ORIGINAL RESEARCH

Internet of Things-Based Home Respiratory Muscle Training for Patients with Chronic Obstructive Pulmonary Disease: A Randomized Clinical Trial

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Purpose: Whether Internet of Things (IoT)-based home respiratory muscle training (RMT) benefits patients with comorbid chronic obstructive pulmonary disease (COPD) remains unclear. Therefore, this study aims to evaluate the effectiveness of IoT-based home RMT for patients with COPD.

Patients and Methods: Seventy-eight patients with stable COPD were randomly divided into two groups. The control group received routine health education, while the intervention group received IoT-based home RMT (30 inspiratory muscle training [IMT] and 30 expiratory muscle training [EMT] in different respiratory cycles twice daily for 12 consecutive weeks). Assessments took place pre-intervention and 12 weeks post-intervention, including lung function tests, respiratory muscle strength tests, the mMRC dyspnea scale, CAT questionnaires, the HAMA scale, and 6-month COPD-related readmission after intervention.

Results: Seventy-four patients with COPD were analyzed (intervention group = 38, control group = 36), and the mean age and FEV_1 of the patients were 68.65 ± 7.40 years, 1.21 ± 0.54 L. Compared to those of the control population, the intervention group exhibited higher FEV_1/FVC (48.23 ± 10.97 vs 54.32 ± 10.31, $p = 0.016$), MIP (41.72 ± 7.70 vs 47.82 ± 10.99, $p = 0.008$), and MEP (42.94 ± 7.85 vs 50.29 ± 15.74, $p = 0.013$); lower mMRC (2.00 [2.00–3.00] vs 1.50 [1.00–2.00], $p < 0.001$), CAT (17.00 [12.00–21.75] vs 11.00 [9.00–13.25], $p < 0.001$), and HAMA (7.00 [5.00–9.00] vs 2.00 [1.00–3.00], $p < 0.001$) scores; and a lower incidence rate of 6-month readmission (22% vs 5%, $p = 0.033$).

Conclusion: Compared with no intervention, IoT-based home RMT may be a more beneficial intervention for patients with COPD.

Keywords: chronic obstructive pulmonary disease, internet of things, respiratory rehabilitation, respiratory muscle training

Introduction

Chronic obstructive pulmonary disease (COPD), one of the most prevalent chronic respiratory illnesses worldwide, is characterized by progressive and persistent respiratory symptoms and limited airflow.[1] Statistics provided by the World Health Organization (WHO) in 2023 indicated that COPD is currently the third leading cause of death.[2] According to a population-based study conducted in mainland China, the incidence of COPD in individuals aged 20 years or older was 8.6%, with approximately 99.9 million patients.[3] A simulation study theorized that COPD will be an increasingly heavy economic burden on society due to its high prevalence and fatality rate, long treatment cycle, and recurrent acute exacerbation in China from 2020 to 2039.[4] Thus, more cost-effective interventions are needed to prevent its occurrence and development.

According to the American Thoracic Society/European Respiratory Society (ATS/ERS), pulmonary rehabilitation (PR) is defined as a comprehensive intervention based on a thorough patient assessment followed by patient-tailored therapies, which include but are not limited to exercise training, education, and behavior change.[5] PR is crucial for the

physical and psychological conditions of people with chronic respiratory disease (CRD). The Global Initiative for Chronic Obstructive Lung Disease (GOLD) strongly recommends PR, as it is the most cost-effective strategy for COPD management.[6] Respiratory muscle training (RMT), which encompasses inspiratory muscle training (IMT) and expiratory muscle training (EMT), is an essential component of the PR.[7,8] IMT can help improve inspiratory muscle strength and exercise capacity while relieving dyspnea,[9] and EMT can alleviate maximal expiratory pressure (MEP).[10] However, the current demand for respiratory rehabilitation for COPD patients has not been met. This is because traditional in-person respiratory rehabilitation approaches provided by healthcare facilities are hampered by transportation difficulties, a lack of rehabilitation research, and other health problems.[11–13] Therefore, there is an unmet need and urgency for a more efficient, sustainable, and convenient technique for COPD respiratory rehabilitation that must be addressed.[14,15] The Internet of Things (IoT) is an industrial tide that involves computers, the Internet, and communication networks and is a vital part of healthcare 4.0.[16] Recently, IoT technologies have included many features, such as continuous evaluation, real-time data transmission, personalized treatment, and remote care, which provide a new alternative for homebound COPD patients.[17] Park et al[18] reported that exercise capacity and quality of life can be improved by including a mobile health care app and IoT wearable devices. However, current IoT-based home RMT for COPD patients is lacking.

This study aims to compare the effects of two interventions (routine health education and IoT-based home RMT) on lung function, respiratory muscle strength, dyspnea, quality of life, mood state, and 6-month COPD-related readmission in patients with COPD.

Materials and Methods

Study Design

This study was a single-center randomized controlled trial.

Participants

From April 2023 to June 2023, individuals with COPD from a local community who had just received COPD-related hospitalization before discharge were enrolled in our study. The inclusion criteria were as follows: (1) aged $\geq$ 18 years; (2) diagnosed with stable COPD according to the GOLD criteria and stable for at least 4 weeks before inclusion, postbronchodilator forced expiratory volume in a 1 s (FEV_1)/forced vital capacity (FVC) ratio < 0.7, GOLD stage 1–4 and not worsened upon enrollment;[19] (3) patients or their family caregivers own a smartphone and can utilize the application after training; (4) patients or their family caregivers can use and are willing to be trained to use the IoT-RMT device; and (5) patients and families who provided informed consent to participate in the study. The exclusion criteria included patients who received any research involving PR or patients with a history of severe liver or kidney dysfunctions, malignant tumors, symptomatic cardiovascular disease, mental illness, or an unwillingness to complete follow-up. All participants were assured of their right to withdraw from the study at any stage. Ethical approval was obtained through the Xiamen Haicang Hospital Ethics Committee (No. SY-2022002), and the study was registered at http://www.chictr.org.cn/(ChiCTR2300070633).

Sample Size, Randomization and Allocation

A priori power analysis of lung function-related indicators (FVC, FEV_1, and FEV_1/FVC) was performed using G*Power (version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Germany) to determine the required sample size. The power (1-β) and α were set to 0.9 and 0.05, respectively, by convention, and the effect sizes d of FVC, FEV_1, and FEV_1/FVC were 1.082, 0.946, and 0.827, respectively, as determined by Cheng[19] et al.[20] The calculated sample size required was 32 in each group. Assuming a 20% withdrawal rate, 76 patients with COPD were expected to be recruited.

The randomization is conducted at the individual level. A random and not repeated sequence was created using a random number website (https://tools.medsci.cn/rand) containing the numbers 1 to 78. The random sequence was placed in 78 sequentially numbered, opaque sealed envelopes by someone without direct involvement in the study. Each envelope was opened in turn according to the order of enrollment. Patients with random sequence numbers ranging from 1–39 (obtained from envelopes) were placed in the control group. The remaining patients were in the intervention group.

The participants and researchers will know what intervention they have undergone. Therefore, only the assessor will be blinded (single blinded).

A flowchart of the participants (Figure 1) shows that 88 subjects were enrolled between April 2023 and June 2023, but 10 participants were excluded because they did not have stable COPD, declined to participate, or had other PRs. Four COPD patients opted out of the study after enrollment for the following reasons: withdrawal or loss to follow-up for two patients and personal reasons for the remaining two patients.

Intervention

The control group received routine health education supported by respiratory physicians and nurses via telephone or the internet at home (including respiratory function exercises [lip contraction breathing and abdominal breathing], effective coughing, precautions for home oxygen therapy, and drug guidance), and telephone follow-ups.

On the other hand, the intervention group received the following IoT-based home RMT: (1) Materials: the IoT-based home RMT system (XEEK [Xiamen] Medical Equipment Co., Ltd., China, http://www.xeek.cn/), which included an IoT-RMT device (Fujian Provincial Food and Drug Administration approved for medical applications [approval number: 20172070241]), an IoT cloud, and a companion application. The IoT-RMT is a pressure threshold breathing training device that can independently adjust IMT and EMT loads and record maximal inspiratory pressure (MIP), MEP, inspiratory/expiratory volume, inspiratory/expiratory times, and total energy. The data obtained from the IoT-RMT device can be updated in real time on the companion application and the IoT cloud. In this way, the respiratory physician was allowed to remotely adapt respiratory loads according to patient feedback and make home PR timely, convenient, and precise for patients. The study staff delivered an IoT-RMT device and assisted participants or family caregivers with downloading the companion application upon enrollment. All devices were functionally tested prior to distribution to patients. (2) Procedures: All participants needed to complete the RMT and
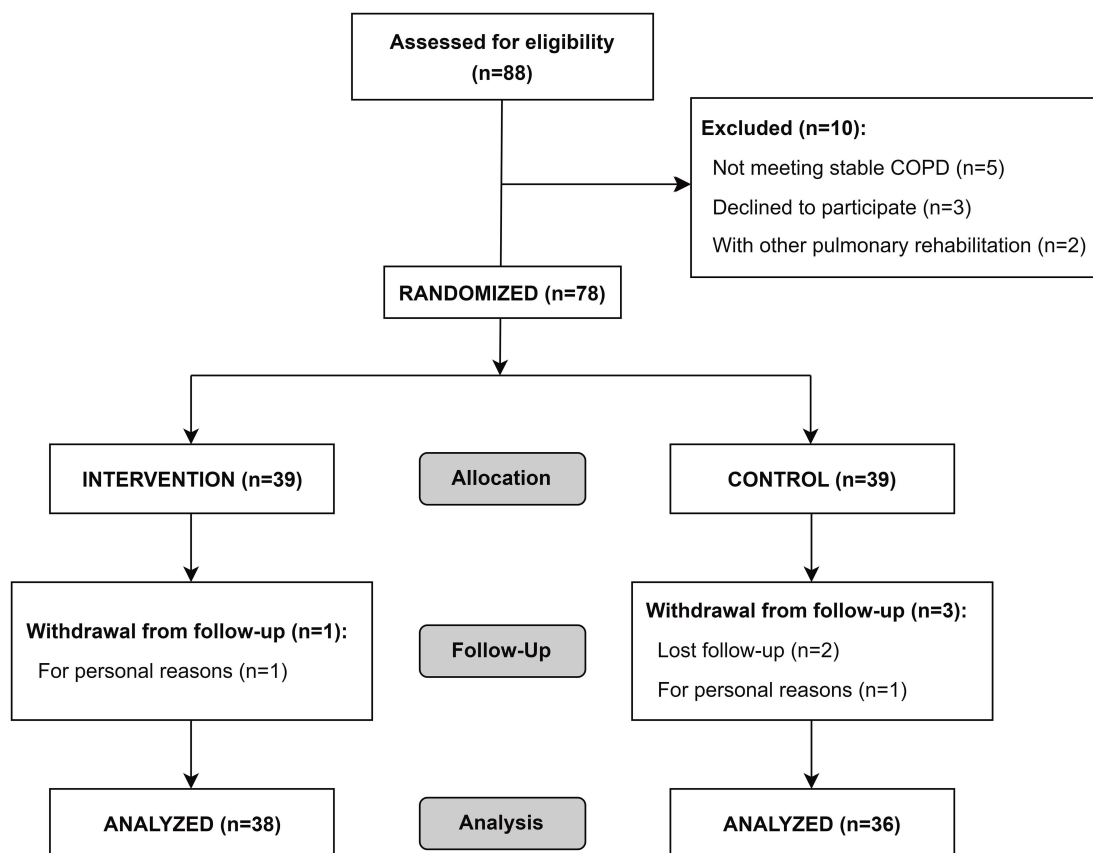

Figure 1 Participants flowchart.

IMT for twelve consecutive weeks. (3) Intervention providers: The IoT-based home RMT procedures were carried out by two respiratory nurses, who had 3 years of experience in respiratory rehabilitation and were properly trained in the use of the device. (4) The modes of delivery of the intervention: respiratory nurses demonstrated (face-to-face) the detailed steps of device and companion application use and how to perform respiratory training until participants could independently repeat these steps. If participants reported any difficulties during the study, the study staff provided remote video coaching. (5) Intervention location: Participants learned about the IoT-based home RMT procedures at the outpatient respiratory clinic of Xiamen Haicang Hospital on the day of enrollment, after which they could complete the IMT and EMT training at home. (6) The number of times the intervention occurred: All participants needed to complete 30 IMT and 30 EMT iterations in different respiratory cycles twice daily for twelve consecutive weeks. (7) Tailoring: The initial inspiratory/expiratory loads of the IoT-RMT device were set by the respiratory physician per 30% of MIP/MEP of patients on the day of enrollment. (8) Modifications: Weekly contact asking how participants feel when they train. If they felt they were slightly strenuous, the physician maintained their original inspiratory and expiratory load, whereas if they felt they were not strenuous at all/not very strenuous, the inspiratory/expiratory load adjusted remotely by the physician per 30% of the average MIP/MEP of the final week via the connection between the IoT-RMT device and the IoT cloud. (9) Regarding intervention adherence, the study staff obtained training data from the IoT cloud, and they sent reminders to participants at 21:00 by telephone if training completion was not acquired by the IoT cloud; additionally, the study staff will phone the participants the next day and then ask verbally about reasons if there is still no training.

Outcome Measures and Data Collection

The primary outcome measures were lung function-related indicators (FVC, FEV_1, and FEV_1/FVC). The secondary outcome measures were respiratory muscle strength-related indicators (MIP and MEP), the modified Medical Research Council dyspnea scale (mMRC, one entry scored from 0–4),[21] the COPD Assessment Test (CAT, consisting of eight entries [cough, expectoration, chest tightness, shortness of breath, ability to perform daily activities, ability to go out, sleep, and energy] with each entry score ranging from 0–5),[22] the Hamilton Anxiety Scale (HAMA, 14 entries and scored from 0–4),[23] 6-month COPD-related readmissions after the intervention began (emergencies were excluded), and the feasibility of the IoT-based home RMT system intervention.

Patient demographic and clinical data were collected from an electronic medical system; if necessary, patients were consulted by telephone for unclear or missing information. All COPD patients completed the lung function test, respiratory muscle test, mMRC dyspnea scale, CAT questionnaires, and HAMA scale before the intervention and 12 weeks after the intervention at the outpatient respiratory clinic. The lung function test was performed using a lung function instrument (PowerCube-body®, GANSHORN, Niederlauer, Germany). The respiratory muscle strength test was performed using an IoT-RMT device (portable pulmonary function instrument X2®, XEEK, Xiamen, China). Dyspnea was measured with the mMRC dyspnea scale, quality of life was measured with the CAT questionnaires, and mood state was measured with the HAMA scale. COPD patients were asked to complete the questionnaires above on site. Participant adherence information was collected from the IoT cloud after the end of the intervention. Thirty patients who completed the IMT or EMT were considered to have one adherence, and the outcome of the feasibility of the intervention was measured as the adherence rate (adherence times/total number of times × 100%). Six months after the start of the intervention, the study staff will phone the patients and verbally ask about COPD-related readmissions. Before collecting the data, all the investigators received unified training.

Statistical Analysis

All the data were entered twice into Excel, and all the statistical analyses were performed using R programming language version 4.3.1 (R Foundation for Statistical Computing, https://www.r-project.org/). Student's *t* tests and Mann–Whitney *U*-tests (either group that did not follow the normal distribution) were used for metrological data. The Chi-square test and Fisher's exact test were used for enumeration data. All tests of statistical significance were two-sided, with a significance value of $p < 0.05$.

Results

Seventy-four (95%) patients completed the study, and the mean adherence rate of seventy-four patients was 81% (attendance ranged between 65% and 100%). The mean (SD) age was 68.08 (5.90) years for the 36 patients in the intervention group and 69.19 (8.64) years for the 38 patients in the control group. The baseline demographic and clinical characteristics are presented in Table 1, and there were no significant differences between the two groups before the intervention (all $p > 0.05$).

As shown in Table 2, the pro-training mean (SD) of FEV_1 ($p = 0.049$), FEV_1/FVC ($p = 0.008$), MIP ($p = 0.042$), and MEP ($p = 0.044$) in the intervention group were markedly higher, and the mMRC score ($p < 0.001$) was lower than the pre-training mean. For group comparisons, there were significant differences in FEV_1/FVC ($p = 0.016$), MIP ($p = 0.008$), MEP ($p = 0.013$), and mMRC scores ($p < 0.001$) between the two groups.

The CAT and HAMA scores of the COPD patients were significantly improved in the group comparison and before and after intervention comparison ($p < 0.001$), as presented in Table 3.

A lower incidence of COPD patients with a 6-month readmission was observed in the intervention group (2/38) than in the control group (8/36) and was statistically significant (x^2=4.549, $p = 0.033$).

Table 1 Baseline Demographic and Clinical Characteristics

Variable	Total (n=74)	Control Group (n=36)	Intervention Group (n=38)	$t/z/x^2$	p value
Age (y), mean (SD)	68.65 ± 7.40	68.08 ± 5.90	69.19 ± 8.64	−0.646	0.520[a]
Male, n (%)	67 (90.5)	34 (94.4)	33 (86.8)	0.518	0.472[b]
Height (m), mean (SD)	1.65 ± 0.08	1.66 ± 0.06	1.65 ± 0.09	0.467	0.642[a]
Weight (kg), mean (SD)	60.66 ± 9.65	60.83 ± 10.68	60.51 ± 8.70	0.144	0.886[a]
BMI (kg/m^2), mean (SD)	22.20 ± 3.14	22.18 ± 3.66	22.22 ± 2.60	−0.063	0.950[a]
Smoker, n (%)	67 (90.5)	34 (94.4)	33 (86.8)	0.518	0.472[b]
Use of medication, n (%)	48 (64.9)	25 (69.4)	23 (60.5)	0.645	0.422[b]
Use of long-term oxygen, n (%)	47 (63.5)	23 (63,9)	24 (63.2)	0.004	0.948 [b]
GOLD stage, n (%)				-	0.570[c]
Stage 1	3 (4.1)	1 (2.8)	2 (5.3)		
Stage 2	23 (32.4)	12 (33.3)	12 (31.6)		
Stage 3	28 (37.8)	16 (44.4)	12 (31.6)		
Stage 4	19 (25.7)	7 (19.4)	12 (31.6)		
GOLD ABE assessment, n (%)				0.029	0.084[b]
B group	26 (35.1)	13 (36.1)	13 (34.2)		
E group	48 (64.9)	23 (63.9)	25 (65.8)		
FVC (L), mean (SD)	2.44 ± 0.76	2.61 ± 0.82	2.27 ± 0.68	1.973	0.052[a]
FVC% predicted (%), mean (SD)	75.13 ± 12.27	75.43 ± 17.27	74.84 ± 17.52	0.146	0.884[a]
FEV_1 (L), mean (SD)	1.21 ± 0.54	1.31 ± 0.54	1.11 ± 0.52	1.587	0.117[a]
FEV_1% predicted (%), mean (SD)	44.13 ± 20.36	46.04 ± 18.06	42.32 ± 22.41	0.783	0.436[a]
FEV_1/FVC (%), mean (SD)	48.58 ± 12.07	49.80 ± 12.34	47.42 ± 11.86	0.846	0.400[a]
MIP (cmH$_2$O), mean (SD)	41.95 ± 10.93	42.00 ± 6.90	41.89 ± 13.82	0.042	0.967[a]
MEP (cmH$_2$O), mean (SD)	43.77 ± 10.54	44.11 ± 6.81	43.45 ± 13.23	0.273	0.786[a]
mMRC score, median (IQR)	2.00 (2.00–3.00)	2.00 (2.00–3.00)	3.00 (2.00–3.00)	−1.814	0.070[d]
CAT score, median (IQR)	18.00 (14.75–23.25)	17.50 (12.00–20.00)	18.50 (16.00–24.25)	−1.661	0.097[d]
HAMA score, median (IQR)	6.00 (5.00–7.00)	6.00 (5.00–7.00)	5.00 (2.00–6.00)	−1.564	0.118[d]

Notes: [a] Student's t-test; [b] Chi-square test; [c] Fisher's exact test [d] Mann–Whitney U-test.
Abbreviations: BMI, body mass index; GLOD, Global Initiative for Chronic Obstructive Lung Disease; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; FEV_1/FVC, forced expiratory volume in 1 s/ forced vital capacity; MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; mMRC, the modified Medical Research Council dyspnea scale; CAT, the COPD Assessment Test questionnaires; HAMA, the Hamilton Anxiety scale; SD, standard deviation; IQR, interquartile range.

Table 2 Comparison of Lung Function-Related Indicators, Respiratory Muscle Strength-Related Indicators and Dyspnea in COPD Patients Between Two Groups

Variable	Control Group (n=36)	Intervention Group (n=38)	p_1 value
FVC (L), mean (SD)			
Pre-training	2.61 ± 0.82	2.27 ± 0.68	
Post-training	2.59 ± 0.78	2.48 ± 0.12	0.520[a]
Mean difference	−0.02 ± 0.25	0.21 ± 0.21	
95% CI	−0.10 to 0.07	0.14 to 0.28	
p_2 value	0.923[a]	0.206[a]	
FVC% predicted (%), mean (SD)			
Pre-training	75.43 ± 17.27	74.84 ± 17.52	
Post-training	75.21 ± 16.98	82.17 ± 21.81	0.131[a]
Mean difference	−0.22 ± 6.49	7.33 ± 8.16	
95% CI	−2.42 to 1.97	4.65 to 10.01	
p_2 value	0.956[a]	0.110[a]	
FEV_1 (L), mean (SD)			
Pre-training	1.31 ± 0.54	1.11 ± 0.52	
Post-training	1.25 ± 0.45	1.36 ± 0.55	0.342[a]
Mean difference	−0.06 ± 0.21	0.25 ± 0.16	
95% CI	−0.13 to 0.01	0.19 to 0.30	
p_2 value	0.605[a]	0.049[a]	
FEV_1% predicted (%), mean (SD)			
Pre-training	46.04 ± 18.06	42.32 ± 22.41	
Post-training	44.04 ± 15.66	51.90 ± 25.18	−0.079 [a]
Mean difference	−2.00 ± 6.69	9.57 ± 7.42	
95% CI	−4.26 to 0.26	7.13 to 12.01	
p_2 value	0.618[a]	0.084[a]	
FEV_1/FVC (%), mean (SD)			
Pre-training	49.80 ± 12.34	47.42 ± 11.86	
Post-training	48.23 ± 10.97	54.32 ± 10.31	0.016[a]
Mean difference	−1.57 ± 5.61	6.90 ± 8.22	
95% CI	−3.47 to 0.32	4.20 to 9.60	
p_2 value	0.570[a]	0.008[a]	
MIP (cmH_2O), mean (SD)			
Pre-training	42.00 ± 6.90	41.89 ± 13.82	
Post-training	41.72 ± 7.70	47.82 ± 10.99	0.008[a]
Mean difference	−0.28 ± 4.05	5.92 ± 7.61	
95% CI	−1.65 to 1.09	3.42 to 8.42	
p_2 value	0.872[a]	0.042[a]	
MEP (cmH_2O), mean (SD)			
Pre-training	44.11 ± 6.81	43.45 ± 13.23	
Post-training	42.94 ± 7.85	50.29 ± 15.74	0.013[a]
Mean difference	−0.17 ± 4.77	6.84 ± 5.10	
95% CI	−2.78 to 0.45	5.17 to 8.52	
p_2 value	0.503[a]	0.044[a]	
mMRC score, median (IQR)			
Pre-training	2.00 (2.00–3.00)	3.00 (2.00–3.00)	
Post-training	2.00 (2.00–3.00)	1.50 (1.00–2.00)	< 0.001[b]
Mean difference	N.A.	N.A.	
95% CI	N.A.	N.A.	
p_2 value	0.682[b]	< 0.001[b]	

Notes: [a]Student's *t*-test; [b]mann–Whitney *U*-test.
Abbreviations: FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; FEV_1/FVC, forced expiratory volume in 1 s/ forced vital capacity; MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; mMRC, the modified Medical Research Council dyspnea scale; SD, standard deviation; 95% CI, 95% confidence interval.

Table 3 Comparison of Quality of Life and Mood State in COPD Patients Between Two Groups

Variable	Control Group (n=36)	Intervention Group (n=38)	p_1 value
CAT score, median (IQR)			
Pre-training	17.50 (12.00–20.00)	18.50 (16.00–24.25)	
Post-training	17.00 (12.00–21.75)	11.00 (9.00–13.25)	< 0.001
Mean difference	−0.03 ± 2.24	−7.42 ± 4.68	
95% CI	−0.78 to 0.73	−8.96 to −5.88	
p_2 value	0.955	< 0.001	
HAMA score, median (IQR)			
Pre-training	6.00 (5.00–7.00)	5.00 (2.00–6.00)	
Post-training	7.00 (5.00–9.00)	2.00 (1.00–3.00)	< 0.001
Mean difference	1.14 ± 2.23	−3.53 ± 2.96	
95% CI	0.38 to 1.89	−4.50 to −2.55	
p_2 value	0.307	< 0.001	

Note: Analyzed by Mann–Whitney U-test.
Abbreviations: CAT, the COPD Assessment Test questionnaires; HAMA, the Hamilton Anxiety scale; IQR, interquartile range; 95% CI, 95% confidence interval.

Discussion

This study aimed to compare the effects of routine health education and IoT-based home RMT interventions in patients with COPD. The results showed that compared to the control population, the intervention group exhibited higher FEV1/FVC, MIP, and MEP; lower mMRC, CAT, and HAMA scores; and a lower incidence rate of 6-month readmission.

The COVID-19 pandemic has driven the increased use of telemedicine.[24] We have seen that advanced information and communications technology implementations, such as the IoT, have grown enormously in medicine in recent years.[25] However, little attention has been given to pulmonary telerehabilitation, and the practical functionality of the IoT in PR remains largely unexplored. IoT-based telerehabilitation has simplified medical visits or treatments because it allows continuous monitoring and direct access to data by healthcare providers. In this study, our research group evaluated the benefits of the IoT-based home RMT system in COPD for the first time. The feasibility and efficacy of IoT-based telerehabilitation have been reported in other fields, such as cardiac rehabilitation, limb rehabilitation after chronic stroke, and postoperative rehabilitation after total hip replacement.[26–28] Currently, IoT-based management of home noninvasive positive pressure ventilation is emerging and yielding positive findings. In our study, our results were positive. Researchers who are concerned about the age of the COPD population are relatively more concerned that they may not have accepted new things, but our findings showed otherwise. Even though the mean age of the intervention group was 69.19 years, their adherence rate (81%) was not low due to sufficient training, continuous technical support and exercise reminders. Patients who adhered to training provided feedback that the IoT-based RMT addresses the needs of home-based rehabilitation and doctor–patient communication. Meanwhile, some patients who did not adhere provided feedback that they wanted to reduce training days per week so that they could take care of grandchildren on weekends. Therefore, an appropriate number of training days per week need to be considered in our follow-up study.

Watsford et al's[29] report on a study of older women indicated that eight weeks of RMT significantly increased MIP by 22%, MEP by 30%, and improved FVC. Similarly, we found that the MIP and MEP in the intervention group were greater before and after the intervention, but the improvement in the MIP did not exceed the minimum clinically important difference (MICID). According to a recent Cochrane review of the IMT, the mean difference in the MIP (14.57 cmH$_2$O) was also not consistent with that of the MICID (17.2 cmH$_2$O).[30] IMT with a 30% MIP inspiratory load was proven to be effective in enhancing MIP and respiratory muscle endurance.[31] In a recent systematic review, EMT was considered beneficial and led to a small but significant improvement.[10] Previous works also demonstrated that muscle plasticity at different age stages varied, but progressive resistive training in older

individuals was similarly effective.[32] Therefore, in our study, the IoT-based home RMT also improved respiratory muscle strength for COPD patients with a higher mean age (68.65 ± 7.40 years). Unlike in Watsford et al's[29] study, in our study, the FEV_1 and FEV_1/FVC improved after training more than before training, but no significant difference in the FVC was found between the two groups. A systematic review showed that IMT combined with EMT improved the MIP and MEP compared with those in the control group.[8] Our results may be because the combined effect of IMT plus EMT increases the strength of respiratory muscles and improves airway resistance, which in turn improves lung function.

Dyspnea is a common clinical symptom in patients with moderate, severe, or very severe COPD. Some patients avoid dyspnea by becoming sedentary or using a high proportion of MIPs to inhale; however, these activities may further aggravate the feeling of dyspnea.[33] Evidence-based clinical practice guidelines note that in addition to optimal medical therapy, IMT may be considered for treating dyspnea symptoms.[34] In our study, we found that patients who participated in the IoT-based home RMT intervention experienced significantly less exertional dyspnea than did those in the control group. Ramirez-Sarmiento et al[35] reported in a randomized trial that both the strength and endurance of the inspiratory muscle increased in the IMT group, and this improvement was associated with structural remodeling of the inspiratory muscles (including increases in the proportion of type I muscle fibers [anti-fatigue] and the size of type II muscle fibers [generate strength]). Therefore, the lower dyspnea in the intervention group may be because of structural remodeling of the inspiratory muscles, which may increase the strength and endurance of the inspiratory muscle and improve the work efficiency of the inspiratory muscle.[36]

Some studies have demonstrated that the threshold IMT device can reduce dyspnea and improve respiratory muscle strength, quality of life, and depressive and anxious moods.[37,38] A previous study revealed that EMT reduces symptoms and improves the quality of life of patients with severe COPD.[39] The findings of the present study corroborate the above studies. Dyspnea is an important variable that affects quality of life,[40] and a decrease in quality of life potentially underlies the development of anxiety.[41] Thus, we speculate that continuous RMT mitigating dyspnea could increase patients' quality of life. Furthermore, the potentially enhanced self-care ability associated with these two factors may have a composite and positive impact on anxiety.

Previous studies established that a 17.9–63.0% incidence of COPD patients with a 6-month readmission,[42] and compared with no readmission, COPD readmission was an independent risk factor for in-hospital mortality.[43] We found that the percentage of COPD patients who were readmitted six months after IoT-based home RMT was significantly lower than that of the control group (5% vs 22%; $p = 0.033$). Previous studies revealed that higher CAT scores (OR: 1.14; 95% CI: 1.04–1.24)[44] and dyspnea (OR: 1.87; 95% CI: 0.98–3.28)[45] were significant risk factors for COPD readmission. Puhan et al[46] reported a reduction in readmission following respiratory rehabilitation after acute exacerbation of COPD (pooled relative risk: 0.26). Therefore, RMT might relieve dyspnea and decrease CAT scores, reducing the overall occurrence of readmission in COPD patients.

Study Limitations

The main limitation of this study is that there is no traditional combined RMT group for identifying the differences or superiorities of IoT-based RMT systems. Second, although this study was single-blind (assessor-blinded), it is possible that the assessor was aware of the patient group because the participants may have revealed their allocated group to the assessor (detection bias). Third, the sample size was relatively small; thus, we could not perform any subgroup analyses per the GOLD guidelines. Fourth, the number of follow-ups (only two times) was low, which does not allow for assessing the effects four or eight weeks postintervention or the best timeframe for the intervention. Fifth, we did not assess subject satisfaction or attitude regarding the IoT-based home RMT. Moreover, in follow-up research, we will focus on patient-relevant outcomes, such as quality of life, and the other limitations above will be explored further in future research.

Conclusion

Our research group evaluated the benefits of the IoT-based home RMT system in COPD for the first time. Compared with routine health education, this 12-week IoT-based home RMT program may be effective at improving pulmonary function

and lowering mMRC scores, CAT scores, HAMA scores, and 6-month readmission of COPD patients. Regarding respiratory muscle strength, the improvement in the MIP was also statistically significant but not clinically significant because it did not exceed the MCID. This study provides essential evidence for respiratory rehabilitation via IoT.

Data Sharing Statement

The data will be shared on reasonable request to the corresponding author.

Ethics Approval and Informed Consent

All procedures performed in this study adhered to the ethical standards of the Xiamen Haicang Hospital and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all participants included in the study.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Agustí A, Celli BR, Criner GJ, et al. Global initiative for chronic obstructive lung disease 2023 report: GOLD executive summary. *Am J Respir Crit Care Med*. 2023;207(7):819–837. doi:10.1164/rccm.202301-0106PP
2. World Health Organization. World health statistics 2023: monitoring health for the SDGs, sustainable development goals; 2023. Available from: https://www.who.int/publications/i/item/9789240074323. Accessed December 2, 2023.
3. Wang C, Xu J, Yang L, et al. Prevalence and risk factors of chronic obstructive pulmonary disease in China (the China Pulmonary Health [CPH] study): a national cross-sectional study. *Lancet*. 2018;391(10131):1706–1717. doi:10.1016/S0140-6736(18)30841-9
4. Park J-E, Zhang L, Ho Y-F, et al. Modeling the health and economic burden of chronic obstructive pulmonary disease in China From 2020 to 2039: a simulation study. *Value Health Reg Issues*. 2022;32:8–16. doi:10.1016/j.vhri.2022.06.002
5. Spruit MA, Singh SJ, Garvey C, et al. An official American thoracic society/European respiratory society statement: key concepts and advances in pulmonary rehabilitation. *Am J Respir Crit Care Med*. 2013;188(8):e13–e64. doi:10.1164/rccm.201309-1634ST
6. Disease GIf COL. Global strategy for prevention, diagnosis and management of COPD: 2023 Report; 2023. Available from: https://goldcopd.org/2023-gold-report-2/. Accessed December 3, 2023.
7. Rochester CL, Spruit MA, Holland AE. Pulmonary Rehabilitation in 2021. *JAMA*. 2021;326(10):969–970. doi:10.1001/jama.2021.6560
8. Neves LF, Reis MH, Plentz RDM, Matte DL, Coronel CC, Sbruzzi G. Expiratory and expiratory plus inspiratory muscle training improves respiratory muscle strength in subjects with COPD: systematic review. *Respir Care*. 2014;59(9):1381–1388. doi:10.4187/respcare.02793
9. Hill K, Cecins NM, Eastwood PR, Jenkins SC. Inspiratory muscle training for patients with chronic obstructive pulmonary disease: a practical guide for clinicians. *Arch Phys Med Rehabil*. 2010;91(9):1466–1470. doi:10.1016/j.apmr.2010.06.010
10. Templeman L, Roberts F. Effectiveness of expiratory muscle strength training on expiratory strength, pulmonary function and cough in the adult population: a systematic review. *Physiotherapy*. 2020;106:43–51. doi:10.1016/j.physio.2019.06.002
11. Brooks D, Sottana R, Bell B, et al. Characterization of pulmonary rehabilitation programs in Canada in 2005. *Canadian Respir J*. 2007;14 (2):87–92. doi:10.1155/2007/951498
12. Johnston CL, Maxwell LJ, Maguire GP, Alison JA. How prepared are rural and remote health care practitioners to provide evidence-based management for people with chronic lung disease? *Aust J Rural Health*. 2012;20(4):200–207. doi:10.1111/j.1440-1584.2012.01288.x
13. Keating A, Lee A, Holland AE. What prevents people with chronic obstructive pulmonary disease from attending pulmonary rehabilitation? A systematic review. *Chron Respir Dis*. 2011;8(2):89–99. doi:10.1177/1479972310393756
14. Cox NS, Dal Corso S, Hansen H, et al. Telerehabilitation for chronic respiratory disease. *Cochrane Database Syst Rev*. 2021;1(1):Cd013040. doi:10.1002/14651858.CD013040.pub2
15. Seidman Z, McNamara R, Wootton S, et al. People attending pulmonary rehabilitation demonstrate a substantial engagement with technology and willingness to use telerehabilitation: a survey. *J Physiother*. 2017;63(3):175–181. doi:10.1016/j.jphys.2017.05.010
16. Osama M, Ateya AA, Sayed MS, et al. Internet of Medical Things and Healthcare 4.0: trends, Requirements, Challenges, and Research Directions. *Sensors*. 2023;23(17):7435. doi:10.3390/s23177435
17. Xiang G, Zhu X, Ma L, et al. Clinical guidelines on the application of Internet of Things (IOT) medical technology in the rehabilitation of chronic obstructive pulmonary disease. *J Thoracic Dis*. 2021;13(8):4629–4637. doi:10.21037/jtd-21-670

18. Park S, Kim JY, Lee JC. Mobile phone app-based pulmonary rehabilitation for chemotherapy-treated patients with advanced lung cancer: pilot study. *JMIR mHealth and uHealth*. 2019;7(2):e11094. doi:10.2196/11094

19. Vogelmeier CF, Criner GJ, Martinez FJ, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease 2017 Report. GOLD executive summary. *Am J Respir Crit Care Med*. 2017;195(5):557–582. doi:10.1164/rccm.201701-0218PP

20. Cheng YY, Lin SY. Respiratory muscle training can improve cognition, lung function, and diaphragmatic thickness fraction in male and non-obese patients with chronic obstructive pulmonary disease: a prospective Study. *J Pers Med*. 2022;12(3):475.

21. Bestall JC, Paul EA, Garrod R, Garnham R, Jones PW, Wedzicha JA. Usefulness of the Medical Research Council (MRC) dyspnoea scale as a measure of disability in patients with chronic obstructive pulmonary disease. *Thorax*. 1999;54(7):581–586. doi:10.1136/thx.54.7.581

22. Jones PW, Harding G, Berry P, Wiklund I, Chen WH, Kline Leidy N. Development and first validation of the COPD Assessment Test. *Eur Respir J*. 2009;34(3):648–654. doi:10.1183/09031936.00102509

23. Hamilton M. The assessment of anxiety states by rating. *Br J Med Psychol*. 1959;32(1):50–55. doi:10.1111/j.2044-8341.1959.tb00467.x

24. Channa A, Popescu N, Skibinska J, Burget R. The rise of wearable devices during the COVID-19 Pandemic: a systematic review. *Sensors*. 2021;21 (17):5787.

25. Sadoughi F, Behmanesh A, Sayfouri N. Internet of things in medicine: a systematic mapping study. *J Biomed Inform*. 2020;103:103383. doi:10.1016/j.jbi.2020.103383

26. Li X, Zhao L, Xu T, et al. Cardiac telerehabilitation under 5G internet of things monitoring: a randomized pilot study. *Sci Rep*. 2023;13(1):18886. doi:10.1038/s41598-023-46175-z

27. Lin L-F, Lin Y-J, Lin Z-H, Chuang L-Y, Hsu W-C, Lin Y-H. Feasibility and efficacy of wearable devices for upper limb rehabilitation in patients with chronic stroke: a randomized controlled pilot study. *Eur J Phys Rehabil Med*. 2018;54(3):388–396. doi:10.23736/S1973-9087.17.04691-3

28. Nelson M, Russell T, Crossley K, Bourke M, McPhail S. Cost-effectiveness of telerehabilitation versus traditional care after total Hip replacement: a trial-based economic evaluation. *J Telemed Telecare*. 2021;27(6):359–366. doi:10.1177/1357633X19869796

29. Watsford M, Murphy A. The effects of respiratory-muscle training on exercise in older women. *J Aging Phys Act*. 2008;16(3):245–260. doi:10.1123/japa.16.3.245

30. Ammous O, Feki W, Lotfi T, et al. Inspiratory muscle training, with or without concomitant pulmonary rehabilitation, for chronic obstructive pulmonary disease (COPD). *Cochrane Database Syst Rev*. 2023;1(1):Cd013778.

31. Larson JL, Kim MJ, Sharp JT, Larson DA. Inspiratory muscle training with a pressure threshold breathing device in patients with chronic obstructive pulmonary disease. *Am Rev Respir Dis*. 1988;138(3):689–696. doi:10.1164/ajrccm/138.3.689

32. Rogers MA, Evans WJ. Changes in skeletal muscle with aging: effects of exercise training. *Exerc Sport Sci Rev*. 1993;21(1):65–102. doi:10.1249/00003677-199301000-00003

33. Supinski GS, Clary SJ, Bark H, Kelsen SG. Effect of inspiratory muscle fatigue on perception of effort during loaded breathing. *J Appl Physiol*. 1987;62(1):300–307. doi:10.1152/jappl.1987.62.1.300

34. Ries AL, Bauldoff GS, Carlin BW, et al. Pulmonary rehabilitation: joint ACCP/AACVPR evidence-based clinical practice guidelines. *Chest*. 2007;131(5 Suppl):4S–42S. doi:10.1378/chest.06-2418

35. Ramirez-Sarmiento A, Orozco-Levi M, Guell R, et al. Inspiratory muscle training in patients with chronic obstructive pulmonary disease: structural adaptation and physiologic outcomes. *Am J Respir Crit Care Med*. 2002;166(11):1491–1497. doi:10.1164/rccm.200202-075OC

36. Gea J, Pascual S, Casadevall C, Orozco-Levi M, Barreiro E. Muscle dysfunction in chronic obstructive pulmonary disease: update on causes and biological findings. *J Thoracic Dis*. 2015;7(10):E418–438. doi:10.3978/j.issn.2072-1439.2015.08.04

37. Beaumont M, Forget P, Couturaud F, Reychler G. Effects of inspiratory muscle training in COPD patients: a systematic review and meta-analysis. *Clin Respir J*. 2018;12(7):2178–2188. doi:10.1111/crj.12905

38. Saka S, Gurses HN, Bayram M. Effect of inspiratory muscle training on dyspnea-related kinesiophobia in chronic obstructive pulmonary disease: a randomized controlled trial. *Complement Ther Clin Pract*. 2021;44:101418. doi:10.1016/j.ctcp.2021.101418

39. Mota S, Güell R, Barreiro E, et al. Clinical outcomes of expiratory muscle training in severe COPD patients. *Respir Med*. 2007;101(3):516–524. doi:10.1016/j.rmed.2006.06.024

40. Katsura H, Yamada K, Wakabayashi R, Kida K. The impact of dyspnoea and leg fatigue during exercise on health-related quality of life in patients with COPD. *Respirology*. 2005;10(4):485–490. doi:10.1111/j.1440-1843.2005.00729.x

41. Panagioti M, Scott C, Blakemore A, Coventry PA. Overview of the prevalence, impact, and management of depression and anxiety in chronic obstructive pulmonary disease. *Int J Chron Obstruct Pulmon Dis*. 2014;9:1289–1306. doi:10.2147/COPD.S72073

42. Njoku CM, Alqahtani JS, Wimmer BC, et al. Risk factors and associated outcomes of hospital readmission in COPD: a systematic review. *Respir Med*. 2020;173:105988. doi:10.1016/j.rmed.2020.105988

43. Hartl S, Lopez-Campos JL, Pozo-Rodriguez F, et al. Risk of death and readmission of hospital-admitted COPD exacerbations: european COPD Audit. *Eur Respir J*. 2016;47(1):113–121. doi:10.1183/13993003.01391-2014

44. Alqahtani JS, Aldabayan YS, Aldhahir AM, Al Rajeh AM, Mandal S, Hurst JR. Predictors of 30- and 90-Day COPD exacerbation readmission: a prospective cohort study. *Int J Chron Obstruct Pulmon Dis*. 2021;16:2769–2781. doi:10.2147/COPD.S328030

45. Bahadori K, FitzGerald JM. Risk factors of hospitalization and readmission of patients with COPD exacerbation--systematic review. *Int J Chron Obstruct Pulmon Dis*. 2007;2(3):241–251.

46. Puhan MA, Scharplatz M, Troosters T, Steurer J. Respiratory rehabilitation after acute exacerbation of COPD may reduce risk for readmission and mortality – a systematic review. *Respir Res*. 2005;6(1):54. doi:10.1186/1465-9921-6-54