Effect of post-extubation inspiratory muscle training on diaphragmatic function in mechanically ventilated patients: A randomized controlled trial

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Abstract

Background. Diaphragmatic dysfunction is a common problem in patients who have been mechanically ventilated.

Objectives. The study aimed to evaluate the effectiveness of inspiratory muscle training (IMT) on diaphragm muscle thickness and function in mechanically ventilated patients.

Materials and methods. A single-blind trial was conducted. Twenty patients were randomly assigned to either the conventional physiotherapy (CP) group or to the IMT group for 5 days following extubation. The CP group received only CP, while the IMT group received CP in addition to IMT. Ten healthy controls (HCs) underwent IMT. Maximum inspiratory pressure (MIP) and physical function were recorded. Diaphragm excursion (DE), diaphragm thickness at the end of inspiration (Td_i), diaphragm thickness at the end of expiration (Td_e), peak contraction velocity (PCV), and peak relaxation velocity (PRV) were evaluated with ultrasonography before and after the intervention.

Results. The IMT group and HCs showed significant improvements in DE ($p = 0.005$; $p = 0.005$, respectively), PCV ($p = 0.028$; $p = 0.015$, respectively) and PRV ($p = 0.029$; $p = 0.020$, respectively) after 5 days of IMT. A significant increase in MIP was recorded in all groups after the intervention (CP: $p = 0.044$; IMT: $p = 0.005$; HC: $p < 0.001$). There was a significant improvement in the Medical Research Council (MRC) and the Physical Function in Intensive Care Test (PFIT) scores in both the CP and IMT groups ($p < 0.001$ and $p < 0.001$, respectively).

Conclusions. Inspiratory muscle training improves diaphragmatic functions, including MIP, diaphragm excursion, PCV, and PRV. We think that IMT applied after extubation may serve as a tool to prevent and facilitate the recovery of diaphragmatic function.

Key words: weaning, inspiratory muscle training, diaphragm dysfunction, diaphragmatic ultrasonography, tissue Doppler imaging

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Background

Mechanical ventilation (MV) is commonly used to alleviate the work of breathing and reduce diaphragm activity in patients with acute respiratory failure.[1] Even though MV is a crucial intervention, studies have shown that within 18–69 h after MV, diaphragm muscle fibers are more susceptible to proteolysis, and the respiratory muscles begin to deteriorate more rapidly. This leads to respiratory muscle weakness that is about twice as prevalent as extremity muscle weakness (63% compared to 34%) in patients who have been on MV for at least 24 h.[2,3] The progressive development of diaphragmatic atrophy during the early periods of MV indicates that there has been prolonged ventilation and an increased risk of complications associated with acute respiratory failure. In patients with respiratory failure, clinical outcomes may improve if diaphragmatic atrophy and function are preserved in the early stages of critical illness.[4] It has been demonstrated that MV-related dysfunction of the diaphragm and respiratory muscles contributes to prolonged MV, weaning failure, persistent dyspnea, and prolonged stay in the intensive care unit (ICU).[5,6]

Diaphragmatic ultrasound (US), which is a bedside, noninvasive and reproducible method, may be a good option for monitoring diaphragmatic structure abnormalities and function in the ICU. It provides reliable measures of diaphragm excursion (DE), diaphragm thickness (DT) and diaphragm thickening fraction (DTF). Tissue Doppler imaging (TDI) is a commonly used method that measures the velocity of moving tissues; however, there is limited research on diaphragmatic TDI. Soilemezi et al. found that the contraction and relaxation velocities of diaphragmatic tissue were significantly lower in the ICU patients compared to the healthy volunteers, which is correlated with a failure to wean. The use of diaphragmatic ultrasound and TDI may early detect diaphragmatic dysfunction and prompt intervention in the ICU.[7]

Inspiratory muscle training (IMT) provides resistance to the respiratory muscles independent of inspiratory flow, based on threshold pressure load and maximum inspiratory pressure.[8,9] It facilitates weaning in mechanically ventilated patients, including those with weaning difficulties such as chronic obstructive pulmonary disease (COPD), by increasing their respiratory muscles' strength and endurance.[10] Inspiratory muscle training can be used as a feasible, well-tolerated clinical strategy to prevent diaphragmatic dysfunction and improve short- and the long-term clinical outcomes.

Objectives

The main objective of our study was to evaluate the effect of IMT on diaphragmatic structure and function in respiratory ICU patients after extubation. This study is the first to investigate the ultrasonographic effects of IMT on diaphragm structure and function following extubation. It is anticipated that this research can make significant contributions to the relevant literature and can potentially serve as a pioneering reference for future studies in this context.

Materials and methods

Study design

A prospective randomized controlled trial (RCT) was conducted as a single-center, single-blind study at a university hospital in the Respiratory ICU. The study was approved by the Marmara University Faculty of Medicine Clinical Research Ethics Committee (protocol No. 09.2020.976) and was performed in accordance with the Declaration of Helsinki. The study was registered as a prospective RCT at clinicaltrails.gov (registration No. NCT05303623).

The study involved 3 groups: IMT group, conventional physiotherapy (CP) group and healthy controls (HCs). Randomizer.org was used to assign patients to either the IMT or the CP group after confirmation of eligibility and baseline assessments.

Participants

Healthy controls aged 18–80 years with a body mass index (BMI) less than 40 kg/m^2 and without any chronic disease or ongoing treatment were included in the study. For the patient group, the inclusion criteria were as follows: age 18–80 years, mechanically ventilated for more than 2 days, Sedation Agitation Score = 4, and hemodynamic stable (heart rate <140 beats/min and stable blood pressure). Patients with severe arrhythmia, congestive heart failure, unstable ischemic heart disease, lack of alertness and cooperation, chest wall trauma and/or deformity, progressive neuromuscular diseases, excessive secretion (requiring aspiration every hour), continuous use of sedative drugs, or home MV before ICU admission were excluded.

Intervention

The CP group received CP, including breathing exercises, thoracic expansion exercises, coughing and gradual mobilization, once a day for 5 days after extubation. In addition to CP, the IMT group underwent IMT while in a high sitting position under the supervision of a physiotherapist. Inspiratory muscle training was performed at 30% of maximum inspiratory pressure (MIP) for 5 days, twice a day, consisting of 30 breaths, 4 sets, 6–8 breaths per set, and 2-min rest between sets using a threshold-loaded PowerBreathe Medic Plus® device (PowerBreathe International Ltd. Southam, UK). The intervention was

terminated if hemodynamic instability occurred before, during or after treatment. Inspiratory muscle training was performed on HCs using the same protocol as that used for the IMT group.

Measurements

Characteristics of patients

Demographic details such as age, gender, body weight, height, and BMI (Table 1), as well as clinical features of patients such as the primary diagnosis upon admission to ICU, duration of MV, length of stay in the ICU, total hospitalization time, medications, comorbidities, and medical history were included (Table 2). The severity of the illness was assessed using the APACHE II within 24 h of ICU admission.

Ultrasonographic assessments

Ultrasonographic assessments were performed on each patient's right hemidiaphragm while lying on the bed at 20–30°. Examinations were performed using a Mindray ultrasound device (Mindray. Shenzhen, China). Diaphragm thickness, excursion and diaphragm tissue Doppler imaging are presented in Fig. 1. The Supplementary files provide further information regarding the ultrasonographic measurements.

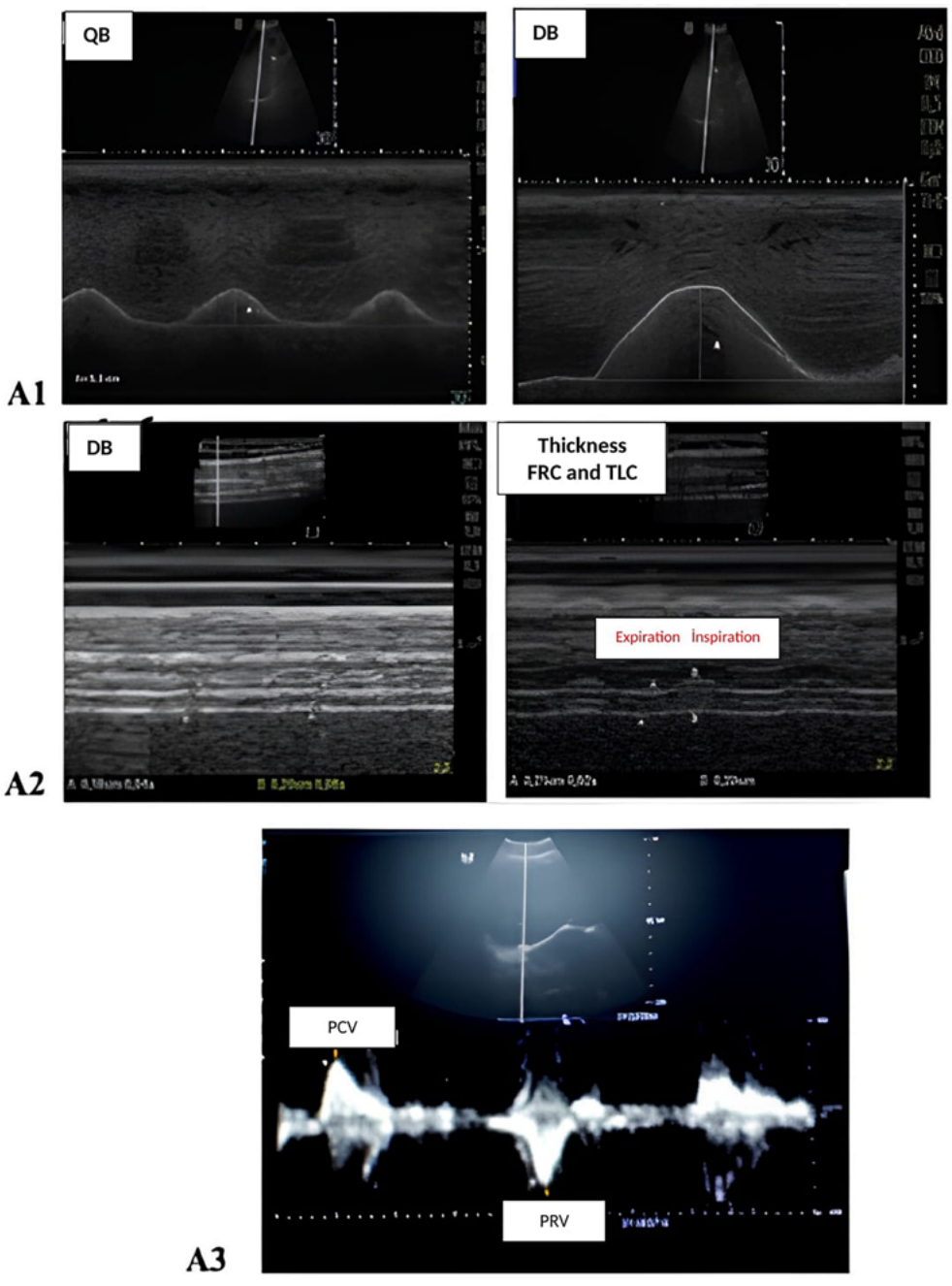

Fig. 1. Panel of diaphragm ultrasound images

A1. M-mode ultrasonography of the right hemidiaphragm showing mobility during quiet breathing (QB) and deep breathing (DB); A2. M-mode ultrasonography of the right hemidiaphragm showing normal end-inspiratory thickness (FRC), normal thickening (TF) and maximal thickness (TLC); A3. Tissue Doppler imaging of right diaphragm showing peak contraction velocity (PCV) and peak relaxation velocity (PRV)

Table 1. Demographics of study participants

Characteristics	CP (n = 10)	IMT (n = 10)	Healthy controls (n = 10)	p-value[a]	Post hoc test p-value[b] G1–G2 G1–G3 G2–G3
Age [year]; M ±SD	62.8 ±16.37	64.10 ±8.21	51.8 ±11.4	0.081[a] F = 2.762	–
Gender [M/F]	8/2	8/2	5/5	0.240[a] X^2 = 2.857	–
Weight [kg], M ±SD	66 ±18.5	79.2 ±8.5	82.5 ±15.5	0.045[a] F = 3.493	0.168 0.057 0.999
Height [cm], M ±SD	165.4 ±6.2	166.1 ±6.7	168.2 ±9.06	0.685[a] F = 0.383	–
BMI [kg/cm^2], M ±SD	23.5 ±5.31	28.93 ±4.4	28.8 ±3.6	0.017[a] F = 4.744	0.035 0.042 0.999

CP – conventional physiotherapy; IMT – inspiratory muscle training; M – mean; SD – standard deviation; BMI – body mass index; [a] one way analysis of variance (ANOVA) test; [b] Tukey's honest significant difference and Games–Howell post hoc tests were performed following ANOVA; G1 – CP group; G2 – IMT group; G3 – healthy control.

Table 2. Baseline characteristics of patients

Characteristics		CP (n = 10)	IMT (n = 10)	p-value
Diagnosis, n (%)	COPD yes/no	9 (90%)/1 (10%)	6 (60%)/4 (40%)	0.051[a] X^2 = 1.053
	Toxic gas inhalation yes/no	1 (10%)/9 (90%)	0 (0%)/10 (100%)	0.305[a] X^2 = 1.574
	Postoperative pneumonia yes/no	0 (0%)/10 (100%)	1 (10%)/9 (90%)	0.531[a] X^2 = 2.102
	Cardiogenic pulmonary edema yes/no	0 (0%)/10 (100%)	1 (10%)/9 (90%)	0.531[a] X^2 = 2.102
	Interstitial lung disease yes/no	0 (0%)/10 (100%)	1 (10%)/9 (90%)	0.763[a] X^2 = 0.001
	Metabolic acidosis yes/no	1 (10%)/9 (90%)	0 (0%)/10 (100)%	0.305[a] X^2 = 1.574
Comorbidities, n (%)	Hypertension yes/no	4 (40%)/6 (60%)	3 (30%)/7 (70%)	0.639[a] X^2 = 0.220
	Diabetus mellitus yes/no	8 (80%)/2 (20%)	4 (40%)/6 (60%)	0.003[a] X^2 = 9.899
	Atrial fibrillation yes/no	1 (10%)/9 (90%)	1 (10%)/9 (90%)	0.763[a] X^2 = 0.001
	Obstructive sleep apnea yes/no	0 (%0)/10 (100%)	1 (10%)/9 (90%)	0.305[a] X^2 = 1.606
	Sequela of tuberculosis yes/no	0 (%0)/10 (100%)	1 (10%)/9 (90%)	0.305[a] X^2 = 1.606
	Anxiety disorder yes/no	0 (%0)/10 (100%)	1 (10%)/9 (90%)	0.305[a] X^2 = 1.606
	Chronic heart failure yes/no	0 (%0)/10 (100%)	1 (10%)/9 (90%)	0.136[a] X^2 = 2.224
Lenght of stay in ICU [days], M ±SD		7.6 ±2.80	7.3 ±2.00	0.910[b] t = 0.278
Lenght of stay in hospital [days], M ±SD		11.7 ±1.80	12.5 ±5.00	0.999[b] t = –0.481
Intubation time [days], M ±SD		4.5 ±1.60	3.9 ±1.20	0.390[b] t = 0.931
APACHE II scores, M ±SD		26.8 ±4.46	27.0 ±4.4	0.922[b] t = –0.099

CP – conventional physiotherapy; IMT – inspiratory muscle training; COPD – chronic obstructive pulmonary disease; M – mean; SD – standard deviation; APACHE II – acute physiology and chronic health evaluation score; ICU – intensive care unit; [a] – Pearson's X^2 test; [b] – independent sample t-test.

B and M mode ultrasonographic evaluation of the diaphragm

B-Mode US at the zone of apposition was used to demonstrate diaphragm muscle between 2 parallel echogenic lines, the diaphragmatic pleura and peritoneal fascia, as previously described.[11] A 10 MHz linear array transducer was positioned perpendicular to the chest wall near the mid-axillary line between the 8th and 11th intercostal spaces. Diaphragm thickness (DT) was measured in the M mode at the end of inspiration (Td_i) and at the end of expiration (Td_e). The diaphragm thickening fraction (DTF) was calculated according to the formula (Eq. 1)

$$DTF = \frac{(\text{end-inspiratory thickness} - \text{end-expiratory thickness})}{\text{end-expiratory thickness}} \times 100\% \quad (1)$$

The subcostal approach was used to evaluate diaphragm excursion (DE). A 5 MHz convex probe was positioned below and parallel to the costal margin between the anterior axillary line (AAL) and the midclavicular line. The diaphragm was visualized with B-Mode US and the DE was calculated with M-Mode US; a single investigator analyzed all US recordings blinded to the clinical outcomes and the patient's research group. All ultrasound measurements were repeated on at least 3 separate breaths and the highest value was recorded.

Tissue Doppler imaging

Tissue Doppler imaging (TDI) views were obtained using a convex probe with a frequency of 2.7 MHz, placed in the subcostal area between the midclavicular and anterior axillary lines. The probe was angled to ensure that the ultrasound waves reached the diaphragm as perpendicular as possible. A sample volume of 5.0 mm and velocity scale of 20.6 cm/s were selected. Two parameters were measured on each TDI waveform: peak contraction velocity (PCV), defined as the maximal diaphragmatic velocity during contraction, measured in cm/s; and peak relaxation velocity (PRV), defined as the maximal diaphragmatic velocity during relaxation, measured in cm/s. Participants were instructed to perform deep breathing during TDI measurements after 8–10 tidal breaths. The highest value for the 3 deep breaths was recorded.

Maximum inspiratory pressure

Maximum inspiratory pressure was measured using the method described using Marini et al. with the MicroRPM® device (Care Fusion, Wokingham, UK), which uses a one-way expiratory valve to selectively allow exhalation while blocking inspiration.[12] Patients were positioned in a high sitting position and performed 3 inspiratory maneuvers. The highest value was recorded. There should be less than 10% or 10 cm H_2O difference between the best measured MIP values.

Physical assessment

Limb muscle strength was assessed using the Medical Research Council (MRC) score which involves evaluating the manual muscle strength of 6 muscle groups bilaterally. Each muscle group was scored on a scale of 0 to 5, with 0 indicating no contraction and 5 indicating full-force contraction. The muscle groups evaluated were shoulder abductors, elbow flexors, wrist extensors, hip flexors, knee extensors, and ankle dorsiflexors. The maximum possible MRC score was 60, and an MRC score of less than 48 was characteristic of ICU-acquired weakness. The Physical Function in Intensive Care Test (PFIT) was performed according to Skinner et al.[13] The PFIT included sit-to-stand with assistance, marching in place, and evaluation of shoulder flexion and knee extension strength. The number of steps taken while marching in place and the time taken to complete each component were recorded. The PFIT score ranges from 0 to 12.

Statistical analyses

IBM SPSS for Windows 22.0 (IBM Corp., Armonk, USA) was used to analyze the data. Numbers, percentages, means (M), and standard deviations (SD) were used for descriptive statistics. Shapiro–Wilk test was used to assess the distribution pattern of the variables (Supplementary data). Results are expressed as mean ± standard deviation (M ±SD) for normal distribution or median (Q1–Q3) for non-normal distribution. Differences between the ratios of categorical variables in the independent groups were analyzed using Pearson χ^2 and Fisher's exact tests. Within group analyses, paired sample t-tests were used for data that followed a normal distribution before and after intervention, while the Wilcoxon signed rank test was used for data that did not follow a normal distribution. Between group analyses, the one-way analysis of variance (ANOVA) test was applied to normally distributed data. Homogeneity of variances in the one-way ANOVA test was assessed using the Levene's test (online supplement). For results where the Levene's test yielded $p < 0.05$, the Welch's test significance values were assessed. The Tukey's honest significant difference post hoc tests were performed following analysis of variance. The sample size with the G*Power 3.1.9.7 (https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower) program (the number of participants that should be included in each group for 80% power) was calculated as at least 10 people (effect size: 0.3, α:0.05).[14]

Results

A total of 122 patients and 11 HCs were recruited between September 2021 and December 2022. Twenty patients and 10 HCs were included in the analysis. A flowchart of the patient and HC subject selection process is presented in Fig. 2. Inspiratory muscle training group completed 95%

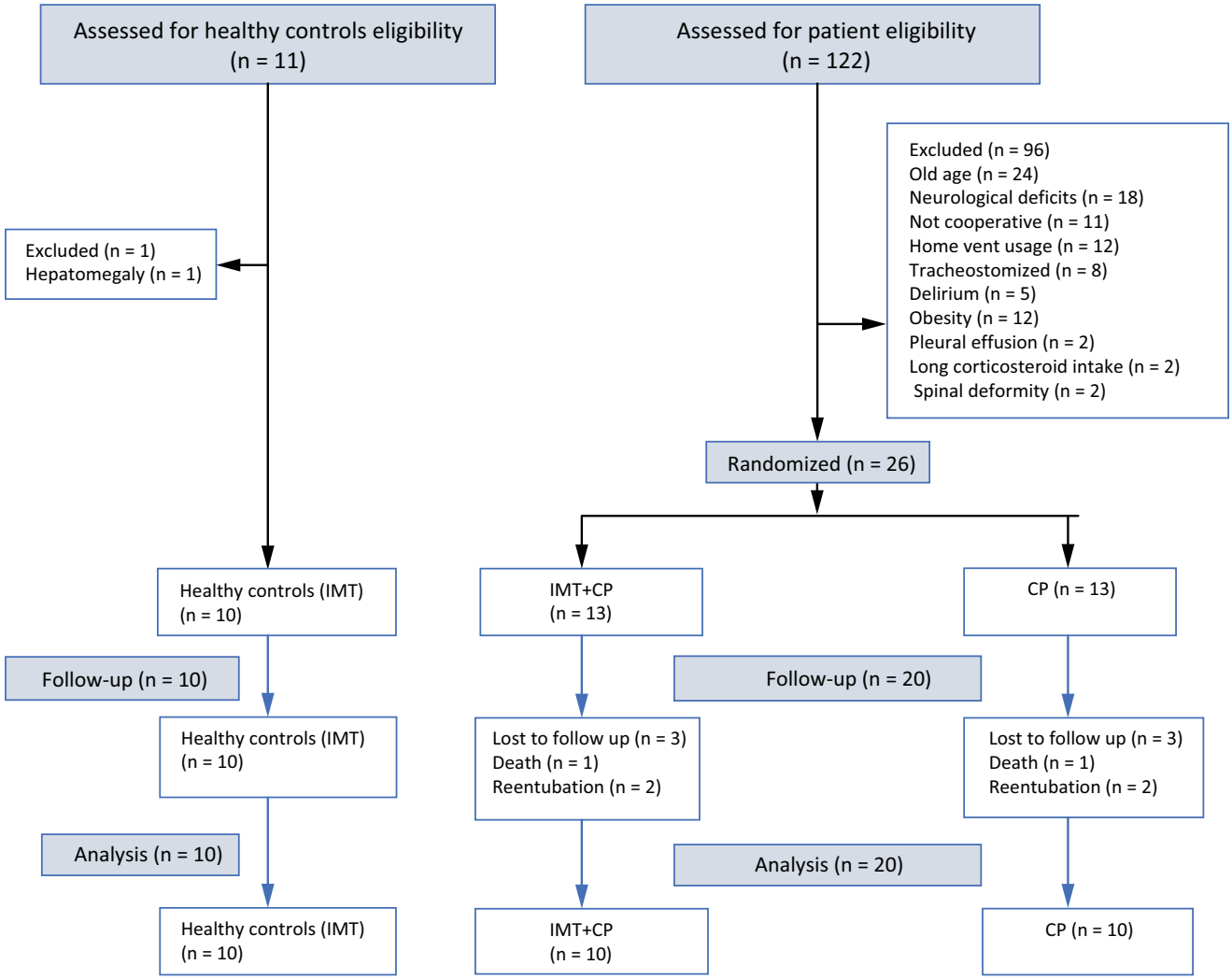

Fig. 2. Flowchart of the study

of planned IMT and physiotherapy sessions, CP group completed 80% of planned physiotherapy sessions, and HC group completed 95% of planned IMT sessions. The participants' characteristics are presented in Table 1. The weight and BMI of the HC group were significantly higher than of the CP group ($p = 0.045$). The IMT group had a significantly higher BMI than the CP group ($p = 0.017$). The baseline characteristics and features of patients were similar for most of the parameters, ICU stay duration ($p = 0.910$) and length of hospital stay ($p = 0.999$) as shown in Table 2. The effects of the intervention on diaphragm function in patients and HCs are presented in Table 3. Diaphragm excursion measurements did not significantly change pre- and post-intervention in the CP group ($p = 0.285$), but significantly increased in the HCs and IMT groups post-intervention compared to pre-intervention ($p = 0.005$ and $p = 0.005$, respectively). The increase in PCV measurements was significantly higher in the IMT and HCs than in the CP group ($p = 0.028$ and $p = 0.015$, respectively). There was a statistically significant difference in the change in PRV pre- and post-intervention between the IMT and HC groups ($p = 0.029$ and $p = 0.020$, respectively). The effects of intervention on MIP in patients and HCs are presented in Table 3. A statistically significant increase was found between pre- and post-intervention MIP in all groups (CP, $p = 0.044$; IMT, $p = 0.005$; and HCs, $p < 0.001$). Only the increase in predicted MIP% in the healthy group was statistically significant ($p < 0.001$). There was no significant difference in pre-intervention MRC and PFIT scores among CP and IMT groups. In the CP group, post-intervention MRC (51.2 ±6.61) and PFIT score (9.00 ±1.41) improved statistically compared to pre-intervention MRC score (47.8 ±7.33) and PFIT score (4.0 ±0.47; $p < 0.001$; $t = -5.667$, $p < 0.001$; $t = -10.607$). In the IMT group, post-intervention MRC (55.6 ±4.79) and PFIT score (10.30 ±2.45) improved statistically compared to pre-intervention MRC score (51.0 ±6.4) and PFIT score (4.80 ±1.38) ($p < 0.001$; $t = -5.438$, $p < 0.001$; $t = -11.524$).

Discussion

This study is the first to demonstrate that IMT can improve diaphragmatic function and MIP in mechanically

Table 3. Comparison of outcomes within groups

Outcomes	Outcomes and groups	Pre-mean	Post-mean	Estimated mean difference (post–pre) mean (95% CI)	Within group p-value
DE [cm]; median (Q1–Q3)	CP group	4.35 (4.97–3.53)	4.81 (3.70–6.08)	0.46 (–1.68–2.95)	0.285[a]; Z = –1.070
	IMT group	3.55 (3.06–4.60)	4.31 (3.77–5.16)	0.76 (0.06–1.98)	0.005[a]; Z = –2.805
	HC group	5.53 (5.38–5.99)	6.24 (5.48–6.57)	0.71 (0.05–1.21)	0.005[a]; Z = –2.803
Td_i [cm]; median (Q1–Q3)	CP group	0.24 (0.21–0.32)	0.25 (0.21–0.30)	0.01 (–0.18–0.07)	0.553[a]; Z = –593
	IMT group	0.28 (0.24–0.32)	0.28 (0.25–0.42)	0.00 (–0.03–0.47)	0.315[a]; Z = –323
	HC group	0.26 (0.24–0.31)	0.28 (0.26–0.32)	0.02 (0.00–0.06)	0.011[a]; Z = –2.555
Td_e [cm]; median (Q1–Q3)	CP group	0.18 (0.16–0.28)	0.20 (0.16–0.23)	0.02 (–0.10–0.02)	0.810[a]; Z = –240
	IMT group	0.22 (0.19–0.25)	0.24 (0.21–0.31)	0.02 (0.00–0.38)	0.200[a] Z = –679
	HC group	0.21 (0.20–0.22)	0.22 (0.21–0.24)	0.01 (–0.01–0.02)	0.058[a] Z = –1.897
DTF (%); M ±SD	CP group	27.63 ±10.6	28.56 ±14.41	–0,93 (–8.94–7.07)	0.798[b];t = –0.263
	IMT group	28.31 ±11.91	28.22 ±9.03	0.093 (–7.33–7.51)	0.978[b];t = 0.028
	HC group	23.78 ±8.99	28.37 ±8.03	–4.59 (–11.7–2.54)	0.179[b];t = –1.456
PCV [cm/s]; M ±SD	CP group	11.05 ±2.30	11.12 ±2.21	–0.07 (–1.29–1.14)	0.893[b]; t = –0.139
	IMT group	9.09 ±2.21	10.02 ±2.60	–0.927 (–1.72––0.12)	0.028[b]; t = –2.625
	HC group	11.02 ±2.39	14.45 ±2.70	–0.738 (–1.29––0.18)	0.015[b]; t = –3.015
PRV [cm/s]; M ±SD	CP group	11.5 ±2.63	10.68 ±1.81	0.81 (–0.68–2.32)	0.251[b]; t = 1.227
	IMT group	11.30 ±3.67	12.9 ±3.43	–1.59 (–2.97––0.19)	0.029[b]; t = –2.587
	HC group	12.90 ±2.98	14.45 ±2.72	–1.55 (–2.79––0.30)	0.020[b]; t = –2.825
MIP; M ±SD	CP group	33.6 ±10.50	40.5 ±14.00	6.9 (–13.81–0.015)	0.044[b]; t = –2.257
	IMT group	36.4 ±13.11	52.5 ±19.0	–16.1 (–21.83––10.36)	0.005[b]; t = –6.348
	HC group	73.1 ±16.0	86.7 ±20.06	–13.6 (19.25––7.945)	<0.001[b]; t = 5.440
MIP% predicted; M ±SD	CP group	34.30 ±10.3	35.55 ±20.9	–1.24 (–15–13)	0.510[b]; t = –0.200
	IMT group	38.51 ±12.84	52.7 ±27.7	–14.18 (–30.7–2.35)	0.084[b]; t = –1.940
	HC group	76.58 ±14.7	91.48 ±20.6	–14.90 (–20.72–9.07)	<0.001[b]; t = –5.791

95% CI – 95% confidence interval; HC – healthy control; CP – conventional physiotherapy; IMT – inspiratory muscle training; DE – diaphragm excursion; Td_i – diaphragm thickness at the end of inspiration; Td_e – diaphragm thickness at end of expiration; DTF – diaphragm thickness fraction; PCV – peak contraction velocity; PRV – peak relaxation velocity; MIP – maximum inspiratory pressure; M – mean; SD – standard deviation; [a] Wilcoxon signed rank test; [b] paired sample t-test.

ventilated patients during the post-extubation period. A study reported that IMT did not reduce hospitalization time or ICU duration, despite being used in conjunction with CP.[5] The diaphragm excursion of HCs was higher than that of the IMT and CP groups at baseline, suggesting that MV negatively affected diaphragm contractility. Our findings also showed that both the IMT group and HCs had greater improvements in diaphragm excursion than those who did not receive IMT. A normative study conducted on healthy volunteers found that the average diaphragmatic excursion was 5.96 cm, with variation according to age and gender.[15] Furthermore, previous studies have shown that diaphragmatic excursion is associated with disease severity, functional capacity and respiratory function in COPD patients.[16,17] These findings suggest that improving diaphragmatic excursion through IMT may restore respiratory function and facilitate weaning in mechanically ventilated patients.

Research has shown that the loss of diaphragm muscle thickness is particularly significant in the first 3 days after MV, even after just 24 h.[18] While numerous studies have examined diaphragm atrophy and function using ultrasonography during MV, there is still a lack of understanding regarding the specific changes in the structure and function of the diaphragm after extubation. Further research is required to fully elucidate the effects of MV on the diaphragm and its recovery after extubation. Our study revealed that the diaphragmatic thickness in the CP group decreased after 5 days of extubation, whereas the diaphragmatic thickness in the group that received IMT increased. Although only the HCs showed a statistically significant increase, the slight increase in the IMT group compared to the decreased diaphragmatic thickness in the control group is an encouraging finding that suggests that IMT may help prevent ongoing diaphragmatic atrophy and maintain respiratory function after extubation. Further research is needed to determine the clinical significance of these findings, including any potential effects on patient outcomes or respiratory function.

A previous research found that there was no significant correlation between diaphragmatic thickness and extubation success in mechanically ventilated patients.

However, they found that the DTF was a positive predictor of extubation success and was strongly associated with the duration of MV and length of stay in the ICU.[19] Some studies have reported no significant differences in DTF between COPD patients and HCs due to increased airway resistance and air trapping in patients with COPD.[20,21] In this study, there were no significant changes in DTF in any group after the intervention, possibly due to the majority of patients in the Respiratory ICU had increased airway resistance and air trapping.

A study assessed real-time diaphragm tissue velocity in healthy individuals and ICU patients using TDI. Pioneer research reported that the PCV and PRV measurements were similar in healthy individuals. However, the TDI patterns of successfully weaned patients differed from those who failed to wean.[8] In obstructive pulmonary diseases, decreased diaphragm displacement due to air trapping and increased respiratory muscle load can lead to loss of diaphragmatic relaxation velocity. This may result in a mechanical disadvantage and delay in expiration by the functional residual capacity. Diaphragm perfusion occurs primarily during relaxation, and it may be inversely related to diaphragm fatigue as the diaphragm rapidly reaches the optimal length when perfused.[22] This study is the only RCT that evaluated the effect of physiotherapy intervention on the velocity of the diaphragm using TDI. We found that IMT increased the PCV, and the PRV decreased in the CP group, whereas it increased in the IMT groups. Supplementary Fig. 1 presents the change in diaphragm peak contraction and peak relaxation velocities of the groups pre- and post-intervention. Our study suggests that IMT may be a feasible alternative to prevent the possible loss of diaphragmatic contraction and relaxation velocities during the weaning process.

Several studies have previously reported an increase in MIP in mechanically ventilated patients who received IMT.[23–25] Papadopoulos et al. reported that MIP improved post-extubation in patients who received chest physiotherapy, which included breathing exercises and bronchial hygiene techniques, compared with those who did not receive chest physiotherapy.[26] Our findings are consistent with prior research in this regard. Similarity-based learning may have contributed to these improvements. A study that applied 50% MIP intensity to patients during weaning, along with T-tube trials, reported a decrease in the MIP value in the intervention group.[27] In contrast, our study observed an increase in MIP without any complications during the IMT sessions, indicating the appropriateness of our training load. In healthy individuals, IMT provides an 8–45% improvement in working MIP, whereas shorter training provides lower improvement in MIP. This phenomenon may be attributed to the dose–response relationship, as in skeletal muscles.[28,29] It is hypothesized that the comparable progress in physical function and muscle strength in both the CP and IMT groups can be attributed to the early mobilization and physiotherapy approaches. In a previous RCT, 2 weeks of IMT application during the post-extubation period did not result in reduced hospitalization and reintubation rates.[4] These findings appear to be in agreement with our study. Future multicenter studies with larger patient populations are warranted to further investigate this issue. Another important point that needs to be highlighted is the increasing significance of point-of-care ultrasound (POCUS) in physiotherapeutic decision-making and management.[30] In this context, our research may provide valuable clinical insights for future studies in this field.

Limitations

One of the limitations of this study was the exclusion of 6 patients due to 4 reintubations and 2 deaths, which resulted in a loss of data. However, these events were not related to the intervention. Furthermore, no complications were observed during either IMT or CP sessions. Although our study was conducted under changing conditions during the pandemic period, it focused on the effects of IMT on the diaphragm in the early post-extubation period. In our study, the intervention was applied to intensive care patients and the HC group, and the changes in diaphragmatic functions were observed pre- and post-intervention. However, future studies with different patient groups or longer follow-up periods may provide different perspectives by providing more information about the effectiveness of the IMT on diaphragm function. Another limitation of our study is that we did not follow-up on the primary outcomes beyond 5 days after extubation. It is possible that some patients may require continued IMT beyond the initial 5-day training period, especially since most did not achieve close to full recovery in diaphragm function and predicted MIP% values during the study.

Conclusions

This study demonstrates that IMT initiated on the day of extubation and continued 5 days significantly improves the functional parameters of the diaphragm. We have concluded that IMT applied after extubation may serve as a tool to prevent and facilitate the recovery of diaphragmatic function. Our study results highlight the need for more effective post-extubation care protocols, and suggest that IMT should be considered as a respiratory ICU clinical routine intervention to support the post-extubation process in mechanically ventilated patients.

Supplementary data

The Supplementary materials are available at https://doi.org/10.5281/zenodo.10066482. The package includes the following files:

Supplementary Fig. 1. Changes in diaphragm excursion, peak contraction and relaxation velocity within groups.

Supplementary File 1. Radiological assessments.

Supplementary Table 1. Normality test and Levene's assumptions.

Supplementary Table 2. Pre- and post-intervention outcomes (95% CI).

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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