Comparison of Trunk Muscle Function Between Women With and Without Diastasis Recti Abdominis at 1 Year Postpartum

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Background. A separation of the abdominal muscles at the linea alba, known as diastasis recti abdominis (DRA), can occur after childbirth. However, the impact of DRA on abdominal muscle function is not clear.

Objective. The objective was to determine if differences exist in trunk muscle function and self-reported pain and low back dysfunction between women with and without DRA at 12 to 14 months postpartum and if differences that emerge from the data are associated with the magnitude of the interrectus distance (IRD).

Design. This study was a prospective, observational, case-control study.

Methods. Women with (IRD ≥2.2 cm; n = 18) and without DRA (IRD <2.2 cm; n = 22) participated. Maximal trunk flexion, extension, and rotation torque-generating capacity (Newton-meters), the Sit-Up test (0 to 3 points), and the Sitting-Rising Test (0 to 10 points), and trunk flexion, extension, and lateral flexion endurance (seconds) were measured. Pain and disability were assessed using numerical pain rating scales (0 to 100) and the Roland Morris Low Back Pain Questionnaire (0 to 24 points). Women were compared using independent t tests and Mann-Whitney U Tests. Pearson product-moment and Spearman rank correlation coefficients were used to determine associations; α = .05 was used for all tests.

Results. Women with DRA demonstrated significantly lower trunk muscle rotation torque and scored lower on the sit-up test than those without DRA. IRD was negatively correlated with both trunk rotation torque (rho = -0.367) and sit-up test score (rho = -0.514).

Limitations. The results of this study should not be generalized to women who present with moderate-to-severe IRDs or to multiparous women.

Conclusion. The presence of DRA in primiparous women at 1 year postpartum is associated with trunk rotation strength and ability to perform a sit-up.
Diastasis Recti Abdominis

Diastasis recti abdominis (DRA) is a separation of the abdominal muscles at the linea alba (LA). DRA can occur as the result of prolonged transverse stresses on the linea alba in men, postmenopausal women, and in women during pregnancy. As the abdomen expands during pregnancy, the LA (the fascia between the rectus abdominis [RA] heads) must soften and expand to accommodate the growing fetus. This process increases the width of the LA, which is reflected in the interrectus distance (IRD). DRA is experienced by some women during their third trimester of pregnancy and immediately after a full-term pregnancy; however, to date, research does not present a consensus on how many women are affected by DRA.

Currently, the literature suggests 33% to 74% of women present with DRA after childbirth, with this large range in incidence likely being the result of variation regarding the definition of DRA. Although ultrasound imaging (USI) is a valid and reliable means of measuring IRD in women, different research groups have reported IRD values at different measurement sites (ie, below the umbilicus, at the superior border of the umbilicus) and have used different IRD values ranging from 1.5 to 2.5 cm as cut-off values to define DRA. The current literature is discrepant regarding the relevance of IRD as a means of evaluating DRA severity.

There is some evidence that shows that the magnitude of the IRD is associated with the severity of self-reported abdominal pain, yet, there is no evidence to support the contention that there is an association between IRD and lumbopelvic pain. Despite suggestions that DRA may be associated with pelvic floor dysfunction, women with DRA have not been shown to demonstrate pelvic floor muscle weakness or higher-incident urinary incontinence or pelvic organ prolapse. In terms of trunk function, a woman’s ability to perform a sit-up was found to be reduced during pregnancy and at 8 weeks after delivery, and IRD was found to be negatively correlated with trunk flexor strength and trunk flexor endurance in a small sample of women who did not present with DRA at 6 months postpartum. However, these associations have not been investigated after DRA has persisted for some time, in this case, at 1 year postpartum.

Despite the lack of robust evidence to support the need for intervention when women present with DRA, a sample of physical therapists in the United States who practiced specifically in the area of women’s health believed that DRA should be managed through therapeutic exercises, specifically those aimed at training the transverse abdominis muscle. The results of 3 small exercise intervention studies have suggested that targeted exercise performed during pregnancy can prevent postpartum DRA. However, it is not clear whether or not DRA caused by pregnancy that persists postpartum is associated with any physical impairment. Because the physical and functional impacts of DRA have not been established, it is premature to test exercise protocols for their effectiveness. First, we must understand if functional implications of postpartum DRA exist before directing interventions toward resolving specific impairments associated with this condition.

The objective of this prospective, observational, case-control study was to investigate the impact of DRA on trunk muscle function at 1 year postpartum, and to determine whether the severity of impairments found in trunk strength and endurance and/or self-reported pain and low back dysfunction were correlated with the magnitude of the IRD.

Methods
The study was found to comply with the standards for the ethical conduct of research by Queen’s University Health Sciences Research and Ethics Board (REH-636-15), and all volunteers provided written informed consent before participating.

Participants
Women who were approaching the end of their first postpartum year (12 to 14 months from the delivery of their first child) were recruited for this study through convenience sampling from the Kingston, Ontario, community. Recruitment was done through word of mouth and through advertising via study posters at local mother and baby groups, gyms, allied health clinics, and family physician offices. Recruitment posters were also placed on social media in local mother support groups.

There were limited data in the literature on which to base estimates of power and sample size. Liaw and colleagues measured timed trunk flexion and found significant differences in mean static trunk flexion endurance times between nulliparous women and women at 6 months postpartum. By using the group means and pooled standard deviations reported by Liaw and colleagues, an effect size of 0.8, an alpha level of 0.05, and a power set at 0.8, we estimated that 52 women (26 women in each group) would be required in order to detect a group difference in endurance between women with and without DRA. At the end of the predetermined recruitment period, we had recruited 40 women. A preliminary analysis was done, and significant group differences were found regarding some variables. Power analyses were then completed on the variables that did not reach statistical significance, the outcome of which suggested that continuing recruitment to n = 52 would not have any meaningful impact on the power to detect differences in these variables. Therefore, recruitment was terminated at this point. Effect size analyses and post hoc power analyses can be found in eTable 1 (available at https://academic.oup.com/ptj)
Diastasis Recti Abdominis

neoplasm); (8) low back pain prior to pregnancy (defined as a history of lumbopelvic, hip, or thigh pain that was severe enough to interfere with work or recreation or required medical attention) in order to study only pain that arose over the course of or after pregnancy; or (9) DRA prior to pregnancy.

Eligible participants completed a series of online questionnaires prior to their physical testing. The Roland-Morris Disability Questionnaire (RDQ) is scored out of 24, where 0 indicates no disability and a score of 24 indicates severe disability. The RDQ has been shown to have high construct validity when compared to pain rating scores, is easily understood by patients, and has been found to be a reproducible and responsive questionnaire. The RDQ is an appropriate questionnaire to use when investigating populations with mild-to-moderate disability due to low back pain. Four numerical pain rating scales (NRS) were also used. The NRS asked the participants to rate their worst pain in the past 24 hours separately for the abdomen, low back, upper-mid back, and pelvis or hips on a 0 to 100 scale (0 indicated no pain; 100 indicated worst pain imaginable). The NRS is valid, reliable, and has demonstrated superior responsiveness and ease of use when compared to a visual analog scale. Participants also completed the International Consultation on Incontinence Questionnaires (ICIQ) for vaginal symptoms (ICIQ-VS) and urinary tract symptoms (ICIQ-FLUTS). Demographic information (ie, age, delivery mode, baby’s birth weight, breastfeeding status, education level, work status, and weekly minutes of moderate-to-vigorous physical activity) was obtained using self-report, and standard procedures were used to measure height, weight, and hip and waist circumference.

Procedure

A physical therapist who was blinded to the participant’s DRA status at the time of testing performed the physical testing. To investigate the function of their abdominal muscles, participants performed 3 trials of strength, endurance, and functional tasks in the order described below.

First, isometric trunk flexion then extension torque were tested using a custom portable dynamometer (IFLEXED); maximum peak torque efforts were captured during each 5-second trial. The IFLEXED has excellent test-retest reliability (ICC 3.1 > 0.973) and concurrent validity (R > 0.829) relative to a Biodex dynamometer. The IFLEXED output signal was conditioned with an amplifier (Model 9243, Burster, Germany) and then sampled at 100Hz using a 12-bit Analog to Digital Conversion Card (USB-201, Measurement Computing Corporation, Norton, Massachusetts). Using a custom Labview 2013 program (National Instruments, Austin, Texas), raw data were saved to a personal computer.

Right and left trunk rotation torques were then measured using 2 Mark-10 Series 5 digital force gauges (Mark-10 Corporation, Copiague, New York). Resistance was provided at a standardized position on the forearm of the participant’s outstretched arms (45 cm from the acromion) and the contralateral thigh (35 cm from the greater trochanter). Each 5-second contraction effort was ramped to the participant’s maximum effort. Peak torque was calculated as peak force obtained multiplied by the perpendicular distance of the point of application of the force to the center of rotation at the acromion, which was kept consistent between trials and participants at 0.45 m.

Participants demonstrated no significant difference between left and right rotation, and therefore, an average of the 6 measures of peak torque was calculated (3 trials of left rotation and 3 trials of right rotation) and retained for statistical analysis. Prior to initiating this study, it was important to assess the intrarater reliability of this measurement. Intrarater test-retest reliability was computed using a convenience sample of 10 women, and the intraclass correlation coefficient (ICC 3.1) was 0.985 or excellent.

Next, participants performed the Sit-Up Test, which was scored on a scale from 0 to 3. A score of 0 indicated the participant was unable to perform a sit-up; a score of 1 indicated the participant could perform a sit-up with their lower extremities straight (long lying position), with their ankles secured to the plinth, and with their arms held at their sides (Task 1); a score of 2 indicated the participant could perform a sit-up in Task 1 and additionally with their hands held behind their head (Task 2); a score of 3 indicated the participant could perform a sit-up with their hands behind their head, hips and knees flexed, and the soles of their feet on the plinth (hook lying position; Task 3) while their lower extremities were not restrained in any way. A sit-up was considered complete if the participant was, after rising from the dependent position and in a controlled manner, able to achieve a position in which their head, shoulders, and upper torso were in line and at a 40-degree angle from horizontal, and the participant was able to hold the position for 5 seconds. A controlled manner was defined as a motion where accessory muscles, compensatory movements, and momentum were not used to achieve the position. The participants had 3 attempts at a task before the test was either terminated (unsuccessful after 3 attempts) or progressed (successful completion of the task).

Although this task has been used in the literature, the reliability of the task has not been tested. Therefore, our research group tested the intra- and interrater reliability of scoring this task on a sample of 10 women prior to initiating this study. Our results suggested that intrarater reliability (ICC 3.1 = 0.938) and interrater reliability (ICC 3.2 = 0.832) were both excellent.

The Sitting-Rising Test (SRT) then measured the participants’ ability to sit down and then rise up from the floor using as little support as possible. Participants were asked to begin by standing in bare feet and with a comfortable base of support. They were then asked to lower themselves to a seated position on the floor without leaning on anything or using their hands for assistance. Once on the floor, they were asked to stand back up, trying not to use support from their hands, knees, forearms, or sides of their legs. A score out of 5 was given for the sitting phase, and another
Diastasis Recti Abdominis

Figure 1.
Plots of test scores that were significantly different between groups. (A) Correlation between mean interrectus distance (IRD) recorded at rest and mean trunk rotation torque in women with DRA (red) and without DRA (black) with best fit regression. (B) Boxplots for mean IRD recorded at rest vs Sit-Up Test scores. DRA = diastasis recti abdominis.

score out of 5 was given for the rising phase. One point was subtracted from the possible total of 5 for each phase each time a support was used and/or if the evaluator observed an unsteady execution of the task or a loss of balance. An overall SRT score (0 to 10) was calculated by adding the sitting and rising scores together. The participants were given 3 attempts at the task, and their best score was recorded. The SRT has been found to be reliable and reproducible between days and raters on a small sample of men and women.

Finally, trunk endurance was assessed using 5 different tasks (flexion, extension, bilateral side planks, and a front plank) (Fig. 2). Electromagnetic sensors (Ascension Technologies, Burlington, Vermont) were adhered to the participants’ thorax at the T2, T6, T12, and S1 vertebral levels, and the data were used to calculate the amount of time (in seconds) that each position was held. Using the motion sensor data, the time during which the participant held the test position in a steady state without any sensors moving more than 2 standard deviations away from their original steady-state position was deemed the endurance time for that task.

Trunk flexor endurance was measured as the amount of time a participant could hold a sit-up position with their trunk angled at 60 degrees from the horizontal while keeping their knees and hips flexed to 90 degrees and with their feet secured to the table by strapping.

Back extensor endurance was tested using the Biering-Sorensen position. The participant’s hips were aligned with the edge of the table, and their pelvis, hips, and knees were secured to the table. Participants held their arms across their chest with their hands on opposite shoulders and were instructed to hold their body straight and parallel to the floor.

Right- and left-side plank endurance were tested by having the participant lie on their side with their hips and knees extended and their feet placed one on top of the other. Participants were asked to lift their hips off the table using their forearm and dependent foot as points of support. Their top arm (uninvolved arm) was held across the chest with the hand placed on the opposite shoulder.

For the front plank task, the participants were asked to lie prone and to lift their body off of the table and attempt to keep their torso and legs in a straight line, using their forearms and the balls of their feet as points of support. The lateral flexion, flexion, and extension trunk endurance tests have been found to have high inter- and intrarater reliability (ICC [3,1] > 0.82).

To prevent fatigue, a 2-minute rest was given between trials of maximum effort trunk flexion, extension, and rotation torque and between trials of the 2 functional tasks, the Sit-Up Test and the Sitting-Rising Test. A 5-minute rest was given between endurance task trials to limit the influence of fatigue on the test outcomes.

Ultrasound Imaging
The ultrasound assessment was performed after the physical testing had been completed, to ensure the investigator was blinded to each participant’s DRA status at the time of the physical assessment, where such knowledge may have biased testing outcomes. The ultrasound assessment was performed by a physical therapist with formal postgraduate training in musculoskeletal ultrasound imaging (USI) and more than 100 hours of clinical and research experience using USI to evaluate the abdominal musculature. A General Electric Voluson-i ultrasound...
Figure 2.
Scatter plot of trunk muscle endurance (in seconds) vs mean IRD (cm) recorded at rest and trunk muscle torque versus mean IRD (cm) recorded at rest in women with DRA (red) and without DRA (black) with best fit regression. DRA = diastasis recti abdominis; IRD = interrectus distance.
system (GE Healthcare, Mississauga, Ontario, Canada) was used, and static 2-dimensional images were recorded in B-Mode using a 10-Megahertz linear transducer with a 53 mm width (Model 9L-RS). Images were captured with the transducer centered between the rectus abdominal heads, along the LA, and at 3 specific spots on the anterior abdominal wall: at the superior border of the umbilicus, 3 cm above the umbilicus, and 5 cm above the umbilicus. Images of the LA were taken at levels above the umbilicus, as previous research has found USI measurements to be reliable and valid at these locations and less reliable and valid below the umbilicus. Three images were captured at rest at each location with the participant in a standardized supine position with knees and hips flexed and arms positioned at their sides.

Classification of DRA
IRDs were measured offline using Image J v1.46r software (National Institutes of Health, Bethesda, Maryland, USA). IRD, the linear distance between the most posterior-medial hypoechoic borders of each rectus abdominis (RA) head at the end of tidal expiration, was measured at each measurement site. Because no diagnostic cut-off for DRA exists in the literature, we identified women as having DRA based on normative values presented by Beer and colleagues; women were deemed to have DRA if the mean of the 3 IRD measures at 3 cm above the umbilicus was greater than the 90th percentile of the normative values reported for nulliparous women (>2.2 cm). For a participant to be allocated to the DRA cohort, they had to meet the following criteria: (1) an IRD greater than 2.2 cm at the site 3 cm above the umbilicus as well as, at a minimum, at least 1 other measurement site; and (2) the mean IRD (calculated as an average of the 3 measures taken at each of the 3 locations) greater than 2.0 cm.

Data Analysis and Statistics
Isometric flexion, extension outcomes were recorded as the mean of the peak torque values determined from the 3 trials of each task performed. Trunk rotation torque was recorded as the mean from 6 trials: 3 from left rotation and 3 from right rotation. The mean endurance time recorded across the 3 trials of each endurance task was also determined.

Data analysis was completed using SPSS version 24 (Chicago, Illinois, USA). Data were first tested for normality using the Shapiro-Wilks test. All data were normally distributed except for trunk extension peak torque and trunk extension endurance. Women with and without DRA were compared using independent-sample t tests (normal data), Kruskal-Wallis H tests (nonparametric data), and chi-square (Fisher exact test; nominal distribution), as appropriate. Associations between mean IRD and variables in which significant differences were found between cohorts were determined using Pearson product-moment correlation coefficients (normal data), and Spearman rank correlation coefficients (nonnormal data). In all statistical tests, alpha was set to .05.

Role of the Funding Source
This research was supported by the OrthoCanada Research Grant and administered by the Physiotherapy Foundation of Canada. The funders played no role in the design, conduct, or reporting of this study.

Discussion
To our knowledge, the present study is the first to investigate the impact of DRA on trunk muscle strength and endurance in primiparous women at 1 year postpartum. The women who presented with DRA had a lower capacity to generate trunk rotation torque than women without DRA. The women with DRA performed worse on the Sit-Up Test when compared to women without DRA. Concurrently, we found significant, moderate, and negative correlations between IRD and trunk rotation peak torque-generating capacity, and between IRD and Sit-Up Test scores.

The correlation analyses of significant variables revealed that IRD was positively associated with the weight of the baby at birth (r = 0.466, P = .002) and that IRD was negatively associated with trunk rotation torque (r = -0.367, P = .02) and ability to perform a sit-up (r = -0.514, P = .0007); larger IRDs were associated with worse performance on both tasks.
Diastasis Recti Abdominis

Table 1.
Demographic Characteristics of Primiparous Women With (n = 18) and Without (n = 22) Diastasis Recti Abdominis

<table>
<thead>
<tr>
<th>Variable</th>
<th>DRA (n = 18)</th>
<th>No DRA (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>31.9 (3.6)</td>
<td>31.2 (4.5)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.5 (6.3)</td>
<td>166.1 (6.1)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.4 (14.6)</td>
<td>66.7 (12.5)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.1 (5.6)</td>
<td>24.1 (3.9)</td>
</tr>
<tr>
<td>Waist-to-hip ratio</td>
<td>0.81 (0.1)</td>
<td>0.79 (0.1)</td>
</tr>
<tr>
<td>Baby's birth weight (kg)</td>
<td>3.6 (0.4)</td>
<td>3.2 (0.5)*</td>
</tr>
<tr>
<td>Delivery mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaginal</td>
<td>14 (77.8%)</td>
<td>17 (77.3%)</td>
</tr>
<tr>
<td>C-section</td>
<td>4 (22.2%)</td>
<td>5 (22.7%)</td>
</tr>
<tr>
<td>Weeks since delivery</td>
<td>56 (4)</td>
<td>55 (4.5)</td>
</tr>
<tr>
<td>Currently breastfeeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>9 (50.0%)</td>
<td>9 (40.9%)</td>
</tr>
<tr>
<td>No</td>
<td>9 (50.0%)</td>
<td>13 (59.1%)</td>
</tr>
<tr>
<td>Education level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school diploma</td>
<td>1 (5.6%)</td>
<td>1 (4.6%)</td>
</tr>
<tr>
<td>College diploma</td>
<td>4 (22.2%)</td>
<td>6 (27.3%)</td>
</tr>
<tr>
<td>University bachelor's degree</td>
<td>6 (33.3%)</td>
<td>10 (45.5%)</td>
</tr>
<tr>
<td>University master's degree or higher</td>
<td>7 (38.9%)</td>
<td>5 (22.6%)</td>
</tr>
<tr>
<td>Work status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not working</td>
<td>4 (22.2%)</td>
<td>9 (40.9%)</td>
</tr>
<tr>
<td>Part-time</td>
<td>4 (22.2%)</td>
<td>4 (18.2%)</td>
</tr>
<tr>
<td>Full-time</td>
<td>10 (55.6%)</td>
<td>9 (40.9%)</td>
</tr>
<tr>
<td>Minutes of moderate to vigorous physical activity per week</td>
<td>101.3 (79.0)</td>
<td>151.1 (125.9)</td>
</tr>
<tr>
<td>ICIQ-VS vaginal symptoms score (max = 53)</td>
<td>6 (4)</td>
<td>5 (4)</td>
</tr>
<tr>
<td>ICIQ-VS sexual matters score (max = 56)</td>
<td>12 (15)</td>
<td>8 (15)</td>
</tr>
<tr>
<td>ICIQ-FLUTS filling symptoms score (max = 15)</td>
<td>3 (3)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>ICIQ-FLUTS voiding symptoms score (max = 12)</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>ICIQ-FLUTS incontinence symptoms score (max = 20)</td>
<td>2 (2)</td>
<td>2 (2)</td>
</tr>
</tbody>
</table>

*Data are mean (SD) or numbers with percentages (%). Independent t test (P < .05), Kruskal-Wallis H tests, and chi-square Fisher exact test were performed on all variables as appropriate, with significant differences between cohorts indicated by an asterisk. BMI = body mass index; DRA = diastasis recti abdominis; ICIQ-VS = International Consultation on Incontinence Questionnaire—Female Lower Urinary Tract Symptoms; ICIQ-FLUTS = International Consultation on Incontinence Questionnaire—Vaginal Symptoms; max = maximum.

A woman’s ability to perform a sit-up also appears to be impacted by whether or not she has DRA and by the extent of the IRD. A reduced capacity to perform a sit-up has also been reported among women during pregnancy and at 8 weeks postpartum. Interestingly, despite this finding, we did not find a significant effect of DRA on isometric trunk flexion torque-generating capacity when measured using the IFLEDX. The IFLEDX tests trunk flexion strength in isolation; that is, the lumbopelvis is stabilized by the sitting position and strapping, and thus participants did not need to use synergists to stabilize their lumbopelvis during the task. The Sit-Up Test likely required more stabilization of the lumbopelvic region than what was required to generate flexion torque using the IFLEDX. If a larger IRD reflects poor transfer of forces generated by the muscles of the lateral abdominal wall across the midline, it is possible that DRA would have a greater impact when trunk flexion force requires concurrent effort to stabilize the spine and pelvis (eg, a sit-up) than when trunk flexor force is measured with minimal influence of gravitational loading and with the pelvis stabilized (eg, on the IFLEDX). This would support our finding that women with larger IRDs performed more poorly on the Sit-Up Test despite not demonstrating a significant association between trunk flexion

significant (t = 3.098; P = .154). It is possible, and even likely, that women who perform more physical activity would have greater trunk strength and endurance, and that group differences in physical activity level may indeed underpin findings of higher trunk strength and endurance in the women without DRA. To investigate whether group differences found in trunk rotation strength were attributable to different levels of fitness between our groups, we included physical activity as a covariate in our ANOVA for trunk rotation; this analysis confirmed that physical activity levels did not significantly influence our results (F = 0.194, P = .662).

Trunk Muscle Strength, Endurance, and Functional Task Performance
The results of this study build on the limited research exploring the influence of DRA on impairment and function in women and show that an association
Diastasis Recti Abdominis

Table 2.
Interrectus Distances (IRD) in Primiparous Women at 12 to 14 Months Postpartum

<table>
<thead>
<tr>
<th>IRD at the superior border of the umbilicus (cm)</th>
<th>DRA (n = 18) Mean (SD)</th>
<th>No DRA (n = 22) Mean (SD)</th>
<th>p&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRD 3 cm above the superior border of the umbilicus (cm)</td>
<td>2.6 (0.4)</td>
<td>1.4 (0.4)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>IRD 5 cm above the superior border of the umbilicus (cm)</td>
<td>2.2 (0.6)</td>
<td>1.3 (0.6)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Overall average IRD (cm)</td>
<td>2.5 (0.4)</td>
<td>1.4 (0.4)</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

<sup>a</sup>DRA = diastasis recti abdominis; IRD = Interrectus distance.
<sup>b</sup>Women in the DRA cohort had: (1) an IRD greater than 2.2 cm at the site 3 cm above the umbilicus (Beer et al.); and at 1 other measurement site, and (2) a mean IRD greater than 2.0 cm.
<sup>c</sup>Independent t tests (p < .05) were performed on all variables, with significant differences between cohorts indicated by an asterisk.

torque-generating capacity and IRD using the IFLEXD.

Both trunk flexor endurance tasks used in the current study were static and required activation of the rectus abdominis muscle, the lateral abdominal wall, as well as some degree of concurrent stabilization of the lumbopelvis. It was somewhat surprising that we did not detect any differences in the trunk flexion or lateral flexion endurance task performance between women with and without DRA. Liaw and colleagues<sup>21</sup> found significant negative correlations between IRD and both static (rho = -0.42, P = .020) and dynamic (rho = -0.36, P = .049) endurance tasks based on a curl-up position (ie, head and scapulae lift off the plinth). It appears that the ability to stabilize the lumbopelvis may be particularly impaired during the trunk curl-up motion when the muscles of the lateral abdominal wall must initially contract, and less so when women approach a full sit-up position. It also appears that once the static position is achieved, the endurance of the trunk muscles is not impaired to any significant extent. As such, the impairments seen in women with DRA seem to be quite specific to the position and the task. The differences in study results among recent studies may reflect the variances in the gravitational force vector experienced by women during the tasks. For example, gravitational force has a larger impact on the amount of trunk flexion force required to move into trunk flexion during the early phase of a sit-up task (ie, curl-up) compared to the later phases of the task. As such, deficiencies in the capacity of the LA to transmit forces generated by the muscles of the lateral abdominal wall may be more evident during a semi-curl-up than during a static hold at 60 degrees of trunk flexion. The difference in the gravitational force vector may also explain why we were able to detect differences between women with and without DRA using the Sit-Up Test but not during the Sitting-Rising Test. Future research is needed to explore the impact of DRA on dynamic flexion, rotation, and lateral flexion task performance before any firm conclusions can be drawn.

Interrectus Distance

The literature suggests that DRA is present when IRD is greater than 2 cm at the level of the umbilicus. However, there is no known clinically meaningful value that defines DRA based on the IRD, or that identifies greater potential for impairment. Through using normative cut-off values defined by Beer and colleagues,<sup>87</sup> the difference in IRD between our groups (>1.1 cm) was relatively large. This magnitude of difference was much greater than the minimal detectable change (MDC) for IRD determined for repeated measurements (0.29 cm to 0.31 cm) reported by Kewshani and McLean<sup>43</sup> as such, we are confident that the mean IRD was significantly different between our 2 groups. The range of IRD values in our sample was still low, however, and it is imperative that future studies investigate the impact of DRA on trunk function in women with larger IRD values.

Self-Reported Pain

Researchers have hypothesized that DRA is associated with lumbopelvic pain,<sup>6</sup><sup>-</sup><sup>9</sup><sup>-</sup><sup>89</sup><sup>-</sup><sup>91</sup> but this association has not been firmly established in the literature.<sup>9</sup> In fact, most studies have found no association between self-reported pain and DRA.<sup>85</sup><sup>-</sup><sup>52</sup> Most studies have, however, focused on studying women in the early postpartum period and have focused on low back pain.<sup>8</sup><sup>21</sup> The results of our study apply beyond the postpartum year, yet still suggest that self-reported low back, pelvic, and abdominal pain, and self-reported dysfunction due to low back pain, do not differ between women with and without DRA. Despite differences in the approach to stratifying women, our results are also comparable to those recently reported by Sperstad and colleagues,<sup>9</sup> who found no difference in self-reported pain between women with and without DRA, assessed using palpation, at 1 year postpartum.<sup>9</sup> These results are also in agreement with previous studies that found no association between DRA and low back or pelvic pain.<sup>89</sup><sup>-</sup><sup>92</sup> We found a trend toward self-reported upper-mid back pain being higher among the women with DRA compared to those without DRA (P = .066), which may be of interest in future work. Future research should also explore if there is an association between mid-back pain and trunk rotation torque in postpartum women.

Limitations

The present study is not without limitations. Because of the cross-sectional and prospective nature of this study, the IRDs in our DRA cohort may be considered to be “mild” by clinical standards.<sup>9</sup><sup>-</sup><sup>17</sup> As such, the results of this study may not be generalizable to women who present with larger IRDs at 1 year postpartum, or to parous women who have DRA that persists for several years. The limited range of IRD values

898 ▶ Physical Therapy  Volume 98  Number 10  October 2018
Table 3.
Difference in Trunk Torque and Endurance Between Women With and Without Diastasis Recti Abdominis

<table>
<thead>
<tr>
<th>Measure</th>
<th>DRA (n = 18) Mean (SD)</th>
<th>No DRA (n = 22) Mean (SD)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak flexion torque (N·m)</td>
<td>67.2 (22.5)</td>
<td>63.7 (15.1)</td>
<td>.56</td>
</tr>
<tr>
<td>Peak extension torque (N·m)</td>
<td>93.7 (53.1)</td>
<td>86.8 (31.2)</td>
<td>.75</td>
</tr>
<tr>
<td>Mean trunk rotation Torque (N·m)</td>
<td>37.0 (3.6)</td>
<td>45.3 (9.8)</td>
<td>.004*</td>
</tr>
<tr>
<td>Trunk flexion (s)</td>
<td>193.5 (119.3)</td>
<td>171.7 (93.4)</td>
<td>.52</td>
</tr>
<tr>
<td>Trunk extension (s)</td>
<td>62.6 (30.9)</td>
<td>62.1 (45.0)</td>
<td>.97</td>
</tr>
<tr>
<td>Front plank (s)</td>
<td>44.6 (26.4)</td>
<td>51.9 (26.7)</td>
<td>.39</td>
</tr>
<tr>
<td>Right-side plank (s)</td>
<td>33.6 (20.0)</td>
<td>36.9 (18.3)</td>
<td>.59</td>
</tr>
<tr>
<td>Left-side plank (s)</td>
<td>39.1 (21.2)</td>
<td>42.2 (22.2)</td>
<td>.66</td>
</tr>
</tbody>
</table>

*DRA = diastasis recti abdominis.

**Women in the DRA cohort had: (1) an interrectus distance (IRD) > 2.2 cm at the site 3 cm above the umbilicus (as described by Beer et al43) and at 1 other measurement site, and (2) a mean IRD > 2.0 cm.

**Independent t-tests were performed at the significance level of .05 on all normally distributed variables and significant differences between cohorts indicated by an asterisk. Kruskal-Wallis H-tests were performed at the significance level of .05 on non-normally distributed variables.

Table 4.
Functional Test, Self-Reported Pain, and Dysfunction Scores Compared Between Women With and Without Diastasis Recti Abdominis

<table>
<thead>
<tr>
<th>Measure</th>
<th>DRA (n = 18)</th>
<th>No DRA (n = 22)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting to Rising Test</td>
<td>9.5 (8–10)</td>
<td>9 (8–10)</td>
<td>.55</td>
</tr>
<tr>
<td>Sit-Up Test</td>
<td>2 (1–2)</td>
<td>3 (2–3)</td>
<td>.02</td>
</tr>
<tr>
<td>Roland-Morris Disability Questionnaire Score</td>
<td>1 (1–2)</td>
<td>0 (0–1)</td>
<td>.22</td>
</tr>
<tr>
<td>Worst abdominal pain in past 24 hours</td>
<td>0 (0–6)</td>
<td>0 (0–1)</td>
<td>.35</td>
</tr>
<tr>
<td>Worst upper-mid back pain in past 24 hours</td>
<td>8 (0–18)</td>
<td>0 (0–5)</td>
<td>.07</td>
</tr>
<tr>
<td>Worst low back pain in past 24 hours</td>
<td>6 (0–11)</td>
<td>7 (0–26)</td>
<td>.90</td>
</tr>
<tr>
<td>Worst pelvis and hip pain in past 24 hours</td>
<td>0 (0–4)</td>
<td>0 (0–11)</td>
<td>.44</td>
</tr>
</tbody>
</table>

*Median scores with interquartile ranges. Women in the DRA cohort had: (1) an interrectus distance (IRD) > 2.2 cm at the site 3 cm above the umbilicus (as described by Beer et al43) and at 1 other measurement site, and (2) a mean IRD > 2.0 cm. DRA = diastasis recti abdominis.

**Mann-Whitney U-Test was performed at the significance level of .05; bold indicates significant differences between cohorts.

and the relatively low BMIs the women presented with in this study may have been the result of self-selection bias. Potential participants interested and willing to participate in a study looking at trunk muscle function after pregnancy may be more physically active than their peers. In the interest of investigating women with larger IRDs, future studies should consider recruiting multiparous women or women with long-standing DRA who seek physical therapy with primary complaints of DRA. Recruiting potential participants through partnerships with local obstetricians, midwives, and family doctors who would be able to screen women who have IRD larger than 2.5 finger breadths (or 3 cm) could help capture a greater range of IRDs without biasing the sample toward women with complaints of pain or dysfunction.

Second, the selection of tasks included in this study may have been too limited to capture impairments that are associated with DRA. Because there is limited research that investigates the functional limitations associated with DRA, we decided to explore a broad range of tasks. Based on our findings, it appears that tasks that require dynamic movements against gravity (the sit-up task) may provide more meaningful information than those tasks that require a participant to hold a static position or tasks performed with external stabilization to the lumbopelvis. Our results suggest that once a test position is set, the static endurance of the trunk muscles in that position is not impaired to a significant extent. Based on these findings, the impairments seen in women with DRA seem to be quite specific to the position and the stabilization demand associated with the task. Isometric trunk strength and endurance may not be impaired in women with DRA. Moving forward, we recommend incorporating (1) functional, anti-gravity tasks that challenge the stability of the lumbopelvis and (2) rotational challenges. In the present study, only primiparous women were investigated, and the women with DRA would be considered mild (mean IRD of 2.6 cm) by most clinical standards. It is possible that demands on the oblique and transversus abdominis muscles to provide stability during tasks such as front or side planks would be impaired in women with more moderate or severe DRA. Moving forward, we recommend incorporating functional, anti-gravity tasks that challenge trunk rotational stability and evaluating the impact of IRD on task performance in women who present with larger IRDs.

Finally, researchers have theorized that DRA may not be the best measure when characterizing the changes that occur to abdominal musculature after pregnancy and that other measures that reflect the capacity of the LA to transmit forces generated by the muscles of the lateral abdominal wall may be more appropriate. Based on the findings of this study, such measures warrant development to better assess the biomechanical function of the linea alba. Future studies should explore tasks that challenge lumbopelvic stability and involve movement through a larger range of trunk flexion and rotation.

**Conclusion**

The presence of mild DRA in primiparous women at 1 year postpartum appears to be associated with trunk rotation torque-generating capacity and the ability to perform a sit-up. However, these impairments do not seem to be associated with self-reported pain or
Diastasis Recti Abdominis

dysfunction when measured using self-report questionnaires. Future research should continue to build on the results of the present study by exploring the relationship between abdominal strength, endurance, and pain in women (both primiparous and multiparous) with moderate, severe, or long-standing DRA.

Author Contributions
Concept/idea/research design: L. McLean, N.F. Hills, R.B. Graham
Writing: N.F. Hills, R.B. Graham, L. McLean
Data analysis: N.F. Hills, L. McLean
Project management: L. McLean
Fund procurement: N.F. Hills, L. McLean
Providing facilities/equipment: L. McLean, R.B. Graham
Providing institutional liaisons: L. McLean
Consultation (including review of manuscript before submitting): L. McLean

Ethics Approval
The study protocol was approved by the Queen's University Health Sciences Research Ethics Board (REH-636-15). All volunteers provided written informed consent before participating.

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Disclosures and Presentations
The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest. No conflicts of interest were reported.

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Diastasis Recti Abdominis


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