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Reliability of transversus abdominis thickness and inter-recti distance during forced expiration with limb adduction in primiparous women following vaginal delivery

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Abstract

Introduction The postpartum period involves significant biomechanical changes that impact maternal health, particularly in the activation of the transversus abdominis (TrA) and the inter-recti distance (IRD), which may contribute to lumbo-pelvic pathologies. While lumbopelvic exercises are beneficial, it remains unclear whether upper or lower limb adduction combined with forced expiration is more effective in activating the TrA. Therefore, the primary objective of this study is to analyze changes in TrA thickness and IRD during four conditions. The secondary objective is to evaluate the intra-observer reliability of these ultrasound measurements.

Methods This cross-sectional study, conducted with a sample of 32 participants, assessed TrA thickness (primary outcome) and IRD (secondary outcome), quantified under four conditions: (1) resting position, (2) forced expiration, (3) forced expiration with upper limb adduction, and (4) forced expiration with lower limb adduction. Differences between the four conditions were analyzed using repeated measures ANOVA. The intra-observer reliability of these measurements was evaluated using intraclass correlation coefficients (ICC).

Results A total of 32 primiparous women between January and April 2024 were included in this study with a mean postpartum period of 9 ± 2.33. Significant variations in TrA thickness were observed across conditions ($p < 0.001$). Differences were noted between resting and forced expiration (MD = -0.17, $p < 0.001$) and forced expiration with lower limb adduction (MD = -0.20, $p < 0.001$) on both sides. For the right TrA, forced expiration differed from upper limb adduction (MD = -0.04, $p = 0.007$), while no difference was found between upper and lower limb adduction (MD = -0.005, $p > 0.05$). For IRD, no significant differences were detected across conditions, including resting and lower limb adduction (MD = -0.018, $p = 0.727$). Excellent intra-examiner reliability was demonstrated for all ultrasound measurements (ICC (1,3) 0.92–0.99).

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Conclusions There were no significant differences in TrA thickness between forced expiration isolated and when combined with adduction exercises. The high ICC values confirm the robustness of ultrasound measurements for TrA and IRD, highlighting the potential for future research in postpartum rehabilitation strategies.

Keywords Rectus abdominis, Postpartum exercise, Transversus abdominis, Ultrasound, Forced expiration, Abdominal rehabilitation

Introduction

During pregnancy, women experience significant physical, hormonal, and biomechanical changes that can notably affect maternal health. The abdominal wall undergoes substantial stretching, and the inter-recti distance (IRD) increases [1], contributing to a reduction in trunk flexor strength and increased tendency for abdominal muscle fatigue [2]. This fatigue is characterized by a diminished ability of the abdominal muscles to sustain or repeat contractions effectively, likely due to impaired force transmission across the abdominal wall caused by the separation of the rectus abdominis muscles [3].

This alteration, along with hormonal changes during pregnancy, such as increased levels of relaxin and progesterone, which affect the elasticity and stability of pelvic connective tissues, predisposes women to potential postural imbalances and disorders in the lumbar spine (such as lower back pain), pain in the sacroiliac joint or in the pubic symphysis [4, 5] and pelvis instability [6]. These conditions are commonly observed in postpartum women, although these associations are still a subject of debate in the literature [7, 8].

Pregnancy and vaginal delivery are natural physiological processes that, although not pathological, may lead to certain changes, including pelvic floor dysfunctions (PFD), including urinary incontinence, pelvic organ prolapse, chronic pelvic pain, or sexual dysfunction [9–11]. However, pre-existing conditions, such as herniated nucleus pulposus or sciatica, may favor the development or exacerbation of these complications during or after pregnancy. These conditions can often diminish a woman's quality of life [12]. While the direct relationship between increased IRD and PFD in the early postpartum period remains unclear [13], IRD has been discussed as a potential factor for various postpartum complications, including dissatisfaction with physical appearance and even postpartum depression [14–16]. The abdominal muscles also undergo morphological and functional changes during and after pregnancy, particularly in the first six months postpartum [17]. The transversus abdominis (TrA) plays a critical role in maintaining trunk stability, contributing to lumbopelvic alignment, and modulating intra-abdominal pressure [18, 19]. Several studies have shown that engaging in global trunk stability exercises positively influences postpartum health by reducing pain and enhancing quality of life [20, 21]. Practices such as Pilates and hypopressive exercises are beneficial for activating deep abdominal muscles [22, 23], though more targeted strength and stability exercises have proven to be even more effective in restoring abdominal and pelvic floor function, especially when performed during pregnancy and the first year postpartum [24–27].

Hodges et al. demonstrated that the TrA, contract synergistically to maintain trunk posture during upper and lower limb movements [28–30]. These findings suggest that coordination between the trunk and limbs is critical for stabilizing the body during dynamic actions. However, there is a lack of detailed analysis on TrA activation and IRD during specific exercises, particularly those involving upper and lower limb adduction [31]. Understanding the role of adduction exercises is important as they may provide targeted activation of the TrA through synergistic muscle activation, potentially improving core stability and postural control.

In addition, forced expiration is a respiratory maneuver where the individual exhales with maximal effort, creating increased intra-abdominal pressure. This process engages the deep abdominal muscles, including the TrA, as part of the body's natural stabilization mechanism [32]. The activation of the TrA during forced expiration is crucial for trunk stability, as the muscle plays a key role in increasing intra-abdominal pressure and supporting the lumbar spine [33, 34]. Research has shown that forced expiration enhances the recruitment of the TrA by increasing the demand for abdominal wall activation, which contributes to core stability and better postural control [35].

Although muscle activation during forced expiration and adduction exercises is well-documented, their combined effects on IRD in the postpartum population remain insufficiently explored. Thus, further investigation is needed to determine whether this exercise combination, along with forced expiration, can effectively reduce IRD in postpartum women, given the lack of clarity surrounding the optimal treatment regimen for IRD [36, 37].

This study hypothesizes that forced expiration combined with isometric adduction of the upper and lower limbs will significantly increase TrA thickness compared to the resting position. Additionally, ultrasound measurements of TrA thickness and IRD are expected to demonstrate high intra-observer reliability, with intraclass correlation coefficients (ICC) exceeding 0.75. Therefore, the primary objective is to analyze TrA thickness in primiparous women using ultrasound imaging during forced expiration combined with isometric adduction of the upper and lower limbs and the secondary objective is to evaluate the intra-observer reliability of these measurements.

Methods

Study design

This observational, cross-sectional, analytical study was conducted in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines. The study protocol was reviewed and approved by the research committee of the European University of Madrid (internal code: 2024 – 443) and adhered to the ethical principles of the Declaration of Helsinki. All participants were thoroughly informed about the study's objectives, procedures, potential benefits, and risks via a Participant Information Sheet. Participation in the study was voluntary, and each participant provided signed informed consent prior to inclusion.

Participants

Recruitment was conducted both face-to-face in various health centers across Valladolid and non-face-to-face through the distribution of posters and leaflets with QR codes in health centers, breastfeeding groups, and nurseries between January and April 2024. The inclusion criteria specified women aged between 25 and 45 years, due to the mean of maternal age [38], who were between six weeks and one year postpartum, had experienced a vaginal birth, and were primiparous. Participants were excluded if they did not have engaged in at least one hour of physical activity per week (as assessed using the Global Physical Activity Questionnaire (GPAQ)), had significant medical conditions, such as cardiovascular or neurological diseases, or a history of abdominal surgeries, including cesarean sections. Women were also excluded if they were pregnant, multiparous, overweight (body mass index (BMI) of 25 or higher), or had an allergy to ultrasound gel. Additionally, individuals with musculoskeletal conditions, such as chronic low back or pelvic pain (e.g., sciatica, spinal pain, subluxation or sacroiliac joint pain) that could interfere with physical activity, or those who had not yet resumed sexual activity postpartum and with a Female Sexual Function Index (FSFI) score below 26.55, indicating potential sexual dysfunction, will be excluded from the study [39], were excluded to ensure that participants had achieved a sufficient level of pelvic health recovery.

Descriptive variables

Women who met the inclusion criteria attended the FISAP Physiotherapy Clinic in Valladolid, where the assessments were conducted. On the first day, demographic and anthropometric data were collected from the participants, including age, height, weight, and BMI. Additionally, participants were asked about the presence of any previous episodes of chronic pelvic pain, depression, low back pain, and their sexual activity during the postpartum period.

The SF-12 Quality of Life Questionnaire is a widely used tool to measure physical and mental health. It includes 12 items that evaluate eight domains of health: physical functioning, role limitations due to physical health problems, bodily pain, general health perceptions, vitality, social functioning, role limitations due to emotional problems, and mental health. These items contribute to two summary scores: the Physical Component Summary (PCS) and the Mental Component Summary (MCS). Each item is scored on a scale from 0 (worst possible health) to 100 (best possible health), with a higher score indicating better health status. The scores are then transformed into norm-based scores, where 50 represents the average population's health. Scores below 50 suggest worse-than-average health, while scores above 50 indicate better-than-average health [40].

The GPAQ, developed by the World Health Organization (WHO), assesses physical activity in three domains: work-related physical activity, travel to and from places, and recreational activities. The questionnaire consists of 16 items, collecting data on the frequency (days per week) and duration (minutes per day) of physical activity at different intensity levels (vigorous, moderate, and light). The GPAQ also evaluates sedentary behavior by asking about the time spent sitting. Physical activity levels are classified into three categories: low, moderate, and high. A low activity level is classified as not meeting the minimum recommended physical activity guidelines of 150 min of moderate-intensity activity or 75 min of vigorous-intensity activity per week. A moderate activity level includes participants who meet or slightly exceed these guidelines, while a high activity level represents a significantly higher level of physical activity [41].

Ultrasound measurements

Ultrasound measurements of the TrA and rectus abdominis diastasis IRD were taken using a LOGIQ P9 (GE Healthcare, United States) ultrasound machine equipped with a linear L3-12-RS transducer. The ultrasound presets, including a frequency of 10 MHz, gain of 66, and depth of 4.0 cm, were individually adjusted for each participant to optimize image quality. Conductive gel (Kefus Ultrasound Gel, Kefus, Spain) was applied for effective transmission, and adaptive lighting was used to further enhance image clarity. All measurements were performed by a physiotherapist with 10 years of experience in musculoskeletal ultrasound, ensuring accuracy and consistency in data collection. The reliability testing measurements were conducted with a fixed interval of 10 min between each assessment.

TrA Measurement: The transducer was positioned along the lateral abdominal wall on the midaxillary line using the reference point located between inferior border of subcostal line and iliac crest. This placement ensures optimal visualization of the TrA muscle, minimizing variability between participants. Special care was taken to apply minimal pressure with the transducer to avoid tissue compression, and sufficient ultrasound gel was used to enhance acoustic coupling. The TrA thickness was measured from the inner border of the deep fascia to the outer border of the muscle's aponeurosis, ensuring a clear delineation of muscle boundaries for accurate and repeatable measurements. The transducer was positioned transversely, perpendicular to the abdominal muscles, to ensure alignment with the muscle fibers (Fig. 1) [42].

IRD Measurement: The transducer was carefully placed 2 cm above the umbilicus, following a standardized protocol for assessing the IRD. The transducer was oriented transversally to capture the separation between the rectus abdominis muscles. To improve measurement precision, particular attention was given to maintaining perpendicularity to the skin surface to avoid off-axis distortions. The distance between the medial borders of the rectus abdominis muscles was recorded, providing a consistent and reliable assessment of IRD (Fig. 1) [43, 44].

Ultrasound measurements of the TrA and IRD were performed under four different conditions:

1. **Resting position**: Participants were placed in a supine position with legs semi-flexed, supported on a 15 cm roller, and arms extended along the body. This stable position allowed for baseline assessment of TrA and IRD. The verbal instruction was to "relax and breathe normally."
2. **Forced expiration**: In the same resting position described above, participants were instructed to "breathe out maximally and hold your breath" during a controlled, forced exhalation (5 s of duration) to assess changes in TrA and IRD during respiratory effort.
3. **Upper limb adduction with forced expiration**: Participants remained supine, with knees flexed over a 15 cm roller and arms flexed at 90°. A 24 cm diameter ball (200 g of weight) was held between their palms. For the upper limb adduction condition, participants performed an isometric contraction by pressing the ball between their palms, moving their hands inward toward the midline. Participants were instructed to "squeeze the ball between your hands while breathing out maximally," ensuring that the contraction was sustained throughout the duration of the forced exhalation (5 s of duration). The intensity of the contraction was monitored and standardized using the Borg Rate of Perceived Exertion (RPE) scale, with participants aiming for an effort level of 7 to 8 on the scale, indicating a "very hard" perceived exertion. This task aimed to assess how upper limb adduction combined with forced expiration affected TrA andFig. (Fig. 2).
4. **Lower limb adduction with forced expiration**: In this condition, participants lay supine with hips and knees flexed at 45°, feet flat on the table. For the lower limb adduction, participants squeezed a 24 cm diameter ball placed between their knees in an isometric manner, engaging their adductor muscles. They were instructed to "squeeze the ball between your knees during maximal exhalation," maintaining the contraction for the entire duration

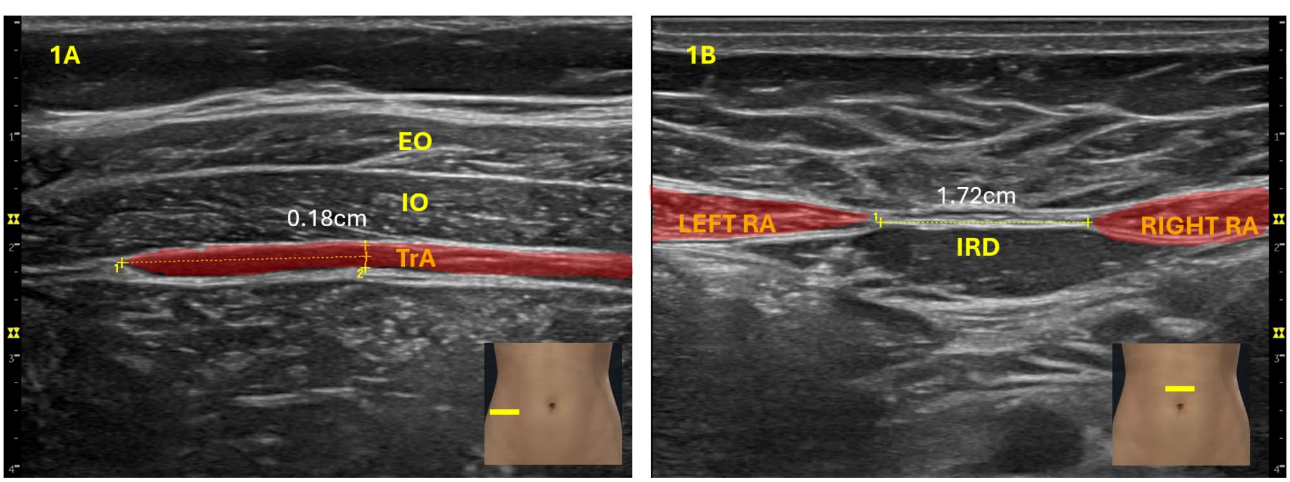

Fig. 1 Probe localization and ultrasound measurement of transversus abdominis (TrA) and inter-recti distance (IRD) (1B). Abbreviations: EO, external oblique; IO, internal oblique; RA, rectus abdominis

Fig. 2 Position for ultrasound evaluation. **A**) During the upper limb adduction exercise with forced expiration. **B**) During the lower limb adduction exercise with forced expiration

of the forced expiration (5 s of duration). Similar to the upper limb task, the intensity of the contraction was controlled using the Borg RPE scale, with participants maintaining a target effort of 7 to 8. This standardized approach ensured consistency in the level of exertion across participants and conditions, facilitating a reliable assessment of TrA andFig. (Fig. 2).

These exercises were carefully selected to explore the functional activation of the TrA and IRD under varying conditions that mimic real-world postural and respiratory demands. The resting position provides a baseline for comparison, while forced expiration isolates the effects of respiratory effort on core muscle activation [45]. The upper and lower limb adduction tasks, combined with forced expiration, were designed to engage additional musculature, testing the interplay between limb movements, respiratory mechanics, and core stability. These tasks simulate functional scenarios, offering insights into the coordination and adaptability of the TrA and IRD in dynamic and isometric conditions.

To evaluate intra-rater reliability, the same physiotherapist performed all measurements across sessions. Ultrasound images were captured during the adduction movement or resting position, and three measurements were taken on both sides (left and right) for the TrA and IRD. The measurements were taken at the end of exhalation, immediately after participants completed a maximal exhalation and before the next inhalation began, to ensure a stable level of muscle activation and minimize variability during the ultrasound image capture. Before the experiment, participants underwent a 10-minute practice session to familiarize themselves with each task. The tasks were performed in randomized order, and each condition was repeated three times to measure the thickness of the left and right TrA, as well as the IRD. A 30-second rest was provided between repetitions, and a 3-minute rest was given between each task to prevent muscle fatigue.

Sample size

The sample size calculation was based on the methodology outlined by Mondal et al. [46] and Walter et al. [47], tailored to our study's parameters. To ensure a reliable estimation of the intra-rater intraclass correlation coefficient (ICC (1)) for reliability testing, we assumed an expected ICC of 0.7 [46], a confidence level of 95%, and a desired power of 80%. The calculation also accounted for three repeated measurements per examiner and four different testing conditions, yielding a required sample size of 32 participants.

Data analysis

Data analysis was performed using SPSS statistical software (version 29 for Windows). Normality of the data was assessed using the Shapiro-Wilk test. Depending on whether the data followed a parametric or nonparametric distribution, results were expressed as mean and standard deviation (for parametric data) or median and interquartile range (for non-parametric data). Intra-examiner reliability for the ultrasound measurements was calculated using the ICC. The ICC values were interpreted as follows: poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90), providing a robust assessment of the consistency of the measurements across conditions. Measurement precision was assessed by calculating the standard error of measurement (SEM) using the formula: $SEM = SD \times \sqrt{(1 - ICC)}$, where SD represents the pooled standard deviation of the three repetitions. A lower SEM value reflects greater consistency and reliability of the measurements. Furthermore, the minimum detectable change (MDC) at a 95% confidence level (MDC95) was computed using the formula: $MDC95 = SEM \times \sqrt{2} \times 1.96$, providing an estimate of the smallest change that exceeds measurement error [48].

To evaluate the differences in TrA and IRD measurements at rest and during various contractions, a repeated measures analysis of variance (ANOVA) was employed, with the type of contraction or rest condition set as a

Table 1 Descriptive table of participant characteristics ($n = 32$)

Variable	Mean ± SD or *n* (%)
Age (years)	35.19 ± 2.93
BMI (kg/m²)	21.54 ± 2.01
Postpartum period (months)	9 ± 2.33
FSFI score	30.11 ± 2.18
SF-12 score	
PCS-12 score	60.12 ± 5.78
MCS-12 score	60.76 ± 8.33
GPAQ (physical activity)	
High	10 (31.25%)
Moderate	17 (53.13%)
Low	5 (15.62%)

Abbreviatures: BMI, body mass index; FSFI, Female Sexual Function Index; GPAQ, Global Physical Activity Questionnaire; MCS, Mental Component Summary; PCS, Physical Component Summary; SD, standard deviation; SF-12, short form Quality of Life Questionnaire

factor. The significance threshold was adjusted for multiple comparisons, with a p-value < 0.0125 applied for the TrA measures (4 measurements) and a p-value < 0.017 for the IRD measures (3 measurements). ANOVA effect sizes were determined using partial eta squared (ηp^2) to evaluate the proportion of variance explained by the different conditions on TrA thickness and IRD. ηp^2 values were categorized as small (0.01), medium (0.06), and large (0.14) according to established guidelines. Effect sizes were also determined using Cohen's d to quantify the magnitude of differences in TrA thickness (right and left) and IRD across conditions. Cohen's d values were categorized as small (0.2), medium (0.5), and large (0.8).

Results

A total of 56 postpartum women were initially recruited for the study. After applying the exclusion criteria, 24 participants were excluded: 16 were not primiparous, 7 had a history of cesarean section or abdominal surgery, and 1 was overweight. Therefore, a total of 32 participants were included in the analysis. The characteristics of the participants, including age, BMI, postpartum period, FSFI score, SF-12 physical and emotional health scores, levels of calmness and energy, discouragement, social activity limitations, overall quality of life, and physical activity levels, are comprehensively detailed in Table 1.

Ultrasound measurements

The measurements of TrA thickness and IRD were performed during different exercises (Table 2). No significant differences were observed between right and left side in TrA thickness ($p > 0.05$). Significant variations were observed in the right TrA across conditions ($p < 0.001$). Specifically, significant differences were found between the resting position and forced expiration (MD = -0.17; $p < 0.001$, d = 2.09), forced expiration with upper limb adduction (MD = -0.21; $p < 0.001$, d = 2.47), and forced expiration with lower limb adduction (MD = -0.20; $p < 0.001$, d = 2.41). Significant differences were detected between isolated forced expiration and upper limb adduction (MD = -0.04; $p = 0.007$, d = 0.46), nor between forced expiration and lower limb adduction (MD = -0.04; $p = 0.033$, d = 0.41). Additionally, no significant difference was observed between upper and lower limb adduction during forced exhalation (MD = -0.005; p = > 0.05, d = 0.06).

For the left TrA, similar significant differences were found across the conditions ($p < 0.001$). Differences were noted between resting and forced expiration (MD = -0.15; $p < 0.001$, d = 1.78), forced expiration with upper limb adduction (MD = -0.20; $p < 0.001$, d = 2.37), and forced expiration with lower limb adduction (MD = -0.21; $p < 0.001$, d = 2.48). There was also a significant difference between forced expiration and lower limb adduction (MD = -0.06; $p < 0.001$, d = 0.72). However, no significant mean difference was observed between forced expiration and upper limb adduction (MD = -0.05; $p = 0.11$, d = 0.60), or between upper and lower limb adduction (MD = -0.01; $p > 0.05$, d = 0.11) (Table 2).

Regarding IRD, no significant differences were observed between the conditions ($p = 0.624$). No significant difference was detected between resting and forced expiration with upper limb adduction (MD = 0.037; $p = 0.727$, d = 0.06), nor between resting and forced expiration with lower limb adduction (MD = -0.018; $p > 0.05$, d = 0.03). Similarly, there was no significant difference between upper and lower limb adduction during forced exhalation (MD = -0.055; $p = 0.155$, d = 0.09) (Table 2).

Excellent intra-examiner reliability was demonstrated for the ultrasound measurements of the right TrA during forced expiration, with an ICC (1,3) of 0.95. Similarly, left TrA measurements during forced expiration showed high reliability (ICC (1,3) = 0.96). For the right TrA during

Table 2 Comparison of right and left TrA thickness measurements and inter-recti distance in the different exercises

	Rest	FE	FE + ADD UL	FE + ADD LL	F	*P*-value (partial eta squared)
TrR (cm)	0.24 ± 0.54	0.41 ± 0.91	0.45 ± 0.86	0.44 ± 0.94	182.34	$P < 0.001$ (0.86)
TrL (cm)	0.26 ± 0.05	0.40 ± 0.10	0.45 ± 0.92	0.46 ± 0.87	218.14	$P < 0.001$ (0.88)
IRD (cm)	1.83 ± 0.60		1.79 ± 0.56	1.85 ± 0.56	0.24	$P = 0.624$ (0.01)

Abbreviatures: ADD, Adduction; cm, centimeters; FE, Forced Expiration; IRD, inter-recti distance; LL, Lower Limbs; TrR, Right Transversus Abdominis; TrL, Left Transversus Abdominis; UL, Upper Limbs

Table 3 Intra-rater reliability. Comparision of the mean and standard deviation of the thickness of the right and left TrA of the different exercises measured 3 times

		Mean & SD 1	Mean & SD2	Mean & SD3	Intra-observer ICC (95%CI)	SEM	MDC95
FE	TrR (cm)	0.41 ± 0.10	0.41 ± 0.10	0.42 ± 0.90	0.95 (0.90–0.97)	0.02	0.06
	TrL (cm)	0.39 ± 0.11	0.40 ± 0.09	0.41 ± 0.10	0.96 (0.93–0.98)	0.02	0.06
UL ADD + FE	TrR (cm)	0.45 ± 0.08	0.45 ± 0.98	0.45 ± 0.95	0.94 (0.90–0.97)	0.02	0.06
	TrL (cm)	0.46 ± 0.10	0.45 ± 0.10	0.43 ± 0.10	0.92 (0.85–0.95)	0.03	0.08
LL ADD + FE	TrR (ADD + LL) (cm)	0.45 ± 0.10	0.45 ± 0.10	0.44 ± 0.10	0.96 (0.93–0.98)	0.02	0.06
	TrL (cm)	0.46 ± 0.10	0.45 ± 0.09	0.46 ± 0.09	0.95 (0.91–0.97)	0.02	0.06

Abbreviatures: ADD, Adduction; CI, confindece interval; cm, centimeters; FE, Forced Expiration; ICC, intraclass correlation coefficient; MDC, minimum detectable change; LL, Lower Limbs; IRD, inter-recti distance; SD, standard deviation; SEM, standard error measurement; TrR, Right Transversus Abdominis; TrL, Left Transversus Abdominis; UL, Upper Limbs

Table 4 Intra-observer reliabiltiy. Comparision of the mean and standard deviation of the IRD of the different exercises measured 3 times

	Mean & SD1	Mean & SD2	Mean &SD3	Intra-observer ICC (95%CI)	SEM	MDC95
IRD (cm) UL ADD + FE	1.78 ± 0.55	1.82 ± 0.56	1.78 ± 0.62	0.97 (0.94–0.98)	0.10	0.26
IRD (cm) LL ADD + FE	1.86 ± 0.62	1.85 ± 0.60	1.84 ± 0.53	0.99 (0.98–0.99)	0.06	0.17

Abbreviatures: ADD, Adduction; CI, confindece interval; cm, centimeters; FE, Forced Expiration; ICC, intraclass correlation coefficient; MDC, minimum detectable change; LL, Lower Limbs; IRD, rectus abodminis distance; SD, standard deviation; SEM, standard error measurement; UL, Upper Limbs

forced expiration with upper limb adduction, the ICC was 0.94, while for the left TrA under the same conditions, the ICC (1,3) was 0.92, indicating excellent reliability. For the forced expiration with lower limb adduction, high reliability was also observed, with ICC (1,3) of 0.96 for the right TrA and 0.94 for the left TrA (Table 3). High reliability was also recorded for IRD measurements during forced expiration with upper limb adduction, with an ICC (1,3) of 0.97. Lower limb adduction showed even higher reliability, with an ICC (1,3) of 0.99 (Table 4).

Discussion

The primary objective of this study was to analyze changes in TrA thickness and IRD during four conditions in primiparous women within 12 months following vaginal delivery. Significant differences in TrA thickness were observed between resting and all conditions involving forced expiration. However, no significant increase in TrA thickness was observed when comparing forced expiration alone to forced expiration combined with upper or lower limb adduction. Additionally, no significant differences in IRD were found across any of the four conditions tested.

These findings support previous research indicating that forced exhalation is an effective method for engaging the abdominal musculature [49–51]. This aligns with earlier studies that have highlighted the role of forced expiration in selectively recruiting the deep abdominal muscles, particularly the TrA, during postpartum recovery. In the present study, TrA thickness increased during forced expiration compared to rest, suggesting deeper muscle recruitment. Yoon et al. proposed maximal exhalation combined with abdominal exercises as the most effective method for improving TrA activation [52]. However, Yoon et al. examined TrA activation during a curl up. In addition, the specific characteristics of the postpartum population studied should be noted as women in this phase often experience significant physical, hormonal, and biomechanical changes, potentially affecting lumbopelvic stability and abdominal muscle function [1, 3, 6]. In contrast to previous studies [53], our results did not show enhanced TrA activation when lower limb adduction was added to forced expiration. However, other studies [53, 54] have found that additional isometric hip adduction enhances abdominal muscle activity during the plank exercise, and assessed RA, IO, and EO thickness, but not TrA.

Similarly, previous studies [28, 55, 56] have demonstrated that rapid shoulder movements can co-activate the deep trunk muscles. However, our study found an increase in TrA thickness during upper limb adduction with forced expiration, but this increase was not significantly greater than with forced expiration alone. This suggests that, while upper limb adduction may activate the TrA, it does not offer additional benefits compared to forced expiration alone in this population. In addition, the rapid shoulder movements differ from our upper limb isometric adduction exercise. In previous studies, different exercises parameters such as duration or intensity have demonstrated differences in deep abdominal wall muscles thickness [51, 57].

In contrast to the significant improvement of TrA thickness, our study found no significant changes in IRD across the different exercise conditions. This aligns with existing literature, where abdominal muscles function in post-partum women has not a direct association with IRD [58]. Some interventions based on TrA activation have proved to be effective in reducing IRD [59–61], although the current evidence about this topic remains unclear [62]. The results suggest that TrA activation through forced expiration or upper and lower limb adduction does not significantly influence IRD at least in the short term, but longer interventions based on these exercises could possibly show positive results [59]. However, they may add value in improving lumbopelvic stability, which could help prevent conditions like low back pain or chronic pelvic pain [22, 23, 27].

Clinical implications and recommendations for practitioners

The observed variations in TrA thickness across different exercises highlight the importance of targeted interventions for optimizing deep abdominal muscle engagement. Clinically, these findings suggest that while forced expiration exercises with limb adduction may not reduce IRD, they could still play a role in postpartum rehabilitation by improving core strength, lumbopelvic stability, and reducing pain [63]. Although not directly impacting IRD, these exercises may benefit other aspects of core stabilization through TrA activation, particularly in preventing postpartum-related musculoskeletal conditions [36] such as lumbopelvic pain.

Moreover, the lack of significant differences in IRD across conditions suggests that these exercises may not exacerbate diastasis recti, a common postpartum condition. This reinforces the safety and suitability of these exercises for women recovering from pregnancy. Clinicians can use these insights to guide exercise prescription, tailoring interventions to maximize the recruitment of specific abdominal muscles while minimizing strain on the linea alba.

Additionally, the minimal difference in muscle activation between upper and lower limb adduction suggests flexibility in exercise selection, allowing therapists to adapt programs based on individual preferences and functional needs. This flexibility can enhance adherence to rehabilitation programs and improve long-term outcomes.

Overall, these findings emphasize the clinical utility of ultrasound imaging as a tool for monitoring muscle activation and ensuring the effectiveness and safety of rehabilitation exercises in diverse populations, as the ultrasound measurements showed excellent intra-examiner reliability.

Limitations

The limitations of this study should be carefully considered when interpreting the results. First, the sample size was determined by convenience, as recruitment and data collection were limited to the FISAP clinic in Valladolid. While this facilitated the study's implementation, it restricts the generalizability of the findings. A larger and more diverse sample, encompassing different geographic regions, socioeconomic backgrounds, and clinical settings, might yield varying outcomes and enhance the applicability of the results. Future studies should aim to recruit a broader and more representative cohort to validate these findings.

Second, the observational, cross-sectional design of this study limits the ability to establish causal relationships between the interventions and their effects on TrA thickness and IRD. Future research employing randomized controlled trials or longitudinal designs is essential to determine both the causal mechanisms underlying the observed effects and the long-term impact of the interventions.

Third, the specificity of the population studied further limits the applicability of the findings. This research focused exclusively on primiparous women who had a recent vaginal delivery and no history of abdominal surgery. The responses to the interventions might differ significantly in other populations, such as multiparous women, those who underwent cesarean sections, or individuals with varying fitness levels and physical conditions, including athletes or individuals with diastasis recti due to other causes. Expanding future research to include a more heterogeneous population would allow for a more comprehensive understanding of how these interventions affect diverse groups.

Fourth, the scope of this study was confined to the measurement of TrA thickness and IRD, without evaluating other key abdominal muscles, such as the internal and external obliques or the rectus abdominis. These muscles play critical roles in core stability and function, and their inclusion in future research would provide a more holistic understanding of the effects of the interventions on abdominal muscle dynamics.

Finally, the ultrasound measurements were taken at a single point in time, offering only a snapshot of the immediate effects of the interventions. This design precludes any insight into the temporal progression or sustained impact of the exercises. A longitudinal study design with follow-up sessions at multiple time points would be invaluable to evaluate the durability and potential long-term benefits or drawbacks of the interventions.

Future lines of research

Future research could benefit from assessing a broader range of abdominal musculature to provide a more comprehensive understanding of how adduction and forced expiration exercises affect the entire abdominal complex. This would also allow for a more holistic approach in postpartum rehabilitation. The study did not include a condition where TrA thickness was measured during adduction of the limbs alone. This limitation may have influenced the interpretation of TrA muscle activity changes specifically attributable to adduction. Future studies should consider incorporating this condition to isolate the effects of adduction from those of forced expiration. In addition, further research may explore the impact of these exercises on long-term functional outcomes and their role in addressing specific postpartum issues such as back pain, pelvic floor dysfunction, and diastasis recti. Finally, while the study assessed intra-examiner reliability, inter-examiner variability was not considered, which may influence the consistency of the ultrasound measurements across different clinicians. Addressing these additional factors could enhance the robustness and applicability of future research. Nevertheless, these findings provide relevant data to consider in postpartum rehabilitation, for the choice of therapeutic exercises.

Conclusions

This study found no significant differences in TrA thickness between upper and lower limb adduction exercises during forced expiration. However, significant increases in TrA thickness were observed when comparing the resting condition to forced expiration, and to forced expiration with both lower and upper limb adduction. In contrast, no significant changes in IRD were noted across any of the four exercise conditions. Additionally, the ultrasound measurements of TrA and IRD showed excellent intra-examiner reliability, with high ICC values confirming the robustness of the measurement methods.

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Author contributions
P.P.P. (Patricia Pérez Pascual), E.V.S. (Elena Vegas Sánchez), and S.O.B. (Sandra Ortiz Barahona) were responsible for data collection and performed the ultrasound measurements, with equal contribution. G.G.P.S. (Guillermo García Pérez de Sevilla) and M.G.-A. (María García-Arrabé) contributed to the study design and data analysis. G.J.C. (Gonzalo Jaén Crespo) supervised the statistical analysis. Á.G.F. (Ángel González de la Flor) provided overall project supervision, contributed to manuscript writing, and coordinated the study team. All authors contributed to the manuscript writing and approved the final version.

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Data availability
The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Research Committee of the European University of Madrid (internal code: 2024 – 443) and adhered to the Declaration of Helsinki. All participants provided written informed consent to participate in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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