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Impact of Inspiratory Muscle Training on Weaning Parameters in Prolonged Ventilator-Dependent Patients: A Preliminary Study

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Abstract

Introduction: Patients require prolonged mechanical ventilation to overcome respiratory failure in the chronic respiratory care ward; however, how to facilitate ventilator weaning using a nurse-led strategy is limited.

Objectives: This study aimed to examine the impact of adjusting ventilator trigger sensitivity as inspiratory muscle training on weaning parameters in patients with prolonged ventilator dependence.

Methods: Multiple pre-test–post-test with a non-equivalent control group design was conducted at a chronic respiratory care ward in southern Taiwan. A convenience sampling method was used to recruit patients who received prolonged mechanical ventilation for more than 21 days into control ($n = 20$) and intervention groups ($n = 22$). Adjustment of ventilator trigger sensitivity started from 10% of the initial maximum inspiratory pressure and increased to 40% after a training period of six weeks. The weaning parameters were collected for pre-test and multiple post-tests, and statistical analysis of treatment effects was performed using the generalized estimating equation.

Results: Magnitude of weaning parameters was significantly higher in the intervention group after the six-week training, including maximum inspiratory pressure, rapid shallow breathing index, tidal volume, and ratio of arterial-to-inspired oxygen.

Conclusion: Adjustment of ventilator trigger sensitivity as inspiratory muscle training can help prolonged ventilator-dependent patients improve their respiratory muscle strength, breathing patterns, and oxygenation.

Keywords

Prolonged mechanical ventilation, inspiratory muscle training, ventilator trigger sensitivity, weaning parameters, ventilator-dependent patient

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Background

Respiration is a basic physiological phenomenon in living beings. Respiratory failure refers to the inability of patients to breathe spontaneously, which causes gas exchange disorders in the body (Chapman & Robinson, 2021). With the rapid development of modern medical technology, patients require the assistance of mechanical ventilation for preventing respiratory failure and maintaining oxygenation; this ensures that the basic bodily functions are maintained and helps in gaining additional time for medical treatment (Elkins & Dentice, 2015). In our clinical experience, patients under prolonged mechanical ventilation (PMV) usually have unresolved underlying diseases and are difficult to wean from mechanical ventilation immediately. Instead, long-term use of mechanical ventilation is required, and some patients become ventilator-dependent (Ahmed et al., 2019). A review reported that the prevalence of ventilator-dependent

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patients varies from 6.6 to 23 per 100,000 people, and that 5%–16.6% of patients underwent PMV in the intensive care unit; of these patients, approximately 50% required prolonged invasive ventilation and failed to wean from mechanical ventilation (Ambrosino & Vitacca, 2018). Therefore, how to facilitate ventilator weaning using a nurse-led clinical protocol in a chronic respiratory ward is an important aspect of nursing development for advanced practice nurses.

Review of Literature

According to the National Association for Medical Direction of Respiratory Care, patients requiring PMV have "the need for greater than or equal to 21 consecutive days of mechanical ventilation for 6 or more hours per day" (MacIntyre et al., 2005). Alternatively, patients who fail to wean from mechanical ventilation even after multiple attempts are regarded as continuous users or fall under the following categories: long-term mechanical ventilation users, users with a ventilator dependence, users requiring chronic ventilation, and users requiring prolonged intubation (Rose et al., 2017). Based on the payment policy of Taiwan National Health Insurance, those who rely on mechanical ventilation for more than 63 days have to be transferred from an acute setting to chronic respiratory care wards (RCWs) to control improvements in their lung compliance or respiratory muscle strengths (Taiwan National Health Insurance, 2022).

The burden of medical expenses for long-term invasive mechanical ventilation is approximately 27.3 times higher than that of general care (National Health Insurance Administration, 2016). Apart from the burden on national healthcare, pathological changes in the respiratory system of prolonged ventilator-dependent patients include impaired physical functions, respiratory muscle weakness, contractile impairments, diaphragm fiber atrophy, and residual dyspnoea, as well as poor clinical outcomes such as prolonged hospitalization and risk of nosocomial infection, sepsis, increased comorbidities, and subsequent death (Ahmed et al., 2019; Loss et al., 2015; Rose et al., 2017). In addition to the burden on medical resources and patients' physiological changes, the psychological distress and financial stress on their families are also significant; therefore, it is important that patients undergoing long-term use of mechanical ventilation are weaned as early as possible.

Many studies support the hypothesis that inspiratory muscle training affects the weaning parameters, including maximal inspiratory pressure, rapid shallow breathing index, weaning duration of ventilation, weaning success, and length of stay in the intensive care unit and hospital (Elkins & Dentice, 2015; Magalhaes et al., 2018; Martin et al., 2011; Worraphan et al., 2020). These studies mainly focused on interventions using inspiratory threshold loading devices, such as the study of Martin et al. (2011), or recruited patients who received mechanical ventilation for less than 21 days in intensive care units, such as studies by Caruso et al. (2005) and Elbouhy et al. (2014). In chronic RCWs, patients usually rely on PMV for more than 21 days, which results in prolonged immobilization, muscular atrophy, diaphragm dysfunction, and multi-morbidity. Therefore, the purpose of this study was to examine the impact of adjustment of ventilator trigger sensitivity as inspiratory muscle training on weaning parameters in patients with prolonged ventilator dependence in the chronic respiratory care ward.

Methods

Research Questions

The study aimed to determine whether patients with prolonged ventilator dependence in chronic RCWs who received the adjustment of ventilator trigger sensitivity training would have significantly (1) lower maximum inspiratory pressure, (2) lower rapid shallow breathing index, (3) higher tidal volume, (4) higher minute ventilation, and (5) higher oxygenation index than those who received the routine care.

Design, Setting, and Sample

A multiple pre-test–post-test with a non-equivalent control group study design was conducted at a chronic RCW in Southern Taiwan. A convenience sampling method was used to recruit 40 patients who required PMV for more than 21 days. The inclusion criteria were as follows: 1) agreement of participation from patients over 19 years of age or from a legal guardian (representative); 2) *ICD-10* diagnosis codes of J96.11- Chronic respiratory failure with hypoxia or J96.12-Chronic respiratory failure with hypercapnia combined with Z99.11-Dependence on respirator [ventilator] status; 3) hemodynamic stability, including body temperature: 36–38°C, blood pressure: between 90–140/60–90 mmHg, heart rate: between 50 and 100 beats/min, breathing pattern: 12–26 beats/min, oxygen saturation: 90%–100%, 4) maximal inspiratory pressure ≤−20 cmH_2O, 5) oxygen ventilation ≤40%, and positive end-expiratory pressure ≤8 cmH_2O; 6) ventilator with non-control mode, pressure support (PSV), and forced ventilation (synchronized intermittent mechanical ventilation, SIMV). The exclusion criteria were as follows: acute onset disease, use of a large amount of sedatives or muscle relaxants, and use of a ventilator with a control mode, which refers to a pressure control mode (pressure control, PCV) and a continuous positive airway pressure mode (continuous positive pressure ventilation, CPPV).

Intervention

The control group received routine care and the experimental group received the adjustment of ventilator trigger sensitivity training. As prolonged ventilator-dependent patients who were bedridden for a long time with ventilator-induced diaphragmatic dysfunction and deterioration of organ function, we consulted a thoracic physician and designed the intensity of intervention, which was once a day for five times a week, over a period of six weeks. The adjustment of ventilator trigger sensitivity training was changed weekly. In the first week of training, we adjusted the ventilator trigger sensitivity to 10% of the patient's initial MIP and trained the patients for 5 min/day for five days. In the second week of training, the adjustment of ventilator trigger sensitivity was increased to 20% of the initial MIP, and the training time increased to 10 min. The trigger sensitivity was increased to 40% of the initial MIP, and the patients were trained for 30 min in the sixth week. During the training, the bed was raised 45°, similar to Semi-Fowler's position, and research assistants constantly monitored patients' breathing patterns and blood oxygen concentrations. If a patient felt uncomfortable and showed symptoms of dyspnoea or shortness of breath, we stopped the training and tried again the next day. After each session, the trigger sensitivity was adjusted back to the original level for patients to rest, and the index was measured at the end of each week.

Outcome Assessment

In the literature, the common indicators for monitoring ventilator weaning are as follows:

1. Maximum inspiratory pressure (MIP or PImax) is the "negative inspiratory force" (NIF), which is considered as a sensitive measure of respiratory muscle strength, with a threshold value of <-30 cmH_2O highly predictive of weaning failure (Bissett et al., 2019).
2. The rapid shallow breathing index (RSBI) is the ratio of respiratory rate (RR) to tidal volume (VT) and is an indicator to identify patients at risk of failed extubation, with a threshold value of >105 breaths/min/L highly predictive of weaning failure (Karthika et al., 2016).
3. Tidal volume (TV or Vt) is the volume of air inhaled or exhaled by the lungs as a vital clinical parameter for proper ventilation, with a normal of approximately 500 ml or 4–6 L/kg of body weight for mechanical ventilation (Hallett et al., 2021).
4. Minute ventilation (MV or VE) is the total volume entering the lungs per minute and is equal to the TV multiplied by the RR, with an acceptable range of 10–15 L/min for ventilated patients (Hallett et al., 2021).
5. Arterial-to-inspired oxygen (PaO_2/FIO_2) ratio (P/F ratio) was calculated as FiO_2 (inspired fraction of oxygen) ÷ PaO_2 (partial pressure of oxygen), with a threshold value of <300 mmHg being highly predictive of weaning failure.

Although most participants in this study had disturbances in consciousness, we measured indicator 1 through the 60 cm H20 NIF pressure meter (NS60-PBR), indicators 2–4 through the Wright™ & Haloscale™ respirometers, and indicator 5 through an arterial blood gas test using a Roche OMNI® C analyzer. The control variables for both groups were sex, age, and laboratory data, including albumin, Na^+, and K^+.

Institutional Review Board Approval and Data Collection

This study was approved by the hospital ethics committee (No. 17-109-A) and registered in the ClinicalTrials.gov protocol registration with the number of NCT03997214. All methods were performed in accordance with the relevant guidelines and regulations. This research was conducted by thoracic physicians, respiratory therapists, and nursing staff in the hospital. The thoracic physician first confirmed that the patient's condition met the eligibility criteria, and the consent form was signed either by the patients themselves or their family members, as most patients were unconscious. The purpose, process, and risks of the study were explained to the family member before data were collected. Serial number coding was based on the actual order of acceptance. The predetermined odd-numbered column represented the control group (n = 20), while the even-numbered column represented the intervention group. After recruiting 40 patients, additional patients were allocated to the intervention group (n = 23) for the prevention of dropout. Participants and research assistance were blinded after assignment to interventions (Figure 1). The data were collected by a research assistant and repeated three times to ensure consistency. During the training period, both the intervention and control groups continued to receive routine care from the respiratory therapist. The intervention group received an additional inspiratory muscle training program to adjust the ventilator trigger sensitivity. The pre-test was performed before the intervention. During the six-week training, the patients' respiratory parameters were measured post-test at the end of each week for post-test analysis.

Statistical Analysis

IBM®SPSS® V22.0 was used for statistical analysis, and the statistical significance was set at $p < .05$. Descriptive statistics, such as percentages, means, and standard deviations, were used to describe the demographic characteristics and weaning parameters. A chi-squared test and independent-sample t-test were used to test for homogeneity of the variables. The treatment effects on weaning parameters were analyzed using the generalized estimating equation technique for repeated measurements.

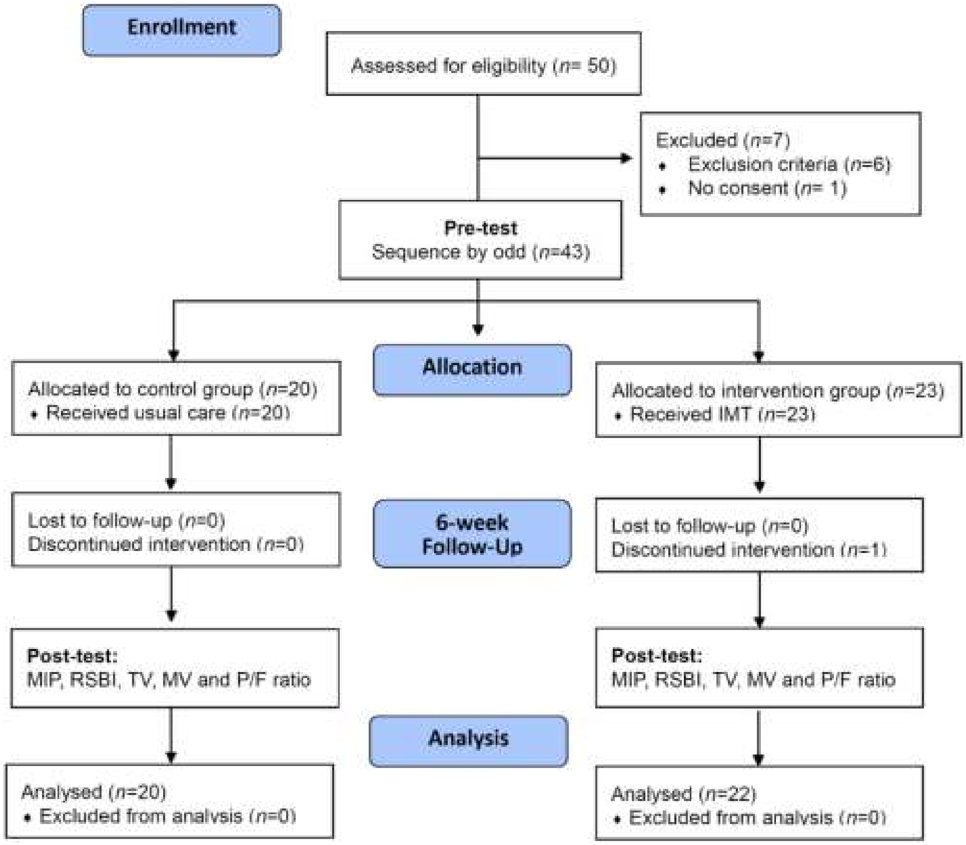

Figure 1. Flow diagram of the study.

Results

Demographic Characteristics and Homogeneity Test

A total of 43 participants were enrolled in this study from July 2018 to January 2019. During the study period, one patient in the training group dropped out of the study because of infection (Figure 1). Table 1 summarizes the demographic and clinical characteristics of the participants. The overall sex distribution was 23 men and 19 women, and the majority were diagnosed with CD. The distribution of sex (χ^2 = 0.423, p = .516) and diagnosis (χ^2 = 1.835, p = .607) between the two groups were homogeneous. The overall age ranged from 46 to 94 years, with mean ages in the intervention and control groups being 75.86 and 69.65 years old, respectively. The homogeneity test showed no significant difference in age between the two groups (t = −1.671, p = .103). The laboratory data of albumin, Na^+, and K^+ were normal before the intervention, with no significant difference between the two groups in albumin (g/dL) (t = 0.124, p = .902), Na^+ (mmol/L) (t = 0.280, p = .781), and K^+ (mmol/L) (t = 0.106, p = .916). The baseline data on MIP, TV, and P/F ratio have found significant differences ($p < .05$) between groups (Table 1). In particular, the control group had better weaning parameters than the intervention group; therefore, we used a generalized estimation equation to test the difference in the slopes of the two groups.

Effects of Inspiratory Muscle Training on Weaning Parameters

After controlling for the six variables of sex, age, diagnosis, electrolytes (Na^+ and K^+), and nutritional status (albumin), the results were as follows (Table 2):

1. Maximum inspiratory pressure (MIP)

There was a significant difference in the progress of MIP in the intervention group compared to the control group. The intervention group improved by 4.02 points ($\beta = -4.02$, p = .001) compared to the control group in the first week (MIP _1), with continued improvement until the sixth week (MIP _6, $\beta = -8.54$, $p < .001$). Figure 2 shows that after the intervention group received inspiratory muscle training, MIP increased with time. In contrast, MIP in the control group decreased over time. The magnitude of MIP increased more significantly in the intervention group than in the control group after the six-week training, as shown in Table 3 (Wald χ^2 = 75.05, $p < .001$).

2. Rapid shallow breathing index (RSBI)

There was no significant improvement in RSB until the fifth week (RSBI_5), and there was a significant difference in the progress of RSBI in the intervention group compared

Table 1. Homogeneity Test at Baseline.

Variables	Control (*n* = 20) *n*	%	Experimental (*n* = 22) *n*	%	Statistics χ^2	*p*
Sex					.42	.516
Female	12	55	11	50		
Male	8	45	11	50		
Diagnosis					1.84	.607
Nervous	2	10	1	5		
Circulatory	11	55	16	73		
Respiratory	4	20	2	9		
Surgical	3	15	3	14		
	Mean	SD	Mean	SD	*t-test*	*p*
Age	69.65	10.29	75.86	13.43	−1.67	.103
Albumin	3.70	.39	3.68	.30	.12	.902
Na^+	138.13	3.36	137.86	3.02	.28	.781
K^+	4.04	.51	4.02	.35	.11	.916
MIP	−19.00	2.00	−12.91	2.52	8.63	<.001
RSBI	139.95	37.59	155.28	25.86	2.08	.129
TV	225.95	33.39	200.95	33.67	1.55	.016
MV	6.88	1.45	6.25	1.66	1.30	0.199
P/F ratio	484.95	91.66	370.11	57.11	4.81	<.001

SD = standard deviation; MIP = maximum inspiratory pressure; RSBI = rapid shallow breathing index; TV = tidal volume; MV = minute ventilation; P/F ratio = ratio of arterial-to-inspired oxygen.

to that of the control group ($\beta = -31.41$). Figure 2 shows that after the intervention group received inspiratory muscle training, RSBI increased in the first week, and this value was maintained with time; in contrast, the value in the control group decreased with time. However, the magnitude of RSBI had a significantly greater increase in the intervention group than in the control group after the six-week training, as shown in Table 3 (Wald χ^2 = 15.44, p = .017).

3. Tidal volume (TV)

There was no notable improvement in TV between the groups for TV_1–TV_4. Until the fifth and sixth week, there was a significant difference in the progress of TV in the intervention group compared to the control group at TV_5 ($\beta = -60.65$) and TV_6 ($\beta = -46.99$). Figure 2 shows that the TV in the intervention group constantly increased with time after receiving inspiratory muscle training; in contrast, the TV in the control group decreased with time. The magnitude of TV increased more significantly in the intervention group than in the control group after the six-week training, as shown in Table 3 (Wald χ^2 = 22.50, p = .001).

4. Minute ventilation (MV)

Until the fifth week, there was a significant difference in the progress of MV in the intervention group compared to the control group at MV_5 ($\beta = 1.73$) and MV_6 ($\beta = 1.41$). Figure 2 shows that the MV in the intervention group steadily increased with time after receiving inspiratory muscle training. On the contrary, MV in the control group increased and decreased with time. Unfortunately, there was no significant difference in the magnitude of MV between both groups after the six-week training, as shown in Table 3 (Wald χ^2 = 8.857, p = .182).

5. Ratio of arterial-to-inspired oxygen (PaO_2/FIO_2, P/F ratio)

There was a significant difference in the progress of P/F ratio in the intervention group compared to that in the control group, and the intervention group had improved by 183.13 points ($\beta = 183.13$, $p < .001$) compared to the control group in the first week (P/F ratio_1). There was continuous improvement until the sixth week (P/F ratio_6, $\beta = 188.17$, $p < .001$). Figure 2 shows that the P/F ratio in the intervention group continually increased with time after receiving inspiratory muscle training. On the contrary, the P/F ratio in the control group decreased with time. The magnitude of the P/F ratio showed a significantly greater increase in the intervention group than in the control group after the six-week training, as shown in Table 3 (Wald χ^2 = 41.156, $p < .001$).

Discussion

This study confirmed that adjustment of ventilator trigger sensitivity for inspiratory muscle training can improve the MIP, RSBI, TV, and P/F ratio in patients with PMV, thereby increasing the possibility of weaning off from mechanical ventilation. In comparison with the Medical Statistics from the 2016 Annual Report on National Health Insurance (National Health Insurance Administration, 2016), the average age of prolonged ventilator-dependent patients in Taiwan was 69.44 years versus 72.90 years in this study, Moreover, the national distribution of sex was 286,083 men (59.64%) and 193,603 women (40.36%), *versus* 23 men (54.76%) and 19 women (45.24%) in the current study. The sex and ages of the patients in this study were similar to the national distribution of prolonged ventilator-dependent patients in Taiwan. The attrition rate in this study was 2.35% (1 of 43) in the intervention group which is acceptable with the following reasons: infection, fatigue, and dyspnoea due to training. The outcomes of this study (1) maximum inspiratory pressure, (2) rapid shallow breathing index, (3) tidal volume, (4) minute ventilation, and (5) oxygenation index are discussed in the following sections:

The MIP showed statistically significant differences between the two groups. The intervention group improved from −12.91 to −15.60 cmH_2O after six weeks of inspiratory muscle training, whereas the control group declined from −19.00 to −16.39 cmH_2O during routine care. In a pivotal analysis to observe intra-group variation, the MIP of the intervention group increased by 4.93% in the first week compared with previous measurements and progressively

Table 2. Comparison of Weaning Parameters Between the Intervention and Control Groups in Post-Tests T1–T6.

Variable_ Time	β	SE	Wald χ^2	*p*	95%	CI
MIP_1	−4.02	1.22	10.90	.001**	−6.41∼	−1.63
MIP_2	−4.00	1.47	7.43	.006**	−6.87∼	−1.12
MIP_3	−5.10	1.56	10.74	.001**	−8.15∼	−2.05
MIP_4	−7.24	1.57	21.34	<.001***	−10.32∼	−4.17
MIP_5	−8.09	1.51	28.61	<.001***	−11.05∼	−5.13
MIP_6	−8.54	1.33	41.51	<.001***	−11.13∼	−5.94
RSBI_1	−15.61	12.34	1.60	.206	−39.79∼	8.57
RSBI_2	−26.16	14.95	3.06	.080	−55.47∼	3.15
RSBI_3	−17.17	15.93	1.16	.281	−48.40∼	14.06
RSBI_4	−14.46	16.08	.81	.369	−45.98∼	17.06
RSBI_5	−31.41	15.47	4.13	.042*	−61.73∼	−1.10
RSBI_6	−22.72	13.47	2.84	.092	−49.12∼	3.68
TV_1	16.94	12.91	1.72	.189	−8.36∼	42.24
TV_2	22.70	15.93	2.03	.154	−8.52∼	53.92
TV_3	17.66	17.14	1.06	.303	−15.93∼	51.25
TV_4	19.64	17.33	1.28	.257	−14.34∼	53.61
TV_5	60.65	16.57	13.39	<.001***	28.17∼	93.13
TV_6	46.99	14.23	10.90	.001**	19.09∼	74.89
MV_1	−.13	.61	.04	.834	−1.32∼	1.06
MV_2	.14	.73	.04	.844	−1.29∼	1.57
MV_3	−.34	.77	.19	.665	−1.85∼	1.18
MV_4	−.08	.78	.01	.916	−1.61∼	1.45
MV_5	1.73	.75	5.28	.022*	.26∼	3.21
MV_6	1.41	.66	4.57	.033*	.12∼	2.70
P/F ratio_1	183.13	50.77	13.01	<.001***	83.63∼	282.64
P/F ratio_2	146.70	55.28	7.04	.008**	38.35∼	255.06
P/F ratio_3	137.44	56.07	6.01	.014*	27.55∼	247.34
P/F ratio_4	171.46	56.12	9.34	.002**	61.47∼	281.45
P/F ratio_5	200.75	55.61	13.03	<.001***	91.76∼	309.74
P/F ratio_6	188.17	52.47	12.86	<.001***	85.32∼	291.02

SE = standard error; CI = confidence interval; MIP = maximum inspiratory pressure; RSBI = rapid shallow breathing index; TV = tidal volume; MV = minute ventilation; P/F ratio = ratio of arterial-to-inspired oxygen; **p* < .05; ***p* < .01; ****p* < .001.

increased to 9.20%–9.40% in the second and third weeks. The results of this study proved that patients with prolonged ventilator dependence who received ventilator trigger sensitivity training had significantly improved MIP compared with those who did not receive it in the chronic respiratory care ward. Only two studies (Caruso et al., 2005; Elbouhy et al., 2014) used adjustments to ventilator trigger sensitivity training in the acute respiratory unit. A significant improvement in MIP after a five-day training was seen in the Elbouhy et al.'s study. However, Caruso et al.'s study did not find a clear trend of improvement in the intervention group. The inclusion criteria of Caruso et al.'s study included patients receiving controlled ventilation or pressure support ventilation, which was different from those in this study. We recruited patients receiving ventilator in non-control mode, that is, pressure support (PSV) and forced ventilation (synchronized intermittent mechanical ventilation, SIMV).

The results of the RSBI breathing index in the intervention group improved from 155.28 breaths/min/L to 149.16 breaths/min/L, whereas that of the control group worsened from 139.95 to 165.99. A significant difference between groups answered our second research question that patients with prolonged ventilator dependence who underwent adjustment of ventilator trigger sensitivity training had significant improvements in RSBI compared to those who did not receive it in the chronic respiratory care ward. No similar study has compared the results of RSBI; however, Elbouhy et al.'s study (2014) found a significant decrease in the RR in the intervention group. The RSBI was found to be the most studied parameter for predictive factors of weaning success from mechanical ventilation and extubation outcomes in a systematic review of 15 studies involving 2159 patients (Baptistella et al., 2018). A study of patients with PMV found that exercise training was effective in improving RSBI (Chen et al., 2012), which was consistent with our findings.

The TV in the intervention group increased from 200.95 to 210.25 ml/kg, whereas that of the control group declined from 225.95 to 210.98 ml/kg. Patients who rely on PMV may have a lower TV due to increased physiological dead

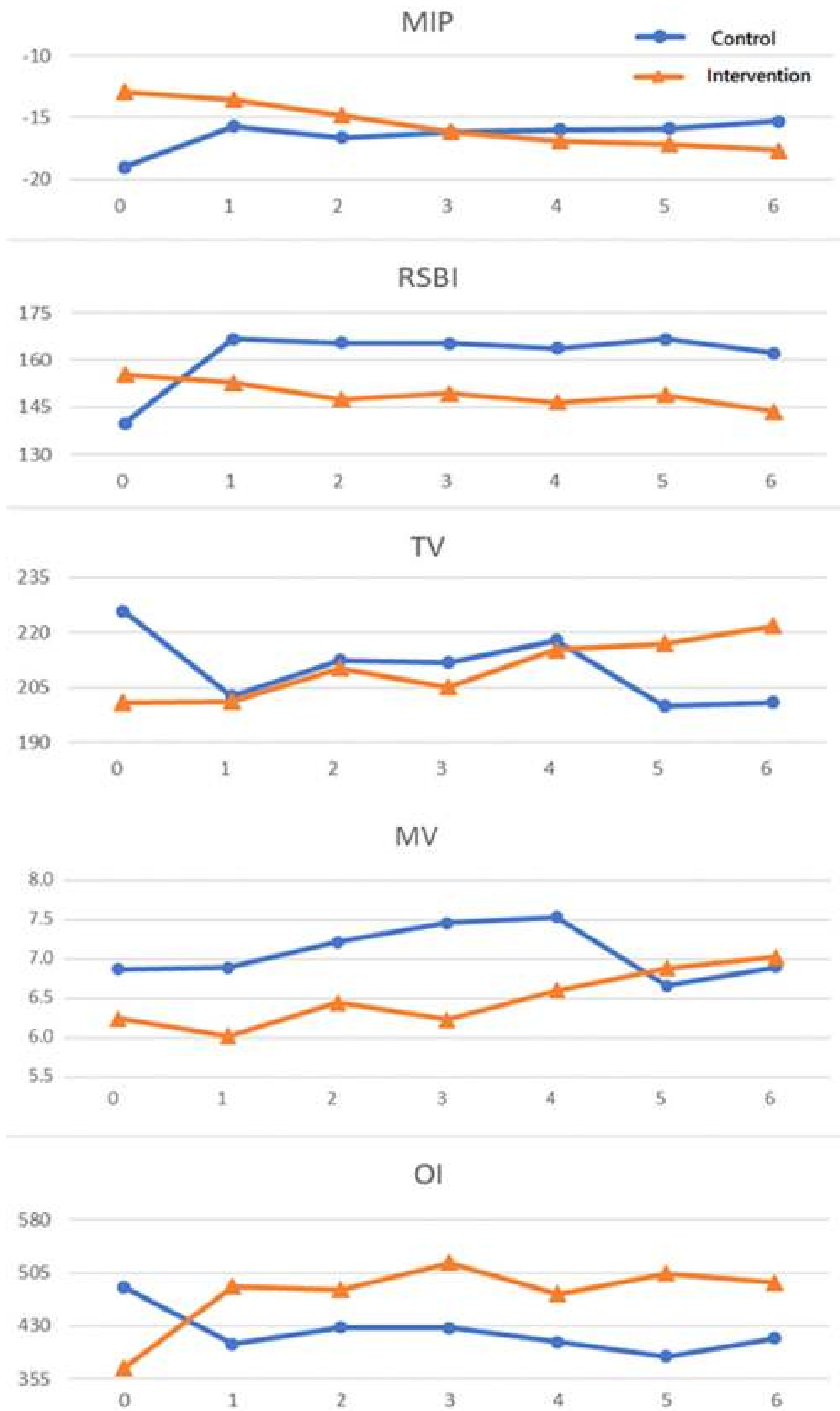

Figure 2. Mean scores of weaning parameters across seven time periods for experimental and control groups.

Table 3. Comparison of Weaning Parameters Between the Intervention and Control Groups in the Pre and Post-Tests.

	Control Pre-test M ± SD	(n = 20) Post-test M ± SD	Intervention Pre-test M ± SD	(n = 22) Post-test M ± SD	Group× Wald χ^2	Weeks p
MIP	−19.00 ± 2.00	−16.39 ± 3.15	−12.91 ± 2.52	−15.60 ± 3.46	75.05	<.001
RSBI	139.95 ± 37.59	165.99 ± 43.14	155.28 ± 25.86	149.16 ± 28.73	15.44	.017
TV	225.95 ± 33.39	210.98 ± 37.62	200.95 ± 33.67	210.25 ± 37.35	22.50	.001
MV	6.88 ± 1.45	7.08 ± 1.41	6.25 ± 1.66	6.50 ± 1.65	8.86	.182
P/F ratio	484.95 ± 91.66	421.48 ± 79.36	370.11 ± 57.11	475.07 ± 130.33	41.16	<.001

SD = standard deviation; MIP = maximum inspiratory pressure; RSBI = rapid shallow breathing index; TV = tidal volume; MV = minute ventilation; P/F ratio = ratio of arterial-to-inspired oxygen.

space, as the breathing circuit does not participate in gas exchange (Intagliata et al., 2021). A pivot analysis showed variations in the intervention group and found that the TV slightly increased by 0.11% in the first week, notably increased by 4.52% in the second week, and fell to 2.42% in the third week compared with pre-test parameters. The overall effectiveness of the adjustment of ventilator trigger sensitivity training on TV was proven, which is similar to the findings of Elbouhy et al. (2014). The similarity in the effects of inspiratory muscle training on TV has also been reported in the literature (Chen et al., 2012; Condessa et al., 2013).

The MV increased from 6.25 to 6.50 L/min in the intervention group, while that of the control group increased from 6.88 to 7.08 L/min. The significance of observed differences between two groups in the fifth and sixth weeks demonstrated the cross-point phenomena, wherein the MV was rising in the intervention group and deteriorating in the control group. However, the overall effects of MV did not differ significantly between the two groups. MV is seldom used as an indicator for weaning parameters because it is equal to the TV multiplied by the RR which is easily affected by factors such as age, sex, body figure, and inspiratory muscle training. Although the TV in this study showed significant improvement after the intervention, the adjustment of ventilator trigger sensitivity training significantly decreased the RR Elbouhy et al.'s study (Elbouhy et al., 2014), which may explain why the MV could not reach a significant difference as the two parameters counterweighed each other. In addition, participants with PMV deteriorated and were bedridden for longer due to the variability in their RR (Guedes et al., 2018).

The P/F ratio in the intervention group improved from 370.11 to 475.07 mmHg, while that in the control group declined from 484.95 to 421.48 mmHg. The overall effectiveness in the two groups was statistically significant. A pivot analysis found that the variations in the P/F ratio in the intervention group increased to 31.15% in the first week and were maintained thereafter. Patients who received ventilator trigger sensitivity training had significantly improved respiratory parameters compared to those who did not. The findings were similar to those of Elbouhy et al. (2014) who found a significant improvement in PaO_2 and O_2 saturation in patients who received ventilator trigger sensitivity training.

Strengths and Limitation

This study has several limitations. Although the homogeneity between intervention group and control group was controlled for sex, age, and laboratory data including albumin, Na^+, and K^+, the control group has better baseline weaning parameters than the intervention group, including MV, TV, and P/F ratio. Therefore, we used GEE statistics to adjust for baseline differences and analyze treatment effects. Second, recruitment was undertaken at one chronic respiratory care ward with small sample size; thus, the characteristics of the patients in the current study may differ from patients in other respiratory care wards, which may limit the generalizability of the study's findings. However, the homogeneity analyses on age and sex between this study and the medical statistics of Taiwan National Insurance have confirmed equal across groups.

Although patients with PMV often have other comorbidities leading to respiratory failure and being bedridden for long periods, due to safety reasons, we chose the outcome variables of weaning parameters instead of outcomes related to weaning success, as well as revised the training intensity to once a day for six weeks and adjustment of ventilator trigger sensitivity to 10% of the initial MIP. This differed from previous studies (Caruso et al., 2005; Elbouhy et al., 2014). For future study, we suggest using a randomized control design for a more robust research trial; recruitment of different settings for large samples; and the use of a study protocol to examine the patients in other contexts, in order to gain more insight into the effectiveness of the adjustment of ventilator trigger sensitivity training among patients of different cultures, in future studies on the topic.

Implications for Practice

On the basis of our findings, the adjustment of ventilator trigger sensitivity is feasible, tolerable, and relatively minimal time requirement for mechanically ventilated patients. Especially, this method does not cost a threshold loading device for inspiratory muscle training as well as manpower for training and is safe for respiratory nurse specialists or practitioners to perform on patients as part of routine care in a chronic respiratory care ward. Adjustment of ventilator trigger sensitivity is feasible and suitable for patients who use a ventilator with non-control mode and without sedation, or physiologic instability. Progressive resistance training starts from 10% of initial maximum inspiratory pressure for 5 min and increases to 40% for 30 min within six weeks of training, suggesting a strengthening effect of training and a potential treatment strategy to facilitate ventilator weaning.

Conclusion

This preliminary study provides valuable insight into the effects of ventilator adjustment on the improvement of weaning parameters in patients with prolonged ventilator dependence in chronic RCWs. In particular, patients in the chronic RCWs are often unconscious, under prolonged immobilization, which causes limb contractures, inability to perform rehabilitation exercises due to muscular atrophy, and weakness from diaphragm dysfunction and multi-morbidity, which render weaning difficult. Inspiratory muscle training is an essential intervention for patients with PMV to help improve their muscle strength and endurance, thereby shortening their fatigue or weakness, which ultimately results in decreased ventilator dependence and an increased chance of successful weaning off ventilation.

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Authors' Note

This study approved by the institutional review board of Antai Tian-Sheng Memorial Hospital (TSMH IRB No. 17-109-A). Clinical Trial Registration Number NCT03997214. Due to the nature of this research, participants of this study did not agree for their data to be shared publicly. However, the data that support the findings of this study are available from the co-author, Hsiang-Chun HSIAO, upon reasonable request without ethical concerns. HYC: conceptualization, methodology, and writing; HCH: project administration, data curation, formal analysis, and reviewing. HLC: resources and reviewing. The effect that all authors have read and approved the manuscript and ensure that this is the case.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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