Received: 2 October 2022 | Accepted: 22 August 2023

DOI: 10.1002/ppul.26655

ORIGINAL ARTICLE

PEDIATRIC PULMONOLOGY WILEY

The effect of inspiratory muscle training in PCD and CF patients: A pilot study

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Funding information
Ofek grant for allied health professionals; Ofek Program for Allied Health Professionals at Rambam Health Care Campus

Abstract

Background: Effective work of breathing and bronchial hygiene requires synergy of inspiratory and expiratory muscles. Inspiratory muscle training (IMT) is a part of pulmonary rehabilitation in chronic obstructive pulmonary disease (COPD). There is some evidence of its efficacy in cystic fibrosis (CF) and, recently, in long COVID-19. We are not aware of studies on IMT in primary ciliary dyskinesia (PCD). Our aim was to assess the effect of IMT on respiratory muscle strength and pulmonary function in PCD and CF patients.

Methods: A single center pilot study. Spirometry, lung clearance index (LCI), maximal inspiratory pressure (MIP), and maximal expiratory pressure (MEP) were measured at baseline (visit 1), after a month of IMT with ®POWERbreathe (visit 2), and at follow-up (visit 3).

Results: The cohort included 27 patients (19 PCD, 8 CF); mean age 18.4 ± 9.8 years. After a month of IMT, there was a significant increase in MIP and MIP% (6.19–7.44, $p = .015$; and 81.85%–100.41%, $p = .046$, respectively), which was sustained at visit 3. Compliance ≥90% led to higher improvement in MIP. In sub-group analysis, improvement in MIP and MIP% remained significant for PCD patients ($p = .026$ and $p = .049$, respectively). No significant changes were found in spirometry, MEP or LCI.

Conclusions: IMT was well-tolerated and led to improved inspiratory muscle strength in PCD patients. The clinical implication of improved MIP should be further investigated. Larger, long-term studies are needed to evaluate long-term effects of IMT on pulmonary function, respiratory muscle strength, pulmonary exacerbations, and quality of life.

KEYWORDS

cystic fibrosis, inspiratory muscle training, maximal inspiratory pressure, primary ciliary dyskinesia

Michal Gur and Eynav Manor contributed equally to this work.

1 | INTRODUCTION

During normal quiet breathing, approximately 50% of the active inspiratory volume change is caused by diaphragm contraction, while the rest is provided by the external intercostal and accessory muscles.[1]

Inspiratory muscle weakness may lead to dyspnea, exercise intolerance, hypoventilation, and respiratory failure in advanced stages, while a decrease in expiratory muscle strength is related to impaired cough efficacy and reduced ability to maintain bronchial hygiene.[2]

Cystic fibrosis (CF) is an autosomal recessive genetic disorder involving the respiratory, digestive, and reproductive systems. lead to Airway obstruction due to thick and sticky mucus results in progressive lung hyperinflation, decreased gas exchange, increased work of breathing and impaired exercise capacity.[3,4] In advanced stages the diaphragm loses up to 60% of its muscle tissue. Hyperinflation-induced diaphragm shortening places the diaphragm in a suboptimal position on its force-length relationship.[5]

Primary ciliary dyskinesia (PCD) is a predominantly autosomal recessive disorder characterized by abnormal ciliary motion and impaired muco-ciliary clearance. Similar to CF, bronchiectasis develops with airway obstruction and progressive hyperinflation, resulting in impaired exercise capacity and increased energy expenditure.[6]

Hence, these two genetic diseases lead to bronchiectasis and reduced exercise capacity. The etiology of impaired exercise capacity includes peripheral muscle dysfunction, systemic inflammation, oxidative stress, poor nutritional status and physical deconditioning.[7]

Peripheral muscle involvement has been described both in CF and PCD.[6,8] In PCD patients, quadriceps femoris and handgrip muscle strength were significantly lower compared to controls.[6] Impaired quadriceps muscle strength and limited exercise capacity were found in the majority of young CF patients.[9] Coelho et al.[10] suggested that abnormalities in muscle oxygenation may also contribute to peripheral muscle dysfunction in CF.

Pulmonary rehabilitation (PR) with exercise training is recommended as a cornerstone for various chronic lung diseases.[7] However, in addition to limited resources and excessive health burden of PR programs, there is an increased risk of cross-infection among patients with bronchiectasis. Home-based self-therapy has the advantage of infection control, is more convenient for the patients and may increase adherence.[11]

Respiratory muscle training (RMT) is a form of exercise training that specifically targets the muscles of inspiration, expiration, or both.[12] Inspiratory muscle training (IMT) is a form of RMT, which applies a specific training load to the inspiratory muscles. Suggested mechanisms include improved strength and endurance of the inspiratory muscles and reduced respiratory muscle fatigue.[13,14]

Previous studies have shown that IMT promotes diaphragm hypertrophy in healthy people and in patients with chronic heart failure; in patients with chronic obstructive pulmonary disease (COPD), the proportion of type I fibers and the size of type II fibers of the external intercostal muscles increased.[15] In asthma patients, IMT improved pulmonary function, respiratory muscle strength and quality of life (QOL).[16] In CF, some studies found a therapeutic potential in IMT, but the long-term clinical benefit remains unclear.[3] Recently, in adults with post-COVID respiratory symptoms, IMT led to clinically meaningful improvements in breathlessness, aerobic fitness and respiratory muscle strength.[17]

Although IMT has been evaluated in several acute and chronic settings, including various chronic lung diseases, we are not aware of studies evaluating its effectiveness in PCD. Therefore, our aim was to evaluate the effect of home-based IMT on respiratory muscle strength and pulmonary function in PCD and CF. Our hypothesis was that IMT would improve maximal inspiratory pressure (MIP).

2 | METHODS

2.1 | Study participants

This was a single center prospective study. The institutional board reviewed and approved the study (RMB 0406-19), and informed consent was obtained from subjects or their legal guardians before recruitment. The study population included patients with PCD or CF treated at our center.

After an initial evaluation, patients received an IMT device—®POWERbreathe. They were instructed to use the device for a month (between visits 1 and 2), twice daily for 30 breathing cycles, and to complete a diary; they were also instructed not to use the device between visits 2 and 3.

Evaluations were performed at baseline (visit 1), after a month of IMT (visit 2) and at a follow-up visit 1 month after the end of IMT (visit 3).

At visit 1, patients who had symptoms consistent with a pulmonary exacerbation during the visit or the preceding week were excluded. Patients with a condition that precluded the use of the IMT device (spontaneous pneumothorax; pulmonary hypertension; significant osteoporosis; ruptured eardrum; large bullae on chest X-ray) were excluded. Patients with desaturation during or following IMT (<94%) were also excluded. Patients with a significant upper respiratory tract infection or sinusitis were instructed not to use the device until resolution of symptoms.[18]

At visit 1, the patients were interviewed by our chest physiotherapist about their physiotherapy (professional/self-treatment) and sports regimens; for each category, frequency of treatment was divided to 0–1 times/week, 2–3 times/week, 4–5 times/week and 6–7 times/week. Patients were instructed to maintain the same regimen throughout the study period.

2.2 | Pulmonary function tests

2.2.1 | Spirometry

Spirometry was performed using smart PFT body box (Medical Equipment Europe GmbH) according to ATS/ERS consensus guidelines.[19] Results are expressed as absolute values and percent predicted (mean ± *SD*) derived from Quanjer[20]

2.2.2 | Lung clearance index (LCI)

Multiple breath washout (MBW) measurements were performed using the Easy-One Pro, MBW Module (NDD Medical Technologies), as first described by Fuchs et al.[21] in 2008. LCI is defined by the number of functional residual capacity (FRC) turnovers required to washout the nitrogen.[22] An increased LCI (>7) indicates more FRC turnovers required for the washout, reflecting inhomogeneous ventilation.[23,24]

2.2.3 | Respiratory muscle strength

MIP and maximal expiratory pressure (MEP) were obtained using a smart PFT body box (Medical Equipment Europe GmbH) according to ATS/ERS consensus guidelines.[25] Results are expressed as absolute values (kilopascal, kPa) and percent predicted (mean ± *SD*).[26]

2.2.4 | Inspiratory muscle training

At the end of visit 1, patients were instructed on the use of ®POWERbreathe Medic Plus (HaB International Ltd.). The device has nine levels of resistance, ranging from 9 to 78 cmH2O.[27] To set the resistance level, MIP results were converted from kPa to cmH2O (1 kPa = 10.19 cmH2O)[25]; the device was set to 50% of MIP.

2.3 | Statistical methods

Statistical analysis was performed using SPSS version 27. The primary outcome was MIP before and after IMT. Secondary outcome measures included spirometry, LCI, and MEP results before and after IMT.

Descriptive statistics in terms of mean, standard deviation and percentiles were calculated for all parameters in the study.

Repeated measure analysis was performed to describe the change of parameters over time. Pearson correlation was calculated to test the correlation between compliance and MIP.

Sample size calculation—to detect an effect of 20% on MIP% after IMT, with 95% level of confidence, 80% power and 5% significance, 20 patients are needed in each group (20 CF patients and 20 PCD); to detect a difference of 15% in MIP%, 23 patients are needed in each group.

A value of $p < .05$ was considered as statistically significant.

3 | RESULTS

Twenty-nine patients (20 PCD, nine CF) were recruited for the study. One patient (PCD) could not tolerate the IMT device and withdrew consent; another patient (CF) started mutation-specific therapy during the study period and improved significantly; therefore, the effect of IMT could not be evaluated. Thus, 27 patients (19 PCD, 8 CF, mean age 18.4 ± 9.8 years) were evaluated.

TABLE 1 Baseline patient characteristics.

	CF; *n* = 9	PCD; *n* = 20	Total; *n* = 29	*p* value
Age	24.7 ± 12.8	15.7 ± 6.7	18.4 ± 9.8	.019
Gender				.43
Female	7 (78%)	12 (60%)	19 (65.5%)	
Male	2 (22%)	8 (40%)	10 (34.5%)	
BMI (kg/m^2)	21.1 ± 5.0	20.8 ± 4.3		

Abbreviations: BMI, body mass index; CF, cystic fibrosis; PCD, primary ciliary dyskinesia.

Table 1 presents the baseline patient characteristics. As can be seen, PCD patients were significantly younger than CF patients. Their gender distribution and BMI were similar.

Figure 1 presents the physiotherapy and sports regimens of the patients at baseline. As can be seen, three patients performed daily sports; of these, one performed daily chest physiotherapy and two 4–5 times/week. Fourteen patients (51.9%) performed sports 2–3 times/week; of these, six also performed daily physiotherapy, seven 4–5 times/week, and one less frequently. Nine patients (33.3%) did not engage in sports at all; of these, six performed daily physiotherapy and two performed physiotherapy 2–3 times/week. One patient did not perform chest physiotherapy or any sports activity.

Overall, 13 patients (48.1%) performed daily chest physiotherapy (professional or self-treatment). Another 11 patients (40.7%) performed a combination of professional and self-treatment) 4–5 times/week; two patients (7.4%) performed chest physiotherapy 2–3 times/week and no sports.

In accordance with instructions, they did not change their regime of sports frequency throughout the study period.

Table 2 presents the results of spirometry, LCI and respiratory muscle strength (MIP and MEP) at baseline, after IMT and at follow-up. At baseline, FEV_1 was mildly reduced and LCI was elevated. Compliance with IMT as reported in patient diaries was high, 86.9 ± 16.8%.

After a month of IMT, there was a significant increase in MIP and MIP% (6.19–7.44, $p = .015$; and 81.85%–100.41%, $p = .046$, respectively); no significant changes were found in flow volume parameters, MEP or LCI. The improvement in MIP was sustained at visit 3. In the sub-group analysis, the improvement in MIP and MIP% remained significant only for PCD patients (5.75 ± 2.76 to 6.84 ± 3.51, $p = .026$; and 79.32 ± 31.29 to 95.63 ± 54.48, $p = .049$, respectively). The patients with the lowest compliance were CF patients. For the two patients who performed physiotherapy 2–3 times/week and no sports, MIP% increased from 109% to 170% and 117% to 156%, respectively; for the patient who performed neither physiotherapy nor sports, MIP decreased from 87% to 81% after IMT. Their reported compliance with the IMT device was 90%, 52% and 50%, respectively. However, the small numbers precluded sub-analysis, and further conclusions cannot be made.

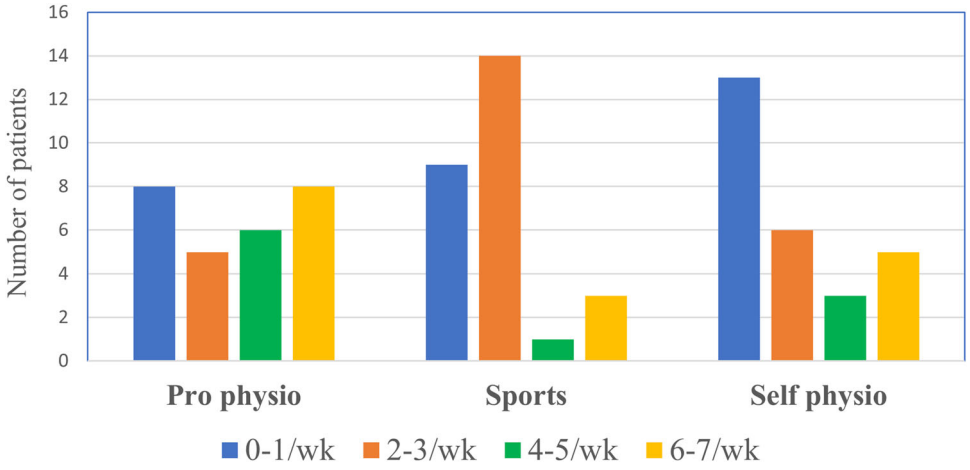

FIGURE 1 Physiotherapy and sports at baseline. Pro = professional; physio = physiotherapy; wk = week.

TABLE 2 Pulmonary function.

	Baseline (visit 1)	After training (visit 2)	Follow up (visit 3)	*p* value
FVC (%)	85.97 ± 16.87	85.53 ± 16.74	83.43 ± 16.64	.15
FEV1 (%)	79.50 ± 19.76	78.43 ± 19.14	77.78 ± 21.11	.47
LCI	10.77 ± 2.78	10.10 ± 2.52	10.31 ± 2.62	.35
FRC LCI (%)	81.34 ± 33.84	85.16 ± 30.17	81.48 ± 22.32	.23
MIP abs (kPa)	6.19 ± 2.52	7.44 ± 3.40	7.46 ± 3.08	.015[a]
MIP (%)	81.85 ± 28.72	100.41 ± 51.91	99.89 ± 41.50	.046[a]
MEP abs (kPa)	6.41 ± 2.84	6.52 ± 2.68	5.84 ± 2.84	.4
MEP (%)	54.48 ± 17.42	56.85 ± 19.07	50.07 ± 20.25	.57

Note: $N = 27$; values are presented as mean ± *SD*.

Abbreviations: abs, absolute; FEV1, forced expiratory volume in 1 s; FRC, functional residual capacity; FVC, forced vital capacity; kPa, kilopascal; LCI, lung clearance index; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure.

[a]Visit 2 vs. visit 1.

Figure 2 presents the stratification of the improvement in MIP% according to the level of compliance for all patients. Patients with compliance ≥90% ($n = 19$) improved from 5.95 ± 2.56 to 7.62 ± 3.37 ($p < .001$) and from 78.58 ± 27.59 to 103.89 ± 55.93 ($p = .007$) for MIP and MIP%, respectively. Patients with compliance <90% ($n = 8$) did not improve (6.83 ± 2.32 to 6.92 ± 0.427, $p = .91$; and 91.22 ± 30.1 to 91.56 ± 40.30, $p = .98$, for MIP and MIP%, respectively).

4 | DISCUSSION

In this single center pilot study, we aimed to evaluate the effect of IMT, a home-based self-therapy, on respiratory muscle strength and pulmonary function in PCD and CF patients. Our hypothesis was that IMT would improve MIP. The device was well-tolerated by the patients and, in accordance with our hypothesis, led to a significant improvement in MIP, which was sustained in the follow-up visit. In sub-group analysis, the improvement remained significant in the PCD group. Moreover, in patients with reported compliance ≥90%, the improvement in MIP was significantly higher than in those with <90% compliance. No improvement was found in the other parameters: spirometry (FVC or FEV1), LCI and MEP.

Patients with chronic lung diseases may manifest muscle weakness; the pathogenesis is multifactorial and includes airway obstruction, malnutrition, decreased exercise capacity and sedentary lifestyle.[6] In addition, hyperinflation may result in a mechanical disadvantage of the diaphragm.[4,15]

MIP is impaired in a variety of conditions: neuromuscular diseases, damage to the inspiratory muscles, sedatives, malnutrition, hypophosphatemia, and steroid treatment. MIP may be impaired for up to 2 weeks even after upper respiratory tract infections and patients can be usually weaned off ventilator support when MIP has risen over 2.9 kPa.[28]

The beneficial effect of IMT is well-established in COPD, and it has been incorporated into the ATS/ERS guidelines on PR.[7] In a

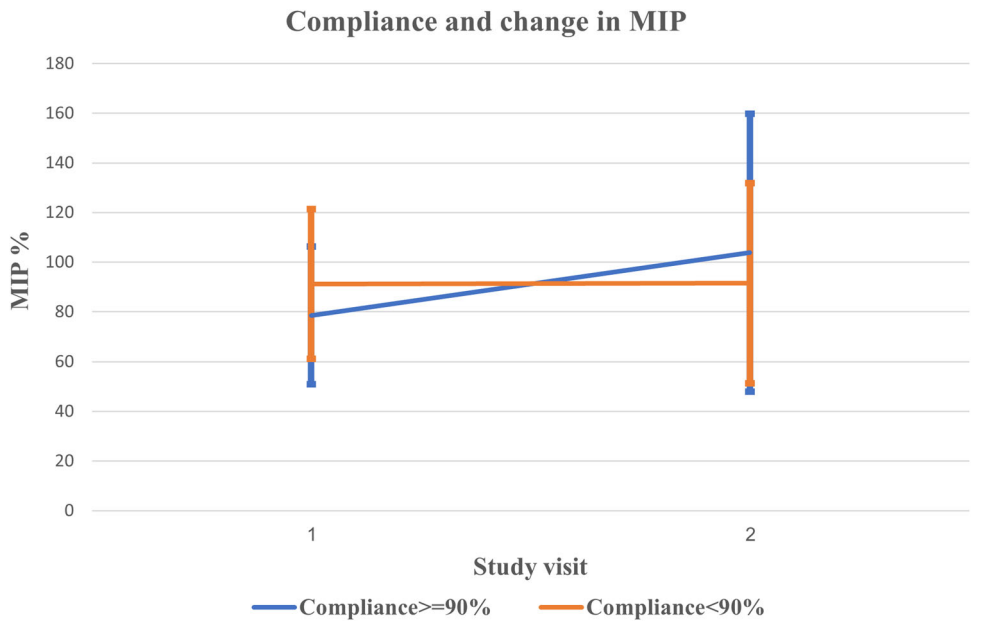

FIGURE 2 Compliance and change in MIP. Horizontal lines depict the error bars. MIP, maximal inspiratory pressure.

group of 150 severe COPD patients, IMT combined with PR led to a similar improvement in dyspnea, and a greater increase in MIP, compared to PR alone.[29] In a systematic review of 43 studies, IMT improved inspiratory muscle strength, QOL and exercise capacity; it also decreased dyspnea in a similar magnitude compared to PR alone.[30] Hence, these studies may offer the use of IMT as a partial home-based PR.

To the best of our knowledge, this is the first study evaluating the effect of IMT in PCD patients. At baseline, our PCD patients had slightly reduced MIP (79.32 ± 31.3%). After a month of IMT, MIP improved by a mean of 16.3%, and the positive effect remained after a month of follow up. In a recent small study by Firat et al.,[6] MIP and inspiratory muscle endurance were significantly lower in PCD than controls, with a mean difference of 16.86 cmH2O. In contrast, MEP values were similar in patients and controls.

There are few studies examining IMT in bronchiectasis. In patients with idiopathic bronchiectasis, IMT added to PR led to similar improvements in exercise capacity and inspiratory muscle strength compared to PR alone.[31] In five patients with non-CF bronchiectasis, high intensity IMT (70% of MIP) increased exercise capacity, respiratory muscle strength and endurance, and QOL.[2]

Chatham et al.[32] found that short-term resistive inspiratory maneuvers (RIM) increased sputum production in CF patients, compared to standard physiotherapy. The mechanism of improved airway clearance was not evaluated. Chatham suggested that the inspiratory maneuvers may move the equal pressure point proximally, enabling increased airflow with less dynamic compression, thus facilitating sputum expectoration. Similar to RIM, IMT produces repeated inspiratory resistance. We found increased MIP without a parallel increase in MEP, FVC, or FEV1. We did not assess closing volume nor sputum production. Hence, the clinical significance of increased MIP without a parallel increase in MEP or flows remains to be studied.

In our study, the small sub-group of CF patients did not improve after IMT; this may reflect the small sample size or a lower compliance to IMT due to high treatment burden, but further conclusions cannot be drawn. Several previous studies examined the effect of IMT in CF, with varying results. A Cochrane review of nine studies concluded that there is insufficient evidence on the effectiveness of IMT, and suggested tailoring the treatment on an individual basis.[12] In a randomized-controlled trial comparing IMT + chest physiotherapy (PT) to PT alone in children with CF, MIP was greater in the IMT + PT group.[4] However, spirometry, MEP and 6-min walk test improved similarly in both groups.

When examining the compliance to IMT in our group, the reported compliance was high, 86.9 ± 16.8%. Participation in a study and short-term use may explain the relatively high compliance. Patients with compliance ≥90% improved significantly both MIP and MIP%, compared with those with <90% compliance. This may be a true finding or may result from the small number of patients with compliance <90%. Compliance with IMT in CF was not reported in the Cochrane review from 2018[12]; in the randomized study from 2019, reported adherence was 97.9% ± 4.2% and 97.5% ± 5.7% in the PT + IMT and PT groups, respectively.[4] None of these studies examined the correlation between compliance and response to IMT. In healthy individuals, studies reported 8%–45% improvement in MIP following IMT; the highest set of MIP for longer duration yielded the greatest improvement in MIP.[1] In children with CF, high pressure load (60% of MIP) was compared to controls (10% MIP). In the study group, MIP increased by 13%, accompanied by improved lung volumes and exercise tolerance.[33] In adults with CF, IMT at 80%

MIP was compared to 20% MIP and controls. After training, MIP improved in both study groups; however, lung volumes, diaphragm thickness and QOL improved only in the group of 80% MIP.[34] In our study, we set the IMT device to 50% of MIP; a higher set of IMT for longer duration should be explored.

While the present study is the first to assess the effect of IMT in PCD patients, it has limitations. The main limitation of our study is the small number of patients. Our hypothesis was that IMT would improve MIP%, with a possible increase in FVC. In adults with COPD, the minimal clinically important difference (MCID) of MIP after IMT was defined as 17 cmH2O.[13] As there are no clear definitions for MCID in CF or PCD, we assumed that MIP would improve by 15%–20% following IMT, thus we needed 20–23 patients in each group. COVID time and the introduction of mutation-specific therapy precluded reaching the target sample size of the CF group. As the study was under-powered, the lack of effect in CF patients may reflect a type II error.

We did not have a control group of healthy participants. Other measures of lung functions, such as lung volumes and airway resistance and exercise tests (6-min walk test or cardio-pulmonary exercise test) were not performed. Compliance was self-reported in a diary; we did not have objective measures of compliance. QOL was not assessed.

In conclusion, the results are encouraging and may imply a positive effect of IMT home-based therapy in PCD, as part of PR, similar to that seen in other chronic lung diseases. Self-guided rehabilitation strategies may have a notable impact, especially in pediatric bronchiectasis. However, the clinical relevance of improved MIP should be further investigated. Larger, long-term studies are warranted, evaluating the effect of IMT on pulmonary function, pulmonary exacerbations, exercise capacity and QOL.

AUTHOR CONTRIBUTIONS

Michal Gur: conceptualization; investigation; writing - original draft; methodology; visualization; data curation; formal analysis. **Eynav Manor**: conceptualization; funding acquisition; methodology; data curation; validation. **Moneera Hanna**: methodology; data curation; visualization; investigation. **Nadeen Simaan**: data curation; visualization; investigation. **Guy Gut**: methodology; formal analysis; conceptualization. **Yazeed Toukan**: validation; visualization. **Fahed Hakim**: conceptualization; formal analysis. **Lea Bentur**: conceptualization; writing - review & editing; supervision; project administration; formal analysis.

ACKNOWLEDGMENTS

The authors acknowledge Mrs. Myrna Perlmutter for professional English language editing, and the statistical help of Mrs. Ronit Leiba from the Medical Statistics Unit, Rambam Health Care Campus. The study was supported by the Ofek Program for Allied Health Professionals at Rambam Health Care Campus.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

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

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REFERENCES

1. Sheel AW. Respiratory muscle training in healthy individuals: physiological rationale and implications for exercise performance. *Sports Med*. 2002;32(9):567-581. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/12096930/
2. Ozalp O, Inal-Ince D, Cakmak A, et al. High-intensity inspiratory muscle training in bronchiectasis: a randomized controlled trial. *Respirology*. 2019;24(3):246-253. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/30209855/
3. Shei RJ, Dekerlegand RL, Mackintosh KA, Lowman JD, McNarry MA. Inspiration for the future: the role of inspiratory muscle training in cystic fibrosis. *Sports Med Open*. 2019;5(1):36. Accessed August 31, 2022. doi:10.1186/s40798-019-0210-3
4. Zeren M, Cakir E, Gurses HN. Effects of inspiratory muscle training on postural stability, pulmonary function and functional capacity in children with cystic fibrosis: a randomised controlled trial. *Respir Med*. 2019;148:24-30. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/30827470/
5. Ottenheijm CA, Heunks LM, Dekhuijzen RP. Diaphragm adaptations in patients with COPD. *Respir Res*. 2008;9:12.
6. Firat M, Bosnak-Guclu M, Sismanlar-Eyuboglu T, Tana-Aslan A. Respiratory muscle strength, exercise capacity and physical activity in patients with primary ciliary dyskinesia: a cross-sectional study. *Respir Med*. 2022:191:106719. Accessed August 7, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/34952415/
7. 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. Accessed August 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/24127811/
8. Gruet M, Troosters T, Verges S. Peripheral muscle abnormalities in cystic fibrosis: etiology, clinical implications and response to therapeutic interventions. *J Cyst Fibros*. 2017;16(5):538-552.
9. Cardoso J, Scalco J, Mucha F, Caputo F, Schivinski CS. Relationship between peripheral muscle strength, exercise capacity and body composition in children and adolescents with cystic fibrosis. *Physiother Theory Pract*. 2022;38(13):3010-3017. Accessed January 10, 2023. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/34470539/
10. Coelho CC, Aquino ES, Diniz ALR, et al. Tissue oxygenation in peripheral muscles and functional capacity in cystic fibrosis: a cross-sectional study. *Exp Physiol*. 2020;105(9):1571-1578. Accessed January 10, 2023. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/32770583/
11. Gurses HN, Ucgun H, Zeren M, Denizoglu Kulli H, Cakır E. Does the effect of comprehensive respiratory physiotherapy home-program differ in children with cystic fibrosis and non-cystic fibrosis bronchiectasis. *Eur J Pediatr*. 2022;181(8):2961-2970. Accessed January 10, 2023. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/35595860/
12. Hilton N, Solis-Moya A. Respiratory muscle training for cystic fibrosis. *The Cochrane database of systematic reviews*. 2018;5(5):006112. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/29797578/

13. 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;2023(1). Accessed January 18, 2023. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/36606682/
14. Bhammar DM, Jones HN, Lang JE. Inspiratory muscle rehabilitation training in pediatrics: what is the evidence? *Can Respir J*. 2022:5680311.
15. Silva IS, Fregonezi GAF, Dias FAL, Ribeiro CTD, Guerra RO, Ferreira GMH. Inspiratory muscle training for asthma. *Cochrane Database Syst Rev*. 2013;2013(9):CD003792. Accessed July 19, 2022. https://pubmed.ncbi.nlm.nih.gov/24014205/
16. Chung Y, Huang TY, Liao YH, Kuo YC. 12-Week inspiratory muscle training improves respiratory muscle strength in adult patients with stable asthma: a randomized controlled trial. *Int J Environ Res Public Health*. 2021;18(6):3267. Accessed July 19, 2022. https://pubmed.ncbi.nlm.nih.gov/33809922/
17. McNarry MA, Berg RMG, Shelley J, et al. Inspiratory muscle training enhances recovery post COVID-19: a randomised controlled trial. *Eur Respir J*. 2022;60(4):2103101. Accessed August 16, 2022. /pmc/articles/PMC8900538/Mar 2.
18. Precautions & Contraindications | POWERbreathe. 2022. Accessed August 17, 2022. https://www.powerbreathe.com/precautions-contraindications/
19. Miller MR. Standardisation of spirometry. *Eur Respir J*. 2005;26(2):319-338.
20. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. *Eur Respir J*. 2012;40(6):1324-1343.
21. Fuchs SI, Sturz J, Junge S, Ballmann M, Gappa M. A novel sidestream ultrasonic flow sensor for multiple breath washout in children. *Pediatr Pulmonol*. 2008;43(8):731-738.
22. Kent L, Reix P, Innes JA, et al. Lung clearance index: evidence for use in clinical trials in cystic fibrosis. *J Cyst Fibros*. 2014;13(2):123-138.
23. Fuchs SI, Eder J, Ellemunter H, Gappa M. Lung clearance index: normal values, repeatability, and reproducibility in healthy children and adolescents. *Pediatr Pulmonol*. 2009;44(12):1180-1185.
24. Robinson PD, Latzin P, Verbanck S, et al. Consensus statement for inert gas washout measurement using multiple- and single- breath tests. *Eur Respir J*. 2013;41(3):507-522. Accessed August 10, 2016. http://www.ncbi.nlm.nih.gov/pubmed/23397305
25. American Thoracic Society/European Respiratory Society ATS/ERS Statement on Respiratory Muscle Testing. This joint statement was adopted by the ATS Board of Directors March 2001, and by the ERS Executive Commitee, June 2001. Accessed August 16, 2022. www.atsjournals.org
26. Neder JA, Andreoni S, Lerario MC, Nery LE. Reference values for lung function tests. II. Maximal respiratory pressures and voluntary ventilation. *Braz J Med Biol Res*. 1999;32(6):719-727. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/10412550/
27. Finta R, Nagy E, Bender T. The effect of diaphragm training on lumbar stabilizer muscles: a new concept for improving segmental stability in the case of low back pain. *J Pain Res*. 2018;11:3031-3045. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/30568484/
28. Karvonen J, Saarelainen S, Nieminen MM. Measurement of respiratory muscle forces based on maximal inspiratory and expiratory pressures. *Respiration*. 1994;61(1):28-31. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/8177969/
29. Beaumont M, Mialon P, Le Ber C, et al. Effects of inspiratory muscle training on dyspnoea in severe COPD patients during pulmonary rehabilitation: controlled randomised trial. *Eur Respir J*. 2018;51(1):1701107. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/29371379/
30. 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. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/29665262/
31. Newall C. Exercise training and inspiratory muscle training in patients with bronchiectasis. *Thorax*. 2005;60(11):943-948. Accessed July 19, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/15994254/
32. Chatham K, Ionescu AA, Nixon LS, Shale DJ. A short-term comparison of two methods of sputumexpectoration in cystic fibrosis. *Eur Respir J*. 2004;23(3):435-439.
33. Sawyer EH, Clanton TL. Improved pulmonary function and exercise tolerance with inspiratory muscle conditioning in children with cystic fibrosis. *Chest*. 1993;104(5):1490-1497. Accessed August 12, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/8222813/
34. Enright S, Chatham K, Ionescu AA, Unnithan VB, Shale DJ. Inspiratory muscle training improves lung function and exercise capacity in adults with cystic fibrosis. *Chest*. 2004;126(2):405-411. Accessed August 12, 2022. https://pubmed-ncbi-nlm-nih-gov.ezlibrary.technion.ac.il/15302725/

How to cite this article: Gur M, Manor E, Hanna M, et al. The effect of inspiratory muscle training in PCD and CF patients: a pilot study. *Pediatr Pulmonol*. 2023;58:3264-3270. doi:10.1002/ppul.26655