The Abdominal Wall After Pregnancy – Should we Open or Close the Gap?

Instructor: Diane Lee
The Abdominal Wall After Pregnancy & Diastasis Rectus Abdominis
Should we Open or Close the Gap?

COURSE DESCRIPTION & OBJECTIVES

It is well known that the abdominal wall plays a key role in function of the trunk and that pregnancy and delivery can have a significant and long lasting impact. Postnatal suboptimal strategies for the transference of loads through the trunk can create pain in a multitude of areas as well as affect the urinary continence mechanism and support of the pelvic organs. These suboptimal strategies are highly variable, individual and task specific and thus require individual assessment and training. For some, the individual muscles of the abdominal wall require attention (release and/or isolation training) prior to training while others do not.

Diastasis rectus abdominis is very common in the obstetric patient. While most women recover both form and function of the abdominal wall in the postnatal period, persistent separation of the rectus abdominis muscles occurs in some. Rehabilitation has traditionally focused on exercises to ‘close the gap’ and reduce this separation. New data, and a controversial new interpretation, (Lee & Hodges 2015 WCPT) support exercises that widen the separation (i.e. increase the inter-recti distance) to increase tension in the linea alba and control the abdominal contents while optimizing the transfer of force between sides of the abdominal wall.

This course will present:

1. the current evidence pertaining to the functional and postnatal abdominal wall
2. through short case reports and live model
   a. describe and demonstrate the assessment of the abdominal wall (muscle recruitment strategies and behaviour of the linea alba in response to the chosen strategy) and the relationship between the recruitment strategy and ‘twists’ between the thorax and pelvis
   b. describe and demonstrate the treatment and training for restoration of form and function of the abdominal wall
3. current clinical theories as to when a surgical consultation should be considered for repair of the linea alba

At the conclusion of this day the participants will have a better understanding of:

1. the anatomy of the abdominal wall including the fascial organization of the linea alba, rectus sheaths, abdominal aponeuroses, and their continuity/organization with the thoracolumbar fascia
2. how to assess the recruitment strategy of the abdominal wall and the behaviour of the linea alba in response to verbal cuing for contraction, the active straight leg raise task (ASLR) and during a curl-up task (clinical and with ultrasound imaging) to determine if the behaviour is optimal or suboptimal
3. the relationship between the posture/position of the thorax (individual lower thoracic rings) and pelvis on the presented recruitment strategy for a three tasks (response to verbal cue, ASLR and curl-up)
4. how to develop individualized treatment/training programs for restoring form and function of the postnatal abdominal wall

8:30 – 10:30     Anatomy and function of the abdominal wall – what do we know from the evidence and what happens in pregnancy
10:30 – 11:00    Morning break
11:00 – 12:30    Assessment of the abdominal wall – how to assess the recruitment strategy of the abdominal wall and behaviour of the linea alba (short cases to introduce the topic and then assess a live model followed by discussion for treatment/training)
12:30 – 1:30    Lunch
1:30 – 3:00     Diastasis rectus abdominis – when to train, when to refer for surgical repair, next steps for more research for formal data to support current clinical training theories
3:00 - 3:15     Afternoon break
3:15 – 4:30     Abdominal wall movement training
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The Abdominal Wall after Pregnancy

Diane Lee PT
South, Surrey BC Canada

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Both pregnancy & delivery present huge challenges to the abdominal wall and thus the whole body.

Specific Abdominal Wall Conditions Related to Pregnancy

- Pelvic Girdle Pain
- Urinary Incontinence
- Pelvic Organ Prolapse
- Diastasis Rectus Abdominis
Pregnancy-related Pelvic Girdle Pain Prevalence

During Pregnancy
- 45% combined LBP and PGP during pregnancy (Wu et al 2004)
- 20% of 2269 pregnant women suffered enough to seek medical attention (Albert et al 2002)

Recovery of Function Postpartum
- 5 – 7% fail to recover (Ostgaard & Andersson 1992)
- Severe disability in 8% (Wu et al 2004)

Urinary Incontinence Prevalence

Pregnancy Related
- Last Trimester: 48% primiparous, 85% multiparous (Morkved & Bo 2003)
- Postpartum:
  - 92% of those still incontinent at 12 weeks will still be incontinent at 5 years (Wiktrup et al 2000)
  - 5-7 years after delivery 44.6% of women have some degree of incontinence (Wilson et al 2002)

Nulliparous elite athletes: 28% (Nygaard et al 1994)
- Gymnasts 67%, Tennis 50%, Trampolists 85%

Age Related (Herschorn et al 2003)
- 18-40: 16%
- 41-64: 33%
- Over 65: 55%

Incontinence is the second most common reason (after dementia) for admission into assisted living (Mason et al 2003)
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**Relationship Between PGP & UI**

Australian Longitudinal Study on Women’s Health (28,000 women surveyed) (Smith et al 2007)
- Pregnant women experienced more back pain than non-pregnant women and more incontinence

Pool-Goudzwaard et al (2005) much smaller sampling of only 66 women
- 52% report a combination of LBP/PGP as well as pelvic floor dysfunction (incontinence, sexual dysfunction and/or constipation)

Spitznagle et al (2007) 66% of women with a DRA had at least one support related pelvic floor dysfunction

**Pelvic Organ Prolapse Prevalence & Risk Factors**

50% of parous women have some degree of symptomatic or asymptomatic loss of POP (Hagen & Stark 2011)

Age Related
- Degree of prolapse progresses over time

Recurrence
- 50% of women who have a surgical repair will experience a recurrence (Whiteside et al 2004)
- 30% of those will have a second surgery within 2 years (Salvatore et al 2010)

Risk factors
- 1 vaginal delivery increases risk X4 (normal or intervened delivery?)
- 2 or more vaginal deliveries increases risk X 8.4 (Mant et al 1997)
- Forceps delivery  53% have major defects in PFM (Ashton-Miller & Delancey 2009)
- Denervation of the levator ani
- Hysterectomy (Altman et al 2008)
- Excessive thoracic kyphosis (Mattox et al 2000)
Diastasis Rectus Abdominis
Prevalence & Risk Factors

Mota, Pascoal, Carita & Bo 2014
DRA defined as 16mm at 2cm BELOW umbilicus

Prevalence at gestational week 35: 100% (mean IRD 64.6mm +/- 19mm)
Range was 22 – 126 mm!

Prevalence at 6/12 postpartum: 35-39%

NO statistical differences found between women with and without DRA at 6/12 postpartum in:
- Pre-pregnancy body mass index
- BMI at 6/12 Postparum
- Weight gain
- Baby’s birth weight
- Abdominal circumference
- Hypermobility
- Women with DRA at 6/12 were NOT more likely to report LBP

Clinical Observations – Pelvic Girdle Pain, Urinary Incontinence, POP & DRA

Often caused by failure to regain optimal strategies for transferring loads through the trunk ➔ why?
Common across all conditions is the loss of function of the muscles (and/or fascia) of the trunk including, but not limited to, the abdominal wall.

What is the definition of the Abdominal Wall?
8 digitations from 5th - 12th ribs
- Upper 5 fascicles (5th - 9th ribs) interdigitate with serratus anterior, lowest 3 (10th – 12th ribs) with latissimus dorsi
- Those from the lowest ribs run almost vertical to insert into the anterior half of the outer lip of the iliac crest
- Middle and upper fibres pass down and forward and become aponeurotic contributing to the ventral rectus sheaths and the ventral zone of the linea alba
- This aponeurosis also forms the inguinal ligament
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External Oblique

- Aponeurosis of the EO crosses the pubic symphysis
- Together with the anterior pelvic floor muscles the EO’s help to force close/stabilize the pubic symphysis

Stecco 2015

Internal Oblique

- Arises from the thoracolumbar fascia posteriorly via the common TrA tendon, the anterior 2/3 of the iliac crest and lateral 1/2 of the inguinal ligament

Willard et al 2012
Internal Oblique

- Posterior fibres run superomedially to the inferior border of the 12th rib
- Intermediate fibres run superomedially to the 11th and 10th ribs. Others become aponeurotic. The aponeurosis fuses with the aponeurosis of the EO to form the ventral zone of the linea alba and variably splits to form both the ventral and dorsal rectus sheaths (above the infraumbilical ‘transition region’)
- Most anterior fibres from the inguinal ligament run horizontally at the level of the ASIS and inferomedially below to form the ventral rectus sheaths

Transversus Abdominis

- Arises from the thoracolumbar fascia posteriorly via the common TrA tendon, the anterior ¾ of the inner lip of the iliac crest, costocartilages of the lower 6 ribs (interdigitating with the diaphragm) and the lateral third of the inguinal ligament

Willard et al 2012
Transversus Abdominis

- Upper fibres run transversely and become aponeurotic forming the dorsal rectus sheaths and intermediate zone of the linea alba above the infraumbilical 'transition region' and ventral rectus sheaths and intermediate zone of the LA below this region
- Middle and inferior fibres curve inferomedially together with the IO to form the inguinal ligament
- Thin layer of loose connective tissue between IO, EO and TrA to allow gliding between muscles

Three Distinct Regions TrA

3 distinct regions TrA

1. Upper thoracic region
   - 6th costocartilage to inferior border of rib cage

Urquhart et al 2005
Upper – Thoracic Region

TrA interdigitates with diaphragm and forms dorsal rectus sheath.
IO aponeurosis split to contribute to both ventral and dorsal rectus sheaths is variable.
EO aponeurosis forms ventral rectus sheath.
Three Distinct Regions TrA

3 distinct regions TrA
2. Middle – lumbar region
> inferior border of the rib cage to the superior borders of the iliac crest

Middle – Lumbar Region

Urquhart et al 2005
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Middle – Lumbar Region
TrA aponeurosis forms dorsal rectus sheath
EO aponeurosis from ventral rectus sheath
IO again appears variable

Three Distinct Regions TrA

3 distinct regions
3. lower – pelvic region
  ➢ Superior border of the iliac crest
to the pubic symphysis

Urquhart et al 2005
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TrA, IO and EO aponeurosis all form the ventral rectus sheath.
**Regions & Variations TrA**

**Variations**
- Complete and partial detachment of TrA from the iliac crest
- Abrupt change in fascicle orientation between the lower and middle regions
- Absence of fascicles below the iliac crest
- Passage of the iliohypogastric and ilioinguinal nerves through the septa
- Fusion of the lower fascicles with IO

*Urquhart et al 2005*

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**Rectus Abdominis**

- Arises from the pubic symphysis, crest and tubercle and runs vertical to the xyphoid and costocartilages of the 5th – 7th ribs
- Contained within the rectus sheaths which is derived from the aponeurosis of EO, IO and TrA
- 3 bands of connective tissue traverse the RA dividing the muscle into 4 compartments (the 8 pack)
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The Aponeurosis of the Abdominal Wall → Linea Alba

Visible Body

The Aponeurosis of the Abdominal Wall → Linea Alba

Gray’s Anatomy, Standring 40th Edition

Axer et al 2000, 2001 Aponeurotic layers DO NOT decussate across the linea alba
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The linea alba – 3 zones and 4 regions
Anteroposteriorly
3 zones: Ventral, Intermediate, Dorsal

Craniocaudally
4 Regions: Supraumbilical, Umbilical, Transition zone, Infraarcuate

The Aponeurosis of the Abdominal Wall
Con-focal Laser Microscopy

Axer et al 2000, 2001

Supraumbilical Region
Superficial ventral zone of obliquely arranged fibrils
Intermediate zone of transverse fibrils
Dorsal zone of thin oblique fibrils
Fibril diameter is thinner in this region

Axer et al 2000, 2001
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The Aponeurosis of the Abdominal Wall
Con-focal Laser Microscopy

Umbilical Region
Circular collagen fibril bundles that interweave with the bundles of the linea alba

Axer et al. 2000, 2001

The Aponeurosis of the Abdominal Wall
Con-focal Laser Microscopy

Infraumbilical Transition Region
Oblique fibrils predominate
Transverse fibril layer is smaller

Axer et al. 2000, 2001
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The Aponeurosis of the Abdominal Wall
Con-focal Laser Microscopy

Infraarcuate Region

Same architectural scheme of fibril orientation as the supraumbilical region

Axer et al 2000, 2001

The Aponeurosis of the Abdominal Wall
Compliance

The highest compliance of the linea alba is longitudinally and the lowest is transversely.
Below the umbilicus compliance is smaller in the transverse direction compared to the oblique direction.
Women have more transverse fibrils than men in the infraumbilical region and the least compliance transversely here.

Gräßel et al 2005
Common TrA tendon divides to form the medial laminar and posterior laminar fibres of the thoracolumbar fascia

Willard et al 2012
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Multiple Functions of the Abdominal Wall

Abdominals work synergistically with all other muscles of the trunk for optimal:
- Abdominal and pelvic organ support
- Orifice support (diaphragm - cardiac sphincter - esophagus, inferior vena cava, aorta, abdominal wall - inguinal canal)
- Breathing
- Elimination: Voiding, defecation, delivery, vomiting, coughing
- Movement control & mobility, trunk, head/neck, upper and lower extremity


Multiple Functions of the Abdominal Wall

Optimal Function Requires
- intact anatomy to facilitate
  - sliding/mobility between the abdominal muscle layers
  - transference of force via their aponeuroses, contributions to fascial sheaths and the linea alba
- optimal activation and relaxation (motor control of all 4 groups) appropriate to task
- adequate strength and endurance appropriate to the task
How do the Layers Slide? Fascia – Traditional Views

Connecting Tissue
Gil Hedley
Fuzz like netting
Tom Myers
Cotton Candy like meshwork

Living Fascia Guimberteau
Chaotic Fibrillar Arrangement
Living Fascia – Guimberteau
Microvacuole – 3D structures
Living Fascia – Guimberteau
Definition of Fascia

- Fascia is the tensional, continuous fibrillar network within the body, extending from the surface of the skin to the nucleus of the cell. This global network is mobile, adaptable, fractal, and irregular. It constitutes the basic structural architecture of the human body.

- This is far more than simple connective tissue – it is our constitutive tissue.

Multi-tasking Behavior of TrA, Diaphragm and PFM

- TrA - Tonically active in gait and phasically responsive to breathing (facilitates expiration) with peaks of activity in response to heel strike (Saunders et al 2004)

- Diaphragm active in trunk rotation (ipsilateral fibres activate) while simultaneously tonically active and phasically responsive to respiration and perturbations from the upper extremity (Hodges et al 1997, 2000)

- PFM are tonically active, phasically responsive to respiration and perturbations from the upper extremity (Hodges et al 2007)
Regional Differences in Behaviour of TrA

- Greater tonic activity of lower TrA in standing
- Earlier onset of middle/lower TrA than upper during postural perturbations
- Opposite activation of lower vs middle/upper TrA during trunk rotation in sitting (role of septa) (asymmetric activation in trunk rotation). TrA has a ‘trivial moment arm to generate rotation’ and Hodges (2008) hypothesizes that this activation may be related to control of the linea alba
- “The results indicate that activity of one region of TrA does not reflect recruitment of the whole muscle and that EMG recordings from several regions of this muscle are required to comprehensively evaluate its function(s)”

Urquhart et al 2005

Clinical Implication: Assessment must include evaluation of function of all 3 parts of abdominal wall (upper, middle and lower) independently

TrA does not reflect recruitment of the whole muscle and that EMG recordings from several regions of this muscle are required to comprehensively evaluate its function(s)"
Other Considerations

- Nerve supply for the abdominal wall is from the thorax - T7 – T11 (lower intercostal nerves as well as the iliohypogastric and ilioinguinal nerves)
- Multiple functions of the abdominal wall require co-ordination with the diaphragm and pelvic floor muscles

Sapsford et al 2001
Neumann & Gill 2002

TrA, Pelvic Floor, and Diaphragm

Herman & Wallace 1988
Sapsford 2004
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Pressure - TrA, Pelvic Floor, and Diaphragm

Herman & Wallace 1988

Pressure - Abdominal Wall, Pelvic Floor, and Diaphragm
Healthy subjects:

10%-15% contraction PFM → isolated recruitment of TrA

- This co-activation of TrA and PFM is commonly lost in subjects with UI
- Women with UI and PGP use predominantly a pattern of chest gripping or bracing during an ASLR
- This strategy increases intra-abdominal pressure, increases respiratory rate and depresses the pelvic floor in subjects with pelvic girdle pain
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More Evidence
Response to Verbal Cue
Co-activation TrA & PFM

Short Head/Neck Curl-up (Abdominal crunch): Requires co-activation of ALL abdominals

Andersson et al 1996

Clinical Experience

Automatic Strategy - Abdominal Crunch - often see absent activation of TrA in a multitude of conditions including pain, UI, POP, and DRA

Lee D 2011
Clinical Experience

When cued, often the TrA contraction is unsustained

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Contemporary theory of motor adaptation in pain

FIGURE 1. Spectrum of changes in motor behavior expressed by people in pain. Motor adaptation can present in many phenotypes, from subtle changes in the manner that a task is completed, to complete avoidance of movement/function, with varying impacts on activity and participation and potentially important implications for selection of treatments that involve movement (physical activity/exercise).


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The Evidence & Clinical Experience

Research shows motor control changes are variable across patients with pain, UI, POP. Clinical experience suggests the same is found in patients with DRA. Specific to low back pain the following is known:

1. Deep Muscles are often compromised (absent, reduced, delayed (TrA, dMF, Glut max, PFM))
2. Superficial muscles are often augmented (dominant, excessive, early (erector spinae, sMF, TFL, adductors))
3. Recruitment strategies are individual, task-specific and there is high variability in which muscles are involved

Common link – strategy is suboptimal for the task
Key message – Changes in deep and superficial systems are individual → need to assess the individual patient
We can’t predict what pain will do, we can’t predict which impairments will cause pain, incontinence, prolapse or diastasis rectus abdominis

Abdominal Wall

Motor control training of the abdominal wall is recommended for individuals with multiple complaints:

1. Low back and pelvic pain
2. Urinary incontinence
3. Pelvic organ prolapse
4. Diastasis rectus abdominis

The evidence is unclear, and at times controversial, as to the best way to restore function of the abdominal wall
If strategies are individual and task specific, they first require assessment
1. Find the driver for the meaningful task (MT)
2. Three sites of Failed Load Transfer for right OLS
   1. Right SIJ
   2. Right hip
   3. 6th thoracic ring

Driver 6th thoracic ring

1. Observe abdominal wall during MT and ABLR
2. Vector analysis of driver co-related with abdominal muscle palpation of
   a) aponeurotic tension
   b) resting tone
   c) response to verbal cue to a PFM contraction (recruitment and release strategy)
Helps determine if the abdominal wall dysynergy is an ‘actor’ or ‘reactor’
3. Impact of correcting the driver on all of the above
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ISM Assessment
When to Train the Abdominal Wall?

4. Assess impact of the driver corrected recruitment strategy on the SIJ which gave way during the meaningful task (ROLS in this case)
5. Evaluated the force closure mechanism

NO Specific TrA training is necessary in this case since symmetric isolated recruitment is restored with correction of the driver – the 6th thoracic ring

ISM – Drivers & Motor Control

- There is a group of individuals with lumbopelvic pain, UI, POP, and DRA who do NOT need specific isolated muscle training of TrA, pelvic floor, dMF
- In this group the recruitment strategy of the entire abdominal canister improves when the driver is corrected (abdominals, pelvic floor muscles and deep and superficial back muscles)
- Vector analysis during ‘correction and release’ of the driver combined with an understanding of anatomy and biomechanics then determines the muscles that require release and the home exercise practice given
ISM – Drivers & Motor Control

- RELEASE AND ALIGN the thorax and pelvis and MOVE (RAM)
- This group typically do well with many movement based programs that aim to lengthen and align the body (e.g. Yoga, Pilates) and programs that don’t specifically address underlying deep muscle deficits in recruitment and capacity

Restoring Synergy Abdominal Wall

Release the system vectors causing suboptimal alignment, biomechanics and control of the driver
a) Neural System: EO, IO, RA, ES (dry needling, release with awareness)
b) Articular system: mobilize any stiff joints
c) Myofascial: stretch/lengthen/restore sliding any muscles/fascia
d) Visceral: restore visceral mobility and alignment

Lee D 2011
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ISM Assessment
When to Train the Abdominal Wall?

Left lumbopelvic pain and UI with box jumping, Meaningful Task: Box Jump, Screening Task: Squat

Poor control 7th thoracic ring and left SIJ in Squat

ISM Assessment
When to Train the Abdominal Wall?

Impact of thoracic ring on motor control strategies: abdominal wall & pelvic floor muscles
ISM – Drivers & Motor Control

- There is a group of individuals with lumbopelvic pain who do need specific isolated muscle training of TrA, pelvic floor, dMF.
- In this group, the recruitment strategy may not change or only become slightly better (still asymmetric, delayed, absent) when the driver is corrected.
- Vector analysis during ‘correction and release’ of the driver combined with an understanding of anatomy and biomechanics then determines the muscles that require release and the home exercise practice given.

ISM – Drivers & Motor Control

- In addition, specific muscle training is indicated.
- RELEASE, ALIGN then
- CONNECT & MOVE Use imagery, cues, sensory input to activate deep muscles, train via neuroplastic principles (RACM).
- This group does not usually do well with only movement programs that are general and require specific training of the deep segmental muscles (maybe even thoracic ring specific) in addition to the release and align work BEFORE strength and capacity training.
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The Integrated Systems Model

Treatment Principles

- Release the Suboptimal Strategy & Restore Alignment
- Teach a New Strategy for Function & Performance
- Remove Barriers
- Based on Meaningful Task

Cognitive
Emotional
Physical
Directed to
the Driver(s)

Re-wire a new neural network for better strategies for posture & movement Pertaining to the meaningful tasks

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When to Assess the Abdominal Wall?

1. When correcting alignment, biomechanics and/or control of the thorax and pelvis does not restore better movement behaviour and patient experience of their meaningful task (squat, one leg stand, curl-up etc.)
2. To understand the role of the abdominal wall in transference of loads through the trunk, upper or lower extremity and relationship of abdominal wall behaviour to the diaphragm and/or PFM
3. To determine if a DRA can be treated or if the person should be referred for surgery
4. After any abdominal wall trauma or surgery

Standing Postural Screen

- Pelvis position over feet
- Relationship between thorax and pelvis
- Position pelvic girdle, thorax, hip (correct, release and feel for vectors)
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Abdominal Profile & Behaviour

- Note any EQ ‘divots’ in standing and pressure belly
- Completely relax and then ‘engage the deep system’

Abdominal Profile & Behaviour

- Pelvis position over feet
- Relationship between thorax and pelvis
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Note response of pelvis, thorax and abdominal wall to active bent leg lift

Note impact of correcting the driver

4th ring

The Abdominal Wall / Assessment

Note response of pelvis, thorax and abdominal wall during abdominal crunch (automatic cu task)
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The Abdominal Wall / Assessment

At level of loss of control (low thorax → upper TrA, lumbar → middle TrA, pelvis → lower TrA)
Palpate for EO aponeurotic tension, IO tone and response to verbal cue (pelvic floor or ASIS cue) for TrA, IO and EO to recruit and relax

The Abdominal Wall / Assessment

At level where there is laxity of the rectus sheaths and linea alba, it is critical to take up tension in the fascia before assessing response to verbal cue of TrA
The Abdominal Wall / Assessment

Remove the ‘twists’ between the thorax and pelvis and reassess

The Abdominal Wall / Assessment

Remove the ‘twists’ from the thorax and pelvis and reassess
Release the Superficial Muscles of the Abdominal Wall
External & Internal Oblique, Rectus Abdominis

When resting tone or recruitment/relaxation pattern doesn’t change → specific release of dominant muscle is indicated.

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TrA/IO & Dry needling

Our Model
The Abdominal Wall After Pregnancy – Should we Open or Close the Gap?

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- Pelvis position over feet
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- Note any EQ 'divots' in standing and pressure belly
- Completely relax and then 'engage the deep system'

Pelvis position over feet
- Relationship between thorax and pelvis
- Position pelvic girdle, thorax, hip (correct, release and feel for vectors)
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Note
response of pelvis, thorax and abdominal wall to active bent leg lift

Note impact of correcting the driver 4th ring

The Abdominal Wall / Assessment

Note response of pelvis, thorax and abdominal wall during abdominal crunch (automatic cu task)
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The Abdominal Wall / Assessment

At level of loss of control (low thorax ➔ upper TrA, lumbar ➔ middle TrA, pelvis ➔ lower TrA)
Palpate for EO aponeurotic tension, IO tone and response to verbal cue (pelvic floor or ASIS cue) for TrA, IO and EO to recruit and relax

The Abdominal Wall / Assessment

At level where there is laxity of the rectus sheaths and linea alba, it is critical to take up tension in the fascia before assessing response to verbal cue of TrA
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The Abdominal Wall / Assessment

Remove the ‘twists’ between the thorax and pelvis and reassess

The Abdominal Wall / Assessment

Remove the ‘twists’ from the thorax and pelvis and reassess
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Release the Superficial Muscles of the Abdominal Wall
External & Internal Oblique, Rectus Abdominis

When resting tone or recruitment/relaxation pattern doesn’t change → specific release of dominant muscle is indicated

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TrA/IO & Dry needling

Our Model
The Abdominal Wall after Pregnancy – Should we Open or Close the Gap?

The Abdominal Wall after Pregnancy

Diane Lee PT
South, Surrey BC Canada

Course Outline

- 9:00 – 10:30 The abdominal wall and conditions related to pregnancy – what do we know from the evidence LECTURE/QUESTIONS
- 10:30 – 11:00 Morning break
- 11:00 – 12:30 Assessment of the abdominal wall – how to assess the 3 R’s of muscle function (rest, recruitment, relaxation) pertaining to the abdominal wall – principles and then assess a live model
- 12:30 – 1:30 Lunch
- 1:30 – 3:00 Diastasis rectus abdominis – how to assess, when to train, when to refer for surgical repair, next steps for more research for formal data to support current clinical training theories
- 3:00 – 3:15 Afternoon break
- 3:15 – 4:30 Abdominal wall movement training practice

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Diastasis Rectus Abdominis

How it all Began
Christy - 2006

32 year old Mom
2 babies 19 months apart both delivered by C-Section
Complaints
Rt buttock pain VAS 4/10
Aggr: Forward bending, vertical loading tasks and moving while supine lying
Relief: Changing positions
No problems with urinary continence
Had done lots of ‘core’ exercises with no benefit
Key Clinical Findings

In spite of our best efforts to restore optimal function to the abdominal canister, she was unable to control motion of the SIJs with an optimal strategy. We felt that she would benefit from surgery to repair the abdominal wall.

Questions in 2006

- How wide can the linea alba be before a surgical repair should be considered?
- What is the best way to close the diastasis and restore the force closure mechanism for trunk control?
- Can we identify specific objective findings that would help us determine who would require a surgical repair before appropriate training could restore optimal strategies for function and performance?
What is the Role of the Anterior Abdominal Fascia and in Particular the Linea Alba in Trunk Control?

What is the Impact of Diastasis Rectus Abdominis on Trunk Control?

Research Grant
CCRE - 2008
University of Queensland, Australia

Behaviour/Morphology of the Linea Alba

17 healthy men & nulliparous women
1. Measured the inter-recti distance (IRD) at Rest (shortest distance between left and right RA), during an Auto Curl-up (Auto-CU) and a Curl-up with pre-contraction of deep system (TrA-CU) at U and UX points \( \rightarrow \) intra and inter-tester reliability confirmed
2. Determined a ‘distortion index’ for the linea alba and measured this for all three tasks (Rest, Auto-Cu, TrA-Cu) at both points

Lee & Hodges 2015 WCPT, 2016 JOSPT
Behaviour/Morphology of the Linea Alba

RESULTS:
1. No difference in the IRD between U and UX points for controls, no difference between men & women
2. Minimal distortion of the linea alba at rest (= no wrinkling, sagging or doming)
3. On average, no change in IRD or increase in distortion regardless of strategy at U or UX point with Auto-Cu or TrA-CU

LA tension is maintained at rest and during CU for both strategies
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Behaviour/Morphology of the Linea Alba
26 Women with DRA

- Curl without spontaneous TrA contraction - IRD reduced, distortion increased from rest
- Curl with voluntary TrA pre-contraction - IRD no change, distortion not increased from rest
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**Behaviour/Morphology of the Linea Alba**

**RESULTS:**
1. IRD greater at rest in DRA than controls, wider at U point
2. IRD reduced in DRA with CU (consistent with findings of Pascoal et al 2014)
3. Distortion index was greater for DRA than controls (linea alba went wrinkly, domed or sagged)
4. Distortion index increased with the Auto-CU
5. Many could reduce the distortion by pre-activating TrA however this strategy INCREASED the IRD

Lee D Hodges P W 2016
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Other evidence

IRD can be Reduced in Postpartum Women with Isometric Contraction of Abdominals Pascoal Dionisio Cordeiro Mota 2014

Abdominal exercises affect inter-rectus distance in postpartum women: a two-dimensional ultrasound study Sancho Pascoal Mota Bo 2015

The Immediate Effects on Inter-rectus Distance of Abdominal Crunch and Drawing-in Exercises During Pregnancy and the Postpartum Period Mota Pascoal Carita Bo, K 2015

- All studies found that an abdominal crunch exercise narrowed the inter-recti distance (IRD) whereas an abdominal hollowing exercise aimed at recruiting TrA widened the IRD
- They suggest that TrA exercises should NOT be given to women with DRA and that abdominal crunches be advised instead with the sole goal of narrowing the IRD

Lee & Hodges - Conclusions

- Findings provide a foundation to consider that rehabilitation of DRA solely focused on IRD narrowing may not be optimal
- The present findings show that, for many individuals, strategies that focus solely on IRD narrowing may allow greater LA distortion, with implications for control of abdominal contents (i.e. cosmetic appearance) and thoracolumbar/lumbopelvic function
- The alternative view is that more optimal cosmetic and functional outcomes may be achieved using abdominal muscle activation strategies that reduce LA distortion (increase LA tension) regardless of the impact on IRD. This requires consideration in clinical trials
Lee & Hodges - Conclusions

- Variation in LA behavior in DRA implies individualized assessment and training prescription is required
- Individual data suggest some individuals may not be able to generate sufficient LA tension despite optimal TrA activation
- In this subgroup, passive support or surgical repair (recti plication) may be required. There is preliminary evidence that recti plication can reduce back pain in major DRA

In summary, these findings provide foundation to reconsider the contemporary view that reduced IRD should be the sole focus of DRA rehabilitation.

Although additional work is required to validate the methods used to estimate LA properties, the data provide compelling insight into LA behaviour during a curl-up and suggest appearance of the abdominal wall and function of the abdominal muscles may be optimised by TrA activation to optimise LA tensioning, despite increased IRD.
Summary – Assessment for DRA

- Abdominal wall profile and behaviour in standing
- Assess the recruitment strategy of the abdominal wall in ABLR and short head and neck abdominal curl-up
- Assess the resting tension/distortion of the linea alba throughout its length
- Assess any change in tension/distortion in automatic abdominal curl-up
- Assess the impact of removing thoracopelvic twists on the abdominal recruitment strategy and behaviour of the linea alba (tension/distortion)
  - Do the abdominal muscles require specific attention (release, recruit, strength, endurance) before the impact of an optimal strategy on the behaviour of the linea alba can be determined?
- Assess the impact of a specific ‘connect cue’ for the TrA and PFM on the recruitment/release strategy of all abdominals and the behaviour of the linea alba
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DRA – Abdominal Wall Assessment

Case Report
Lee D Chapter in:
Jones & Rivett (eds)
Clinical Reasoning
for Physiotherapists,
2nd edn
Elsevier at press

Assessment for DRA

Rest:
1. Palpate the tension in the linea alba from the xyphoid to the pubic symphysis
2. Note the width of the IRD at rest (finger widths for clinical assessment)

Automatic Curl-up Task:
1. Any invagination or protrusion of linea alba (distortion); Yes: No:
2. Change in tension of linea alba: Increases: Decreases:
3. Ability to separate the recti while curled: Yes: No:
4. IRD width: Decreases: Increases: Remains Same:

TrA Curl-up Task:
1. Note how far you have to pull your thumbs apart to create a line of tension between the left and right sides
2. Note the impact of activation of TrA on:
   a. Noted invagination or protrusion of linea alba (distortion): Yes: No:
   b. Change in tension of linea alba: Increases: Decreases:
   c. Ability to separate the recti while curled: Yes: No:
   d. IRD width: Decreases: Increases: Remains Same:
Collaboration with Plastic & General Surgeons


“The object of a successful abdominoplasty is a flat abdomen....”

Was critical of studies that measured success of a surgical repair by its ability to endure over time and said....

“The success of an abdominoplasty should be judged by the flat appearance of the abdomen and not by whether or not the diastasis repair endured.”

Collaboration with Plastic & General Surgeons

One of the subjects illustrated in this article was clearly EO dominant with a “DRA” of only 1” in the infraumbilical region. She had this surgically repaired.
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Surgical Outcomes Absorbable vs Non-absorbable Sutures

Nahas et al 2005 Long-term follow-up of correction of rectus diastasis
12 women were followed for 76 – 84 months (up to 7 years) after abdominoplasty whereby the anterior rectus sheaths were plicated with nonabsorbable sutures
Results: The IRD remained the same – there was no recurrence of the DRA

van Uchelen et al 2001 The long-term durability of plication of the anterior rectus sheath assessed by ultrasonography
40 women were reassessed by ultrasound imaging between 32 and 109 months after abdominoplasty whereby the ‘abdominal wall was plicated with absorbable material’
Results: A recurrence of the DRA was noted in 40% of the women measured

Based on our collaboration and an understanding of motor control theories of the trunk Dr. Demianczuk now plicates both the anterior and posterior rectus sheaths with non-absorbable sutures
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DRA is not Exclusive to Women

DRA Can also be iatrogenic
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Post Abdominal Laparoscopic Surgery

DRA can Also be Seen in Children

Very poor abdominal and back strategy
No tension in curl-up
Doming LA in curl-up
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DRA can Also be Seen in Children

3.06 cm at rest
1.12 cm during CU no TrA

Jack after 4 Weeks of Abdominal Training

After 4 weeks of training transversus abdominis and posture
Can now tension the LA in curl-up
Can control the doming in curl-up
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Jack after 4 Weeks of Abdominal Training

- 3.06 cm at rest
- 2.32 cm during CU with TrA

Jack after 3/12 of Abdominal Training

- 3.06 cm at rest
- 2.80 cm during CU with TrA
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Clinical Expertise → Research
We needed more clinical expertise before we could research ‘smart questions’

2006 questions answered:
1. How wide can the linea alba be before a surgical repair should be considered?

There is no relationship between the IRD and the distortion – this means that distortion can be large regardless of the length of the separation

Hypothesis: Tension is more important than width

P Hodges validated that the distortion index correlates to tension using ultrasound elastography - 8 subjects (to be published)

Clinical Expertise → Research
We needed more clinical expertise before we could research ‘smart questions’

2006 questions answered:
2. What is the best way to close the diastasis and restore the force closure mechanism?

Closure is not necessary, in fact closure can be a ‘bad’ thing depending on whether or not tension is present with the closure

There are many different reasons/mechanisms underlying a DRA therefore a multi-modal program is required to restore optimal strategies for function and performance.

There are no recipes or protocols for this condition
2006 questions answered:

3. Can we identify specific objective findings that would help us determine who would require a surgical repair before appropriate training could restore optimal strategies for function and performance?

Clinical Expertise → Research
We needed more clinical expertise before we could research ‘smart questions’

Clinical expertise suggests that surgery is recommended if:

- Poor control of the joints of the thorax, lumbar spine and/or pelvis during multiple functional tasks &
- Optimal neuromuscular function of the deep and superficial muscles of the abdominal canister and
- No ability for this apparent optimal strategy to control motion of the relevant joint/joints
- No tension generated in the linea alba between the left and right rectus abdominis during a contraction of deep system or during a short curl-up task
Clinical Implications for Rehabilitation of DRA

- Rehabilitation of DRA solely focused narrowing the IRD may not be optimal.
- More optimal cosmetic and functional outcomes may be achieved using abdominal muscle activation strategies that reduce LA distortion (increase LA tension) regardless of the impact on IRD.
- Individual data suggest some individuals may not be able to generate sufficient LA tension despite optimal TrA activation.
- In this subgroup, passive support or surgical repair (rectification) may be required.
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Muscle activation [motor control] is challenging to investigate for several reasons

1. First the specific pattern of muscle changes are generally unique to the individual patient, and within the individual they may be unique to the movement, posture or task that is assessed

2. There will not be one strategy of muscle activation that is universally ideal for control of the spine and pelvis and not one strategy universally adopted by all patients in pain

3. Back pain patients present with a redistribution of activity within and between muscles (rather than inhibition or excitation of muscles in a stereotypical manner)

4. All of the multisegmental muscles of the trunk contribute to movement and control

5. If the goal of rehabilitation (e.g. using motor learning strategies) is to modify the adaptation (remove, modify or enhance) then this needs to be considered on an individual basis with respect to the unique solution adopted by the patient
Consensus from the Evidence
Pain and motor control
Integrated clinical approach to motor control

Muscle activation [motor control] is challenging to investigate for several reasons
1. First the specific pattern of muscle changes are generally unique to the

Motor control is influenced by thoughts, beliefs, experiences (sensorial) that are both task and individual specific

2. There will not be one strategy of muscle activation that is universally ideal for control of the spine and pelvis and not one strategy universally adopted by all patients in pain
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5. If the goal of rehabilitation (e.g. using motor learning strategies) is to modify the adaptation (remove, modify or enhance) then this needs to be considered on an individual basis with respect to the unique solution adopted by the patient

JEK 21(2011) Hodges
2013 Hodges, Van Dillen, McGill, Brumagne, Hides, Moseley Chapter 21

The Integrated Systems Model
Treatment Principles

Release the Suboptimal Strategy & Restore Alignment
Remove Barriers
Cognitive
Emotional
Physical
Directed to the Driver(s)

Teach a New Strategy for Function & Performance
Based on Meaningful Task
Re-wire a new neural network for better strategies for posture & movement Pertaining to the meaningful tasks
Principles for Treatment

Treatment – every treatment has components of RACM:

- **Release** – applied to cognitive, emotional, social, and physical barriers, using a variety of techniques - release overactive muscles and adhesions (myofascial, articular, neural & visceral impairments)
- **Align** – cues/corrections to align the body both within and between regions
- **Connect/control** – cues for activation and co-ordination of the deep and superficial muscle systems
- **Move** – use the principles of neuroplasticity to rewire (reset) brain maps and create more efficient strategies for function & performance
- **Consider all treatment priorities such as tissue specific requirements (e.g. stage of healing & loading needs for muscle strains, tendinopathy, ligament sprains)**

Release the Suboptimal Strategy & Restore Alignment

Release Cognitive Emotional Physical Barriers
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Release Barriers

Cognitive & Emotional

- Books - Explain Pain, The Brain that Changes Itself, Mindsight
- Explain problem – provide a logical hypothesis that explains both their pain experience and their disability
- Create a safe environment to explore barriers such as fear, belief systems (“I’ll never get better”)
- Meditation, breathing practice (parasympathetic facilitation)

Release the Suboptimal Strategy by Addressing Barriers

Release Barriers

Common Neurotoxins & Systemic Issues

- High blood glucose levels (sugar)
- Alcohol
- Hydrogenated oils (takes 4 months to leave cells)
- Aspartame (Nutrasweet) – breaks down to methanol then formaldehyde
- Hormone imbalance

Eliminate Neurotoxins from Diet Optimize Endocrine Health

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Release Barriers

System barriers
- Oscillatory mobilizations, manipulation
- Muscle energy, PNF, Contract relax, Neuromyofascial release
- Dry needling, dermoneuromodulation via K-tape
- Visceral mobilization

Release with Awareness (Lee D 2001 Imagery for Core Stabilization)
Neuromyofascial release technique

Principles
- Monitor the muscle - gentle pressure
- Move the joint or muscle to shorten the origin and insertion
- Wait
- Cue the patient to ‘release’ with manual and verbal cues to let go, melt
- Once maximum release is obtained, gently take the muscle through a full stretch listening to its response and avoiding any recurrence of overactivity
Specific Release Techniques
Chapter 10 PG 4

Ischiococcygeus

Superficial MF and ES

Taping & Belts & Binders
The Baby Belly Belt

Role of tape and belts for pelvic control

Role of binding the abdominal wall for DRA

Role of binding the abdominal wall immediately after delivery
  ?how
  ?for how long
Teach a New Strategy

What is neuroplasticity?
The ability of the nervous system to respond to intrinsic and extrinsic stimuli by reorganising its structure, function and connections

Snodgrass et al 2014

Neurons that fire together wire together
Donald Hebb

Use neuroplasticity to create new neural networks for new strategies for function & performance

There is overwhelming evidence that the brain is continuously remodelled in response to new or novel experiences
Therefore, an appreciation of the influence of the CNS on all forms of movement as well as pain should underpin all forms of rehabilitation

Kleim & Jones 2008
### Training Strategies

| Neurons that fire together wire together | Synergize deep segmental muscles |
| Specific Muscle Recruitment | Coordinate with appropriate superficial muscle training (working towards the meaningful task/goals) |
| Support | Taping/Support belts/braces |
| Integrated Meaningful Movement Training | Integrate into functional and sport specific training |

### Key Factors Required for Neuroplastic Change

- Focused Attention
- Training tasks that have meaning
- Massed practice – high quality (more later)
- Sensory input – normalize
- Positive feedback
- Importance of specificity principle
If poor recruitment of TrA persists when release/alignment of the trunk is corrected, then specific training is indicated.

Reset the brain map (re-wire a better strategy) using imagery:

Pelvic floor cues
1. Superficial layer (1) (shorten the penis, nod the clitoris)
2. Urogenital diaphragm (Layer 2) (squeeze the urethra)
3. Levator Ani (Layer 3) (draw anus to back of pubic bone)

Abdominal cues
- Imagine a force connecting the left and right ASIS to the midline
- Imagine a force connecting one ASIS to the midline (book cover cue)

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Hides et al 2006 An MRI investigation into the function of the transversus abdominis muscle during “drawing-in” of the abdominal wall

Subjects were asked ‘to draw in the abdominal wall without moving the spine’ Thickness of the TrA and IO were then measured via UI and MRI

Results: This cue resulted in significant increase in thickness of both TrA and IO

Clinical translation: Asking someone to draw in the abdomen without moving their spine will not result in an isolated contraction of TrA
Restoring Synergy
Abdominal Wall

Use load effort task analysis with old and new strategies
1. To bring awareness to the impact that different strategies can have on performance of task (Focused attention)

2. To teach a home self-check for accuracy of performance

Massed practice
1. Goal - 3 sets of 10 10 second holds [Tsao et al 2007], maintaining breathing

2. At least twice [Tsao et al 2010], preferably 3-4 times per day

3. 2 weeks [Tsao et al 2010] can be as little as 7 – 10 days (clinical expertise)

Mrs. M 4 kids, twins 7 years old
Main concern is appearance of abdominal wall
Mrs. M 4 kids, twins 7 years old
Main concern is appearance of abdominal wall
Mrs. M 4 kids, twins 7 years old
Main concern is appearance of abdominal wall
Mrs. M 4 kids, twins 7 years old
Main concern is appearance of abdominal wall

UX point

Mrs. M 4 kids, twins 7 years old
1 week after training
Mrs. M 4 kids, twins 7 years old
1 week after training
Mrs. C - one child, unhappy with abdominal appearance and lack of core strength with her training program
Mrs. C - one child, unhappy with abdominal appearance and lack of core strength with her training program

Connect/Control & Move Training Integrated with Release & Align

Too extensive for slides!

The entire Chapter 6 of the new book Diastasis Rectus Abdominis: A clinical guide for those split down the middle describes all we will do and has 50 videos of the exercises/training

www.learn.dianeleee.ca
Pelvic Floor Release & Abdominal Exercises

1. Pelvic rock in 4 point kneeling with manual release of levator ani
2. Supine modified Happy Baby Pose for release and stretch of the superficial transverse perineal muscles
3. Down dog with assist for alignment and release of the long trunk compressors (ES, Lats, Abdminals etc.)
4. Squat sumo
5. Isolation training for TrA & PFM
   a. Supine ABLR test with PF and abdominal cuing and palpation. Find best cue that reduces effort to lift leg, 3 sets of 10 10 second holds to train a brain map that synergizes deep system with breath – use exhale
   b. Progress to leg loading (bent knee fall out, single leg left, single leg extension, contralateral arm elevation)
6. Integration with superficial abdominals – Supine supported position
   a. Supine – wipers
      i. Connect on the inhale
      ii. Wipers to the right on the exhale
      iii. Inhale to hold
      iv. Exhale to return to neutral using pelvic rotation and not initiating the movement with the knees
   b. Supine – upper abd curls
      i. Connect on the exhale and feel the LA tense no abdominal bulging EVER
      ii. Short head-neck cu on exhale, continue to palpate LA for tension and no bulge
      iii. Palpate the infrensternal angle – should be no change
         1. If widens → connect to deep system, then layer on EO X prior to curl
         2. If narrows → connect to deep system, keep angle consistent i.e. no narrowing prior to curl on exhale
   c. Supine – lower abd curls
      i. Connect on the exhale → sitz bones widen then posterior pelvic tilt and release (reverse curl)
   d. Supine – roll up down (synchronized abdominal concentric action and ES eccentric action
      i. Connect on the exhale and do a reverse curl-up to approx. T4-5-6 region
      ii. Inhale to hold
      iii. Exhale and lower reaching tail bone long as you lower one segment at a time
   e. Supine wipers repeat
7. Integration – 4 point kneeling
   a. Cat – cow (connect in neutral, then reverse curl first cue segmental flexion, then posterior pelvic tilt and segmental extension)
b. 4 point Cross support (in neutral spine, float opposite hand and knee off floor, no pelvic rotation

c. 4 point hover – flex one hip then other – no pelvic rock or rotation

8. Integration and function

a. Sitting in pelvic neutral (chair) feet on floor knees aligned with feet:
   i. reverse curl and return
   ii. reverse curl with rotation
   iii. reverse curl with rotation and arm elevation
   iv. reverse curl with rotation and arm elevation with load
   v. lift one leg, rotate thorax, lift other leg rotate thorax

b. High kneeling, one hip and knee flexed
   i. Center hips, stack and lengthen thorax then
      1. Rock back off center (co-activation all abds)
      2. Rock back off center and twist
      3. Add theraband resistance (use another person to do rhythmic stabilization or apply resistance to flexed knee extended arms

c. Standing squat, stand on theraband → PNF patterns for arms into flexion (static control and/or with mobility)

d. Standing squat, theraband on door → PNF patterns for arms into extension (static control and/or with mobility)

e. Lunge → rotate thorax – elbow to knee and resist (can also use theraband for resistance

When people can do this they can move on to higher level exercises with longer lever arms i.e. boat pose, double leg extensions, more crunchies but always need to ensure no bulging, breath holding, PF descent and Linea alba sagging or loss of tension

Demo other ideas and favourite exercises.
Behavior of the Linea Alba During a Curl-up Task in Diastasis Rectus Abdominis: An Observational Study

The linea alba (LA) comprises highly organized collagen fibers1 that continue from the rectus sheaths2 derived from the abdominal muscle aponeuroses. The distance between the rectus abdominis (RA) muscles, the inter-rectus distance (IRD), widens in pregnant women by their third trimester.3,11,23 More than half remain abnormally wide 8 weeks after delivery, and, although some recover by 6 months (60.7%,23), many have not at 1 year.5,17 The width of the LA is equivalent to the IRD.

The abdominal wall is essential for lumbo-pelvic function through multiple mechanisms, including the transfer of force through fascial tension.2,20 A diastasis rectus abdominis (DRA) is present when the IRD exceeds normal values4 and can exist at 1 or more regions of the LA. Widening of the LA in DRA potentially modifies its tensile properties and its capability to transfer force across the midline of the abdomen. How abdominal muscle activation may affect the behavior of the LA and how to rehabilitate individuals with DRA are under debate.2,12,17,26 Rehabilitation often focuses on exercises that narrow the IRD. Some encourage this using abdominal crunch or curl-up exercises,26 whereas others argue that the curl-up should be avoided to limit strain on the stretched LA.7

In women with DRA, the IRD narrows (measured with ultrasound imaging) during a curl-up,26 most likely by approximation of RA muscles as they straighten on contraction (FIGURE 1).

**STUDY DESIGN:** Cross-sectional repeated measures.

**BACKGROUND:** Rehabilitation of diastasis rectus abdominis (DRA) generally aims to reduce the inter-rectus distance (IRD). We tested the hypothesis that activation of the transversus abdominis (TrA) before a curl-up would reduce IRD narrowing, with less linea alba (LA) distortion/deformation, which may allow better force transfer between sides of the abdominal wall.

**OBJECTIVES:** This study investigated behavior of the LA and IRD during curl-ups performed naturally and with preactivation of the TrA.

**METHODS:** Curl-ups were performed by 26 women with DRA and 17 healthy control participants using a natural strategy (automatic curl-up) and with TrA preactivation (TrA curl-up). Ultrasound images were recorded at 2 points above the umbilicus (U point and UX point). Ultrasound measures of IRD and a novel measure of LA distortion (distortion index: average deviation of the LA from the shortest path between the recti) were compared between 3 tasks (rest, automatic curl-up, TrA curl-up), between groups, and between measurement points (analysis of variance).

**RESULTS:** Automatic curl-up by women with DRA narrowed the IRD from resting values (mean U-point difference, –1.45 cm; 95% CI: –0.93, –0.93; P < .001) but LA distortion increased (mean UX-point between-task difference, 0.02 cm; 95% CI: –0.22, 0.19; P = .86). LA distortion was less (mean U-point between-task difference, –0.02 cm; 95% CI: –0.037, –0.012; P < .001 and mean UX-point between-task difference, –0.02 cm; 95% CI: –0.038, –0.005; P = .03). Inter-rectus distance and the distortion index did not change from rest or differ between tasks for controls (P ≥ .55).

**CONCLUSION:** Narrowing of the IRD during automatic curl-up in DRA distorts the LA. The distortion index requires further validation, but findings imply that less IRD narrowing with TrA preactivation might improve force transfer between sides of the abdomen. The clinical implication is that reduced IRD narrowing by TrA contraction, which has been discouraged, may positively impact abdominal mechanics. J Orthop Sports Phys Ther 2016;46(7):580-589. doi:10.2519/jospt.2016.6536

**KEY WORDS:** diastasis rectus abdominis, inter-rectus distance, rehabilitation, transversus abdominis
horizontal force vector of the lateral abdominal muscles should increase the IRD when contracting alone (FIGURE 1).\textsuperscript{26} Widening of the LA has been reported with a “drawing-in” action that targets these muscles (including the transversus abdominis [TrA]).\textsuperscript{21} Widening of the IRD with contraction of the TrA underpins advice to avoid such contraction. Contraction of the TrA during a curl-up could either widen the IRD or decrease the narrowing induced by RA straightening. Other clinical advice encourages lateral abdominal muscle training to narrow the IRD,\textsuperscript{22} but how this achieves narrowing is unclear.

Although reduction of the IRD may appear to be an obvious rehabilitation objective, the alternative view is that LA tension, which may require an increase in the IRD, is necessary to support the abdominal contents\textsuperscript{27} and to transfer force between opposite sides of the abdominal wall.\textsuperscript{22} Reduction of the IRD would approximate the LA attachments and reduce LA tension (FIGURE 1). A slackened LA could be distorted (bulged) when challenged by elevated intra-abdominal pressure (IAP) and could also limit the effective transfer of force between opposing abdominal muscles. Rehabilitation to optimize abdominal support and lumbo-pelvic function may require consideration of strategies that increase LA tension, and this may involve TrA contraction to widen the IRD or reduce IRD narrowing.

We used a novel ultrasound measure of LA distortion (distortion index) and conventional IRD measures to test 2 interrelated hypotheses: first, during a curl-up, the IRD would be greater in women with DRA if the curl-up involved voluntary preactivation of the TrA; and second, despite greater IRD during a curl-up with TrA preactivation, LA distortion would be less than without TrA preactivation. Based on clinical observation, we also predicted that the reduction of LA distortion with TrA activation would vary between individuals, and that IRD and the distortion index in control participants with no stretch of the LA would differ little between curl-ups performed naturally or with TrA activation.

**METHODS**

**Participants**

Twenty-six women with DRA (1 nulliparous, 25 parous; mean ± SD births, 2.9 ± 0.9; 15 ± 19 months before assessment) and 17 volunteers without DRA (11 nulliparous women, 6 men) participated (TABLE 1). Diastasis rectus abdominis was defined as IRD (measured with ultrasound imaging) of greater than 22 mm at 30 mm above the umbilicus, or greater than 15 mm inferior to the xiphoid. Participants were recruited from a physical therapy clinic and personal trainers. Participants with DRA were seeking treatment for a variety of conditions concomitant with their DRA. Exclusion criteria for both groups included current pregnancy or any major respiratory or neurological condition. The University of Queensland Medical Research Ethics Committee approved the study.

**Ultrasound Imaging**

Ultrasound imaging was used to measure the IRD and distortion index, and for feedback to train TrA contraction (see
Procedure section). Ultrasound measures of IRD are reliable and valid. Videograms were captured in brightness mode (B-mode) using a MyLab 25 (Esaote SpA, Genoa, Italy) and a 12-MHz linear transducer. The transducer was placed transversely across the abdomen, with its center aligned to the midline and the medial portion of the left and right RA muscles visible at 2 points that were standardized to control for between-subject differences in abdominal-wall dimension. These 2 points were just above the umbilicus (U point) and halfway between the U point and the xiphoid (UX point). The abdominal midline and measurement points were marked on the skin. Still images were captured from the videos and exported to JPEG format.

Procedure

Participants were positioned in supine lying, with the head supported on a pillow, hips and knees flexed, feet supported on the table, and the arms by the sides. In separate trials, the LA was imaged at the U point and UX point for 3 repetitions (separated by a brief rest) of 3 conditions that were performed in the following order (order could not be randomized, as training for the final task would interfere with performance of the second task):

1. Rest: measures were made with the participant lying supine for approximately 5 seconds before performing the curl-up.
2. Automatic curl-up: participants lifted the head and neck until the top of the scapula just cleared the bed without any instruction about abdominal muscle contraction (arms beside the body). Movement was performed slowly and smoothly at a self-regulated speed that approximated 3 seconds and was held for approximately 3 seconds, at which time data were recorded before the participant returned to supine.
3. Curl-up with preactivation of TrA (TrA curl-up): the curl-up task was repeated but with the instruction to activate the TrA muscle gently prior to the curl-up (arms beside the body).

Care was taken to train participants to emphasize TrA activation, with minimal activation of more superficial abdominal muscles. This pattern was selected because the TrA has a unique relationship with the LA and posterior rectus sheath. The TrA aponeurosis continues as the transverse fibers of the dorsal rectus sheath and lamina fibrae transversae of the LA. The oblique abdominal aponeurosis continues as the oblique fibers of the ventral rectus sheath and forms the more ventral lamina fibrae oblique of the LA. Because LA compliance is lowest (ie, greatest stiffness) in the transverse direction, the TrA has the greatest potential to increase LA tension and is critical for support of the abdominal wall/resistance of IAP.

Transversus abdominis training involved feedback with ultrasound (FIGURE 2). The lateral abdominal muscles were visualized in B-mode using a 3.5- to 5.0-MHz curvilinear probe (which differed from the linear transducer used for LA measures), placed transversely across the abdom- men above the iliac crest and oriented to image the medial fascial margins of the TrA and oblique abdominal muscles. Contraction of the TrA independently from the oblique abdominal muscles was achieved with verbal instructions that have been shown to encourage the target action. These included, “Slowly and gently contract the muscles of the pelvic floor,” “Think about squeezing the urethra as if to stop the flow of urine,” “Think about drawing the anus up and forward toward the pubic bone,” and “Imagine a guy wire or line that connects the left and right anterior superior iliac spines and gently connect the ‘hip bones’ along that line.” Although abdominal-muscle images were observed during training prior to performance of the TRA curl-up and all participants could achieve a contraction of the TrA, they could not be recorded concurrently with LA imaging and consequently were not recorded for analysis.

Ultrasound images of the LA at the U point and UX point were made in separate trials. The order in which the points were measured was randomized. Recordings were made first at rest. The automatic curl-up was always performed before the TrA curl-up so that the natural pattern of abdominal muscle activation was not affected by the training procedure.

Analysis

Ultrasound images were exported from the videos at times that corresponded to the rest and hold phases of each curl-up. Images were analyzed using ImageJ (National Institutes of Health, Bethesda, MD) by an examiner blinded to participant grouping. To measure the IRD, the most medial borders of the RA were identified and the distance between these points measured. 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 its attachments (FIGURE 3). The premise of this measure is that deviation of the LA from the shortest path depends on LA tension or stiffness, that is, greater distortion if the LA is less stiff/tensed. To calculate the distortion index, the medial edges of the RA muscles were identified (at the same location as the measures of IRD) and the shortest path between these 2 points was measured. Next, the actual path of the LA was traced (FIGURE 3). This path may follow the shortest distance (minimal distortion), a smooth curved path (ventral or dorsal distortion relative to the attachments), or an undulating trajectory. The area bounded by the LA path and the shortest path was calculated using ImageJ, and the distortion index was calculated by division of the area by the shortest distance. The distortion index is not a perfect measure of LA tension, as a curved LA may also become tense if loaded by IAP. Thus, the measure is not expected to maintain a linear relation to tension, but to provide a surrogate index that can be quantified without highly specialized equipment (eg, elastography). Pilot data from a validation study were calculated. This analysis was performed separately for control and DRA participants. Data are presented as mean ± SD throughout the text and figures. Means, mean differences, and 95% confidence intervals for all comparisons of the IRD and distortion index are shown in TABLES 2 and 3, respectively.

Statistical Analysis
Sample size was based on data from Mota et al.\textsuperscript{20} Using mean ± SD values of IRD measured at a site similar to the UX point (18.7 ± 8.4 mm) and a change with abdominal curl-up of 11%, 17 participants per group were required for a power of 80% and alpha of 5%. As no data were available to power the novel distortion index, the sample with DRA was inflated by approximately 50%.

The IRD and distortion index were compared between groups (DRA versus control), regions (U point versus UX point; within-subject factor), and conditions (rest versus automatic curl-up versus TrA curl-up; within-subject factor) using repeated-measures analysis of variance. Post hoc testing involved a Bonferroni test. Significance was set at $P<.05$. Several additional analyses were undertaken. First, the IRDs for the control group at the UX point and U point were compared between male and female participants using $t$ tests for independent samples. Second, to investigate whether the distortion index of the LA was related to the IRD, we fitted a regression line to the relationship between the baseline IRD and the distortion index during automatic curl-up and TrA curl-up. Although we expected that a change in the IRD would be related to a change in the distortion index within a participant (less distortion with greater IRD widening), we predicted that a linear relationship might not be apparent between participants, as the amount of stretch of the LA would vary between individuals (some women could have greater stretch of the LA and thus greater potential for distortion even with substantial IRD widening). Pearson correlation coefficients were calculated. This analysis was performed separately for control and DRA participants. Data are presented as mean ± SD throughout the text and figures. Means, mean differences, and 95% confidence intervals for all comparisons of the IRD and distortion index are shown in TABLES 2 and 3, respectively.

RESULTS

Inter-rectus Distance

The average IRDs at the U and UX points for the DRA and control participants are presented in TABLE 2. Participants with DRA had a wider IRD at rest than those without (interaction:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Condition & Group & IRD (m) & Distortion Index (mm) \\
\hline
Rest & Control & 15.2 ± 4.3 & 0.08 ± 0.03 \\
& DRA & 19.7 ± 6.8 & 0.12 ± 0.04 \\
\hline
Automatic curl-up & Control & 17.6 ± 5.2 & 0.10 ± 0.03 \\
& DRA & 22.1 ± 7.0 & 0.15 ± 0.04 \\
\hline
TrA curl-up & Control & 20.4 ± 6.5 & 0.13 ± 0.04 \\
& DRA & 25.3 ± 8.2 & 0.17 ± 0.05 \\
\hline
\end{tabular}
\caption{Comparison of Inter-rectus Distance and Distortion Index between Control and DRA groups.}
\end{table}
group by region by task, \(P < .001\), and this was present at both the U point (post hoc, \(P = .002\)) and UX point (post hoc, \(P < .001\)) (TABLE 2). The IRD at the U point was wider than that at the UX point for the DRA group (post hoc, \(P < .001\)), but there was no difference in the IRD between points for the controls (post hoc, \(P = .08\)). There was no difference in the IRD between the male and female control participants at the U (\(P = .06\)) and UX (\(P = .12\)) points (data for the whole group and controls, separated by sex, are presented in TABLE 2). If the groups were compared with the male participants excluded, the results of the analysis were identical (interaction of group by region by task, \(P = .0038\)).

When participants performed the curl-up without preactivation of the TrA (automatic curl-up), the IRD reduced in the DRA participants (post hoc U point and UX point, \(P < .001\)) but did not change for controls (post hoc U point and UX point, \(P > .17\)) (FIGURE 4). There were some differences in the response when the TrA was preactivated before the curl-up (TrA curl-up). In the DRA group, the IRD did not reduce at the UX point (reduction of approximately 0.2 mm) during the TrA curl-up from that measured at rest (post hoc, \(P = .86\)), which was less than the IRD reduction during automatic curl-up (approximately 5 mm greater IRD reduction with automatic curl-up, \(P < .001\)) (FIGURE 4, TABLE 2). At the U point, although the IRD reduced from that measured at rest (post hoc, \(P < .001\)), the reduction was less than that during automatic curl-up (reduction of approximately 12 mm [automatic curl-up] versus approximately 6 mm [TrA curl-up]; post hoc, \(P < .001\)) (FIGURE 4, TABLE 2). In support of our first hypothesis (that TrA preactivation would lessen the reduction in IRD during the curl-up), the IRD was wider with preactivation of the TrA during the curl-up than without TrA preactivation. In the control participants, IRD was wider during the TrA curl-up than at rest at the U point (\(P = .02\)) and UX point (\(P = .007\)), but the amplitude was very small (1.4 mm and 0.6 mm, respectively) (FIGURE 4).

**Distortion Index**

The distortion index was greater for DRA participants than for controls (interaction of group by task, \(P < .001\); post hoc, all \(P < .01\)) (TABLE 3) at the U point and UX point (interaction of group by task by region, \(P = .72\)) (FIGURE 4). For controls, the distortion index did not change between rest and either of the curl-up tasks (post hoc, all \(P > .55\)). For DRA participants, the distortion index increased from rest during the automatic curl-up at both regions (post hoc, \(P < .05\)), but did not change from baseline during the TrA curl-up at both regions (post hoc, \(P > .43\)). That is, preactivation of the TrA prevented LA distortion during the curl-up. Correspondingly, the distortion index was greater during automatic curl-up than TrA curl-up (post hoc, \(P = .01\)) (FIGURE 4). Again, the results of this analysis were identical when the groups were compared with the male participants excluded (interaction: group by task, \(P = .045\); interaction: group by region by task, \(P = .77\)).

When data were considered for individuals in the DRA group, 62% of participants reduced the distortion index by at least 20% at the U point by TrA preactivation before curl-up, and this was achieved by 77% at the UX point. These data support our second hypothesis: despite greater IRD in TrA curl-up than in automatic curl-up, there would be less LA distortion with preactivation of the TrA in the TrA curl-up.

**Relationship Between IRD and Distortion Index**

Correlation between the baseline IRD and distortion index during the automatic curl-up and TrA curl-up was generally greater in the control group than in the DRA group (FIGURE 5). At the U point, distortion was not dependent on the IRD separation in DRA (ie, the distortion index could be low despite large separation, and vice versa). At the UX point, the relationship between the IRD and distortion index was significant for both groups. In general, the percentage of variation in distortion explained by the IRD was small and supports our prediction that baseline IRD is not the sole determinant of LA tension.

**DISCUSSION**

The main findings of this study are that in DRA, activation of the TrA before a curl-up results in a relatively wider IRD than that during an automatic curl-up (hypothesis 1), yet, despite no or reduced IRD narrowing, LA distortion is less (hypothesis 2). This supports the view that decreased LA distortion (which would imply greater LA tension) via TrA activation should be considered as an objective for rehabilitation to support abdominal contents and optimize transfer of force between sides of the abdominal muscles. This questions the clinical assumption that rehabilitation should solely focus on IRD narrowing. The study provides evidence of potential utility for the distortion index as a measure of LA function.

**Reinterpretation of Reduced IRD**

Contemporary clinical opinion considers reduction of the IRD as the target of DRA rehabilitation.\(^{11,26}\) This is based on the assumption that restored RA muscle alignment restores function\(^{25}\) and improves cosmetic appearance.\(^{24}\) The present data show that in DRA, an acute reduction of IRD during a curl-up increases LA distortion. This commonly presented as undulating LA deformation (FIGURE 3). Although not directly measured, this is unlikely to optimally support the abdominal contents (potentially producing less desirable cosmetic appearance), and could induce less effective mechanical function. These potential outcomes should be directly measured in future studies.
Recent studies using ultrasound imaging have shown narrowing of the IRD during a curl-up, or abdominal crunch. A demonstrated in Figure 1, this can be explained by straightening of the left and right RA muscles from their arc-like orientation at rest. Conversely, widening of the IRD oc-

### TABLE 2

**INTER-RECTUS DISTANCE AT REST AND DURING CURL-UP**

<table>
<thead>
<tr>
<th>Measure</th>
<th>DRA*</th>
<th>Controls*</th>
<th>Between-Group MD†</th>
<th>P Value</th>
<th>Female Controls*</th>
<th>Male Controls*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>UX point</td>
<td>2.11 ± 0.70</td>
<td>0.60 ± 0.26</td>
<td>-1.51 (-1.87, -1.15)</td>
<td>&lt;.001</td>
<td>0.61 ± 0.29</td>
<td>0.57 ± 0.29</td>
</tr>
<tr>
<td>U point</td>
<td>3.40 ± 0.77</td>
<td>0.78 ± 0.34</td>
<td>-2.62 (-3.02, -2.22)</td>
<td>.002</td>
<td>0.77 ± 0.34</td>
<td>0.80 ± 0.38</td>
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<tr>
<td>UX point versus U point</td>
<td></td>
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<td></td>
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<tr>
<td>P value</td>
<td>-.001</td>
<td>0.08</td>
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</tr>
<tr>
<td>MD†</td>
<td>1.29 (0.95, 1.62)</td>
<td>0.18 (-0.02, 0.39)</td>
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<tr>
<td>Automatic curl-up</td>
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<tr>
<td>UX point</td>
<td>1.60 ± 0.56</td>
<td>0.62 ± 0.26</td>
<td>-0.98 (-1.27, -0.68)</td>
<td>&lt;.001</td>
<td>0.67 ± 0.27</td>
<td>0.53 ± 0.22</td>
</tr>
<tr>
<td>U point</td>
<td>2.21 ± 0.79</td>
<td>0.85 ± 0.37</td>
<td>-1.36 (-1.78, -0.94)</td>
<td>.003</td>
<td>0.87 ± 0.44</td>
<td>0.81 ± 0.24</td>
</tr>
<tr>
<td>Rest versus automatic curl-up</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>-.001</td>
<td>.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>-0.51 (-0.69, -0.34)</td>
<td>-0.02 (-0.03, 0.08)</td>
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<tr>
<td>Rest versus TrA curl-up</td>
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</tr>
<tr>
<td>P value</td>
<td>.86</td>
<td>.007</td>
<td></td>
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</tr>
<tr>
<td>MD†</td>
<td>0.02 (-0.22, 0.19)</td>
<td>0.06 (0.02, 0.11)</td>
<td></td>
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</tr>
<tr>
<td>TrA curl-up versus automatic curl-up</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>-.001</td>
<td>.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>-0.19 (-1.45, -0.93)</td>
<td>-0.07 (-0.03, 0.17)</td>
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<tr>
<td>Rest versus TrA curl-up</td>
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<td></td>
</tr>
<tr>
<td>P value</td>
<td>.02</td>
<td>.02</td>
<td></td>
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</tr>
<tr>
<td>MD†</td>
<td>-0.56 (-0.82, -0.31)</td>
<td>0.14 (0.02, 0.26)</td>
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<td></td>
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<tr>
<td>TrA curl-up versus automatic curl-up</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>-.001</td>
<td>.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>0.63 (0.41, 0.84)</td>
<td>-0.07 (-0.02, 0.16)</td>
<td></td>
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</tr>
</tbody>
</table>

**Abbreviations:** DRA, diastasis rectus abdominis; MD, mean difference; TrA, transversus abdominis; U point, just above the umbilicus; UX point, halfway between the U point and the xiphoid.

*Values are mean ± SD centimeters.

*Values in parentheses are 95% confidence interval.

In the presence of structural changes of the LA in DRA, IRD reduction has the potential to have counterproductive consequences for cosmetic appearance, alignment, and function. Greater IRD to enhance LA tension may be necessary for an optimal outcome. Transversus abdominis activation is one possible strategy that would achieve this objective.

**Effect of TrA Contraction on the LA and DRA**

The effect of different abdominal-muscle activation strategies on the IRD in women with DRA has been investigated. Recent studies using ultrasound imaging have shown narrowing of the IRD during a curl-up, or abdominal crunch. As demonstrated in Figure 1, this can be explained by straightening of the left and right RA muscles from their arc-like orientation at rest. Conversely, widening of the IRD oc-
activation of the lateral abdominal, as the abdominal crunch in women with DRA immediately has been shown to reduce the IRD.20,26 On the basis of the present data, it may be argued that to focus solely on IRD narrowing may be suboptimal. The observation of less LA distortion (better control of abdominal contents, and better transfer of force between the right and left abdominal muscles for tasks outcomes in women with DRA is a matter of debate. Women with DRA have been advised to avoid abdominal crunches to prevent further stretching of the LA from increased IAP, with the assumption that the abdominal wall may be weakened after pregnancy.6,17 Recently, it has been suggested that abdominal crunch exercises may be more effective for management of DRA than exercises that focus on activation of the lateral abdominal, as the abdominal crunch in women with DRA immediately has been shown to reduce the IRD.20,26 On the basis of the present data, it may be argued that to focus solely on IRD narrowing may be suboptimal. The observation of less LA distortion (better control of abdominal contents, and better transfer of force between the right and left abdominal muscles for tasks

### TABLE 3

**Distortion Index at Rest and During Curl-up**

<table>
<thead>
<tr>
<th>Measure</th>
<th>DRA*</th>
<th>Controls*</th>
<th>Between-Group MD†</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UX point</td>
<td>0.043 ± 0.037</td>
<td>0.014 ± 0.008</td>
<td>-0.029 (-0.047, -0.010)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>U point</td>
<td>0.066 ± 0.040</td>
<td>0.015 ± 0.008</td>
<td>-0.051 (-0.071, -0.031)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td><strong>Automatic curl-up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UX point</td>
<td>0.067 ± 0.049</td>
<td>0.014 ± 0.008</td>
<td>-0.054 (-0.078, -0.030)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Rest versus automatic curl-up</td>
<td>.02</td>
<td>.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>0.025 (0.004, 0.045)</td>
<td>0.0002 (-0.006, 0.006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U point</td>
<td>0.083 ± 0.059</td>
<td>0.014 ± 0.006</td>
<td>-0.069 (-0.098, -0.040)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Rest versus automatic curl-up</td>
<td>.046</td>
<td>.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>0.018 (0.0003, 0.041)</td>
<td>0.0002 (-0.004, 0.004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TrA curl-up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UX point</td>
<td>0.046 ± 0.037</td>
<td>0.013 ± 0.005</td>
<td>-0.033 (-0.052, -0.015)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Rest versus TrA curl-up</td>
<td>.69</td>
<td>.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>0.003 (-0.013, 0.019)</td>
<td>0.001 (-0.006, 0.003)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TrA curl-up versus automatic curl-up</strong></td>
<td>.01</td>
<td>.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>-0.021 (-0.038, -0.005)</td>
<td>0.001 (-0.006, 0.003)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U point</td>
<td>0.059 ± 0.046</td>
<td>0.015 ± 0.007</td>
<td>-0.043 (-0.066, -0.020)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Rest versus TrA curl-up</td>
<td>.43</td>
<td>.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>0.007 (-0.027, 0.022)</td>
<td>-0.0004 (-0.005, 0.006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TrA curl-up versus automatic curl-up</strong></td>
<td>&lt;.001</td>
<td>.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD†</td>
<td>-0.025 (-0.037, -0.012)</td>
<td>-0.0006 (-0.003, 0.004)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations:** DRA, diastasis rectus abdominis; MD, mean difference; TrA, transversus abdominis; U point, just above the umbilicus; UX point, halfway between the U point and the xiphoid.

*Values are mean ± SD.
†Values in parentheses are 95% confidence interval.
could imply that optimal TrA activation occurred without cuing during automatic curl-up for this group, or that low LA extensibility prevented distortion regardless of strategy, or both. Similar LA behavior between male and nulliparous female controls concurs with IRD measures in human cadavers made superior to the umbilicus.\textsuperscript{1,12}

The role of tissue strain in collagen matrix production/healing requires consideration. Although exercise that narrows the IRD is recommended in DRA,\textsuperscript{20,26} this may be counterproductive, as decreased mechanical strain reduces fibroblast activity.\textsuperscript{9} Increased collagen synthesis to strengthen the LA may be enhanced by stretch.\textsuperscript{16}

**Individual Variation**

Although the data from the DRA group support the hypothesized LA behavior during curl-ups, variability of the behavior between individual participants (as exemplified by wide SDs for the DRA group) highlights that multiple mechanisms may likely influence the capacity to control tension in the LA. Most, but not all, DRA participants reduced the LA distortion observed during an automatic curl-up by TrA preactivation. There are several possible sources of variation. First, reduced LA distortion would depend on TrA recruitment. Second, interaction between abdominal muscle layers, which have differing relationships to the LA,\textsuperscript{1,2,12} would affect LA distortion. Third, despite adequate TrA contraction, excessive LA laxity in some individuals may limit the capacity of the TrA to influence LA tension. Fourth, variation in IAP generated during the curl-up would affect LA distortion. A common clinical observation involves the LA “sagging” inward, secondary to reduced IAP by thorax expansion. Alternatively, the LA bulges outward when IAP increases. Both strategies were observed during automatic curl-up, and TrA activation reduced this in some. The range of potential moderators of the effect of TrA activation on the LA highlights the necessity for individualized rehabilitation for DRA.

**FIGURE 4.** (A) Inter-rectus distance and (B) distortion index at rest and during the automatic curl-up and curl-up with preactivation of the TrA muscle. Mean ± SD values of group data are shown for controls (blue circles) and participants with diastasis rectus abdominis (orange circles). *P<.05 for comparison between tasks. Abbreviations: TrA, transversus abdominis; U point, just above the umbilicus; UX point, halfway between the U point and the xiphoid.
Distortion Index
We developed a novel measure of LA distortion as an index of tension. The premise was that a less tense LA would undergo greater distortion in response to elevated IAP during the curl-up. Although logical, the relationship between tension and the distortion index may not be linear, as the distortion may depend on multiple factors such as the applied force, the structural characteristics of the LA, and the performed task. The measure is difficult to interpret in the resting state, when applied forces (eg, IAP) are low—the LA may adopt the shortest path between attachments, despite low tension. Comparison of the distortion index with more direct measures of tissue properties is required to study its validity and interpretation in different contexts.

Clinical Implications
The findings of the present study provide a foundation for considering a rehabilitation of DRA solely focused on IRD narrowing to be suboptimal. The present findings show that, for many individuals, this may lead to greater LA distortion, which has implications for control of abdominal contents (ie, cosmetic appearance) and thoracolumbar/lumbopelvic function. The alternative view is that more optimal cosmetic and functional outcomes may be achieved using abdominal muscle activation strategies that reduce LA distortion (increase LA tension), regardless of the impact on IRD. This requires consideration in future clinical trials.

Variation in LA behavior in DRA implies that individualized assessment and training prescription is likely to be required. Further, individual data suggest that some individuals may not be able to generate sufficient LA tension, despite optimal TrA activation. In this subgroup, passive support or surgical repair (rectiplication) may be required. There is preliminary evidence that rectiplication can reduce back pain in major DRA.31 Although the present data suggest that individual variation can be identified with ultrasound imaging, future work could also assess whether this distinction can be made on the basis of palpation of LA tension or depth.

CONCLUSION
In summary, these findings provide a foundation on which to reconsider the contemporary view that reduced IRD should be the sole focus of DRA rehabilitation. Although additional work is required to validate the methods used to estimate LA properties, the data provide compelling insight into LA behavior during a curl-up and suggest that the appearance of the abdominal wall and function of the abdominal muscles may be optimized by TrA activation to optimize LA tensioning, despite reduced IRD narrowing.

KEY POINTS

**FINDINGS:** The LA in women with DRA is wider and behaves differently during a curl-up task than in individuals without the condition, and this behavior varies according to the abdominal wall recruitment strategy used for the task. An automatic abdominal curl-up results in narrowing of the IRD in most women with DRA. Although preactivation of the TrA reduces the narrowing of the IRD (widens the LA), this strategy decreases the distortion of the LA during the task.

**IMPLICATIONS:** Exercises, or training, for women with DRA that focus solely on narrowing the IRD may not achieve best cosmetic or functional outcomes for the abdominal wall, as narrowing allows greater distortion of the LA. Widening of the IRD may be beneficial rather than negative, but not all women achieved the same reduction of distortion of the LA with preactivation of the TrA; thus, women with DRA require individual assessment.
CAUTION: This study cannot conclude what type of abdominal training may lead to better cosmetic or functional outcomes for women with DRA, but indicates that exercise that widens the IRD cannot be dismissed. Novel measures of LA distortion, although logical, require validation with direct measures of LA tension/stiffness.

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