Exercise Program Reduces Inter-Recti Distance in Female Runners Up to 2 Years Postpartum

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ABSTRACT

Background: Pregnancy and childbirth are associated with increased inter-recti distance (IRD)/diastasis recti abdominis (DRA), pelvic joint laxity, and decreased physical activity levels. Recreational running is an accessible, popular form of exercise that may challenge pelvic stability in postpartum women.
Objectives: To assess the impact of an 8-week abdominal muscle retraining program on IRD and pelvic running mechanics in women up to 2 years postpartum.
Study Design: Pre/posttest single-arm intervention study.
Methods: Thirteen postpartum women (32.8 ± 2.7 years of age; 1-3 pregnancies; 7 weeks to 2 years postpartum) who were recreational runners participated. Ultrasound imaging measured IRD above and below the umbilicus. Thickness of the internal oblique (IO) and transversus abdominis (TrA) muscles was assessed with ultrasonography at rest and during performance of an abdominal draw-in maneuver. Participants underwent an 8-week abdominal muscle retraining program utilizing ultrasonography as biofeedback. Running gait was assessed with 3-dimensional motion capture at study enrollment (baseline), end of the intervention, and 6-week follow-up.
Results: Inter-recti distance below the umbilicus decreased from baseline to end of intervention ($P = .013$) and remained stable at follow-up ($P = .459$). Inter-recti distance above the umbilicus, IO and TrA activation ratio, and running mechanics did not change ($P > .05$). Women reported increased running speed following the intervention ($P = .021$).
Conclusion: An 8-week abdominal muscle retraining program reduced IRD below the umbilicus in recreational runners up to 2 years postpartum, suggesting therapeutic exercise may be part of conservative management for DRA.

Key Words: abdominal muscles, diastasis recti abdominis, exercise, gait mechanics, physical therapy

INTRODUCTION

Pregnancy and childbirth can have a significant impact on the integrity of abdominal wall tissues, including skeletal muscle and connective tissue/fascia, and on pelvic joint motor control,[1–3] which may influence functional mobility. Resuming prepregnancy activity levels is important for general health, as women who do not return to a prepregnancy weight by 6 months postpartum are at an increased risk for the development of chronic diseases, such as heart disease, type II diabetes, and arthritis.[4] Recreational running is considered the most common exercise activity in the general US population due, in part, to its accessibility. In particular, the growth of running among women has increased substantially over the past 2 decades.[5] Women now comprise 55% of running race finishers, with a current estimate of 1 million women participating in their first running race each year.[5] This increase in popularity of running among women has also led to more women engaging in recreational running during and after pregnancy.

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While distance running is a popular form of exercise, it is also associated with a high incidence of injury.[6] Approximately 35% of women report musculoskeletal pain upon returning to running after childbirth, and the low back, pelvis, and hips are the primary locations of pain in 91% of postpartum runners with pain.[7] In addition, 32% of postpartum runners report noticeable separation of the rectus abdominis muscles in the first 2 years after childbirth.[7] Abdominal muscle activation, in particular the transversus abdominis (TrA), is important to maintaining motor control of the pelvis, has been shown to be altered in pregnant and postpartum women and may play a role in the development and persistence of postpartum lumbopelvic pain.[8–12] While TrA is tonically active during running,[13] it is unclear how altered activation may affect pelvic motion during running.

Recent studies have shown that postpartum women demonstrate significantly lower trunk flexor strength than nulligravid women and that fatigability of the trunk flexor and lumbopelvic stabilizing muscles—including TrA—is also impaired in postpartum women up to 6 months after childbirth.[14,15] A plethora of data also exists to show that the increase in inter-recti distance (IRD), resulting from the progressive and prolonged stretch experienced by the abdominal wall and other factors that influence intra-abdominal pressure during pregnancy, persists after childbirth.[2,7,14–17] Animal studies have identified the importance of the abdominal fascia in transferring force generated by the abdominal muscles,[18] and studies of postpartum women have identified a relationship between IRD and fatigability of the abdominal muscles: women with a larger IRD are more fatigable than those with a narrower IRD.[14,15] These impairments in fascial integrity (increased IRD), strength and fatigability of trunk muscles, and increased pelvic joint laxity may make it challenging for postpartum women to engage in physically demanding activities such as running.[19]

While deficits in abdominal muscle strength and fatigability, as well as impaired fascial integrity, have been identified in postpartum women, rehabilitation protocols to ameliorate these deficits have not been well established, particularly pertaining to a reduction in IRD in recreational athletes.[20–23] Exercise, including abdominal muscle strengthening, during pregnancy has been associated with a smaller increase in IRD in the postpartum period as compared with nonexercisers.[24] Evidence suggests that abdominal muscle exercise may also be helpful for reduction in IRD in postpartum women[25,26]; however, the current evidence is insufficient.[24] In addition, current evidence on reduction in IRD with therapeutic exercise is limited to the first postpartum year[25,26] and no studies have assessed changes in IRD in response to deep abdominal muscle retraining exercises in recreational athletes.[22,23] Furthermore, guidelines for returning to vigorous physical activity, such as running, after childbirth are vague and the impact of abdominal muscle dysfunction on postpartum running mechanics is not well described. However, a case study of a postpartum woman with pain during running did identify impairments in both running mechanics and deep abdominal muscle activation, which were improved following physical therapy intervention, including abdominal muscle retraining.[27] As such, the purposes of this study were to describe the impact of a deep abdominal muscle retraining program on (1) IRD and (2) hip and pelvic biomechanics during running in a group of pain-free recreational runners who were up to 2 years postpartum and demonstrated impaired deep abdominal muscle activation.

METHODS

Participants

Participants were recruited via flyers placed in a local running shoe store and a local gym. Phone screening of all interested individuals was performed prior to enrollment to ensure inclusion criteria were met. All participants were females who had given birth within the previous 2 years and engaged in recreational running (minimum of 1 d/wk, 9.6 km/wk) following the birth of their child. Women who demonstrated impaired deep abdominal muscle activation, as evidenced by fair to poor performance of an abdominal draw-in maneuver (ADIM), were enrolled in an 8-week physical therapy intervention. Women who were able to appropriately perform an ADIM would only perform the baseline and follow-up assessments to serve as a control group; however, only 3 of the 16 women enrolled in the study met criteria for the control group; thus, only the intervention group was included in statistical analysis. As a number of studies suggest that changes following pregnancy can last up to 12 months postpartum and longer in women who choose to breastfeed,[17,28–30] 2 years after childbirth was chosen as a cutoff to capture the time when the neuromuscular system is still adapting to the changes that occurred during pregnancy. All participants were older than 18 years, cleared by their physician to participate in exercise, and had no known cardiovascular, pulmonary, or neurological disease. Women were excluded from participating if they experienced musculoskeletal pain while running, pain that would limit the amount of running in which they were able to participate, or pain that changed how they ran. Musculoskeletal pain was defined as a pain in muscles, joints, tendons, ligaments, or bones that lasted for more than 24–72 hours after physical activity, as would be expected from delayed-onset muscle soreness. Women were also excluded if they were pregnant at the time of study participation or had a history of abdominal surgery (excluding cesarean delivery). All participants provided written informed consent. This study was approved by the Health Sciences Institutional Review Board at the University of Wisconsin-Madison.

Variables and Data Sources/Measurement

Abdominal Ultrasonography

Real-time ultrasonography (SonixTouch with 10-MHz linear transducer; bk Ultrasound, Peabody, Massachusetts) was used to measure IRD, or the distance between the medial borders of the right and left rectus abdominis muscles. Inter-recti distance was assessed 2.5 cm below and above the umbilicus while the abdominal muscles were at rest, at end expiration of quiet breathing. Diastasis recti abdominis (DRA), which indicates a pathological increase in IRD, was defined as 2.8 cm when measured above the umbilicus and 2.1 cm when measured below the umbilicus.[31]

Ultrasonography was also used to assess contraction of the deep abdominal muscles, particularly internal oblique (IO) and TrA, during performance of an ADIM. Thickness of the IO and TrA muscles was measured at rest and during contraction (ADIM) and recorded as the activation ratio (contracted thickness/resting thickness)[32] for both the right and left IO and TrA muscles.

Participants were positioned in supine hook-lying with knees and hips slightly bent[17,33] for all ultrasound measurements. The same investigator, who was a physical therapist with advanced training in musculoskeletal ultrasonography, performed all ultrasound measurements. Ultrasound measurements were recorded upon enrollment in the study (baseline), at the end of the 8-week training program (end of intervention), and again 6 weeks after completion of the physical therapist–led training program (6-week follow-up), which occurred 14 weeks after study enrollment.

Intrarater reliability of ultrasound measurements of TrA muscle thickness was made within (2 measurements obtained on the same day) and between sessions (1 measurement obtained on 2 separate days). Three trials were performed for each measurement (ie, a total of 6 images were used to determine within-session reliability).

Abdominal Muscle Retraining Protocol

Participants attended one 30-minute therapy session per week for 8 weeks, during which they were instructed in a progression of exercises to facilitate activation and strengthening of the deep abdominal muscles. Exercise progression in the therapy sessions and prescription of a home exercise program (HEP) are described in Table 1. Abdominal retraining began with an ADIM and progressed to performance of a single-leg squat with ADIM. The HEP was designed to be completed in under 10 minutes, and participants were instructed to perform the HEP daily. Participants were asked about their HEP every week at their 30-minute physical therapy session and demonstrated the exercises from the HEP, with ultrasound imaging for biofeedback, at each session.

Ultrasound imaging provided biofeedback in the therapy sessions so that study participants could see

Table 1. Abdominal Muscle Retraining Protocol and Progression[a]

		Intervention Sessions							
		Weeks During the Intervention							
Exercise	**Home Program Parameters**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ADIM	10 s, 10 reps, 1x/d	x	x	x	x	x	x	x	x
ADIM with bridge on heels with ball squeeze	10 s, 10 reps, 1x/d		x	x	x				
ADIM with bridge with unilateral heel raise	10 s, 10 reps, 1x/d			x	x	x			
ADIM with hip flexion march	10 s, 10 reps, 1x/d				x	x	x		
ADIM with 4-point opposite arm/leg reach	10 s, 10 reps, 1x/d					x	x	x	
ADIM with side-plank on knees	10 s, 6 reps each side						x	x	x
ADIM with standing double-leg squat	10 reps, 2 sets 1x/d						x	x	x
ADIM with standing unilateral squat	20 reps, 2 sets each leg, 3x/wk						x	x	x
Home exercise program at 8 wk	ADIM, ADIM with unilateral squat, ADIM 4-point opposite arm/leg, ADIM with side-plank on knees with the aforementioned listed parameters								

Abbreviations: ADIM, abdominal draw-in maneuver; reps, repetitions; s, seconds; 1x, 1 time; 3x, 3 times; wk, week.

[a] Participants began retraining with performance of an ADIM using real-time ultrasonography for visual feedback of contraction quality. "X" next to each exercise under a given week indicates when in the study each exercise was introduced and performed as part of the skilled therapy session. Exercises were added to the home exercise program following introduction and mastery in the skilled therapy session.

the change in muscle thickness of the TrA and IO muscles. The physical therapist also evaluated quality of muscle contraction by watching movement of the abdominal wall and utilizing the same grading scale used for study inclusion: a "good" contraction resulted in a hollowing of the abdomen, with the belly button moving downward toward the spine; a "fair" rating for the deep abdominal muscle contraction was given to subjects who not only were able to move the belly button downward toward the spine but also exhibited at least 1 compensatory strategy; a "poor" contraction was defined as the inability to move the belly button downward and demonstration of 1 or more compensatory strategies. Superior movement of the abdominal wall toward the rib cage and/or significant breath holding during contraction characterized compensatory strategies. Verbal cues were provided to correct these strategies and focus on engaging TrA, in addition to using the ultrasound images as visual feedback.

Running Habits

Participants completed a survey at baseline, end of intervention, and at the 6-week follow-up time point, indicating their average running mileage per week and average running speed. Average miles per week and average running speed were self-reported for the following time points: prior to most recent pregnancy, time of study enrollment (baseline), end of intervention, and 6-week follow-up.

Biomechanical Data and Musculoskeletal Modeling

To determine pelvic and lower extremity motion, we obtained biomechanical data as each subject ran on an instrumented treadmill (Bertec Corporation, Columbus, Ohio) at her preferred speed. Fifty-five reflective markers were placed on each subject, with 23 located on anatomical landmarks (see Supplemental Digital Figure 1, available at: http://links.lww.com/JWHPT/A28). Participants first walked on the treadmill for 2 minutes to acclimate to the treadmill and motion capture setup. Participants then ran at their preferred speed for at least 30 seconds prior to initiation of data collection. Data were collected during 15 seconds of running. A static standing trial was performed to determine segment lengths, and subjects performed a standing hip circumduction trial to estimate functional hip joint center.[34,35] To determine pelvic motion, the body was modeled as a 14-segment, 31-degree-of-freedom-articulated linkage. Anthropometric properties of body segments were scaled to each individual using the subject's height, mass, and segment lengths.[36] For each trial, joint angles (including pelvic motion) were computed using a global optimization routine to minimize the weighted sum of squared differences between the measured and model marker positions.[37] Participants ran at the same speed during motion capture at all 3 study time points (baseline, end of intervention, and 6-week follow-up).

Three-dimensional whole-body kinematic data were collected at 200 Hz using an 8-camera passive marker system (Motion Analysis Corporation, Santa Rosa, California). All biomechanical data were collected with Cortex software (Motion Analysis Corporation) and analyzed offline using custom MATLAB code (MATLAB version 2018a; The Mathworks, Inc, Natick, Massachusetts).

Primary running gait variables of interest included pelvic drop excursion (frontal plane), pelvic rotation excursion (transverse plane), and peak hip adduction during stance.

Statistical Analysis

Changes in body mass, IRD, activation ratio with ADIM, and biomechanical variables were assessed with repeated-measures analysis of variance (ANOVA) with α level of .05. When significance was reached, post hoc analysis was completed with a paired-samples *t* test to assess change from baseline to end of intervention and from end of intervention to 6-week follow-up. Measures of effect size are reported as the partial eta squared (η_p^2) for ANOVAs and 95% confidence interval (95% CI) for *t* tests. The following cut points were used to determine the magnitude of η_p^2 effect sizes: 0.01 = small effect; 0.09 = moderate effect; and 0.25 = large effect.[38] Changes in weekly running mileage and average running speed over time (prepregnancy, baseline, end of intervention, 6-week follow-up) were assessed with the Wilcoxon signed ranks test. Reliability for ultrasound measurement of muscle thickness was assessed with 2-way random-effects model intraclass correlation coefficients [ICC (2,3)]. Statistical analysis was performed with IBM SPSS Statistics version 25.

RESULTS

Thirteen postpartum women (32.8 ± 2.7 years of age; vaginal delivery: n = 9; assisted vaginal delivery: n = 1; cesarean delivery: n = 3) completed the intervention and were included in data analysis. Participants had an average of 1.5 ± 0.5 live births (1.6 ± 0.7 pregnancies; range, 1-3 pregnancies) and were an average of 7.9 ± 7.8 months (range, 7 weeks-2 years) postpartum at the time of study enrollment. Mean running speed during gait testing was 2.8 ± 0.2 m/s (range, 2.65-3.08 m/s). Subject characteristics—body mass, IRD, breastfeeding status, and running habits—are provided in Tables 2 and 3. There was a main effect of time for change in body mass

Table 2. Subject Characteristics

	Baseline	End of Intervention	6-wk Follow-up
Body mass, kg	61.4 ± 8.1	60.9 ± 8.5	59.7 ± 8.0[a]
IRD above umbilicus, cm	2.3 ± 0.7	2.3 ± 0.8	2.3 ± 0.7
IRD below umbilicus, cm	1.8 ± 0.9	1.2 ± 0.6[b]	1.1 ± 0.6[b]
Breastfeeding status (% of participants breastfeeding)	77%	69%	54%

Abbreviation: IRD, inter-recti distance.
[a]Different from end of intervention ($P < .05$).
[b]Different from baseline ($P < .05$).

($P = .008$, $\eta_p^2 = 0.585$), but it did not change over the course of the 8-week intervention (baseline: 61.4 ± 8.1 kg; end of intervention: 60.9 ± 8.5 kg; $P = .386$; 95% CI, −0.7 to 1.7). Body mass did decrease during 6 weeks postintervention (end of intervention: 60.9 ± 8.5 kg; 6-week follow-up: 59.7 ± 8.0 kg; $P = .001$; 95% CI, 0.6 to 1.9).

Inter-Recti Distance

At baseline, 3 women had an IRD greater than 2.8 cm above the umbilicus and 5 women had an IRD greater than 2.1 cm below the umbilicus. At the end of intervention, 1 woman had an IRD greater than 2.8 cm above the umbilicus and greater than 2.1 cm below the umbilicus.

There was no change in group mean IRD measured above the umbilicus (baseline: 2.3 ± 0.7 cm; end of intervention: 2.3 ± 0.8 cm; $P = .711$, $\eta_p^2 = 0.060$) across time, but group mean IRD below the umbilicus did decrease over time ($P = .006$, $\eta_p^2 = 0.602$) (Figure; see Supplemental Digital Figure 2, available at: http://links.lww.com/JWHPT/A27). Post hoc testing showed that IRD decreased from baseline (1.8 ± 0.9 cm) to end of intervention (1.2 ± 0.6 cm; $P = .013$; 95% CI, 1.4 to 9.3). Inter-recti distance did not change between the end of intervention (1.2 ± 0.6 cm) and the 6-week follow-up (1.1 ± 0.6 cm; $P = .459$; 95% CI −2.0 to 4.2).

Reliability of Abdominal Muscle Thickness Ultrasound Measurements

Intrarater reliability was 0.894 (95% CI, 0.716 to 0.975) for within session (images taken on the same day) and 0.900 (95% CI, 0.732 to 0.977) for between sessions (images taken on separate days).

Assessment of Deep Abdominal Muscle Contraction

Activation ratio for the group did not change over time for the TrA (left side: $P = .091$, $\eta_p^2 = 0.353$; right side: $P = .355$, $\eta_p^2 = 0.173$) or the IO (left side: $P = .556$, $\eta_p^2 = 0.101$; right side: $P = .160$, $\eta_p^2 = 0.283$) (Table 4).

Running Habits

Weekly mileage decreased from prior to most recent pregnancy to study baseline ($P = .033$). No change in weekly mileage was noted from baseline to end of

Table 3. Running Habits

	% Total Participants			
	Prepregnancy	Baseline	End of Intervention	6-wk Follow-up
Average miles/wk				
<10	38.5	76.9[a]	38.5[a]	61.5[a]
10-20	38.5	23.1[a]	61.5[a]	38.5[a]
20-30	23.1	0[a]	0[a]	0[a]
Average speed, min/mile				
6-7	7.7	0[a]	0[a,b]	0[a,b]
7-8	30.8	0[a]	7.7[a,b]	7.7[a,b]
8-9	30.8	15.4[a]	38.5[a,b]	46.2[a,b]
9-10	30.8	53.8[a]	53.8[a,b]	46.2[a,b]
10-11	0	30.8[a]	0[a,b]	0[a,b]

[a]Different from prepregnancy.
[b]Different from baseline.

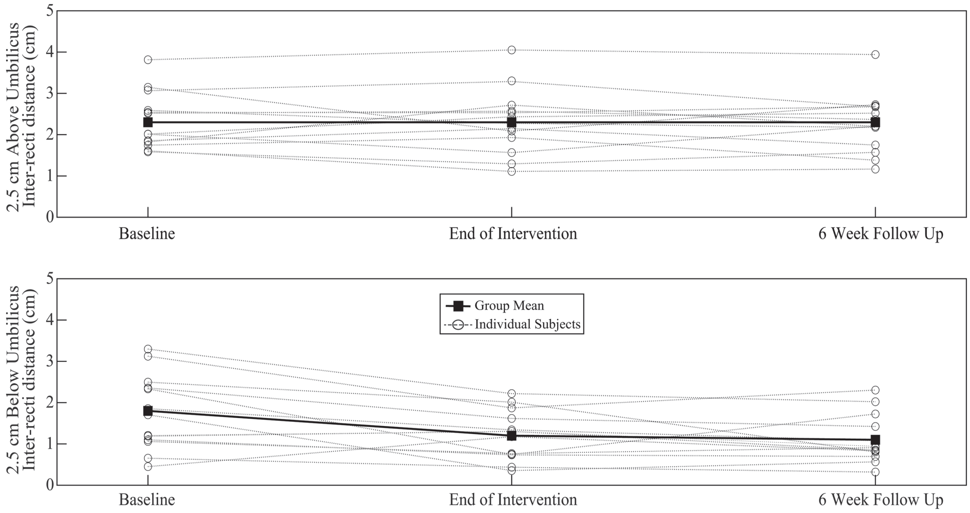

Figure. Change in inter-recti distance. Inter-recti distance was measured above (A) and below (B) the umbilicus at each time point (baseline, end of intervention, and 6-week follow-up). No change in inter-recti distance was noted across time above the umbilicus; however, it did decrease significantly below the umbilicus from baseline to end of intervention and remained stable at 6-week follow-up.

intervention ($P = .059$) or from end of intervention to 6-week follow-up ($P = .180$).

Average running speed slowed from prepregnancy to study baseline ($P = .005$) and then increased from study baseline to end of intervention ($P = .021$). Average running speed remained stable from end of intervention to 6-week follow-up ($P = .564$).

Running Mechanics

No change was observed across time in step rate ($P = .462$, $\eta_p^2 = 0.131$), stride length ($P = .572$, $\eta_p^2 = 0.097$), or percentage of the gait cycle spent in stance phase (left: $P = .109$, $\eta_p^2 = 0.332$; right: $P = .114$, $\eta_p^2 = 0.326$) (Table 5).

Pelvic Drop Excursion

Values for pelvic drop excursion at each time point are provided in Table 5. No change was observed across time ($P = .981$, $\eta_p^2 = 0.003$) in pelvic drop excursion.

Transverse Plane Pelvic Rotation Excursion

Group means for pelvic rotation excursion are provided in Table 5. Group mean for transverse plane pelvic rotation excursion did not change over time (left stance: $P = .131$, $\eta_p^2 = 0.309$; right stance: $P = .084$, $\eta_p^2 = 0.363$).

Peak Hip Adduction During Stance

Mean peak hip adduction at baseline was 12.4° ± 4.8° in left stance and 10.4° ± 4.1° in right stance (Table 5). No change in peak hip adduction in stance phase was detected over time (left stance: $P = .184$, $\eta_p^2 = 0.265$; right stance: $P = .193$, $\eta_p^2 = 0.259$).

DISCUSSION

The primary findings of this study are as follows: (1) 8 weeks of abdominal muscle retraining did decrease IRD below the umbilicus in women who were up to 2 years postpartum, and this improvement in IRD was maintained 6 weeks after concluding the intervention; (2) we did not detect a change in pelvic or hip kinematics following abdominal muscle retraining in this group of pain-free recreational runners. Postpartum women in this sample also reported an increase in average running speed after the 8-week intervention.

Reduction in IRD in recreational runners up to 2 years postpartum is a novel finding. At baseline, 23% of the women in our sample had an IRD above the umbilicus that met diagnostic criteria for DRA whereas 38% of the women in our sample met DRA diagnostic criteria below the umbilicus.[31] Following the physical therapist–led intervention, only one

Table 4. Activation Ratio

	Baseline		End of Intervention		6 wk Follow-up	
	Left	Right	Left	Right	Left	Right
TrA activation ratio	1.8 ± 0.5	1.8 ± 0.05	1.5 ± 0.2	1.6 ± 0.2	1.5 ± 0.3	1.6 ± 0.3
IO activation ratio	1.3 ± 0.3	1.3 ± 0.3	1.1 ± 0.2	1.2 ± 0.2	1.2 ± 0.1	1.1 ± 0.2

Abbreviations: TrA, transversus abdominis; IO, internal oblique.

Table 5. Running Mechanics

	Baseline		End of Intervention		6-wk Follow-up	
Step rate, steps/min	172.5 ± 8.5		173.6 ± 8.5		173.0 ± 9.3	
Pelvic drop excursion, degrees	15.0 ± 3.6		14.9 ± 5.1		14.9 ± 4.2	
Transverse plane pelvic rotation excursion, degrees	16.0 ± 4.9		15.1 ± 4.9		15.5 ± 4.1	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Stride length (left), m	2.0 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	2.0 ± 0.1	2.0 ± 0.1
Time in stance phase, %	37.9 ± 2.9	37.9 ± 3.2	37.7 ± 3.1	37.8 ± 3.5	37.1 ± 3.2	37.3 ± 3.3
Peak hip adduction during stance, degrees	12.4 ± 4.8	10.4 ± 4.1	12.0 ± 4.3	9.2 ± 5.3	11.2 ± 4.8	11.2 ± 2.6
Abbreviations: min, minute; m, meters.						

woman had IRD above and below the umbilicus that met diagnostic criteria for DRA. This study supports the use of deep abdominal muscle retraining in minimizing IRD below the umbilicus in recreational runners, which may prove beneficial in postpartum recreational athletes with DRA and/or lumbopelvic pain.

While we did not detect a change in the group mean IRD above the umbilicus, the number of women meeting diagnostic criteria for DRA above the umbilicus did decrease. The lack of change in IRD above the umbilicus may be because the exercises chosen for this intervention target the lower abdominal muscles. Some evidence exists to support use of deep abdominal muscle retraining for decreasing IRD above the umbilicus; however, the study designs and target populations of these studies vary from those of the current study.[25,26] For example, the majority of the studies demonstrating improvement in IRD above the umbilicus were conducted within the first year postpartum,[25,26] while our study included women up to 2 years postpartum. In addition, none of the existing literature has examined change in IRD in response to abdominal muscle retraining in a recreationally athletic population, such as this sample. Thus, additional research on recreational and elite athletes is needed to determine the impact of deep abdominal muscle retraining on IRD above the umbilicus in these populations.

Inter-recti distance above and below the umbilicus has been associated with fatigability of the trunk flexor muscles and lumbopelvic stabilizing muscles, but IRD below the umbilicus has a stronger association with fatigability than that above the umbilicus.[14,15] Thus, improvement in IRD below the umbilicus without change in IRD above the umbilicus may still be meaningful for improvement in neuromuscular function. Given that postpartum women have also been shown to have trunk flexor muscles that are weaker than those in nulligravid women,[15] abdominal muscle exercise may also help improve strength and reduce fatigability; however, strength and fatigability were not assessed in this study. Furthermore, much of the current evidence on the impact of exercise on IRD has used less precise measurements of IRD, such as finger widths, dial calipers, or tape measurers.[24–26,39] This study provides a more reliable measurement of IRD by utilizing ultrasound imaging.[15] Future studies are needed to examine other properties of the linea alba, such as stiffness and distortion,[40] as well as abdominal muscle strength and fatigability to determine whether these metrics also change with the reduction in IRD following physical therapy intervention.

Activation ratio of the TrA and IO from rest to ADIM was not statistically different across time. However, fewer participants demonstrated a percent change in IO muscle thickness that met or exceeded the minimal detectable change (MDC)[41] at the end of intervention as compared with baseline (baseline: left and right IO—8 participants met MDC for change in muscle thickness; end of intervention: left—3 participants met MDC for change in muscle thickness, right—5 participants met MDC for change in muscle thickness). This was not well maintained at the 6-week follow-up, with 8 participants demonstrating change in muscle thickness of the IO on the left at or above MDC and 6 participants meeting or exceeding MDC for change in IO muscle thickness on the right. Despite demonstrating no significant change in muscle thickness measurements, this exercise intervention still successfully reduced IRD below the umbilicus. The change in IRD may have been a result of changes in the rectus abdominis muscles, which were not assessed in this study. It is also possible that the abdominal muscle retraining program elicited changes in neural activation (ie, timing of muscle firing) that may have contributed to the reduction in IRD but which are not represented by measurement of changes in muscle thickness with contraction.[42] Thus, the abdominal muscle retraining program utilized in this study may have been effective in altering abdominal muscle recruitment despite demonstrating no difference in activation ratio.

In this study sample of pain-free postpartum runners, the majority of participants demonstrated greater than normal pelvic and hip kinematics at baseline. Normal kinematics were defined by calculating a 95% CI using normative data for women during treadmill running at 2.7 m/s.[43] Values exceeding the upper boundary of the 95% CIs (10.7° for pelvic drop excursion and 11.5° for peak hip adduction in stance) were considered greater than normal. At baseline, 12 participants (92%) demonstrated pelvic drop excursion that was greater than 10.7° whereas 10 participants (77%) demonstrated pelvic drop excursion greater than 10.7° at the end of the intervention. At baseline, 4 participants (31%) had peak hip adduction in stance greater than 11.5° bilaterally and 3 participants (23%) demonstrated peak hip adduction greater than 11.5° unilaterally. At the end of the 8-week intervention, peak hip adduction in stance was greater than normal in 5 participants (38%) bilaterally and in 2 participants (15%) unilaterally. There are no current prospective cutoffs based on running kinematics to assess risk of lumbopelvic or hip injury; thus, it is unknown whether the higher values for pelvic drop excursion and peak hip adduction in this sample predispose these women to low back, pelvic girdle, or hip injuries in the future. However, risk of patellofemoral joint injury, which is common in the general running population,[6] is increased in women when peak hip adduction in stance is in excess of 11°.[44] Group means for peak hip adduction in stance ranged from 9.2° ± 5.3° to 12.4° ± 4.8°, with 5 of 13 participants demonstrating peak hip adduction greater than 11° at baseline and end of intervention. As such, 38% of this study sample may be at risk for future patellofemoral injury despite being pain free during participation in this study.

The abdominal retraining program failed to significantly influence gait mechanics in this study sample. The lack of change in running kinematics following a brief muscle retraining program is not uncommon[45,46]; however, our laboratory has demonstrated improvements in running mechanics in a postpartum runner with low back pain, utilizing a similar rehabilitation protocol as this study.[27] The case study also utilized manual therapy, stretching, and targeted gait retraining in addition to the abdominal muscle retraining program, suggesting that TrA retraining alone may not be sufficient to impact pelvic and hip mechanics during running. Further research is needed to determine whether the rehabilitation approach utilized in the current study would influence pelvic mechanics during running in postpartum women who experience pain while running, as all of the participants in this study were pain free when running.

This study had a relatively small sample size; thus, it may have lacked the power to identify changes in pelvic and hip kinematics with motion capture. Despite the small sample size, this is still an important study, as we detected greater than normal pelvic drop excursion and peak hip adduction in stance in pain-free postpartum runners and did show a decrease in IRD/DRA following the intervention. Current evidence regarding the impact of therapeutic exercise interventions on IRD in the postpartum period is primarily from case studies[24,39] or conducted within the first year postpartum[25,26]; we were able to show a reduction in IRD below the umbilicus in a group of 13 recreationally active women up to 2 years postpartum. However, further research in a larger group of recreationally active women is warranted to substantiate these findings.

Another limitation of this study is the heterogeneity of our participants, including variations in time since most recent delivery, parity, and mode of delivery (vaginal vs cesarean). Inter-recti distance has been shown to spontaneously decrease over time up to 1 year postpartum[2,17,28] and to be associated with cesarean delivery and multiparity.[47] However, in our study, 10 of the 13 participants demonstrated a reduction in IRD below the umbilicus at the end of the intervention period. The 3 women who did not show a decrease in IRD—instead demonstrated an *increase* in IRD at the end of intervention—were in the early postpartum period (7 weeks, 8 weeks, and 12 weeks postpartum at study enrollment). This suggests that the improvement in IRD of the remaining 10 participants was not spontaneous in nature, as 40% of the women with reduced IRD were more than 12 months postpartum at study enrollment. All of the women in our study who demonstrated an increase in IRD had a vaginal or assisted vaginal delivery, with no history of cesarean delivery. Thus, our sample did not demonstrate that cesarean delivery influenced the effectiveness of the exercise intervention on reducing IRD. In addition, 40% of the women in our study with decreased IRD were multiparous while 2 of the 3 women with increased IRD at the end of intervention were multiparous. Further research with a larger sample size of primiparous and multiparous women is needed to determine whether parity influences the success of abdominal muscle retraining for decreasing IRD; however, these preliminary data suggest that the exercise intervention was effective in both primiparous and multiparous women.

Also worth considering is the influence of time since childbirth before resuming high-impact exercise, such as running, on IRD. As stated, the 3 women in this sample who demonstrated an increase in IRD were all within the "fourth trimester"—or the first 12 weeks postpartum—and had already resumed running at least 6 miles per week at the time of study enrollment. All 3 women reported an increase in weekly mileage and average running speed from baseline to end of intervention. The woman with the greatest increase in IRD below the umbilicus reported being back to her prepregnancy weekly mileage by the end of the intervention, at which point she was 15 weeks postpartum. While there are currently no evidence-based guidelines on safe return to or progression of exercise following childbirth, the increase in IRD observed in this individual may be a result of returning to and progressing exercise too quickly. Despite lack of pain with running, these women may be at risk for impaired abdominal muscle strength and fatigability,[14,15,48] which may increase risk of lumbopelvic injury. Further research is needed to determine timing and dosage of exercise, and injury risk based on IRD, particularly in recreational athletes.

CONCLUSIONS

An 8-week abdominal muscle retraining program utilizing real-time ultrasound imaging as biofeedback was successful in reducing IRD below the umbilicus in pain-free recreational runners up to 2 years postpartum. While we did not detect a change in running mechanics, women did report being able to increase their average running speed following the intervention. Given that little evidence exists on effective methods of decreasing IRD, particularly in athletes, this study is promising for development of treatment protocols to treat DRA, which is a common occurrence in pregnant and postpartum women. Further research is needed in a larger sample size and in randomized control trials to determine the impact of pain, parity, and mode of delivery on effectiveness of this exercise intervention on reduction in IRD.

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