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Original Research

Breathing Patterns Regulated by Tension-Free Abdominal Breathing Training Are Associated With Improved Pelvic Floor and Brain Function in Postpartum Females With Pelvic Floor Dysfunction: A Pilot Feasibility Study

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Abstract

Background: We investigated the effects of breathing patterns regulated by tension-free abdominal breathing training on pelvic floor, mood, fatigue, sleep, and brain function in postpartum women with pelvic floor dysfunction. Postpartum women commonly present with varying degrees of pelvic-abdominal injuries, which directly impair pelvic-abdominal motor function. Tension-free pelvic-abdominal respiratory training modulates pelvic-abdominal movements via respiratory exercises, and this study intends to investigate its effects on pelvic floor and brain function in postpartum females. **Methods:** Medical records of postpartum women with pelvic floor dysfunction who underwent tension-free abdominal breathing training were retrospectively collected. Pre- and post-treatment brain function test indicators and scores from the Pelvic Floor Distress Inventory-20 (PFDI-20), Edinburgh Postnatal Depression Scale (EPDS), Fatigue Scale-14 (FS-14), Pittsburgh Sleep Quality Index (PSQI), and Self-Rating Anxiety Scale (SAS) were recorded to assess treatment effectiveness. **Results:** A total of 88 postpartum women (40 vaginal deliveries, 48 cesarean sections) were included. Significant differences were observed in PFDI-20 ($p < 0.001$) and EPDS ($p < 0.001$) scores following breathing pattern regulation. Brain function assessment showed significant changes in anxiety tendency ($p = 0.02$), depressive tendency ($p < 0.001$), introverted brain ($p = 0.03$), brain inhibition ($p = 0.02$), and brain stability ($p = 0.04$). Correlation analysis demonstrated that PFDI-20 scores were positively correlated with EPDS ($p < 0.001$), SAS ($p < 0.001$), FS-14 ($p < 0.001$), and PSQI ($p = 0.027$) scores. Among brain function indices, PFDI-20 scores were positively correlated with anxiety tendency ($p = 0.002$) and outside focus ($p = 0.01$), and negatively correlated with introverted brain ($p = 0.043$), brain stability ($p = 0.016$), inner focus ($p = 0.042$), and brain emptying ($p = 0.024$). **Conclusions:** Tension-free abdominal breathing training may warrant further investigation as an intervention for pelvic floor dysfunction in postpartum women, given its potential to restore pelvic floor function, alleviate anxiety and depression, and improve brain function as assessed by electroencephalography (EEG).

Keywords: breathing training; pelvic floor dysfunction; brain function; postpartum women

1. Introduction

Pelvic floor dysfunction arises during pregnancy as uterine enlargement increases pressure on the pelvic floor and abdomen, with additional injury occurring to the pelvic floor during delivery [1,2]. Widening of the lower thoracic segment [3], increased kyphosis [4], and decreased spinal flexibility during pregnancy contribute to alterations in thoracic breathing patterns or exacerbation of pre-existing breathing patterns [5], dysregulation of breathing movements involving the thoracic and pelvic diaphragm [6], and exacerbation of pelvic floor dysfunction or impairment of pelvic floor recovery [7]. Due to hormonal fluctuations and role changes in the postpartum period, women are more likely to experience emotional disturbances, including fatigue, depression, and anxiety, which adversely affect quality of life [8,9]. Maternal pelvic floor tissue injury, mood abnormalities, and changes in breathing patterns may all contribute to changes in brain function of varying degrees and dimensions [10,11].

Neuromuscular electrical stimulation combined with Kegel pelvic floor muscle training has been widely used for pelvic floor rehabilitation [12,13]. However, the role of female breathing patterns in pelvic floor rehabilitation has been largely overlooked. Restoring overall core function from the perspective of respiratory dynamics may be essential for effective recovery of pelvic floor function in postpartum women [7,14]. Abnormal postpartum breathing patterns can disrupt the movement patterns of the inner core musculature, including the diaphragm, transverse abdominis, and pelvic floor muscles, thereby exacerbating pelvic floor dysfunction or impairing the recovery of pelvic floor function [15]. Breathing training may be utilized as a complementary intervention alongside pelvic floor muscle training for postpartum pelvic floor rehabilitation, albeit with limited evidence [16]. For breathing training targeting maternal abdominal and pelvic floor muscle injuries, forceful inspiratory muscle training and expiratory muscle training are the commonly employed modalities [17,18]. Tension-free abdominal breathing emphasizes smooth and gentle breathing, avoiding excessive increases in pelvic and abdominal pressure. This approach promotes activation of the inner core and restoration of tissue elasticity, regulates the balance between the inner and outer cores, and facilitates mechanical coordination of the pelvis and abdominal cavity [19].

Brain functional state detection employs prefrontal lobe EEG signal records of different sensory, psychological, cognitive, and motor activities, from which data are extracted, classified, processed, and analyzed. The key technical challenge in brain function research lies in the purposeful feature extraction, classification, processing, and analysis of these EEG signals [20,21]. EEG-based brain–computer integration has attracted considerable interest in the field of engineering and represents an emerging research area at the intersection of life science and computer science [22]. Breathing is closely related to the brain center; therefore, breathing-based training may exert an effect on brain function, which can be captured by EEG.

The purpose of this study was to investigate the effects of tension-free abdominal breathing training on pelvic floor function, sleep, mood, and other effects on postpartum women, as well as associated changes in brain function, with the aim of providing a more effective approach to breathing pattern regulation for pelvic and abdominal dysfunction and evaluating the clinical significance of brain function testing.

2. Materials and Methods

2.1 Study Design

This retrospective analysis reviewed clinical data from postpartum women who received tension-free abdominal breathing training at the Rehabilitation Center of West China Second Hospital of Sichuan University from August 2022 to September 2023. After screening, 88 cases were included, comprising 48 cesarean deliveries and 40 vaginal deliveries. Patient demographic information, treatment details, and pre- and post-treatment assessment data were collected. The study was approved by the ethics committee of West China Second Hospital of Sichuan University, which granted an exemption from informed consent (Fig. 1).

2.2 Eligibility Criteria

Inclusion criteria for postpartum women clinical data were as follows: (1) postpartum women who received tension-free abdominal breathing training records; and (2) patients who are 20 to 50 years old. The exclusion criteria were as follows: (1) patients with incomplete and missing records of indicators to be observed; (2) patients who had records of breathing training sessions for less than 3 days; (3) patients with a medical history of lumbar and abdominal surgery; (4) a history of tumors; and (5) a history of respiratory diseases.

2.3 Training Methods

Tension-free abdominal breathing training was performed under professional supervision. Training was performed in 4 positions: supine position with legs flexed to 90º–110º, supine position with hip flexed to 90º and knees flexed to 90º, sitting position, and standing position (Fig. 2). During breathing exercises, the diaphragm and pelvic floor muscles contract and relax in synchrony. In tension-free breathing, the patient is instructed to inhale gently and slowly; inspiratory airflow enters the thoracic cavity through the nasal cavity, and pressure is transmitted from the thoracic cavity to the abdominal and pelvic cavities. During expiration, the patient is instructed to gently release and relax her lips while exhaling slowly; positive thoracic pressure drives airflow out of the lungs through the mouth, allowing tissues and organs to rebound from the abdominopelvic region toward the thoracic cavity (Fig. 3). This breathing method was applied across all body positions, with patients instructed to avoid excessive ribcage expansion, excess anterior abdominal pressure, and breath-holding during the exercise. Each training session lasted 60 minutes and was conducted once daily for 3 consecutive days. All therapists providing breathing training guidance underwent standardized training and passed a competency assessment to ensure standardized guidance.

2.4 Evaluation Data

Brain Function Evaluation

Brain function was measured using a multifunctional combined monitor (HXD-I, Heilongjiang Huaxiang Technology Development Co., Ltd., Harbin, Heilongjiang, China) to record brain wave activity. Noninvasive EEG electrodes were placed according to the international 10/20 scalp electrode positioning system, with electrodes positioned 2 cm above the center point of both forehead and brow arches bilaterally, and above the brow arches on both sides; reference electrodes were placed on both earlobes (Fig. 4). EEG signal measurement was initiated after a 2-minute resting period, and effective EEG signals were continuously recorded for 6 minutes. The recordings included eye-opening, eye-closing, a second eye-opening, and a focused attention task performed under real-time voice prompts from the system. The collected EEG signals were processed using the wavelet algorithm-based EEG analysis software package Brain State Quantitative Assessment System V5.0 (2015SR077517; CN201310566688 - A Method for Obtaining Objective Quantitative Indicators of Brain State; Beijing E-Fly Huatong Technology Development Co., Ltd., Beijing, China). Using EEG waves of a specific window length as units, wavelet analysis, spectral analysis, and pattern recognition analysis were applied to

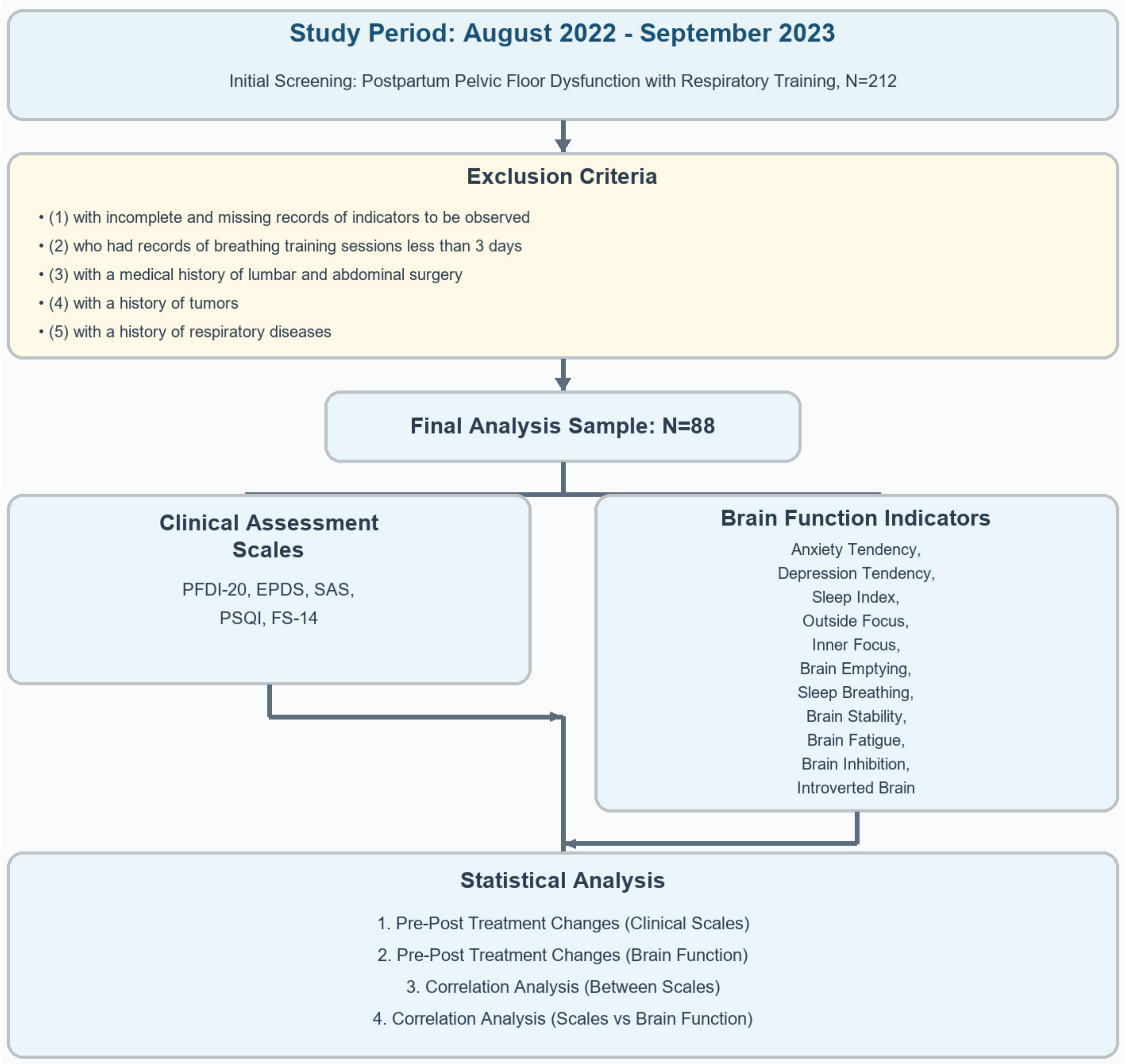

Fig. 1. Study flowchart. PFDI-20, Pelvic Floor Distress Inventory-20; EPDS, Edinburgh Postnatal Depression Scale; SAS, Self-Rating Anxiety Scale; PSQI, Pittsburgh Sleep Quality Index; FS-14, Fatigue Scale-14.

calculate relevant brain functional characteristic indicators, thereby extracting reproducible and regular feature change metadata from the EEG signals. The core mechanism involves the establishment of a cortical and subcortical two-compartment model of the EEG. Brain function index data were obtained through automated analysis, including anxiety tendency, depressive tendency, sleep-breathing index, brain stability, brain fatigue, brain inhibition, introverted brain, sleep index, outside focus, inner focus, and brain emptying indices [23,24,25,26].

Questionnaire data were completed by the patients according to their own subjective perceptions before and after the breathing training. Specifically, it included Pelvic Floor Distress Inventory-20 (PFDI-20), Edinburgh Postnatal Depression Scale (EPDS), Self-Rating Anxiety Scale (SAS), Pittsburgh Sleep Quality Index (PSQI), and Fatigue Scale-14 (FS-14) (**Supplementary Table 1**).

2.5 Statistical Analysis

Statistical analysis was performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Paired *t*-test or Wilcoxon signed-rank test was applied as appropriate. Normality was assessed using the Shapiro-Wilk test. Spearman rank correlation was used for correlation analysis. $p < 0.05$ was considered statistically significant. As this is a pilot feasibility study, correlation analyses were performed for exploratory purposes without adjustment for multiple comparisons. Findings should therefore be interpreted as preliminary, hypothesis-generating results.

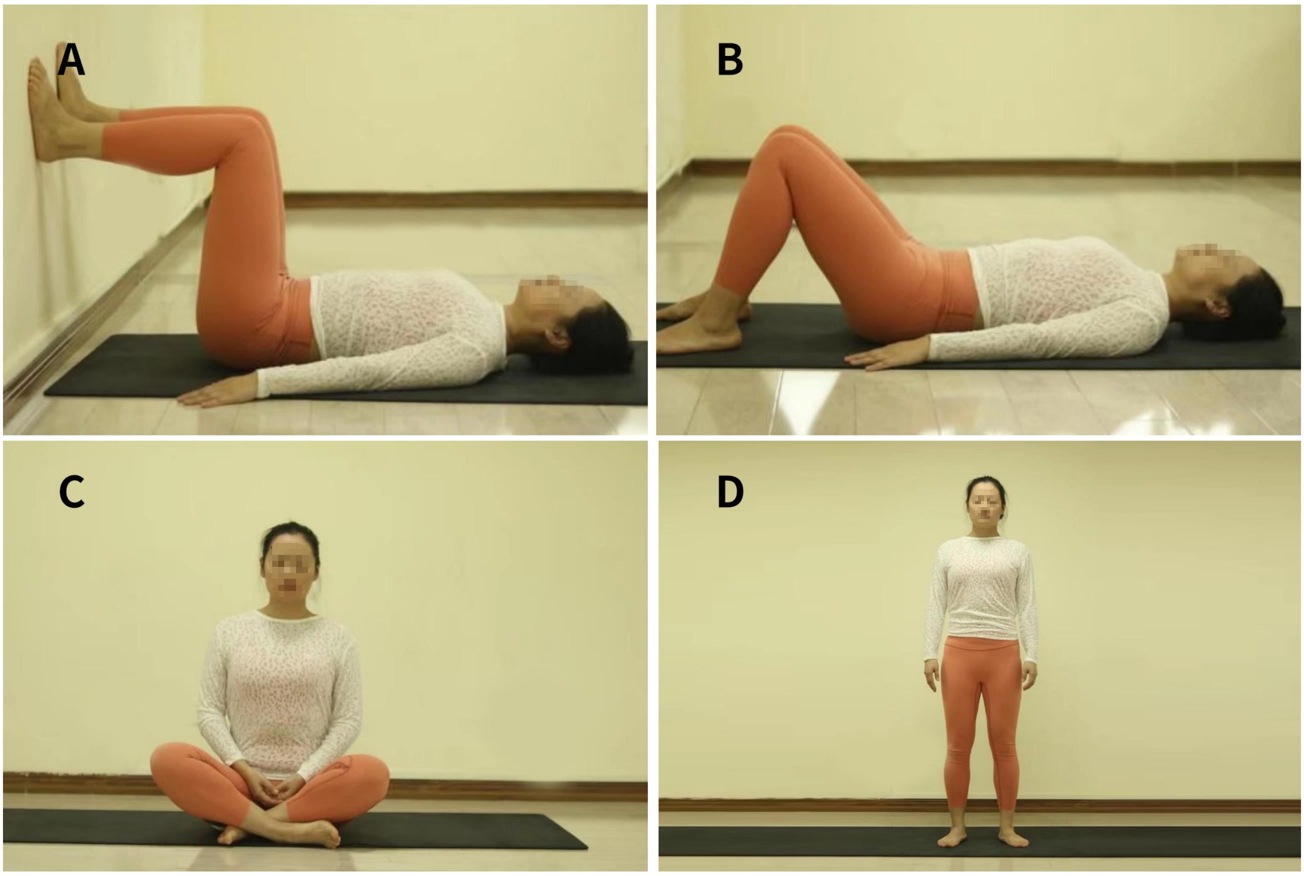

Fig. 2. Breathing training positions. (A) Supine position with hips flexed to 90º and knees flexed to 90º. (B) Supine position with legs flexed to 90º–110º. (C) Sitting position. (D) Standing position.

3. Results

3.1 Patient Characteristics

Demographic data, including age, height, weight, and body mass index (BMI), were recorded for all 88 women, comprising 40 vaginal deliveries and 48 cesarean sections. The majority of patients were primigravidas (51.1%), and 76.1% were primiparous (Table 1A, Table 1B).

3.2 Pre- and Post-Treatment Questionnaire Results

Among the 5 scales evaluated, PFDI-20 scores changed from 24.99 (10.41, 53.64) to 25.00 (7.28, 48.95) ($p < 0.001$) and EPDS scores decreased from 8.00 (6.00, 12.00) to 7.00 (5.00, 11.00) ($p < 0.001$) following 3 breathing training sessions, with both reaching statistical significance. No significant differences were observed in SAS ($p = 0.06$), FS-14 ($p = 0.77$), and PSQI ($p = 0.42$) scores pre- and post-treatment. Subgroup analysis by mode of delivery showed no significant improvements in any scale among vaginal delivery patients pre- and post-treatment. By contrast, cesarean section patients demonstrated statistically significant differences in both PFDI-20 ($p = 0.01$) and EPDS ($p = 0.01$) scores following treatment (Table 2).

3.3 Pre- and Post-Treatment Brain Function Variables

Breathing training affected 7 brain function indicators. With the exception of sleep-breathing and brain fatigue indicators, significant improvements were observed in anxiety tendency ($p = 0.02$), depressive tendency ($p < 0.001$), introverted brain ($p = 0.03$), brain inhibition ($p = 0.02$), and brain stability ($p = 0.04$) across all 88 cases. Subgroup analysis by mode of delivery revealed that vaginal delivery patients showed statistically significant differences in sleep-breathing ($p = 0.03$), brain fatigue ($p = 0.05$), and brain inhibition ($p = 0.05$) indices, whereas cesarean section patients showed statistically significant differences solely in the depressive tendency ($p < 0.001$) index (Table 3).

3.4 Correlation Analysis of Evaluation Indicators

Pre-treatment correlation analysis revealed that pelvic floor dysfunction was positively correlated with anxiety ($p < 0.001$), depression ($p < 0.001$), fatigue ($p < 0.001$), and sleep quality ($p = 0.027$), with all associations reaching statistical significance. Positive correlations were also observed among the remaining variables. More severe pelvic floor dysfunction was associated with increased levels of anxiety, depression, fatigue, and poorer sleep quality (Table 4). Pre-treatment correlation analysis between scale

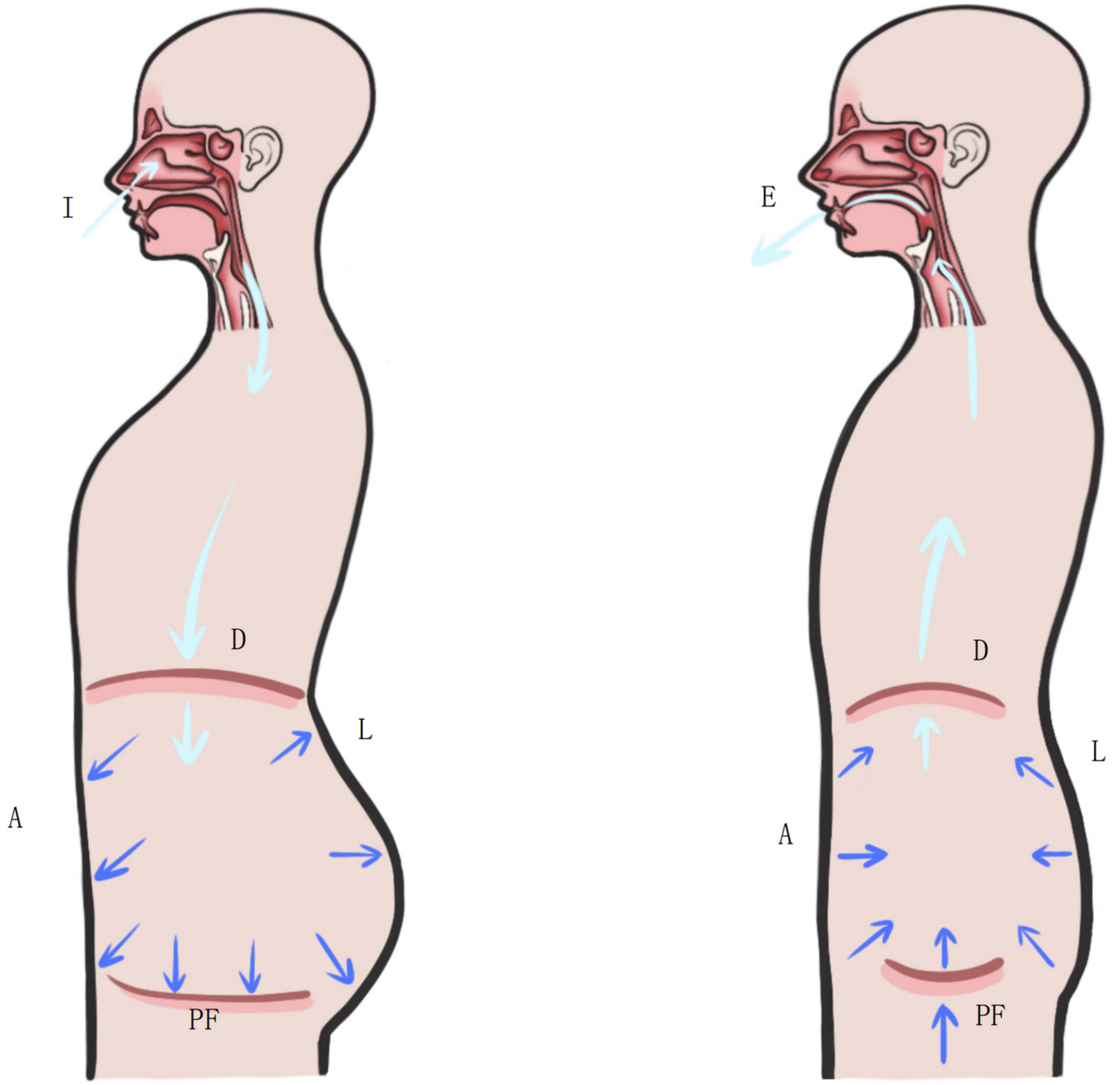

Fig. 3. Schematic diagram of changes in inhalation and exhalation airflow. A, abdominal muscles; D, diaphragm; E, exhalation; I, inhalation; L, lumbar muscles; PF, pelvic floor. Light-blue arrows indicate airflow; dark-blue arrows show the direction of pelvic-abdominal movement.

scores and brain function index value showed that pelvic floor function was positively correlated with anxiety tendency (p = 0.002) and outside focus (p = 0.01), and negatively correlated with introverted brain (p = 0.043), brain stability (p = 0.016), inner focus (p = 0.042), and brain emptying (p = 0.024). The results suggest that greater severity of pelvic floor dysfunction is associated with higher anxiety levels and increased attention to external factors, while the focus on internal factors decreased, brain stability decreased, and brain emptying became more challenging, as reflected by the brain function indices. Statistically significant positive correlations were observed between anxiety, depression, and sleep quality scale scores and the corresponding brain function indices of anxiety tendency ($p <$ 0.001; p = 0.001; p = 0.002), depressive tendency ($p <$ 0.001; $p <$ 0.001; p = 0.001), brain fatigue ($p <$ 0.001; p = 0.006; p = 0.041), negative correlation was observed for the sleep index. FS-14 scores were positively correlated with depressive tendency ($p <$ 0.001) and brain fatigue ($p <$ 0.001) indices. These findings further verified that subjective scale assessments were consistent with the EEG-based brain function analysis results (Table 5).

Fig. 4. Noninvasive EEG electrode placement method. (A) Anterior view. (B) Lateral view. EEG, electroencephalography.

Table 1A. Patients' baseline characteristics.

Variable		(Min, Max)	(Mean ± SD)
Age (years)		(24, 49)	32.82 ± 4.49
Height (cm)		(148, 172)	159.84 ± 4.86
Weight (kg)		(35, 76)	55.93 ± 7.75
BMI (kg/m^2)		(14.95, 29.62)	21.86 ± 2.72
Variable		**Frequency (n)**	**Percentage (%)**
Mode of delivery	Vaginal delivery	40	45.45
	Cesarean section	48	54.55
Number of pregnancies	1	45	51.1
	2	24	27.3
	≥3	19	21.6
Number of deliveries	1	67	76.1
	2	21	23.9

BMI, body mass index; SD, standard deviation.

4. Discussion

Pelvic floor muscle injury affects respiratory function in the postpartum period, and respiratory pattern disturbances may exacerbate dysfunction or hinder recovery [1,3,7]. Adjustment of respiratory dynamics may improve postpartum health. Breathing regulates autonomic nervous system activity and endocrine balance, thereby reducing psychological stress and anxiety, as well as regulating sleep, mood, cortisol levels, abdominal and pelvic floor muscle function, and physical pain [27,28,29,30]. During breathing training, rhythmic respiratory movements promote blood flow throughout the pelvic and abdominal cavity, ensuring adequate blood circulation to pelvic organs, tissues, and pelvic floor muscles. Adequate blood circulation may help boost metabolism, enhance collagen flexibility, and support muscle fiber repair [31,32]. Tension-free abdominal breathing training has rarely been reported as an intervention for postpartum pelvic floor dysfunction and abnormal breathing patterns. Its significance is currently emphasized in a Canadian expert consensus on the treatment

Table 1B. Patients' baseline characteristics by mode of delivery.

Variable		Vaginal deliveries (n = 40)	Cesarean sections (n = 48)	*Z*/*t*	*p*-value
Age (years)		32.0 (29.0, 35.0)	33.0 (29.8, 37.2)	–0.796	0.428
Height (cm)		160.90 ± 5.07	159.00 ± 4.54	1.854	0.067
Weight (kg)		57.08 ± 7.56	54.97 ± 7.86	1.274	0.206
BMI (kg/m^2)		22.01 ± 2.39	21.74 ± 2.98	0.457	0.649
Variable		**Vaginal deliveries (n = 40)**	**Cesarean sections (n = 48)**	χ^2	***p*-value**
Number of pregnancies	1	19 (47.5)	26 (54.17)		
	2	13 (32.5)	11 (22.92)		
	≥3	8 (20)	11 (22.92)	1.010	0.603
Number of deliveries	1	28 (70)	39 (81.25)		
	2	12 (30)	9 (18.75)	1.520	0.218

Data are presented as mean ± SD for normally distributed data, or median (Q1, Q3) for non-normally distributed data, and n (%) for categorical data.

Table 2. Pre- and post-treatment scale assessment results.

All (n = 88)	Pre-treatment	Post-treatment	*Z*/*t*	*p*-value	Effect size
PFDI-20	24.99 (10.41, 53.64)	25.00 (7.28, 48.95)	−3.00	<0.001	0.32
EPDS	8.00 (6.00, 12.00)	7.00 (5.00, 11.00)	−3.14	<0.001	0.33
SAS	38.00 (33.00, 45.00)	38.00 (31.00, 42.75)	−1.88	0.06	0.20
FS-14	7.00 (5.00, 10.00)	8.00 (5.00, 11.00)	−0.30	0.77	0.03
PSQI	7.00 (5.00, 9.00)	7.00 (5.00, 8.00)	−0.80	0.42	0.09
Vaginal delivery (n = 40)					
PFDI-20	24.89 (16.13, 59.63)	27.60 (14.32, 49.72)	−1.64	0.10	0.26
EPDS	8 (6.00, 12.00)	7.5 (5.00, 11.00)	−1.85	0.07	0.29
SAS	39.58 ± 7.71	39.08 ± 7.83	0.55	0.58	0.07
FS-14	8 (5.00, 10.00)	8 (4.25, 10.75)	−0.04	0.97	0.01
PSQI	6.35 ± 2.68	6.50 ± 2.77	−0.42	0.68	0.05
Cesarean section (n = 48)					
PFDI-20	17.68 (8.32, 47.91)	11.97 (4.16, 48.17)	−2.64	0.01	0.38
EPDS	8 (6.00, 12.00)	6 (4.00, 9.75)	−2.60	0.01	0.38
SAS	38 (32.00, 44.50)	36.5 (30.00, 42.75)	−1.70	0.09	0.25
FS-14	7 (6.00, 9.00)	7 (5.00, 11.00)	−0.47	0.64	0.07
PSQI	7 (5.00, 9.00)	7 (5.00, 8.75)	−1.69	0.09	0.24

Data are presented as mean ± SD for normally distributed data, or median (Q1, Q3) for non-normally distributed data. Effect sizes were reported as Cohen's d for paired-samples *t*-tests and r for Wilcoxon signed-rank tests. PFDI-20, Pelvic Floor Distress Inventory-20; EPDS, Edinburgh Postnatal Depression Scale; FS-14, Fatigue Scale-14; PSQI, Pittsburgh Sleep Quality Index; SAS, Self-Rating Anxiety Scale.

of postpartum diastasis recti, both during pregnancy and in the postpartum period [19]. Additionally, breathing-based interventions targeting diaphragm and abdominal muscle coordination have been used to improve postpartum urinary incontinence [33]. Therefore, tension-free abdominal breathing may modulate thoracic breathing patterns through the diaphragm, supporting the restoration of pelvic floor function in women with postpartum pelvic floor dysfunction.

The tension-free abdominal breathing intervention used in this study was mainly used to adjust pelvic and abdominal dynamics in postpartum women. Our results suggest that three breathing training sessions may be associated with improvements in pelvic floor function and depressive symptoms, but showed no significant improvement in anxiety, fatigue, or sleep. Although the changes in pelvic floor function and depressive symptoms reached statistical significance, they did not reach the minimal clinically important difference (MCID). Therefore, these findings should be interpreted solely as preliminary evidence from an exploratory pilot study. Postpartum sleep, anxiety, and fatigue are influenced by multiple factors, including chronic pain, nighttime breastfeeding and parenting, and changes in life roles and environment, all of which may directly affect sleep and increase the possibility of anxiety and fatigue [34]. Furthermore, outcomes may be influenced by patients' learning concentration, proprioceptive differences, and subjective improvement expectations

Table 3. Pre- and post-treatment brain function variable analysis.

All (n = 88)	Pre-treatment	Post-treatment	Z/t	p-value	Effect size
Sleep breathing	0 (0.00, 9.75)	0 (0.00, 18.00)	−1.87	0.06	0.20
Brain fatigue	29 (19.0, 40.50)	27 (13.25, 41.75)	−1.03	0.30	0.11
Anxiety tendency	11 (6.00, 25.75)	8 (5.00, 18.00)	−2.34	0.02	0.25
Depressive tendency	36 (29.25, 48.75)	32.50 (21.25, 41.75)	−3.93	<0.001	0.42
Introverted brain	39.74 ± 10.71	41.76 ± 12.534	−2.15	0.03	0.17
Brain inhibition	54 (44.25, 60.00)	56 (46.00, 62.00)	−2.37	0.02	0.25
Brain stability	50.81 ± 9.03	52.99 ± 11.281	−2.11	0.04	0.21
Vaginal delivery (n = 40)					
Sleep breathing	0 (0.00, 8.50)	0 (0.00, 28.75)	−2.17	0.03	0.34
Brain fatigue	37 (27.00, 49.00)	28.5 (13.25, 41.75)	−1.98	0.048	0.31
Anxiety tendency	12.5 (6.00, 32.50)	9.5 (6.00, 22.50)	−1.30	0.19	0.21
Depressive tendency	37 (31.25, 48.75)	36 (29.25, 41.50)	−1.47	0.14	0.23
Introverted brain	44 (27.50, 49.00)	42 (34.25, 51.75)	−1.79	0.07	0.28
Brain inhibition	51.00 ± 11.74	55.00 ± 11.289	−2.07	0.045	0.35
Brain stability	49.40 ± 8.30	52.72 ± 12.075	−1.90	0.07	0.32
Cesarean section (n = 48)					
Sleep breathing	0 (0.00, 13.00)	0 (0.00, 16.75)	−0.42	0.67	0.06
Brain fatigue	24 (15.00, 31.00)	26 (13.50, 41.75)	−0.87	0.39	0.13
Anxiety tendency	10 (6.00, 20.50)	7 (4.00, 14.5)	−1.92	0.06	0.28
Depressive tendency	35 (24.00, 48.75)	30 (15.25, 41.75)	−4.18	<0.001	0.60
Introverted brain	40.5 (34.00, 45.00)	44 (33.25, 49.75)	−1.26	0.21	0.18
Brain inhibition	55 (43.50, 61.00)	55.5 (45.25, 62.00)	−1.77	0.08	0.26
Brain stability	51.98 ± 9.53	53.21 ± 10.699	−1.03	0.31	0.15

Data are presented as mean ± SD for normally distributed data, or median (Q1, Q3) for non-normally distributed data. Effect sizes were reported as Cohen's d for paired-samples *t*-tests and r for Wilcoxon signed-rank tests.

Table 4. Correlation analysis of scale assessment results.

Variable (n = 88)		PFDI-20	EPDS	SAS	FS-14	PSQI
PFDI-20	r_s	1	0.334	0.501	0.323	0.167
	p-value	/	**<0.001**	**<0.001**	**<0.001**	**0.027**
EPDS	r_s	0.334	1	0.624	0.393	0.485
	p-value	<0.001	/	**<0.001**	**<0.001**	**<0.001**
SAS	r_s	0.501	0.624	1	0.507	0.376
	p-value	<0.001	<0.001	/	**<0.001**	**<0.001**
FS-14	r_s	0.323	0.393	0.507	1	0.395
	p-value	<0.001	<0.001	<0.001	/	**<0.001**
PSQI	r_s	0.167	0.485	0.376	0.395	1
	p-value	0.027	<0.001	<0.001	<0.001	/

p-values < 0.05 are shown in bold.

[35,36]. Subgroup analysis also revealed that three breathing training sessions had a greater effect on pelvic floor function in women who underwent cesarean section compared to those who underwent vaginal delivery, which may be attributable to the greater degree of pelvic floor injuries associated with vaginal delivery [37]. Longer duration and higher frequency of respiratory therapy warrant further analysis and observation. Correlation analysis between pelvic floor scale scores and other scale scores showed a strong positive correlation between pelvic floor dysfunction and women's mood, sleep, and fatigue. This suggests that tension-free abdominal breathing may exert positive therapeutic effects on mood, sleep, and fatigue alongside improvements in pelvic floor function; however, these benefits may not have been apparent due to the multiple confounding factors and the short treatment duration.

Considerable evidence in the literature has reported that breathing disorders are closely associated with brain function. EEG recordings have demonstrated that distinct respiratory states, including spontaneous breathing, breath-

Table 5. Correlation analysis of scale assessment and brain function variables results.

Variable (n = 88)		PFDI-20	EPDS	SAS	FS-14	PSQI
Sleep breathing	r_s	−0.140	−0.071	−0.110	−0.065	−0.131
	p-value	0.064	0.349	0.147	0.393	0.084
Anxiety tendency	r_s	0.236	0.258	0.292	0.145	0.229
	p-value	**0.002**	**0.001**	**<0.001**	0.056	**0.002**
Depressive tendency	r_s	0.134	0.385	0.296	0.268	0.238
	p-value	0.076	**<0.001**	**<0.001**	**<0.001**	**0.001**
Sleep index	r_s	−0.126	−0.314	−0.263	−0.098	−0.533
	p-value	0.096	**<0.001**	**<0.001**	0.194	**<0.001**
Introverted brain	r_s	−0.153	−0.056	−0.059	−0.012	0.007
	p-value	**0.043**	0.462	0.434	0.878	0.932
Brain inhibition	r_s	−0.063	0.093	0.089	0.051	−0.064
	p-value	0.404	0.218	0.242	0.500	0.397
Brain stability	r_s	−0.181	0.017	−0.061	−0.006	−0.007
	p-value	**0.016**	0.819	0.422	0.937	0.932
Outside focus	r_s	0.195	0.023	0.057	−0.032	0.039
	p-value	**0.010**	0.764	0.449	0.670	0.606
Inner focus	r_s	−0.153	0.065	−0.072	−0.015	−0.017
	p-value	**0.042**	0.393	0.342	0.845	0.819
Brain fatigue	r_s	0.145	0.207	0.292	0.381	0.154
	p-value	0.055	**0.006**	**<0.001**	**<0.001**	**0.041**
Brain emptying	r_s	−0.170	0.072	−0.015	0.029	0.111
	p-value	**0.024**	0.340	0.848	0.699	0.142

p-values < 0.05 are shown in bold.

holding, and paced breathing, modulate brain connectivity and network topology [38]. To demonstrate the effect of tension-free breathing training on brain function, assessments were conducted using EEG recordings and data analysis. The findings showed significant improvements in anxiety and depressive tendency indices based on EEG analysis, along with greater brain stability and inhibition, and improvement in the sleep-breathing index in the vaginal delivery. Changes in brain stability, introverted brain, and sleep-breathing indices may positively influence emotional stability, memory, and learning ability in postpartum women. The number of brain function indicators showing significant improvement was slightly better in women who underwent vaginal delivery than in those who underwent cesarean section. This may be attributable to more severe abdominal wall injury in women who underwent cesarean section, in whom scarring leads to mechanical segmentation of the abdominal cavity and pelvis, collectively disrupting respiratory dynamics and potentially affecting brain function improvement [39,40]. Although the treatment effect of three breathing sessions did not show statistically significant improvements in subjective scale scores, significant improvements in brain function indices were obtained, suggesting that EEG-based brain function assessment provides more immediate feedback than subjective self-report measures.

Scale scores were strongly correlated with brain function indicators. Mood, sleep, and fatigue were interrelated, and multiple EEG indicators showed strong correlations. Pelvic floor function was correlated with brain stability, changes in outside and inner focus, and improvement of brain emptying ability as measured by EEG. Research on brain–computer function has advanced significantly, with EEG-based detection now applied to the assessment of pain under anesthesia, cognitive function, and emotional state assessment [20,41]. To our knowledge, this study is the first to apply brain function testing for the evaluation of breathing training outcomes in postpartum women. The strong correlations between EEG indices and assessment scale scores in the study also suggest that it could be used as an additional objective detection and evaluation method. However, further research is required to clarify the clinical significance and theoretical basis of these associations.

Limitations

This tension-free abdominal breathing training, based on pelvic-abdominal dynamics, is designed to regulate breathing patterns in postpartum women, and our center has accumulated long-term clinical experience with this approach. The present study observed changes following short-term training; however, long-term effects remain unclear, as no long-term follow-up was conducted. The absence of a control group precludes direct comparison of treatment outcomes and represents an additional limitation of this study. Moreover, the sample size of the present study was limited. To determine the therapeutic effects and benefits of tension-free abdominal breathing training and to explore the overall treatment approaches combining this intervention with other pelvic floor treatments, a larger controlled trial is warranted. As a retrospective study, the reliability and validity of the outcome scales were not formally analyzed in this sample. Furthermore, the application of MCID to evaluate clinical value should be carefully addressed in future research.

5. Conclusions

Tension-free abdominal breathing training was associated with improvements in pelvic floor function and brain function in postpartum women through breathing pattern regulation and may represent a valuable component of pelvic floor dysfunction treatment. Brain function indices were correlated with pelvic floor disorders, anxiety, depression, fatigue, and sleep disturbance, suggesting that EEG-based brain function testing may serve as an objective method for postpartum health evaluation.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

Conceptualization: WS, HL; Data curation: WS, YC; Formal analysis: WS, HL; Investigation: XY, YC; Methodology: WS; Project administration: WS, HL; Resources: WS; Supervision: XY, HL; Validation: WS, HL; Writing - original draft: WS, XY; Writing - review & editing: WS, XY. All authors contributed to the conception and editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki and was formally approved by the Ethics Committee of West China Second Hospital of Sichuan University, the ethics approval number is 2023(176) in 2023.09.14. Due to the retrospective nature of the study, the requirement for informed consent from the study participants was waived by the Ethics Committee. Written informed consent for publication of the identifiable images shown in Figs. 2,4 was obtained from the individual depicted in the figures.

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Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/CEOG48783.

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