involves pressures that the PF cannot withstand and support against [1].

The aim of this article is to critically review the literature on DRA and to propose a treatment framework for rehabilitation and support of the abdominal wall when DRA is present with consideration of the impact on the PF. A review on DRA was written by Mota *et al.* [2], but since publication, there have been some salient developments.

1.1. Methodology for Research Articles

A search strategy using the electronic databases of Medline Full-text (EBSCO), Cochrane Systematic Reviews

*Address correspondence to this author at the Private Practice Physiotherapist, Associate at Shelbourne Physiotherapy 100B-3200 Shelbourne V8P 5G8 Victoria, BC, Canada; Tel: 1 (250) 598-9828;
E-mail: laura.werner@hotmail.com

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(EBSCO), CINAHL Complete (EBSCO), and PubMed was developed to look for published studies on DRA from April 5, 2017 to June 2, 2017. Grey literature was also searched for using Google Scholar, Trip Database and PEDro. All studies were filtered for publication from January 1, 2007 to June 2, 2017 (within the last 10 years of publication). Manual searching of the reference lists of the included studies and citation tracking was conducted to ensure that all relevant research was found. Research articles in English were included.

2. ANATOMY OF THE ABDOMINAL WALL

The abdominal wall consists of a layered configuration that includes muscular layers and their corresponding fascia/aponeurosis. The transversus abdominis (TrA), internal oblique (IO), and external oblique (EO) comprise the lateral abdominal musculature that has attachments on the thoracic cage, pelvis and vertebral spine *via* the thoracolumbar fascia [3]. The RA runs in a vertical orientation in the midline of the abdominal wall and is encased in the flat sheet-like aponeurosis of the TrA, IO and EO that form the rectus sheath. The rectus sheath is made of an anterior and posterior layer. The layers meet at the lateral edge of the rectus along a curved line, the linea semilunaris, that spans from the 9th costal cartilage to the pubic tubercle [2] and meet medially at the LA. The arcuate line (or linea semicircularis) is a horizontal line approximately halfway between the umbilicus and the symphysis pubis that is the boundary of the lower limit of the posterior layer of the rectus sheath [2]. It is not a sharp line, but rather a transitional zone where the posterior rectus sheath changes to the anterior rectus sheath [2]. The function of the rectus sheath is to allow sliding of the muscles through neighbouring structures and protect the muscle fibers of the RA [2]. The EO muscle fibers are approximately horizontal in the uppermost portion (becoming oblique in the lower portions) and its aponeurosis contributes to the anterior portion of the RA sheath [2]. Above the arcuate line, the aponeurosis of the IO splits, allowing one layer to pass anteriorly and the other posteriorly to the RA muscle, contributing to the anterior and posterior rectus sheaths, respectively. Below the arcuate line, the aponeurosis of the IO passes anteriorly contributing to the anterior rectus sheath [2]. Above the arcuate line the TrA aponeurosis lies behind the RA muscle and blends with the posterior rectus sheath. Below the arcuate line the TrA aponeurosis passes in front of the RA muscle and blends with the anterior rectus sheath [2, 4]. Below the arcuate line the transversalis fascia/transverse fascia is the only structure that separates the rectus abdominus from the parietal peritoneum [2].

The LA is comprised of highly organized collagen fibres [5] that continue from the rectus sheaths [6]. The collagen structure of LA is formed by a 3-D meshwork of fibers that are in the same orientation as the muscle fibers of the ventrolateral abdominal wall (TrA, IO, EO) [5]. The LA spans from the xiphoid process to the pubic bone [2]. The LA and rectus sheaths can be divided into craniocaudal regions: supraumbilical; umbilical; transition zone (transitional area where aponeurosis of EO, IO and TrA pass anteriorly to the rectus to become the arcuate line); and infra-arcuate [6]. The infra-umbilical (from umbilicus to symphysis pubis) region has a greater amount of transverse fibers, which provides greater ability to resist tensile stresses imposed on the LA [6, 7]. The function of the LA is to maintain the abdominal muscles at a certain proximity to each other [8] and to provide lumbopelvic function and abdominal visceral support through multiple mechanisms, including the transfer of force through fascial tension [2, 9]. The LA in conjunction with the rectus sheaths are regarded as the most important structures for the stability of the anterior abdominal wall from a mechanical point of view [5, 7, 10]. The abdominal wall has functions in posture, lumbopelvic stability, respiration, trunk movement and support of the abdominal viscera [11].

2.1. Normal IRD

Rath *et al.* [12] studied the IRD in 40 fresh cadavers and 40 abdominopelvic computed tomography (CT) scans at rest at supine. This study determined the normal IRD in males and females under 45 years of age to be 10 mm at the supraumbilical reference point (halfway between the umbilical ring and xyphoid), and 9 mm at the infraumbilical reference point (halfway between the umbilical ring and pubic symphysis). The authors found that above age 45 there was an increase in IRD at the supraumbilical and infraumbilical locations by only 5 mm. The umbilical level IRD was not affected by age. Limitations of the study include a nonhomogeneous population in the cadaver study with a mix of men and women with a range of lean to obese body builds and a high average age of 83 years (range: 62-99 years old), a mixture of men and women with a broad age range from children to seniors in the CT population, and the information regarding the number of pregnancies in the women are missing [12].

To evaluate the normal width of the LA in nulliparous women, Beer *et al.* [8] examined 150 nulliparous women between 20 and 45 years of age with a body mass index < 30 kg m^{-2} by ultrasound at three reference points: the origin at the xiphoid, 3 cm above and 2 cm below the umbilicus. The width was of LA was evaluated in a supine position, with the neck slightly flexed and the legs fully extended with relaxed rectus muscles and normal breathing. The examination revealed a broad range of widths at the three reference points. The LA was widest at 3 cm above the umbilicus, followed by the reference point 2 cm below the umbilicus and then the origin at the xiphoid. For the definition of the normal width of the linea, the 10th and 90th percentiles were taken. The LA can be considered "normal" from 2 to 15 mm at the xiphoid, 6 to 22 mm at the reference point 3 cm above the umbilicus and from 2 to 16 mm at the reference point 2 cm below the umbilicus in nulliparous women [8].

As part of their study, Liaw *et al.* [13] conducted ultrasound measurements on 20 nulliparous controls. Measurements were taken *via* ultrasound with the subject resting in supine with two pillows under the knees. Still images were obtained in resting at the end of a normal expiration, to control for the influence of respiration. Measurements were taken at 4 locations: upper and lower margins of the umbilical ring, 2.5 cm above the upper margin of the umbilical ring, and 2.5 cm below the lower margin of the umbilical ring. The mean of the measurements at the four locations from cranial to caudal for the nulliparous woman were 8.5, 9.9, 6.5, and 4.3 mm, respectively. The largest IRD for both nulliparous and parous women were measured at the upper margin of the umbilical ring, and the smallest IRD values were found 2.5 cm below the lower margin of the umbilical ring. The authors noted that the subjects' demographic and anthropometric data such as age, body height, weight, and ethnic background may contribute to differences between studies, and therefore recommended that future studies include a nulliparous control group in postpartum studies for reference purposes [13].

2.2. Definition and Etiology of DRA

DRA is when the IRD exceeds "normal" values [8]. Criteria and the IRD cut-off value for the diagnosis of DRA vary in the literature and to date, there is no international agreement on the measurement location [2]. It has also been defined as a visible midline bulge on exertion [14].

The viscoelastic properties inherent to the collagen makes the LA prone to increase length when the mechanical stress is prolonged in time [10] as in the case of lasting increased intra-abdominal pressure (IAP). Long lasting increased IAP from a growing fetus and expanding uterus combined with hormonal changes [15, 16] on connective tissue create a physiological (normal) widening of the IRD creating a DRA in pregnancy [2]. The anterolateral abdominal wall undergoes dramatic changes as the pregnancy progresses. For example, the weight of the uterus increases from 40 g at a non-pregnant state to 1000 g at term and the capacity increases from 4 ml in the non-pregnant state to 4000 ml at term [17]. The maternal inferior thoracic diameter is increased [18]. The two muscle bellies of the RA elongate and curve round as the abdominal wall expands [2] similar to suspenders on obese man. At 38 weeks gestation, the length of the abdominal muscles increase a mean of 115% compared to the beginning of pregnancy [19]. As previously stated, the infra-umbilical (from umbilicus to symphysis pubis) region of the LA has a greater amount of transverse fibers, which provides greater ability to resist tensile stresses imposed on it [6, 7]. Liaw *et al.* [13] noted that during pregnancy the infraumbilical region might sustain a longer duration of stretch during pregnancy (as the growing uterus rises out of the pelvis at 12 weeks and makes contact with the abdominal wall). Their data indicated that IRD values were larger for the 2 locations above the umbilicus compared to those below the umbilicus, and suggested that the infraumbilical region of the LA has a greater ability to resist stresses imposed over a longer period of time [13].

DRA can also occur in males with repeated increases in IAP from prolonged strenuous exercises such as weightlifting or full-excursion sit-ups [20], or with conditions that increase IAP such as chronic obstructive pulmonary disease [21]. DRA can also be congenital [22].

DRA is characterized by a thinning and widening of the LA and potential for the midline to 'bow out' with increased IAP [23]. A DRA contributes to a bulging or protrusion of the anterolateral abdominal wall due to increased laxity in the myofascial system that supports abdominal viscera [23]. In cases of marked DRA, only the peritoneum, attenuated fascia/LA, subcutaneous fat, and skin comprise the middle portion of the anterior abdominal wall [24].

DRA is often referred to as abdominal muscle separation, but the condition involves stretch rather than separation [25].

2.2.1. DRA vs. Ventral Hernia

DRA and primary ventral hernias both occur in the midline. A clear differentiating factor of a DRA compared to a ventral hernia is the absence of a hernia sac and an intact LA, and that DRA is mostly asymptomatic and is not associated with strangulation of bowel [26]. Another surgeon echoes this notion, noting DRA is by itself not a true hernia and is not associated with the risks of intestinal strangulation [27].

3. PREVALENCE AND RISK FACTORS

3.1. Prevalence

The reported prevalence of DRA varies between studies and may be inaccurate due to different IRD cut-off values for the diagnosis and the use of different measurement assessment methods [2] (*i.e.*, palpation *vs.* caliper *vs.* ultrasound, rest *vs*. active, and location of measurement).

Early studies found DRA to affect between 30-70% of pregnant women [28], and the increased IRD can persist in the immediate postpartum period in 35-60% of women [29]. DRA has been found in 39% of older, parous women undergoing abdominal hysterectomy [24], and in 52% of urogynecological menopausal patients [15], suggesting that DRA can persist past childbearing years.

Mota *et al.* [30] completed a longitudinal study following a cohort with ultrasound assessment of the IRD from late pregnancy to 6 months postpartum. Still images were collected at the end of exhalation with the subjects in supine crook-ly with the abdominals relaxed. The authors used the same definition for DRA as used by Beer *et al.* [8] (IRD >16 mm at the reference point 2 cm below the umbilicus) and found that the prevalence of DRA decreased from 100% in late pregnancy (gestational week 35) to 39% at 6 months postpartum. The authors suggest that at 6 months postpartum, recovery is still in progress [30].

Sperstad *et al.* [31] found a prevalence of DRA of 33.1% at gestation week 21, 60% at 6-weeks postpartum, 45.4% at 6 months postpartum, and 32.6% at 12 months postpartum. DRA was defined as a palpated separation of greater than or equal to 2 fingerbreadths either 4.5 cm above or at 4.5 cm below the umbilicus during an abdominal crunch until the shoulder blades were off the bench [31].

3.2. Risk Factors

Candido *et al.* [32] found that women with and without DRA did not differ significantly with respect to age, ethnicity, height, history of abdominal surgery or back or neck injury, weight gain during pregnancy, pre-pregnancy weight, gestational age at delivery, method of delivery, multiple pregnancy (*e.g.*, twins, triplets, *etc.*), or diabetes (pre-existing or gestational).

Rett *et al.* [33] found no correlation between the development of DRA and mother's age, body mass index, gestational age or duration of labour.

Two recent studies concluded that Caesarian delivery does not increase the risk of DRA [34, 35].

Mota *et al.* [30] investigated possible risk factors for women with and without DRA at 6 months postpartum including age, BMI before pregnancy and 6 months postpartum, weight gain during pregnancy, Beighton's hypermobility score, baby weight at birth, abdominal circumference at gestational week 35 or exercise training level before, during and after pregnancy. There were no statistically significant differences between groups for any factor. The authors noted that the small sample size (n=84) may explain the non-significant results [30].

Sperstad *et al.* [31] conducted a longitudinal study following a cohort from 21 weeks gestation to 12 months postpartum. The authors examined risk factors for DRA in 178 primiparous women of European ethnicity between the ages of 19 and 40 years old. Risk factors assessed included age, height, mean weight before this pregnancy, weight gain during pregnancy, delivery mode, baby's birth weight, benign joint hypermobility syndrome (BJHS) assessed with Beighton score, heavy lifting, and level of abdominal and PF muscle exercise training and general exercise training at 12 months postpartum. The study found no significant difference in evaluated risk factors when comparing women with and without DRA at 12 months postpartum [31]. The study did not describe the technique of the abdominal and PF exercises nor lifting strategies employed.

Sperstad *et al.* [31] found the OR (odds ratio - compares the occurrence of the outcome in the presence of a particular exposure, with the occurrence of the outcome in the absence of a particular exposure) for DRA to be twice as high among women reporting heavy lifting 20 times or more per week compared to women reporting less weight lifting (this information was collected through a questionnaire and was neither defined nor measured directly). The authors indicate that the wide CI for the OR on heavy lifting indicates this result should be interpreted with caution [31]. A 2005 study found that among multiparous women with DRA there was a significant correlation with the provision of childcare ($P<0.001$), but the study was limited by its small sample size [32]. The frequent lifting and carrying of young children, especially if done with a Valsalva maneuver, increase strain on the abdominal wall, thereby increasing the risk of developing or worsening DRA [36]. Authors have called for this proposed risk factor to be investigated further [31].

Many studies examining DRA have focused on primiparous populations carrying single fetuses [30, 31]. It has been proposed that multiparity increases the risk and prevalence of DRA due to repeated and prolonged stretch on the abdominal wall [14, 28, 32], and that multiple pregnancies close together in time further increases the risk of DRA because there is insufficient time for the abdominal wall to recover between pregnancies [37]. Spitznagle *et al.* [15] offer the possibility that multiple pregnancies, as well as other factors such as lack of exercise, may contribute to cumulative mechanical stress to the connective tissue of the abdominal wall contributing to the development of a DRA [15]. Rett *et al.* [33] compared the prevalence of DRA in the immediate postpartum period of both primiparous women and multiparous women. The study found that the prevalence of DRA above the umbilicus was identical between primiparae and multiparae, but the prevalence of DRA below the umbilicus was significantly greater among the multiparae [33]. Two studies found that women with DRA have a greater number of pregnancies and deliveries [15, 33]. One study reported that multiple pregnancy or a large baby was a risk factor for DRA, rationalizing that with the increasing size of the baby (or babies), an increased IAP is exerted on the abdominal wall with a subsequent increase in stretching. Significance was found between the development of DRA and multiple gestation (27.3% compared to 1.7% in controls, $p<0.0001$) and increased weight of baby (3637.0 g compared to 3263.5 g, $p<0.001$) [14]. Interestingly, this was not supported by the following study by the same authors, but this study had only 10 women with multiple pregnancies. The authors concluded that this potential risk factor was too uncommon for significance in their study [32].

Spitznagle *et al.* [15] in 2007, study on multiparous middle-aged women found that DRA was more prevalent in those with a history of prior abdominal surgery, but the type of surgery was not specified [15]. Midline surgery might weaken the LA when the scar is subjected to increasing IAP caused by obesity or pregnancy [23]. Incorrect abdominal muscle technique could also be a factor, with valsalva and bracing putting repetitive strain on the incision over time.

A 2017 prospective cohort study followed 178 nulliparous pregnant women from gestational week 21 to 12-months postpartum [35]. The authors found a positive association between women with DRA at mean gestational week 21 and lower BMI pre-pregnancy and at gestational week 21, and that significantly more women with DRA had participated in general physical activity 3 or more times/week (the type and technique of physical activity was not specified) pre-pregnancy and at 21 weeks gestation. Maternal age and participants doing abdominal training did not differ between those with and without DRA [35].

4. HOW TO MEASURE IRD/DRA

In research and in practice when measuring IRD, the position of the subject and the activity performed at the time of the measurement varies. Some studies measure IRD while the abdominal muscles are at rest in a supine crook-lying position [8, 13, 30, 38], or intra-operatively in supine [23]. Some studies measure IRD during a partial curl-up where the subject lifts the head and shoulders off the bench just until the scapula clears the surface of the bench [31-33, 39-42] or with neck flexion in hook-lying [43]. Some studies do not specify if they measured at rest or with a curl-up or some other active abdominal engagement [35, 44].

Recent studies have shown that a curl-up, which activates RA [45], or an isometric contraction of RA [46] reduces the IRD in women with DRA [34, 47, 48]. Lee *et al.* [49] rationalize the approximation of RA muscles (and therefore reduction of IRD) with the straightening of the RA on contraction (Fig. **1**).

The way that IRD is measured is extremely important because the way that it is measured can yield different results. For example, an individual might have an IRD measurement with a partial curl-up that is less than the cut-off for diagnosis of DRA, when at rest the IRD measurement is above the cut-off for DRA diagnosis, therefore providing a

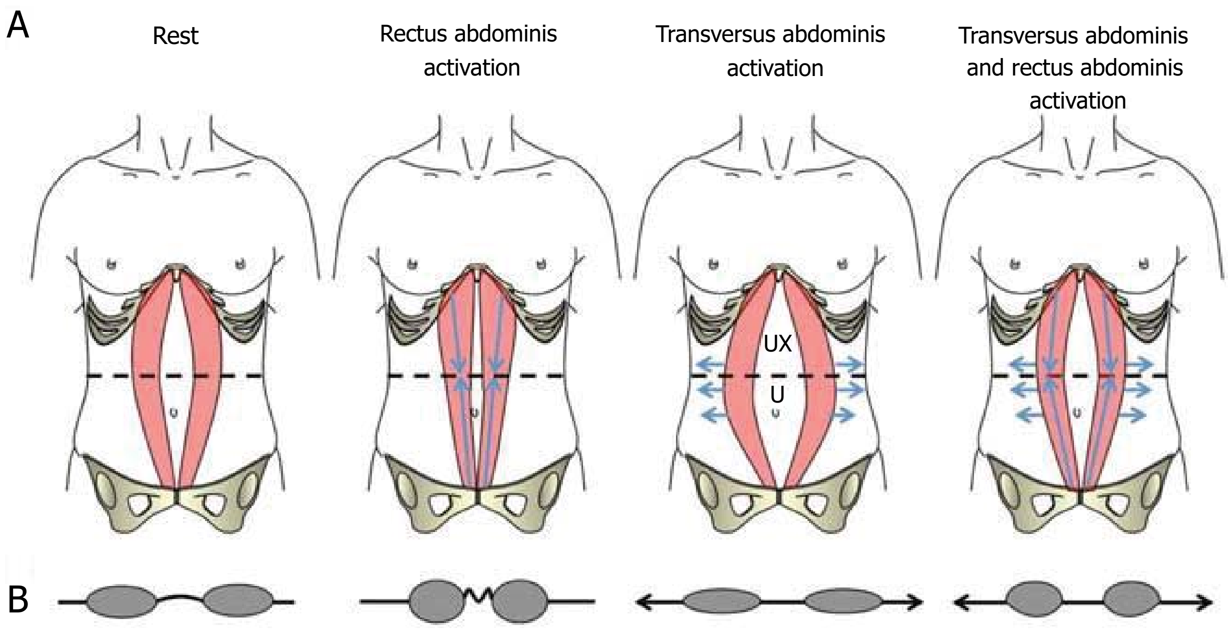

Fig. (1). Proposed effect of abdominal muscle activation on the inter-rectus distance. (**A**) Anatomical representation of the rectus abdominis muscle at rest (left panel) and during contraction (middle left panel), contraction of the transversus abdominis (middle right panel), and combined contraction of both transversus abdominis and rectus abdominis muscles (right panel). (**B**) Cross-sectional representation of the rectus abdominis and interposed linea alba at the location of the dashed lines in (**A**) during the tasks shown in (**A**). Note the slackening of the linea alba with narrowing of the inter-rectus distance as the rectus abdominis muscles straighten from the resting curved alignment on contraction. Note the tension on the linea alba from transversus abdominis contraction, and the reduced narrowing of the inter-rectus distance during rectus abdominis contraction combined with transversus abdominis contraction. Abbreviations: U point, just above umbilicus; UX point, halfway between the U point and the xiphoid. Reprinted with permission from Lee D, Hodges PW. Behavior of the linea alba during a curl-up task in diastasis rectus abdominis: an observational study. J Orthop Sports Phys Ther 2016; 46: 580-589. https://doi.org/10.2519/jospt.2016.6536. ©Journal of Orthopaedic & Sports Physical Therapy®.

false negative result. For example, the IRD measured at rest was more than twice the width of that measured during an active muscle contraction in women who were 11-weeks postpartum [50].

The measurement tool to identify IRD varies between studies. Palpation, tape measure, caliper, and ultrasound imaging are common ways to measure IRD and are clinically feasible in a clinical setting.

For palpation based measurements (including tape measure and calipers), the influence of the thickness of subcutaneous fat can be a confounding factor [13]. There is also a potential error of identification of medial aspects of RA with calipers, especially below the umbilicus if the individual has excessive subcutaneous tissue, adiposity, or a thick and rounded muscular configuration (Fig. **2**) [51]. Standardization of palpation methods (including calipers, tape measures, and finger width) can be a clinical challenge, and require a standardization protocol – for example, knowing how broad the examiner's fingers are in cm or mm [52].

In a recent study, palpation was reported to have sufficient reliability to be used in clinical practice, with palpation showing good intra-rater reliability and moderate inter-rater reliability [53]. Van de Water and Benjamin (2016) argue that palpation may be a sufficient method for detecting the presence of DRA [52].

When measuring above the umbilicus, caliper measurements had similar estimations of DRA compared to ultrasound, and in this study are reported as being a valid tool to measure IRD at this location [51].

Ultrasound imaging has been named the gold standard for non-invasive IRD assessment [11]. IRD measurements *via* ultrasound are valid compared to intra-operative surgical compass measurements when imaging is performed at or above the level of the umbilicus [54]. Ultrasound has produced consistent IRD measurements between sessions when performed by the same operator [55, 56]. Ultrasound imaging is also more responsive to changes in IRD than palpation [53] as it provides a measure of IRD on a continuous scale (*i.e.*, millimetres) [43], thus ultrasound is a more accurate and valid method and is recommended in future research of IRD [53]. When using ultrasound, inter-rater reliability is acceptable when IRD is measured above or below the umbilicus, but poor when measured at the level of the umbilicus [57]. Liaw *et al.* [13] noted that the medial margins of the RA appear to be indistinct where the fascial borders become less clear in postpartum women on ultrasound imaging. A recent study investigated the effect of transducer angle (cranial or caudal tilts up to 15 degrees) on acquiring IRD measurements [58]. The study found no significant effect of transducer angle in IRD measurements with participants at rest or during a head lift, concluding that tilt errors in transducer angle do not appear to pose a problem when measuring IRD [58].

An IRD greater than 4 or more fingerbreadths [31] or 5 cm during a curl-up has been classified as a severe DRA [32,

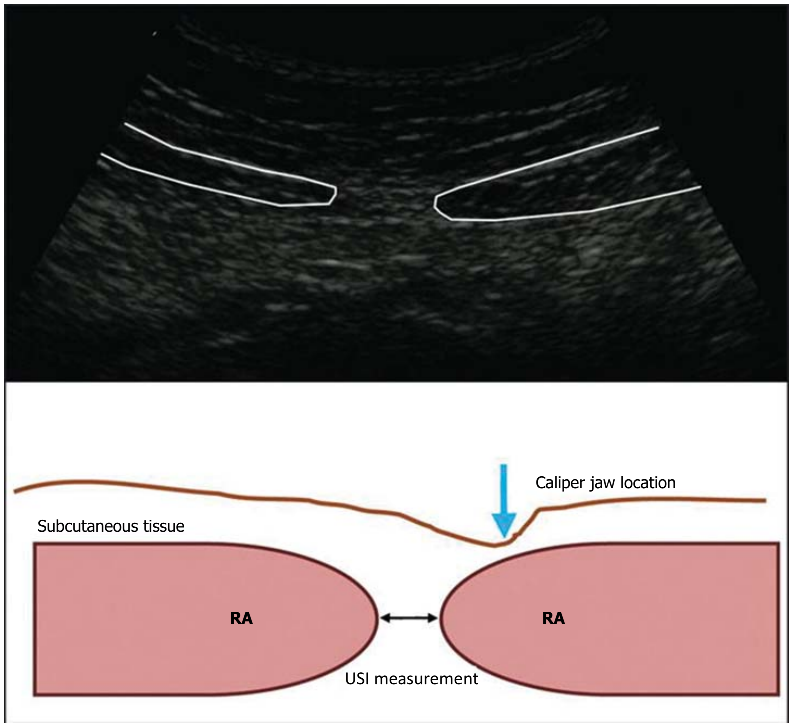

Fig. (2). Image and diagram showing the potential source of discrepancy between measurements of interrecti distance made with ultrasound imaging (USI) and the digital nylon calipers. As thickness of subcutaneous tissue increases, palpation of the inner edge of the rectus abdominis (RA) is potentially made more difficult, leading to overestimation of the distance when using calipers. Reprinted with permission from Chiarello CM, McAuley JA. Concurrent validity of calipers and ultrasound imaging to measure interrecti distance. J Orthop Sports Phys Ther. 2013; 43: 495-503. https://doi.org/10.2519/jospt.2013.4449. ©Journal of Orthopaedic & Sports Physical Therapy®.

42]. In women with a severe DRA, the width of the LA may be as large or larger than the width of the ultrasound transducer making it impossible to measure with conventional ultrasound imaging. When this occurs, methods that enable complete visualization of the LA must be used [43]. Keshwani *et al.* [43] conducted a study to investigate the validity and reliability of IRD measurement using extended field-of-view techniques during ultrasound imaging in parous women. The study found that panoramic ultrasound imaging and ultrasound imaging with acoustic standoff pads produce valid IRD measurements for separations of less than 3 finger widths (at superior border of umbilicus, assessed during neck flexion in hook-lying), suggesting that either extended field-of-view technique is a potentially valid choice to allow for complete visualization of the width of the LA when the IRD is too large to measure using conventional ultrasound imaging [43].

Although ultrasound imaging was found to be reliable (the extent to which an experiment, test, or measuring procedure yields the same results on repeated trials) in healthy and post-natal women, data on all types of measurements on longitudinal validity (ability of an instrument to measure what it is supposed to measure) and responsiveness (ability of a tool to detect small differences or small changes) is lacking [52].

To date, all studies have conducted measurements for IRD in a horizontal position. It would be interesting to assess IRD measurements in parous women in a standing position. Standing is a functional position in which most activities of daily living and exercise are performed in. It is also the position where the DRA and myoaponeurotic laxity is most visible creating the protrusion of the anterolateral abdominal wall.

5. EFFECT/IMPLICATIONS OF DRA

There are significant morphological changes to the anterolateral wall with the occurrence of a DRA. The widening of the LA in DRA potentially modifies its tensile properties and may its capability to transfer force across the midline of the abdomen [38, 49] and therefore influence the function of the abdominal muscles. The increase of the anterior abdominal dimensions may alter the angle of attachment and angle of insertion, which may alter the muscles line of action and therefore their ability to produce torque [18, 19]. Coldron *et al.* [38] studied the cross-sectional area, thickness and width of RA as well as IRD in the postpartum period. It was found that the RA was thinner and wider, and the IRD was larger in the postpartum group compared to nulliparous controls, and that these changes were maintained at 1-year. The authors propose that these properties occurred likely due to stretch-induced changes in the contractile and connective tissue components of the muscle belly, the fascial aponeurosis surrounding RA, and the underlying transversalis fascia that occurred during pregnancy [38]. The change in contractile tissue is supported by the work of Blazevich *et al.* [59] who found after a 3 week stretch training there were increases in both whole muscle and fascicle elongation during a maximal tolerable stretch. To date, there are no studies that look at the morphological muscle changes of the lateral abdominal muscles (TrA, IO, EO) in DRA.

Only two studies analyze the relationship between DRA and abdominal muscle dysfunction – Gilleard & Brown (1996) [19] and Liaw *et al.* [13]. Gilleard & Brown [19] examined 6 primiparous women who were physically active and between the ages of 28 and 33 years old. They related some morphological parameters inherent to the perinatal period with changes in abdominal muscle functional capacity. The authors reported IRD changes between week 14 of pregnancy to the 8^{th} week postpartum in 9 intervals. The ability to perform a curl-up test (assessed according to an ordinal scale of functionality from minor to major) and the abdominal muscle test (keep a backward tilt position while performing lower limb flexion-to-extension in supine) was assessed. The authors found that the curl-up capacity and the ability to stabilize the pelvis in a backward pelvic tilt position are compromised in pregnant women and up to 8 weeks after delivery, particularly in women with a DRA higher than 3.5 cm measured by palpation when measured during a head raising maneuver in crook-ly at the end of pregnancy [19].

Liaw *et al.* [13] investigated the relationship between IRD and abdominal muscle function at 7-weeks and 6-months postpartum. 30 postpartum women were involved in the study (mean age of 31.3 years), and both primiparous (n=17) and multiparous (n=13) women were included in the study. All had carried single fetuses to term with mean weight of baby of 6.5 lbs. The control group was 20 age-matched nulliparous women. All women had not received any abdominal muscle training or engaged in any other regular exercises within the previous 6 months or during the follow-up period. Function of the abdominal muscles was determined by examining the strength and endurance for trunk flexion and rotation. Strength was assessed using manual muscle testing graded upon the ability to raise the trunk against gravity in supine. Static endurance and dynamic endurance of the trunk flexor and rotators was assessed in hook-lying with instructions to lift head, neck and upper trunk from the table until the inferior angles of scapula had risen clear off table in either a sustained hold (static endurance), or repetitions (dynamic endurance). A negative relationship was found between mean IRD values and abdominal muscle function at both 7-weeks and 6-months postpartum. A reduction in IRD between 7-weeks and 6-months postpartum was associated with improved trunk flexor and rotation strength and static endurance, though the authors noted these improvements were relatively small and the values remained below the values of their nulliparous matched counterparts. Overall, the abdominal muscle strength and endurance in women at 6-months postpartum was significantly ($P<0.001$) less than the nulliparous women. The authors suggest that incomplete recovery of the structural integrity (width) of the LA may lead to a mechanical deficit, resulting in a reduction in force production capacity of the abdominal muscles [13].

It must be noted that the above two studies only assessed function of the abdominal wall in a supine position.

Many recent studies have disputed a cause-effect relationship of DRA to lumbopelvic pain. Mota *et al.* [30] found that women with DRA were not more likely to report lumbopelvic pain than women without DRA. Parker *et al.* [39] had similar findings of no significant difference between women with and without DRA reporting lumbopelvic pain using the Modified Oswestry Low Back Pain: Disability Questionnaire. Sperstad *et al.* [31] followed 178 first-time pregnant women from pregnancy until 12 months postpartum. Their findings echoed Mota *et al.* [30] and Parker *et al.* [39] that women with and without DRA reported the same amount of low back and/or pelvic girdle pain at 12 months postpartum [31]. The authors did note that their study only had women with mild diastasis (except 2 that were moderate) and that at the time of their study they stated that there is little knowledge on women with a larger separation [31].

Not to be forgotten is the effect of a DRA on the on the woman's self-perception, body image and emotional state due to the change in abdominal appearance. A woman with DRA is often asked if she is pregnant, and this can be understandably upsetting. Expectations of our society to rebound right back to the pre-pregnancy state are everywhere - in the media as well as our own pre-conceived notions. Marketed programs for DRA promising to "close the gap" do not help this pressure either.

Nahas [22] provided a qualitative description of DRA and provided four types of myoaponeurotic deformity from a group of 88 women undergoing abdominoplasty for DRA. He described four different types of myoaponeurotic deformities that included DRA as well as potential myofascial defects including lack of adequate tension of the lateral and infraumbilical areas and poor waistline definition. One type included congenital DRA. Proposed surgical correction included recti plication for the DRA as well as potential plication of EO aponeurosis, advancement of the EO muscles with rotation toward the midline at the lower abdomen, as well as a specific correction for congenital DRA [22]. Veríssimo *et al.* [60] investigated the effect of repair of abdominal wall deformity with simultaneous repair in both the transverse and longitudinal directions. Their results revealed a successful vertical shortening of the musculoaponeurotic layer immediately after suturing and 6 months postoperatively. The authors report new questions including what is the aesthetic benefit of a vertical shortening of the musculoaponeurotic layer? Does vertical shortening play a significant role in the aesthetic and postural appearance of the patient? The authors call for further studies to answer these questions [60]. The qualitative descriptions and required surgical management of various myoaponeurotic deformities by Nahas [22] and Veríssimo *et al.* [60] support the theory that the protrusion and stretching of the anterolateral abdominal wall are caused by the stretching of the entire musculofascial abdominal wall and not only the LA [23].

5.1. DRA and the PF

The abdominals and the PF muscles are both part of the abdominal canister and are closely related through changes in IAP [61]. Therefore, some hypothesize that a weakness in the abdominal wall may create a deficiency in PF muscle strength and endurance. The suggestion is that if the abdominal wall cannot co-contract effectively during the PF contraction, the PF contraction will be less effective in it's urogynecolgical functions [15]. A 2009 systematic review investigating the evidence for the benefit of TrA training in relation to pelvic floor muscle training (PFMT) stated that there is insufficient evidence for the use of TrA training instead of or in addition to PFMT for women with urinary incontinence [62]. Dumoulin *et al.* [63] and Sriboonreung *et al.* [64] did not find any additional effect of adding abdominal training to PFMT on incontinence. Upon reviewing the available randomized controlled trials, Bø *et al.* [65] concluded that the evidence is currently ambivalent and does not provide strong support for the effectiveness of abdominal muscle training for stress urinary incontinence (SUI). The above-mentioned evidence does not support the theory that an abdominal wall weakness will result in a less effective PF contraction or limit PF rehabilitation for (SUI), a form of SPFD.

Spitznagle *et al.* [15] conducted a retrospective chart review examining multiparous middle-aged (52.45 years +/- 16.65 SD) women investigating the prevalence of DRA (measured with palpation at 1 inch above or below the umbilicus with a head lift maneuver; DRA = 2 cm or greater) in a urogynecological patient population. The authors found that patients with DRA were older, reported higher gravity and parity, and had weaker PF muscles than patients without DRA. 66% percent of all the patients with DRA had at least one SPFD diagnosis (SUI, fecal incontinence, and pelvic organ prolapse (POP)) [15].

Bø *et al.* [35] compared vaginal resting pressure (VRP), PF muscle strength and endurance, the prevalence of urinary incontinence and POP with and without DRA at gestational week 21 and at 6-weeks, 6-months, and 12-months postpartum. The prospective cohort study followed 178 nulliparous pregnant women from gestational week 21 to 12-months postpartum. VRP, PF strength and endurance were measured with vaginal manometers. Urinary incontinence (either stress, urge, or mixed urinary incontinence) was assessed with the ICIQ-UI-SF questionnaire. POP was assessed with POP-Q by gynaecologists in a half-sitting lithotomy position. POP was defined as POP-Q greater than or equal to stage 2 of any compartments, and no POP as POP-Q stage 0 or 1. DRA was diagnosed with palpation of greater than or equal to 2 fingerbreadths 4.5 cm above, at, or 4.5 cm below the umbilicus. The study did not specify if the measurement for IRD was taken at rest or with head and shoulder lift. The results revealed the VRP, and PF muscle strength and endurance were better in women with DRA at mean gestational week 21. No significant differences in PF muscle function were found between women with or without DRA at 6-weeks, 6-months or 1-year postpartum. At 6-weeks postpartum 15.9% of the women without DRA had POP *versus* 4.1% of the women with DRA (P=0.001). There were no significant between-group differences in the prevalence of POP at any other assessment points (21-weeks gestation, 6-months and 12-months postpartum). No significant difference was found in the prevalence of urinary incontinence in women with and without DRA at any assessment points. In summary, the authors concluded that in their study, women with DRA were not more likely to have weaker PF muscles, urinary incontinence or POP than their counterparts with no DRA neither during pregnancy nor during the first postpartum year [35].

Unfortunately, one cannot compare the results of Spitznagle *et al.* [15] and Bø *et al.* [35] due to the differing age of populations (Spitznagle *et al.* [15] group older/most menopausal and multiparous *versus* Bø *et al.* [35] group younger/childbearing age and nulliparous/primiparous) and different measurement locations of DRA. Bø *et al.* [35] recognized that POP may not be as manifested in the early age (and early parity) of their population, and this may explain the differences between their results and those of Spitznagle *et al.* [15].

The study by Bø *et al.* [35] challenges the belief that DRA negatively effects the function of the PF muscles and is associated with urinary incontinence and POP. The authors state that clinicians should use caution when postulating associations between PF muscles, PF dysfunction, and the abdominal muscles until more research is available. They note that the results of the study do not support recommendations to include clinical assessment of DRA or restoration of DRA in the treatment of women with PF dysfunctions [35]. Although clinically it may be relevant ensuring proper abdominal technique, abdominal core strength, endurance, and functional use are concurrent goals of a client with SPFD. The authors of this article also observed that there is no support found in the literature for treating a DRA with pelvic floor exercises.

6. TREATMENT/INTERVENTION

6.1. Natural Resolution?

Coldron *et al.* [38] investigated cross-sectional area, thickness and width of RA and IRD in 115 postnatal women (both primiparous [n=72] and multiparous [n=43]) and 69 nulliparous female controls of childbearing age (18-45 years, mean age 27). Postpartum subjects were studied on the first day postpartum, 8 weeks postpartum, 6 months postpartum, and 12 months postpartum. Measurements were taken *via* ultrasound with the probe just cephalad to the umbilicus in crook lying and knees flexed over 2 pillows and muscles at rest. The study found that in the postpartum women, RA was significantly thinner and wider, and the IRD was significantly larger compared to controls, and that none of these variables had returned to control values by 12 months postpartum. Only the cross-sectional area of RA had returned to normal over an 8 week period. The authors found that the most recovery of IRD occurred between day 1 and 8-weeks postpartum when IRD reached a plateau and no further improvement was noted at the end of the first year. The mean IRD at 1 year was 22.3 mm, but the measurements ranged from 10.2 to 42.1 mm with a third of the subjects presenting with a wider gap than the mean [38]. The article does not specify if women were or were not engaging in any rehabilitative exercise for the duration of the study.

Part of a 2011 study [13] investigated the natural recovery of IRD in the postpartum period at 7 weeks and 6-months postpartum. The authors reported that the IRD significantly decreased from 7-weeks to 6-months postpartum, but that at 6-months postpartum, the averaged IRDs taken at the 2 supraumbilical sites and the 2 infraumbilical sites were 2.1 and 2.7 times those of nulliparous women, respectively. This study clarified that the postpartum women were not engaging in any abdominal muscle training or regular exercises during the follow-up period, nor had they (or the nulliparous group) received any abdominal muscle training or engaged in any other regular exercises within the previous 6 months prior to the study. The authors noted the limitation of the assessment of recovery as it was compared to data obtained from a nulliparous control group, as opposed to data obtained in pre-pregnancy or early pregnancy gathered longitudinally from the experimental group [13].

The lack of recovery of increased IRD in all parous women may indicate the presence of an irreversible/unrecoverable connective tissue stretch that can occur in soft tissues at the damaged state, also called a permanent set [66]. Gasser *et al.* [67] postulate that the primary mechanism of permanent set in biological tissues is the rupture of proteoglycan bridges between adjacent collagen fibrils, which allows for relative sliding of the fibrils and plastic deformation of the matrix material in the direction of the fibers.

6.2. Postpartum Abdominal Support/Binder

Many have suggested the theory that the regular use of a postpartum support belt/abdominal binder can reduce back pain and strain on muscles and ligaments and suggest it could be of use to reduce IRD in the postpartum period [16, 41, 68]. The literature review by Mota *et al.* [2] reports that there are no high-quality clinical studies to support these statements. Benjamin *et al.* [11] propose that external compression garments may provide biofeedback for and assist the proprioception of TrA to aid with its activation, but clarify that evidence is lacking about their use in the management of DRA and further research is required. Wearing an abdominal binder may increase IAP, and monitoring the capacity of the PF to support against this pressure is necessary.

6.3. Surgical Repair

Hickey *et al.* [25] conducted a systematic review of the outcomes of surgical correction of DRA. The study reports that surgical correction is largely cosmetic as DRA does not carry the same risks of actual herniation. The authors note that progressive surgical techniques have resulted in risk reduction with no associated surgical mortality, however, the outcomes may be imperfect, with unsightly scarring, local sepsis and the possibility of recurrence. The most common complication seen was the development of a seroma. Other common complications included haematomas, minor skin necrosis, wound infections, dehiscence, post-operative pain, nerve damage and recurrence, the rate of which may be as high as 40% [25].

Mommers *et al.* (2017) observed that surgical treatment of DRA (*via* recti plication) only corrects the widening of the LA and will not influence the general laxity of the ventral abdominal wall, suggesting that physiotherapy could be a useful addition to surgical intervention for DRA to achieve a satisfying functional outcome [26].

6.3.1. Indication for Surgical Repair

Most surgeons state that surgical repair of DRA is done for cosmetic reasons. Akram *et al.* [27] conducted a review to investigate indications for surgical repair. Both Akram *et al.* [27] and Brauman [23] suggest that the protrusion of the abdomen, rather than the diastasis itself should influence the decision of repair when the repair is done for cosmetic reasons.

Lee *et al.* [49] observed that some individuals may not be able to generate sufficient LA tension despite optimal TrA activation and that in this subgroup, passive support (*via* an abdominal binder) or surgical repair may be required.

Mommers *et al.* (2017) reported that guidelines on indication and methods for repair of DRA do not exist [26].

6.4. Exercise Rehabilitation

There is no recommendation from the available evidence to identify at what width of IRD necessitates a referral to physiotherapy.

A recent systematic review concluded that, as of now, there are no high-quality randomized controlled trials (RCT)s on the effect of abdominal training programs to guide clinical practice in this area [11]. Due to the poor quality of available evidence, the authors state that non-specific exercise may or may not help to prevent or reduce DRA during the ante- and postnatal periods. Only eight relevant studies were found to include in the review. The studies were of varying design and methodological quality, and had inadequately powered sample sizes. Definitions of DRA and methods of measuring DRA also varied between studies and therefore the authors were unable to draw strong conclusions. The exercise interventions in the studies were highly variable and were carried out in isolation or along with corset/binding and/or education. The exercise settings, delivery, frequency, and duration varied between the studies. Five of the studies investigated TrA activation and strengthening. These exercises were varied in how this activation was achieved [11].

A 2017 systematic review of treatment options for DRA reported that physiotherapy programs were unable to reduce the IRD in a relaxed state [26]. It was noted that the literature regarding physiotherapy interventions is heterogeneous in nature and of low quality. The authors reported that the reduction of the IRD during muscle contraction was described, but whether this has an influence on functional outcomes or quality-of-life is unknown [26].

Coldron *et al.* [38] encourage the use of exercises that target the return of a normal IRD, RA width, thickness and length without loading and compressing the lumbar spine. This is based on the assumption that restored RA muscle alignment restores function [69], and improves cosmetic appearance [22].

Some authors encourage exercises that narrow the IRD such as crunch or curl-up exercises [46]. An additional three studies showed that the IRD narrowed when the abdominal crunch exercise was performed and that the "drawing in" maneuver aimed at the contraction of TrA resulted in the widening of the IRD compared to rest in all locations measured on the LA [34, 47, 55].

On the contrary, some have said that curl-ups should not be recommended as an exercise for postpartum women, as curl-ups performed with the Valsalva maneuver can increase the IAP and stress the already weakened abdominal wall (and PF) after pregnancy, predisposing the abdomen to DRA [16], and others report that abdominal crunches are considered a risk exercise for development (and worsening) of DRA [70].

Some clinical instruction encourages lateral abdominal muscle training to narrow the IRD [41, 71, 72], but how this achieves narrowing is unclear [49]. The basis of most abdominal strengthening programs is that the contraction of the abdominal muscles will reduce the horizontal abdominal diameter (corsetting) in such a way that a horizontal force will be generated producing the approximation of the right and left RA, especially at the umbilical level [19]. However, there is no data to support this suggestion [2], and in fact some rationalize that the horizontal force vector of the lateral abdominal muscles should increase the IRD when contracting [46] due to the overall action of the lateral abdominal muscles (EO, IO and TrA) which attach anteriorly to the linea semilunaris [2] and posteriorly to the thoracolumbar fascia [34].

Although, it has been suggested by some early studies that exercise in the prenatal period may have a protective effect on DRA and that exercise may improve DRA in the postpartum period, caution should be implied due to the limited amount and poor quality of studies provided [11]. Recent studies investigating risk factors for DRA have shown no correlation between antenatal exercise preventing the development of DRA [30] nor in the postpartum period with general exercise [30, 31], or when comparing abdominal and PF muscle exercise training at 12 months postpartum [31]. Interestingly, a 2017 study found a significant correlation between women with DRA and participation in general physical activity $\geq$ 3 days/week pre-pregnancy and at 21weeks gestation [35]. It should be noted that abdominal muscle technique during the exercises was not described.

A recent study by Lee *et al.* [49] provides findings that challenge the contemporary view that reduced IRD should be the sole focus of DRA rehabilitation, and that TrA activation to create LA tension (despite reduced IRD narrowing, or in some cases, widening) could optimize the function of the abdominal muscles and the appearance of the abdominal wall [49]. Lee *et al.* [49] proposes an alternative view that LA tension, which may require an increase in IRD, is necessary to support the abdominal contents [73] and to transfer force between opposite sides of the abdominal wall [74].

As stated previously, Lee *et al.* [49] propose the approximation of RA muscles with the straightening of the RA on contraction (Fig. **1**). In this model, the LA slackens with the narrowing of the IRD as the RA muscles straighten from the resting curved alignment on contraction. A slackened LA could be distorted (bulge/dome/tent) when challenged by elevated IAP and could also limit the effective transfer of force between opposing abdominal muscles [49].

Lee *et al.* [49] conducted a study to observe the behaviour of LA during a curl-up when DRA is present. Study participants included 26 women with DRA (one nulliparous and 25 parous [mean births 2.9 ± SD 0.9]) and 17 volunteers without DRA (11 nulliparous and 6 men). DRA was defined as IRD (measured with ultrasound imaging) of greater than 22 mm at 3 cm above umbilicus or greater than 15 mm below the xiphoid in accordance with Beer *et al.* [8]. Measurements were taken in a supine position, head supported on a pillow, hips and knees flexed, feet supported on the table, and the arms by the sides. Images were taken at rest, with an automatic curl-up (lifting the head and neck until the top of the scapula just clears the bed), and with a curl-up with preactivation of TrA at the U (just above umbilicus) and UX (halfway between U point and the xiphoid) points. The IRD and distortion index were measured in each test condition. The distortion index was developed to estimate LA distortion as an estimate of tension. The distortion index measures the average amount of deviation of the path of the LA from the shortest path between it's attachments (Fig. **3**). The study found that with an automatic curl-up, there is a narrower IRD compared to rest, but there is more distortion of LA (LA is less stiff/tensed). With preactivation of TrA before curl-up there is a wider IRD compared to automatic curl-up, but there is a more direct path of the LA creating less distortion (LA is more stiff/tensed) [49].

Based on their findings, Lee *et al.* [49] propose that rehabilitation to optimize abdominal support and lumbopelvic function may require strategies that increase LA tension, and this may involve TrA contraction to widen the IRD or reduce IRD narrowing [49].

Lee *et al.* [49] reported training TrA activation with minimal activation of the superficial abdominal muscles, and that this pattern was selected because the TrA aponeurosis continues as the transverse fibers of the dorsal/posterior rectus sheath and lamina fibrae transversae of the LA [5, 6]. As previously stated, the stiffness of LA is greatest (*i.e.*, compliance is lowest) in the transverse direction [7], therefore the TrA has the greatest potential to increase the LA tension and is critical for support of the abdominal wall and resistance of increased IAP [5, 6]. Lee *et al.* [49] used ultrasound biofeedback for TrA training.

The authors found that when participants with DRA performed the automatic curl-up (without preactivation of TrA), the IRD reduced. When the controls performed the automatic curl-up, the IRD did not change. With an automatic curl-up, the distortion index was greater for the DRA group than for controls. For controls, the distortion index did not change between rest or either of the curl-up tasks. The authors proposed that this could imply that optimal TrA activation occurred without cueing during automatic curl-up in this group, or that low LA extensibility prevented distortion regardless of strategy, or both [49]. These combined findings suggest a novel way to define DRA and/or a dysfunctional LA, with individuals with DRA exhibiting a reduction in IRD and/or an increased distortion index with an automatic curl-up.

For participants with DRA, the distortion index increased from rest during the automatic curl-up at both U and UX points. In the same group, the distortion index did not change from rest with the TrA curl-up at both U and UX points, showing that pre-activation of the TrA prevented LA distortion during the curl-up [49].

The authors clarified that the magnitude of DRA is not the sole determinant of LA tension. It was found that at the U point, distortion was not dependent on the IRD separation in DRA (*i.e.*, the distortion index could be low despite large IRD and *vice versa*). The authors outlined four areas of potential variation between individuals that could influence the capacity to control tension in the LA: a) the ability to recruit TrA, b) the interaction between the other abdominal muscle layers which have differing relationships to the LA, c) some individuals might exhibit excessive laxity which may limit the capacity of TrA to influence LA tension, and d) the

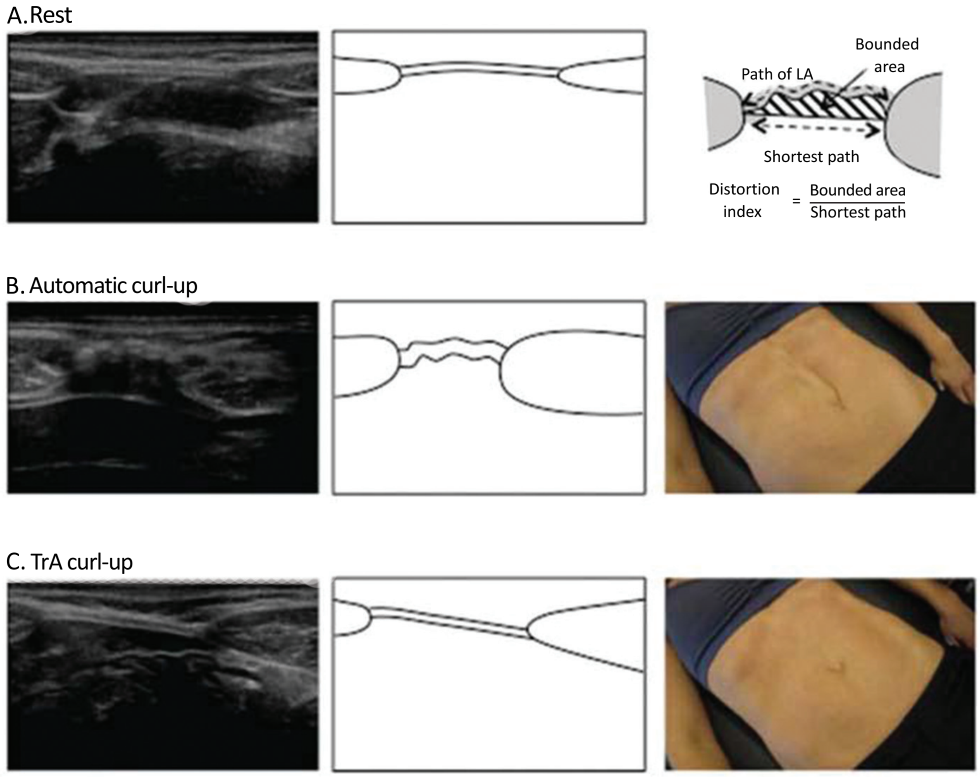

Fig. (3). Distortion index. Interpretation of the distortion index (**A**) at rest, (**B**) during the automatic curl-up, and (**C**) TrA curl-up tasks. Ultrasound images (left panel), line drawings of ultrasound images (middle panel), and photographs of the abdominal wall during the curl-up tasks (middle and bottom right panels). The inset at the top right defines the calculation of the distortion index from the area bounded by the path of the LA from the automatic curl—up task and the shortest distance between the LA attachments. Note the distortion of the LA with narrower inter-rectus distance during automatic curl-up and the wider inter-rectus distance but more direct path of the LA in the TrA curl-up. Abbreviations: LA, linea alba; TrA, transversus abdominis. Reprinted with permission from Lee D, Hodges PW. Behavior of the linea alba during a curl-up task in diastasis rectus abdominis: an observational study. J Orthop Sports Phys Ther 2016; 46: 580-589. https://doi.org/10.2519/jospt.2016.6536. ©Journal of Orthopaedic & Sports Physical Therapy®.

variation in IAP generated during the curl-up would affect LA distortion (*i.e.*, with reduced IAP *via* thoracic expansion, the LA would invaginate or "sag inwards" *versus* bulging outwards when IAP increases). Lee *et al.* [49] highlights the importance and necessity of individualized rehabilitation for DRA due to the range of potential moderators on the capacity to control tension in the LA. The authors also note that some individuals may not be able to generate sufficient LA tension despite optimal TrA activation and that in this subgroup, passive support (abdominal binder) or surgical repair may be required. The authors note that excessive LA stretch (in individuals with a wider IRD) would reduce the potential benefit of the proposed mechanism above and that additional measures such as elastography of the LA are necessary to directly estimate the effect of abdominal muscle recruitment on LA tension and to consider individual difference [49].

Lee *et al.* [49] suggest that although not directly measured, it is possible that an increase in LA distortion from an acute reduction of IRD during an automatic curl-up may not optimally support the abdominal contents (potentially producing less desirable cosmetic appearance), and could induce less effective mechanical function. The authors recommend that these potential outcomes should be directly measured in future studies. Lee *et al.* [49] recommend rehabilitation objectives that employ strategies to decrease LA distortion (increase LA tension) *via* TrA activation for optimal support of abdominal contents and to optimize the transfer of force between the sides of abdominal muscles. The authors reason that a more direct path of the LA between its attachments would equate to greater force transmission than an undulating path [49], as is similar to the uncrimping of tendon collagen fibers when tensed and transmitting force [75]. Lee *et al.* [49] mentions the role of tissue strain in collagen matrix production/healing, and that increased collagen synthesis to strengthen the LA may be enhanced by stretch/tension [76] with activation of TrA [49]. The study concludes with a cautionary statement that it cannot conclude what type of abdominal training may lead to better cosmetic or functional outcomes for women with DRA, but points out that exercises that widen the IRD cannot be dismissed [49].

In another publication, Lee & Hodges [77] report future investigation to test the hypothesis that IRD narrowing in parous women with DRA causes more distortion in LA and less potential for generating tension between the sides of the abdominal wall in a subgroup of women with DRA and concurrent lumbopelvic pain and impairment.

6.4.1. PF Consideration with Abdominal Exercise

In healthy individuals, there is an automatic sub-maximal co-contraction of the PF muscles with the activation of the

TrA [78-80]. This co-contraction is important during activities that increase IAP (such as lifting or coughing) as the PF and TrA counteract the increased IAP to provide organ support and continence [81]. There is evidence that a co-contraction of the PFM with TrA contraction can be lost or altered in women with urinary incontinence [62]. Additionally, an increase in IAP without simultaneous co-contraction of the PF may cause caudal displacement of the PF [1, 81]. This poses a risk of creating or worsening SPFD [82] such as SUI (inability of the PF and endopelvic facia to maintain closure on the urethra against an increase in IAP) and POP (the downward descent of the female pelvic organs into or through the vagina that can occur with damage to the PF muscles and endopelvic facia) [82]. During the antenatal and postnatal period, the PF is vulnerable from stresses placed on it during pregnancy, vaginal delivery, and postpartum. If abdominal rehabilitation for DRA is done in a way that creates IAP exceeding what the PF can bear, there can be negative consequences to the PF.

6.4.2. Proposed Treatment Framework for DRA

Traditional approaches to treatment of DRA have been solely directed towards the reduction of the IRD. Studies have identified a negative relationship between IRD and abdominal muscle function [13, 19]. Unfortunately, "function" was assessed in a supine position which is not a position that most activities of daily living and exercise are performed in. Additionally, evidence does not demonstrate long-term sequelae of musculoskeletal function in women with mild and moderate DRA [30, 31, 39].

Recent research by Lee *et al.* [49] challenges the notion that IRD must be reduced to rehabilitate DRA. The authors suggest that the closure of the IRD may not even be necessary for function [49]. There needs to be a shift in paradigm from the notion of achieving an "optimal IRD" [51] and excessive focus on IRD measurement, towards supporting and strengthening the morphological adaptations that have occurred to the abdominal wall. More realistic and attainable goals in rehabilitation of DRA include the restoration of abdominal wall tone with possible recovery of morphological contractile tissue changes in the lateral abdominal musculature, strengthening of the LA, improvement of form of the abdominal wall, and a safe and supportive return of function to desired activity levels. A reduction of DRA may be seen with rehabilitation, but a portion of the IRD may not be recoverable with exercises alone due to irreversible connective tissue changes that have occurred in the LA.

Which abdominal muscle activation strategy would be optimal to improve both functional and cosmetic outcomes in women with DRA is a matter of debate [49]. Lee *et al.* [49] suggests that TrA activation to create LA tension (despite reduced IRD narrowing, or in some cases, widening) could optimize the function of the abdominal muscles and the appearance of the abdominal wall. Along with creating LA tension, the contraction of the TrA also tensions the thoracolumbar fascia and increases the IAP, modulating this pressure with other trunk muscles including the diaphragm [62], and the PF [61]. Many therapists and trainers cue the PF in hopes of achieving a TrA contraction, relying on the automatic co-contraction of these muscles that occur in healthy individuals. As previously mentioned, there is evidence that a co-contraction of the PFM with TrA contraction can be lost or altered in women with urinary incontinence [62]. To the author's knowledge, there is no evidence of the loss of TrA co-contraction with PFC, but the author has seen this in clinical practice. Bø *et al.* [62] cautions that in clinical practice one cannot assume that PF and TrA co-contractions occur involuntarily [62], and therefore the importance of individual assessment and treatment is crucial. In addition, no RCTs have been identified that investigate whether PF contractions are effective in increasing TrA strength and function [62]. Based on the above information, rehabilitation for DRA should include proprioception and motor control exercises for the abdominal wall using cueing from the abdominal wall, for example, cueing to gently pull the low abdomen towards the spine with confirmation of proper recruitment of TrA with palpation and Real-Time Ultrasound Imaging (RTUS). Using a cue from the abdominal wall will also provide increased awareness for the individual to monitor the abdominal wall's response to exercise and activity intensity.

For individuals with DRA, the safety and technique of abdominal exercise needs to be considered. As previously stated, the development of DRA occurs with lasting increases in IAP [10], and DRA can also be caused in males with increased IAP with prolonged strenuous exercise [20]. It would be reasonable to extrapolate that participating in exercises or activities that create sustained IAP beyond what the abdominal wall and LA can support against could increase the risk of developing or worsen an existing DRA. Sustained IAP with poor abdominal muscle technique could also exacerbate pre-existing SPFD [1, 81, 82]. Upon synthesizing the available research on DRA, including knowledge that all abdominal muscles can be effected in the resulting abdominal wall protrusion [23, 27], along with knowledge of the abdominal wall and PF function, it is clear that the treatment framework for rehabilitation of DRA must consider rehabilitation of the whole abdominal wall and the impact of the training on the PF. Rehabilitative exercise for DRA must take into consideration the myofascial support of the abdominals and PF, existing SPFD, individual differences in proprioception and motor control for the abdominals and PF, and presence or absence of the co-contraction between TrA and the PF.

Rehabilitative exercises for the abdominal wall should be instructed and performed in ways that create a drawing in of the abdominal wall *via* TrA with an automatic co-contraction of the PF if that is naturally occurring, or with the absence of pressure down on the PF. Individual differences in proprioception and motor control for these deep muscles may provide different activation patterns depending on the instruction given, and therefore a combination of palpation, RTUS and feedback from an experienced clinician is key. RTUS is valuable in the clinical setting as it allows for the real-time study of the muscles as they contract, and has been found to be a valid and reliable non-invasive technique to measure abdominal muscle thickness and estimate relative muscle activity [83]. As previously noted, Lee *et al.* [49] necessitates individualized rehabilitation for DRA due to the range of potential moderators on the capacity to control LA tension. In addition, some isometric abdominal muscle activation strategies (*i.e.*, bracing with excessive IO, EO or RA

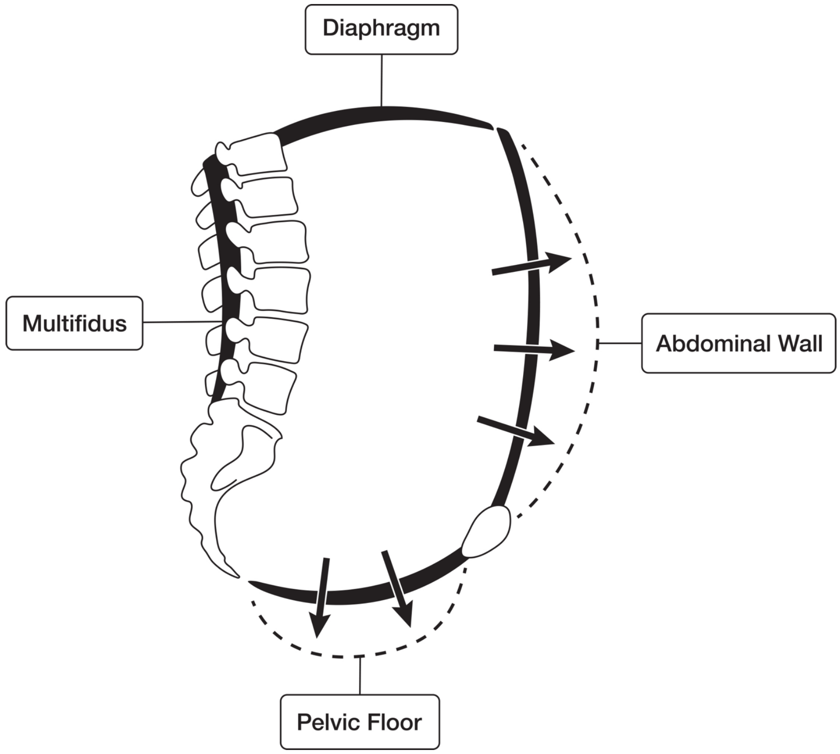

Fig. (4). Potential effects to the abdominal canister if an increase in IAP caused by an activity or task exceeds what the abdominal wall and/or PF can support against. This non-optimal strategy creates an outward pressure causing the abdominal wall and/or PF to bulge outwards. This outward pressure/bulging has the potential to strain the myofascial structures of the abdominal wall, the LA, and the PF especially if repeated over time. Abbreviations: IAP, intra-abdominal pressure; PF, pelvic floor; LA, linea alba.

recruitment) can create an outward movement/bulging of the abdominal wall and result in high pressures on pelvic organs, fascia and the PF [1, 81, 82]. Regarding an exercise or activity itself, the direction that the abdominal wall and/or PF moves in response to an increase in IAP with a task provides a clue on how the abdominal canister/capsule (lumbar vertebrae, deeper layers of multifidus, respiratory diaphragm, TrA and PF) [78, 80] is managing the IAP caused by the task and/or technique. For example, if the abdominal wall and/or PF cannot sustain support against an increase in IAP induced by a task or exercise, there will be an outward movement of the abdominal wall and/or PF (Fig. **4**). This outward motion may strain the LA and the PF and has potential to worsen existing or create DRA and/or SPFD, especially if done repeatedly as an exercise. This may be particularly true if these myofascial structures are vulnerable from recent pregnancy and delivery. The outward movement of the abdominal wall can be assessed for with palpation along the LA and the lower abdominal wall. The outward/caudal movement of the PF can be assessed with internal digital exam screening for descent of the anterior vaginal wall and cervix and/or with RTUS assessing for caudal movement of the bladder.

Interventions for DRA might be better termed as Abdominal Wall Rehabilitation, given the changes to all abdominal layers discussed in this paper. The individual must be taught how to self-identify when the abdominal wall and/or PF is not managing the IAP caused by the activity or if the abdominal muscle activation strategy is creating a bulging of the abdominal wall or the PF. These factors would mean that the abdominal wall muscle strategy in terms of timing and sequencing appropriate to demand (load and direction of movement) is faulty. This skill in self-identification is a vital component for management of DRA and PF in both pregnancy and postpartum as the ability of the abdominal wall and PF to appropriately manage the IAP may change as the pregnancy progresses or as skill, strength, and endurance of the abdominal wall and PF improve. Rehabilitation should include the progression of exercises striking a balance of challenge with the maintenance of control carried out in a variety of positions, including positions of function as well as integration into the functional activities themselves. The progression of exercises should include the appropriate sequencing and timing of activation of IO, EO, and RA according to the demands of the activity (direction and load) while maintaining the foundation of an indrawing of TrA and a flat abdominal wall with normal breathing. Lo *et al.* [14] provided parameters of abdominal exercise including the avoidance of breath holding and bulging. Education that DRA is not something to be feared, but rather to be respected, is vital to communicate to the individual. Building skills of muscular control and body awareness will foster self-efficacy for the individual and allow the transfer of these skills into life tasks with confidence.

A conceptual shift could also be made in the diagnosis of DRA. Lo *et al.* [14] offered a qualitative diagnosis of DRA with a visible midline bulge on exertion. Lee *et al.* [49] found that individuals with DRA had a reduction in IRD and/or an increased distortion index with an automatic curl-up, where these measures did not change in controls with the same activity. These findings offer an alternate or additional way to screen and assess for DRA. If the diagnosis of DRA is to be made by measurement, the IRD should be assessed in a supine resting position for two reasons: a) norm values for IRD have been established in a supine resting position [8], and b) the IRD reduces with a partial curl-up [34, 47, 48] which may provide a false negative diagnosis of DRA. Mommers *et al.* (2017) echos this notion stating that the IRD should be measured while the RA are relaxed as referenced values of normal midline width of LA are measured/based on measurements during muscle relaxation [26].

7. CALL FOR RESEARCH

There is a need for high-quality studies that are adequately powered to investigate various aspects on the development and rehabilitation of DRA. An international agreement on a standardized location and method (rest *vs.* active) for measurement of IRD and cut-off for diagnosis for DRA would allow for a synthesis of and easier comparison between studies. Longitudinal studies that include pre-pregnancy and early pregnancy, as well as late pregnancy and postpartum measurements of IRD, would be useful to properly identify natural resolution if any. Further investigation of risk factors such as multiple pregnancy and effect of childcare/heavy lifting should be done. Research on the effect of severe DRA is also needed. Investigation of potential morphological muscle changes of the lateral abdominal muscles (TrA, IO, EO) in DRA and possible recovery of these morphological contractile tissue changes with rehabilitation would be of use. Measurement of IRD in a standing position could provide insight into a more functional effect of DRA. Liaw *et al.* [13] called for testing of abdominal muscle function with more accurate and sensitive methods of measurements such as instrumented dynamometer, functional tests, and self-report questionnaires that assess function with daily activities. Benjamin *et al.* [11] called for adequately powered, high-quality prospective RCTs targeting specific non-surgical management strategies to enable a single exercise intervention (such as the treatment framework proposed in this review), noting that this would save time and resources for therapists and individuals with DRA. Studies on the combination of physiotherapy and surgical intervention for the abdominal wall are needed.

CONCLUSION

DRA is a common condition that may or may not resolve naturally. Evidence does not demonstrate long-term sequelae of musculoskeletal function in women with mild and moderate DRA. Conventional rehabilitation with a primary focus on closing the gap may be suboptimal, and new research shows that exercises that target TrA have potential to improve form and restore function of the abdominal wall. Consideration of the myofascial support of the abdominal wall and PF, existing SPFD, individual differences in proprioception and motor control of the abdominals and PF, and presence or absence of the co-contraction of TrA and PF must be included in the rehabilitation of DRA. Active therapy including education, self-awareness, and self-efficacy of the integration of optimal abdominal and PF function and technique into exercise and function should be facilitated for each individual with DRA.

LIST OF ABBREVIATIONS

BJHS	=	Benign joint hypermobility syndrome
CT	=	Computed tomography
DRA	=	Diastasis recti abdominis
EO	=	External oblique
IAP	=	Intra-abdominal pressure
IO	=	Internal oblique
IRD	=	Inter-recti distance
LA	=	Linea alba
PF	=	Pelvic floor
PFMT	=	Pelvic floor muscle training
POP	=	Pelvic organ prolapse
RA	=	Rectus abdominis
RCT	=	Randomized controlled trial
RTUS	=	Real-time ultrasound imaging
SPFD	=	Support-related pelvic floor dysfunction
SUI	=	Stress urinary incontinence
TrA	=	Transversus abdominis
VRP	=	Vaginal resting pressure

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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