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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 fibers[1] that continue from the rectus sheaths[2] 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.[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.[7,8,17] The width of the LA is equivalent to the IRD.

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 between-task difference, –1.19 cm; 95% confidence interval [CI]: –1.45, –0.93; $P<.001$ and mean UX-point between-task difference, –0.51 cm; 95% CI: –0.69, –0.34; $P<.001$), but LA distortion increased (mean U-point between-task difference, 0.018; 95% CI: 0.0003, 0.041; $P = .046$ and mean UX-point between-task difference, 0.025; 95% CI: 0.004, 0.045; $P = .02$). Although TrA curl-up induced no narrowing or less IRD narrowing than automatic curl-up (mean U-point difference between TrA curl-up versus rest, –0.56 cm; 95% CI: –0.82, –0.31; $P<.001$ and 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, –0.025; 95% CI: –0.037, –0.012; $P<.001$ and mean UX-point between-task difference, –0.021; 95% CI: –0.038, –0.005; $P = .01$). Inter-rectus distance and the distortion index did not change from rest or differ between tasks for controls ($P\geq.55$).

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*

The abdominal wall is essential for lumbopelvic function through multiple mechanisms, including the transfer of force through fascial tension.[3,29] A diastasis rectus abdominis (DRA) is present when the IRD exceeds normal values[4] 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.[5,15,17,21,26] 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.[17]

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**). The

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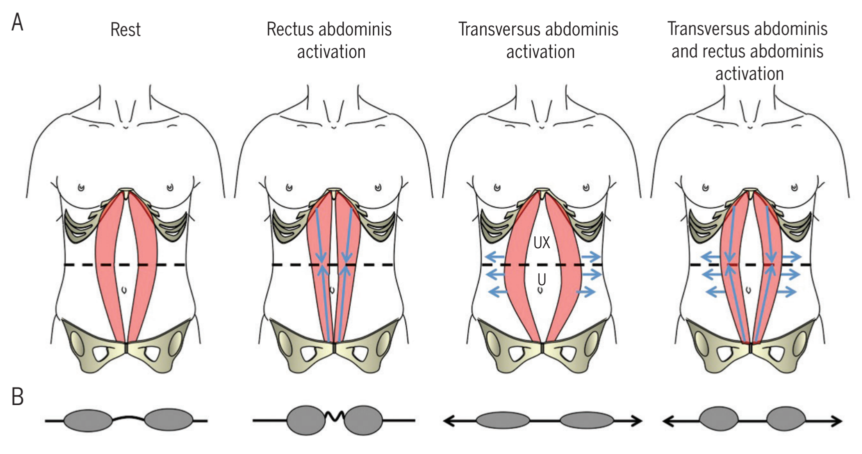

FIGURE 1. Proposed effect of abdominal muscle activation on the inter-rectus distance. (A) Anatomical representation of the rectus abdominis muscle at rest (left panel) and during contraction (middle left panel), contraction of the transversus abdominis (middle right panel), and combined contraction 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 of 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 the umbilicus; UX point, halfway between the U point and the xiphoid.

TABLE 1 PARTICIPANT DEMOGRAPHICS*

Characteristic	DRA	Female Controls	Male Controls
Age, y	34 ± 4	25 ± 2	28 ± 3
Height, cm	165 ± 5	170 ± 7	181 ± 11
Weight, kg	56 ± 7	59 ± 8	77 ± 10

Abbreviation: DRA, diastasis rectus abdominis.
**Values are mean ± SD.*

horizontal force vector of the lateral abdominal muscles should increase the IRD when contracting alone (**FIGURE 1**),[26] and widening of the LA has been reported with a "drawing-in" action that targets these muscles (including the transversus abdominis [TrA]).[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,[32] 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[27] and to transfer force between opposite sides of the abdominal wall.[33] 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 lumbopelvic 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.[4] 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.[4,18,21,22] Videos 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.[1,2] The oblique abdominal aponeurosis continues as the oblique fibers of the ventral rectus sheath and forms the more ventral lamina fibrae obliquae of the LA. Because LA compliance is lowest (ie, greatest stiffness) in the transverse direction,[12] the TrA has the greatest potential to increase LA tension and is critical for support of the abdominal wall/resistance of IAP.[1,2] 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 abdomen above the iliac crest and oriented to image the medial fascial margins of the TrA and oblique abdominal muscles.[30] 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,"[28] "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

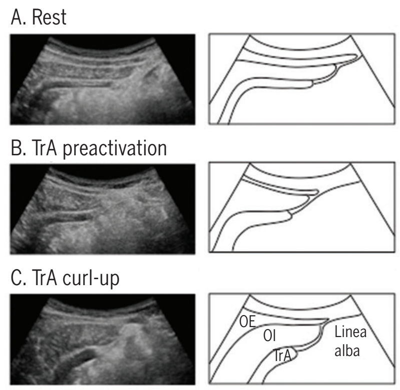

FIGURE 2. Ultrasound images of lateral abdominal muscles in 3 conditions. Ultrasound images (left) and line drawings of ultrasound images (right) are shown (A) at rest, (B) during preactivation of the TrA in supine, and (C) during the curl-up with preactivation of the TrA muscle. Note the lateral displacement, shortening, and thickening of the TrA with preactivation in (B) and the contraction of all muscles, but with maintained contraction of the TrA during curl-up, in (C). Abbreviations: OE, obliquus externus abdominis; OI, obliquus internus abdominis; TrA, transversus abdominis.

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

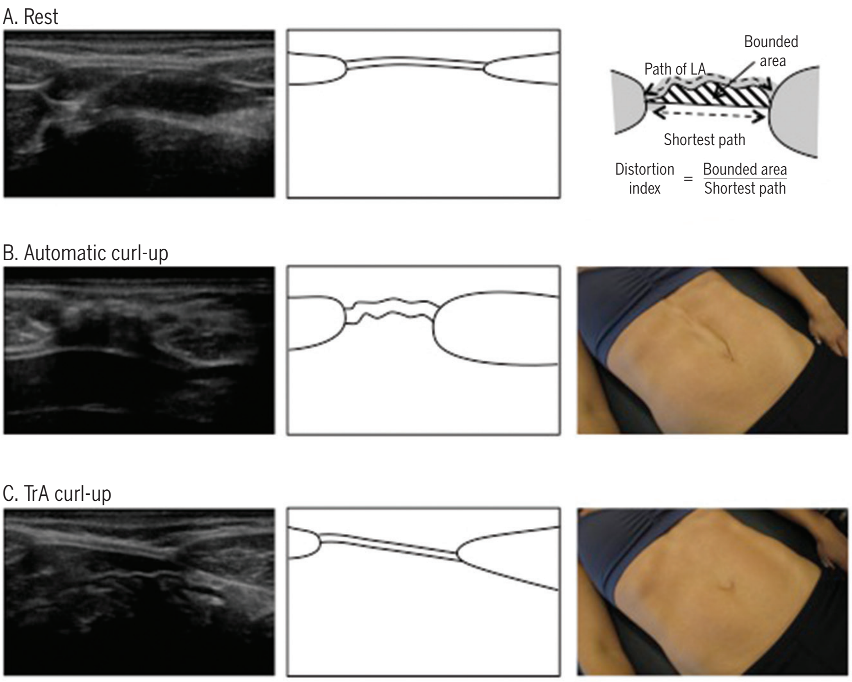

FIGURE 3. Distortion index. Interpretation of the distortion index (A) at rest, (B) during the automatic curl-up, and (C) TrA curl-up tasks. Ultrasound images (left panel), line drawings of ultrasound images (middle panel), and photographs of the abdominal wall during the curl-up tasks (middle and bottom right panels). The inset at 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.

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 to compare the distortion index and measures made with elastography support this proposal (unpublished data). The IRD and distortion index were measured from the 3 repetitions of each test condition.

Statistical Analysis

Sample size was based on data from Mota et al.[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:

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, $P\geq.17$) (**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 $P\geq.55$). 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, $P\geq.43$). 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.

TABLE 2	Inter-rectus Distance at Rest and During Curl-up					
Measure	DRA*	Controls*	Between-Group MD†	*P* Value	Female Controls*	Male Controls*
Rest						
UX point	2.11 ± 0.70	0.60 ± 0.28	−1.51 (−1.87, −1.15)	<.001	0.61 ± 0.29	0.57 ± 0.29
U point	3.40 ± 0.77	0.78 ± 0.34	−2.62 (−3.02, −2.22)	.002	0.77 ± 0.34	0.80 ± 0.38
UX point versus U point						
P value	<.001	.08				
MD†	1.29 (0.95, 1.62)	0.18 (−0.02, 0.39)				
Automatic curl-up						
UX point	1.60 ± 0.56	0.62 ± 0.26	−0.98 (−1.27, −0.68)	<.001	0.67 ± 0.27	0.53 ± 0.22
Rest versus automatic curl-up						
P value	<.001	.39				
MD†	−0.51 (−0.69, −0.34)	−0.02 (−0.03, 0.08)				
U point	2.21 ± 0.79	0.85 ± 0.37	−1.36 (−1.78, −0.94)	.003	0.87 ± 0.44	0.81 ± 0.24
Rest versus automatic curl-up						
P value	<.001	.17				
MD†	−1.19 (−1.45, −0.93)	−0.07 (−0.03, 0.17)				
TrA curl-up						
UX point	2.09 ± 0.08	0.67 ± 0.26	−1.42 (−1.82, −1.04)	<.001	0.67 ± 0.27	0.66 ± 0.27
Rest versus TrA curl-up						
P value	.86	.007				
MD†	0.02 (−0.22, 0.19)	0.06 (0.02, 0.11)				
TrA curl-up versus automatic curl-up						
P value	<.001	.11				
MD†	0.50 (0.29, 0.70)	0.04 (−0.01, 0.10)				
U point	2.84 ± 0.78	0.92 ± 0.40	−1.92 (−2.33, −1.50)	.009	0.87 ± 0.44	1.01 ± 0.34
Rest versus TrA curl-up						
P value	<.001	.02				
MD†	−0.56 (−0.82, −0.31)	0.14 (0.02, 0.26)				
TrA curl-up versus automatic curl-up						
P value	<.001	.12				
MD†	0.63 (0.41, 0.84)	−0.07 (−0.02, 0.16)				

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,[19] 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.[20] Recent studies using ultrasound imaging have shown narrowing of the IRD during a curl-up, or abdominal crunch.[20,26] 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-

TABLE 3 Distortion Index at Rest and During Curl-up

Measure	DRA*	Controls*	Between-Group MD†	*P* Value
Rest				
UX point	0.043 ± 0.037	0.014 ± 0.008	−0.029 (−0.047, −0.010)	<.001
U point	0.066 ± 0.040	0.015 ± 0.008	−0.051 (−0.071, −0.031)	<.001
Automatic curl-up				
UX point	0.067 ± 0.049	0.014 ± 0.008	−0.054 (−0.078, −0.030)	<.001
Rest versus automatic curl-up				
P Value	.02	.95		
MD†	0.025 (0.004, 0.045)	0.0002 (−0.006, 0.006)		
U point	0.083 ± 0.059	0.014 ± 0.006	−0.069 (−0.098, −0.040)	<.001
Rest versus automatic curl-up				
P Value	.046	.92		
MD†	0.018 (0.0003, 0.041)	0.0002 (−0.004, 0.004)		
TrA curl-up				
UX point	0.046 ± 0.037	0.013 ± 0.005	−0.033 (−0.052, −0.015)	<.01
Rest versus TrA curl-up				
P Value	.69	.55		
MD†	0.003 (−0.013, 0.019	0.001 (−0.006, 0.003)		
TrA curl-up versus automatic curl-up				
P Value	.01	.61		
MD†	−0.021 (−0.038, −0.005)	0.001 (−0.006, 0.003)		
U point	0.059 ± 0.046	0.015 ± 0.007	−0.043 (−0.066, −0.020)	<.01
Rest versus TrA curl-up				
P Value	.43	.87		
MD†	0.007 (−0.027, 0.012)	−0.0004 (−0.005, 0.006)		
TrA curl-up versus automatic curl-up				
P Value	<.001	.74		
MD†	−0.025 (−0.037, −0.012)	−0.0006 (−0.003, 0.004)		

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.

curs during an "abdominal drawing-in" maneuver,[20] a strategy known to activate transversely orientated lateral abdominal muscles, in particular the TrA. These findings are consistent with those of the present study, which show no or reduced narrowing of the IRD when the TrA is preactivated before the curl-up. However, which abdominal muscle activation strategy would be optimal to improve both functional and cosmetic 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

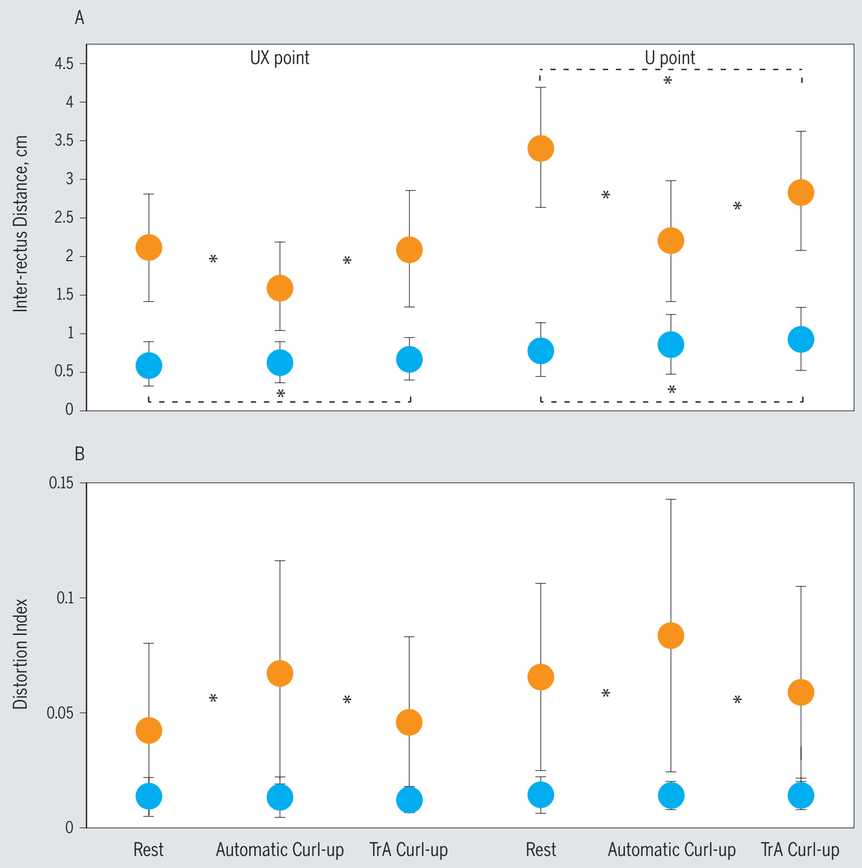

FIGURE 4. (A) Inter-rectus distance and (B) distortion index at rest and during the automatic curl-up and curl-up with preactivation of the TrA muscle. Mean ± SD values of group data are shown for controls (blue circles) and participants with diastasis rectus abdominis (orange circles). *P<.05 for comparison between tasks. Abbreviations: TrA, transversus abdominis; U point, just above the umbilicus; UX point, halfway between the U point and the xiphoid.

such as rotation[33] and lumbar spine and pelvis control[14]) during the TrA curl-up supports the argument that strategies to tense the LA are an important training target, despite reduced IRD narrowing. This proposition requires further consideration. Although LA tension cannot be directly inferred from the distortion index, it is plausible that a more direct path of the LA between its attachments would equate to greater force transmission than an undulating path. This is similar to the uncrimping of tendon collagen fibers when tensed and transmitting force.[10] Complete LA separation would render IRD widening ineffective for LA tensioning. Although DRA, by definition, involves stretch rather than separation,[13] excessive LA stretch would reduce the potential benefit of the proposed mechanism. 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 differences.

A limitation of the present study was the inability to concurrently evaluate the LA behavior and TrA activation. Thus, changes in the distortion index and IRD cannot be directly related to TrA activation quality (eg, amplitude, symmetry, etc). This requires further investigation.

As predicted, in women and men with no history of DRA, TrA preactivation had no impact on the IRD or distortion index during a curl-up. This observation 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.[1,12]

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

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 (recti plication) may be required. There is preliminary evidence that recti plication 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.

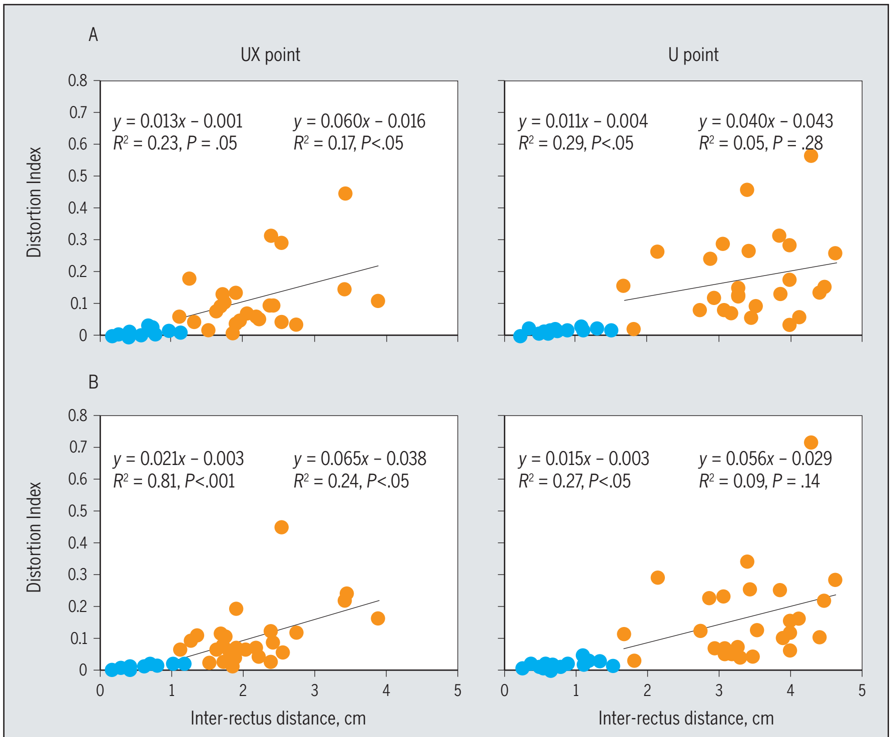

FIGURE 5. Correlation between baseline inter-rectus distance and distortion index during the (A) automatic curl-up and (B) curl-up with preactivation of the TrA muscle. Correlations were calculated separately for controls (blue circles) and participants with diastasis rectus abdominis (orange circles) and for the U point and UX point. Abbreviations: TrA, transversus abdominis; U point, just above the umbilicus; UX point, halfway between the U point and the xiphoid.

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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