

Physical Therapy

Journal of the American Physical Therapy Association



Efficacy of a Novel Method for Inspiratory Muscle Training in People With Chronic Obstructive Pulmonary Disease

Daniel Langer, Noppawan Charususin, Cristina Jácome, Mariana Hoffman, Alison McConnell, Marc Decramer and Rik Gosselink

PHYS THER. 2015; 95:1264-1273.

Originally published online April 9, 2015

doi: 10.2522/ptj.20140245

The online version of this article, along with updated information and services, can be found online at: <http://ptjournal.apta.org/content/95/9/1264>

Online-Only Material

<http://ptjournal.apta.org/content/suppl/2015/08/19/ptj.20140245.DC1.html>

Collections

This article, along with others on similar topics, appears in the following collection(s):

[Airway Clearance](#)
[Chronic Obstructive Pulmonary Disease](#)
[Therapeutic Exercise](#)

e-Letters

To submit an e-Letter on this article, click [here](#) or click on "Submit a response" in the right-hand menu under "Responses" in the online version of this article.

E-mail alerts

Sign up [here](#) to receive free e-mail alerts

Efficacy of a Novel Method for Inspiratory Muscle Training in People With Chronic Obstructive Pulmonary Disease

Daniel Langer, Noppawan Charususin, Cristina Jácome, Mariana Hoffman, Alison McConnell, Marc Decramer, Rik Gosselink

D. Langer, PT, PhD, KU Leuven, 3001 Leuven, Belgium.

N. Charususin, PT, MSc, KU Leuven.

C. Jácome, PT, MSc, School of Health Sciences, University of Aveiro (ESSUA), Aveiro, Portugal.

M. Hoffman, PT, MSc, Department of Physical Therapy, Universidade Federal de Minas Gerais, Minas, Brazil.

A. McConnell, PhD, Centre for Sports Medicine and Human Performance, Brunel University, London, United Kingdom.

M. Decramer, MD, PhD, Respiratory Medicine, KU Leuven.

R. Gosselink, PT, PhD, Rehabilitation Sciences, KU Leuven, Ter-
vurevest 101, 3001 Leuven, Belgium. Address all correspondence to Dr Gosselink at: rik.gosselink@faber.kuleuven.be.

[Langer D, Charususin N, Jácome C, et al. Efficacy of a novel method for inspiratory muscle training in people with chronic obstructive pulmonary disease. *Phys Ther*. 2015;95:1264–1273.]

© 2015 American Physical Therapy Association

Published Ahead of Print:
April 9, 2015

Accepted: March 23, 2015
Submitted: June 2, 2014

Background. Most inspiratory muscle training (IMT) interventions in patients with chronic obstructive pulmonary disease (COPD) have been implemented as fully supervised daily training for 30 minutes with controlled training loads using mechanical threshold loading (MTL) devices. Recently, an electronic tapered flow resistive loading (TFRL) device was introduced that has a different loading profile and stores training data during IMT sessions.

Objective. The aim of this study was to compare the efficacy of a brief, largely unsupervised IMT protocol conducted using either traditional MTL or TFRL on inspiratory muscle function in patients with COPD.

Design. Twenty patients with inspiratory muscle weakness who were clinically stable and participating in a pulmonary rehabilitation program were randomly allocated to perform 8 weeks of either MTL IMT or TFRL IMT.

Methods. Participants performed 2 daily home-based IMT sessions of 30 breaths (3–5 minutes per session) at the highest tolerable intensity, supported by twice-weekly supervised sessions. Adherence, progression of training intensity, increases in maximal inspiratory mouth pressure (P_{imax}), and endurance capacity of inspiratory muscles (T_{lim}) were evaluated.

Results. More than 90% of IMT sessions were completed in both groups. The TFRL group tolerated higher loads during the final 3 weeks of the IMT program, with similar effort scores on the 10-Item Borg Category Ratio (CR-10) Scale, and achieved larger improvements in P_{imax} and T_{lim} than the MTL group.

Limitations. A limitation of the study was the absence of a study arm involving a sham IMT intervention.

Conclusions. The short and largely home-based IMT protocol significantly improved inspiratory muscle function in both groups and is an alternative to traditional IMT protocols in this population. Participants in the TFRL group tolerated higher training loads and achieved larger improvements in inspiratory muscle function than those in the MTL group.



Post a Rapid Response to
this article at:
ptjournal.apta.org

Inspiratory muscle training (IMT) has frequently been applied in patients with chronic obstructive pulmonary disease (COPD) to improve inspiratory muscle function, exertional dyspnea, and exercise tolerance. Results of the latest meta-analysis indicate that IMT as a stand-alone treatment yields clinically meaningful improvements in inspiratory muscle strength and endurance, functional exercise capacity, dyspnea, and quality of life.¹ Studies included in the meta-analysis implemented fully supervised training protocols with controlled training loads and mostly consisted of daily training with mechanical threshold loading (MTL) devices for about 30 minutes.¹ To our knowledge, only a single shorter (42 minutes of weekly training in comparison with 150–210 minutes) but still fully supervised IMT protocol has previously been studied in patients with COPD.^{2,3} This shorter IMT protocol resulted in improvements in inspiratory muscle function that were comparable to longer programs.^{4–6} There is currently a scarcity of research relating to the efficacy of short and largely unsupervised (home-based) IMT programs in patients with COPD. The latest systematic review¹ was accompanied by an editorial that questioned the role of IMT in the comprehensive rehabilitative treatment of patients with COPD, with the main argument that time spent supervising patients during IMT sessions should instead be spent offering them general exercise training, which would be more beneficial for them.⁷

Recently, an electronic IMT device was introduced (POWERbreathe KH1, POWERbreathe International Ltd, Southam, Warwickshire, United Kingdom) that applies a dynamically controlled tapered flow resistive loading (TFRL).⁸ Another novel feature of the electronic IMT device is that flow and pressure data are stored continuously during IMT sessions, permitting objective monitoring of home-based IMT programs from a distance. We hypothesized that this feature would reduce the amount of supervision needed for a short IMT program to be efficacious. Large differences that have been observed in response to previous training interventions that were not performed fully supervised might have partly been due to insufficient adherence to the training intervention. This lack of adherence, however, could not be reliably assessed. This is why we believed that an intervention that has the potential to reduce weekly training time and time spent supervising patients (by electronically controlling training adherence) would be worthy of further exploration.

We further hypothesized that TFRL would enable higher intensities of IMT to be tolerated than MTL. Gradual reduction of the *absolute* load during inhalation against the TFRL accommodates the pressure-volume relationship of the inspiratory muscles and thereby helps to maintain resistance at the same *relative* intensity throughout inhalation. This approach theoretically should enable patients to tolerate higher training intensities (see Method section for more detail).

The aims of the current study, therefore, were: (1) to assess the efficacy of a short and largely home-based IMT program and (2) to find out whether performing and monitoring this program with an electronic TFRL device would enable patients

to reach higher training intensities and achieve larger improvements in inspiratory muscle function than after training with an MTL device.

Method

Interventions started after participants gave written informed consent, and outcomes were evaluated after 8 weeks. Patients with clinically stable COPD and inspiratory muscle weakness (maximal inspiratory mouth pressure [P_{imax}] <100% of the predicted normal value) who were participating in a multidisciplinary pulmonary rehabilitation program were eligible for participation in the study. Patients were eligible to participate in the rehabilitation program if they: (1) were younger than 75 years of age, (2) had a forced expiratory volume in 1 second (FEV_1) that was less than 65% of the predicted value, and (3) had a clinical condition that was stable at inclusion, with no infection or COPD exacerbation in the previous 4 weeks. Exclusion criteria consisted of: (1) diagnosed psychiatric or cognitive disorders, (2) progressive neurological or neuromuscular disorders, (3) severe orthopedic problems having a major impact on daily activities, (4) previous inclusion in a rehabilitation program (<1 year), and (5) severely reduced maximal inspiratory mouth pressures (P_{imax} <60 cm H_2O). The latter group of patients with severe weakness was not eligible because they were included in an ongoing multicenter trial.⁹ Allocation concealment was ensured by using a previously described method to assign patients randomly to receive either MTL IMT or TFRL IMT, using sequentially numbered, opaque, sealed envelopes.¹⁰

Training Method

Analogous to training protocols that have frequently and successfully been applied in people who were healthy,¹¹ the participants per-



Available With
This Article at
ptjournal.apta.org

- **Video:** Example of a supervised IMT session performed with the tapered flow resistive loading device.

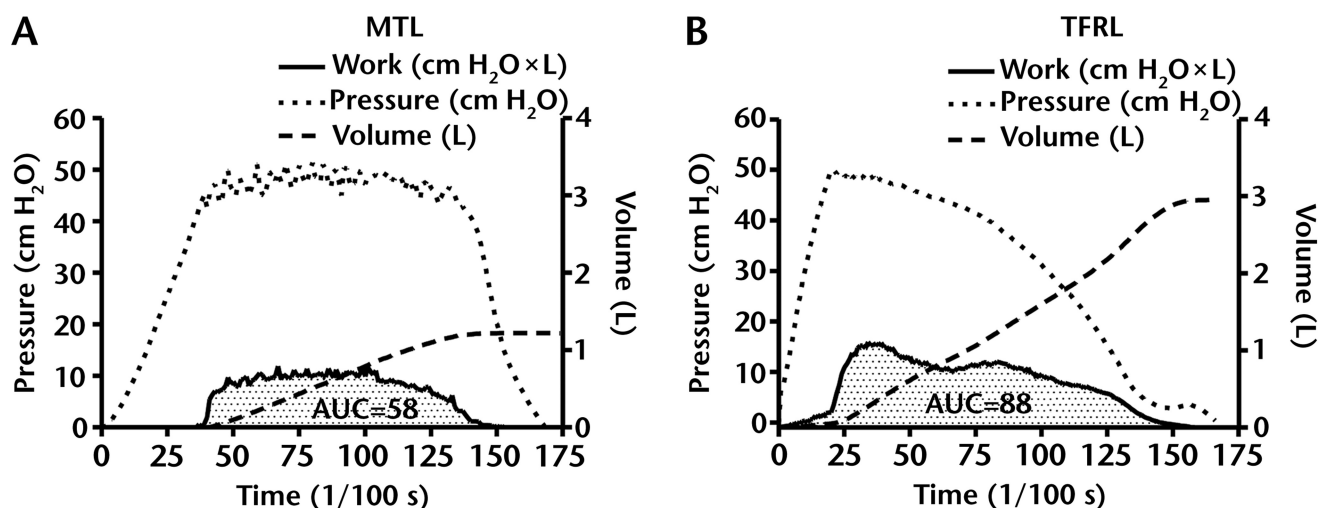


Figure 1.

Comparison between 2 training devices during a typical inhalation against a resistance corresponding to 60% of baseline maximal inspiratory pressure (50 cm H₂O): (A) MTL=mechanical threshold loading, (B) TFRL=tapered flow resistive loading. AUC=area under the curve for total external inspiratory work as integrated from mouth pressure (cm H₂O) and volume (L) signals over time.

formed 2 daily sessions of 30 breaths of MTL IMT (Threshold, Philips Respironics, Brussels, Belgium, or POWERbreathe Medic, POWERbreathe International Ltd) or TFRL IMT (POWERbreathe KH1) at the highest tolerable intensity. As the highest resistance that the Threshold trainer can provide is 41 cm H₂O, the POWERbreathe Medic device (maximal resistance of up to 90 cm H₂O) was used in participants who were able to tolerate higher training intensities. An example of a supervised TFRL IMT session is provided in the [video clip](#) (available at ptjournal.apta.org). Differences in the characteristics of the applied inspiratory resistances between devices are summarized in Figure 1. Methods used to obtain these data from both the MTL and TFRL devices using continuous registrations of flow and pressure with external laboratory measurement equipment have previously been reported.⁸

Figure 1 illustrates the comparison of a single inhalation undertaken by a patient during MTL and a single inhalation undertaken by the same patient during TFRL. The TFRL

device applies a tapered resistance provided by an electronically controlled, dynamically adjusted valve, which contrasts to the constant load applied by the MTL device. After flow-independently overcoming an initial threshold load (in this case, 50 cm H₂O, corresponding to 60% of the individual's P_{imax} on both devices), pressure remained constant during MTL, whereas pressure was volume-dependently tapered during TFRL. This reduction of the absolute load during inhalation against the TFRL accommodates the pressure-volume relationship of the inspiratory muscles and thereby helps to maintain resistance at the same relative intensity throughout inhalation.¹² This application of a tapered load allows end-inspiratory volume to approach total lung capacity, even at high training intensities. It is apparent from the example shown in Figure 1 that this patient with COPD, training at 60% of his P_{imax}, was able to achieve an inspiratory volume during TFRL that was twice that achieved during MTL. Furthermore, due to this higher inspiratory tidal volume, more external work was performed per breath

(see Fig. 1, area under the curve), despite a lower mean inspiratory pressure during inhalation. These observations confirm limitations to the intensity of pressure threshold loading that were recently identified in healthy people.¹³ In that study, the authors found that the amount of external mechanical work undertaken during loading >60% of P_{imax} decreased considerably due to impairment of tidal volume expansions and premature termination of inhalation.¹³ In this way, high-intensity TFRL (in contrast to MTL) provides a training stimulus to the inspiratory muscles at shorter lengths that corresponds to operating lengths of these muscles during exercise (especially in patients with COPD who dynamically hyperinflate).

The TFRL approach is novel and was developed specifically to overcome the limitations of previous inspiratory flow resistive loading (IFRL) techniques and devices (eg, Pflx, [Philips Respironics, Amsterdam, the Netherlands], DHD IMT [DHD Medical Products, Diemolding Healthcare Division, Canastota, New York],

and Test of Incremental Respiratory Endurance [TIRE]).¹⁴⁻¹⁶ The inherent limitation of traditional nontargeted IFRL devices is that inspiratory pressure (ie, training load) varies with inspiratory flow (the slower the inspiratory flow, the smaller the resistive load) and not only with orifice size (the smaller the orifice, the greater the resistive load). Although this specific limitation is overcome by devices that provide biofeedback of load (TIRE) or flow (DHD IMT), these devices have their own limitations. The TIRE (RT2 and Trainair, Project Electronics Ltd, Kent, United Kingdom) overcomes the primary limitation of IFRL by setting inspiratory pressure relative to an individual's P_{max} and by providing biofeedback via a target template. However, the functional relevance of the approach is questionable because each breath maneuver requires a full inspiratory inhalation through a very small inspiratory orifice (comparable to the inspiratory valve leak of a mouth pressure meter), resulting in nonphysiological inspiratory flow (inspiratory time can exceed 20 seconds); the method is also time-consuming and very demanding for the patient. The main limitation of the target flow IMT (eg, combining an incentive spirometer with DHD IMT) is that there is no monitoring or control of inspired volume, which is a crucial determinant of inspiratory work.¹³

All of these limitations are overcome with the TFRL device. The valve in the TFRL device adjusts dynamically (100 times per second), in real time, to accommodate within-breath changes in inspiratory flow rate. These adjustments maintain the pressure load that is delivered to the inspiratory muscles at the same relative intensity (percentage of P_{max}) across the vital capacity. It is a dynamic adjustment to a prescribed target, not the passive decrease in pressure, that occurs in response to

decreasing inspired flow rate with IFRL. Moreover, TFRL also incorporates an initial threshold load that must be overcome before the flow-dependent, dynamical adjustments to the resistive load come into play.

Perhaps more importantly, TFRL also facilitates simultaneous high-pressure and high-flow training across the full vital capacity (typical inspiratory times at resistances of ~50%-55% P_{max} are about 2 seconds; also see [video](#) and previously published data⁸). Tidal volume is unconstrained by functional weakening of the inspiratory muscles because the load tapers during inhalation, thereby permitting full use of the inspiratory capacity, maintenance of maximal inspiratory flow rate, and maximized inspiratory muscle work and power. Patients with expiratory flow limitation (EFL) must overcome high elastic and resistive loads (due to EFL and acute-on-chronic dynamic hyperinflation) during exercise, while simultaneously being forced to generate high inspiratory flow rates (high inspiratory work and power) to meet their increasing ventilatory needs. Further functional weakening occurs by being forced to operate at shorter lengths due to increases in end-expiratory lung volume. The loading characteristics delivered by TFRL are optimized to these demands, and it is hypothesized that the resulting training stimulus will prepare the inspiratory muscles better for these specific task requirements.

A further advantage of the TFRL device over previously used MTL devices (especially during unsupervised training programs) might be the ability to store parameters of up to 38 IMT sessions. Continuous registrations of pressure and flow (500 Hz) provide data on the external work of breathing and allow control of both quantity and quality of unsupervised training sessions. The

device reliably stores data on average mean pressure (cm H₂O), average mean power per breath (watts), average peak flow per breath (L/s), and total external mechanical work of breathing (joules) during training sessions of 30 breaths.⁸

Two weekly IMT sessions in both the TFRL and MTL groups were performed under supervision of a physical therapist, and all other sessions were performed by the patients at home, without supervision. Participants had to wear noseclips during all IMT sessions. Both groups were instructed to perform fast and forceful inspirations and were encouraged to achieve maximal inhalation and exhalation with every breath (ie, to start inhaling from residual volume and to finish their breath as close to total lung capacity as possible). The main aim of this training method was to increase inspiratory muscle power output by improving both strength and velocity of contractions over the full range of motion.

We aimed to initiate IMT at a minimum of 40% of baseline P_{max} (assessed from residual volume). In both groups, inspiratory load was increased during each supervised session to the highest tolerable intensity at that moment. Intermediate measurements of P_{max} were performed once weekly. The *a priori* aim in both groups was to increase training loads during the program to equal at least 50% of the participants' actual P_{max} in every week. Rates of perceived inspiratory effort on a modified 10-Item Borg Category Ratio (CR-10) Scale¹⁷ and subjective impressions of physical therapists during supervised sessions were taken into account to determine the highest tolerable load for each patient. Respiratory effort scores between 4 and 6 were aimed at to stimulate participants to train at the highest tolerable intensity. Adher-

ence to the IMT protocol was assessed by a written training diary in the MTL group and by analyzing objectively registered and automatically stored training session parameters (pressure, flow, power, and work) in the TFRL group. Physical therapists compared performance data from the TFRL group during supervised sessions with results from home-based sessions to elicit full effort during unsupervised IMT. This comparison was not possible in the MTL group.

Measurements

Primary endpoints (P_{imax} and inspiratory muscle endurance) and secondary end points (changes in breathing pattern during the inspiratory muscle endurance task) were assessed by experienced investigators who were not involved with the IMT sessions and thereby blinded to group allocation. The physical therapists who provided the IMT sessions to the participants in both groups were not blinded to the intervention.

Inspiratory muscle strength.

Maximal inspiratory pressure was recorded at the mouth as a surrogate of inspiratory muscle force. Measurements were performed from residual volume using the technique proposed by Black and Hyatt.¹⁸ An electronic pressure transducer (MicroRPM, Micromedical, Kent, United Kingdom) was used. Assessments were performed on 2 separate days and were repeated at least 5 times on each occasion until the 3 best measurements differed from each other by less than 5 cm H₂O. Reference values published by Rochester and Arora¹⁹ were used to define normal respiratory muscle force.

Inspiratory muscle endurance.

Participants were asked to breathe against a submaximal inspiratory load provided by the TFRL device (POWERbreathe KH1) until task fail-

ure due to symptom limitation (T_{lim}). At baseline, an inspiratory load was selected that allowed participants to continue breathing for 3 to 7 minutes. After an initial familiarization trial at 40% P_{imax}, the load was either increased or decreased for the next test based on the participant's performance during the trial. Up to 2 additional trials were performed on the same day to determine a load that would allow participants to continue breathing for 3 to 7 minutes. On a separate day, the test was repeated at least once against the established load, and the best result was recorded as the baseline T_{lim} value. Breathing instructions were the same as during the training sessions. Number of breaths, average inspiratory time as a fraction of the total respiratory cycle duration, average mean load, average mean power, and total external inspiratory work were derived from continuous measurements of flow and pressure during the test and recorded by the previously validated electronic loading device.⁸ Simultaneous continuous measurements of flow and pressure also were performed with external laboratory measurement equipment according to methods previously described.⁸ After 8 weeks of IMT, the endurance test was repeated using an identical load. Improvements in T_{lim} and changes in breathing parameters were recorded as main outcomes. A limit of 15 minutes was handled as the maximum duration of the test performed after 8 weeks. In case participants were not symptom limited at this time point, the assessor stopped the test.

Pulmonary function. Spirometry and whole-body plethysmography were performed according to international guidelines for pulmonary function testing (V_{max} Autobox, SensorMedics BV, Bithoven, the Netherlands).^{20,21}

Data Analysis

In the absence of an established minimal clinically important difference, the sample size calculation was based on a P_{imax} effect size of 1.41 that was reported in a study by Belman and Shadmehr²² on the effects of high-intensity versus low-intensity targeted resistive IMT in people with COPD. To detect this effect size with a degree of certainty (statistical power) of 80% and risk for type I error (α) <5%, a sample size of 7 participants for each group was calculated. Taking an expected dropout rate of 30% into account, we included 10 participants in each group. Differences between the MTL and TFRL groups after the intervention were compared, adjusting for baseline differences, in an analysis of covariance (ANCOVA).²³ The idea behind using an ANCOVA is that a correction is made for regression to the mean.²⁴ Regression to the mean at follow-up is expected to occur when the mean baseline values of the intervention and control groups differ. Correction for regression to the mean using an ANCOVA was achieved by addition of the baseline value as a covariate in an analysis in which the follow-up measurement was the outcome variable and group allocation was the independent variable. Not correcting for baseline differences in this way has been shown to lead to either overestimation or underestimation of the intervention effect.²⁵

A 2-way analysis of variance (ANOVA) using post hoc tests with Bonferroni corrections on a group \times time interaction was performed to compare tolerated training intensities between groups. This analysis was done to investigate whether the groups (TFRL and MTL) had the same influence on training intensity at all time points.

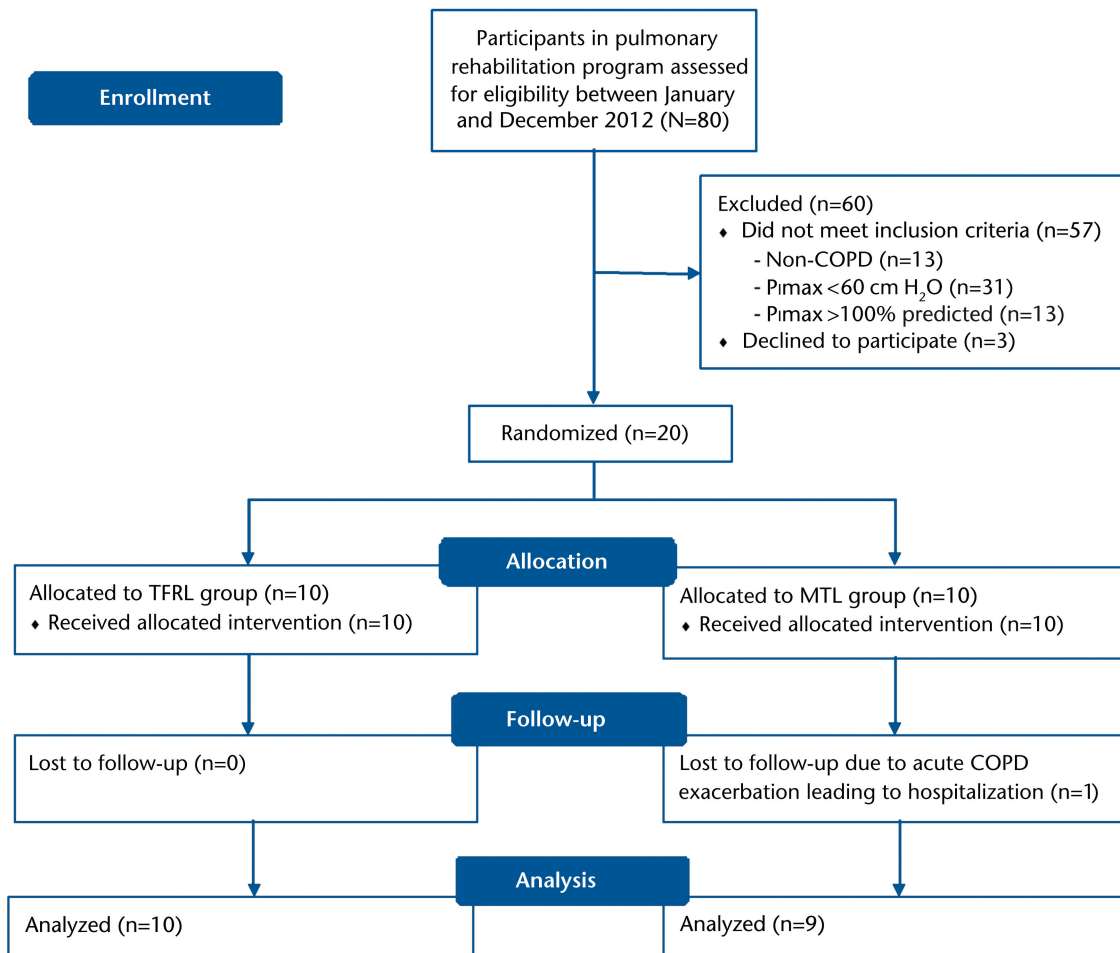


Figure 2.

Diagram summarizing the flow of participants through the study. COPD=chronic obstructive pulmonary disease, P_{imax}=maximal inspiratory pressure, TFRL=tapered flow resistive loading, MTL=mechanical threshold loading.

Results

Twenty participants were selected and randomized between January and December 2012 (10 in the TFRL group and 10 in the MTL group). A diagram summarizing the flow of participants through the study is presented in Figure 2. All patients who were recruited for this study were categorized in spirometric Global Initiative for Chronic Obstructive Lung Disease (GOLD) stages II and III.²⁶ After 8 weeks of IMT, outcomes from 10 participants in the TFRL group and 9 participants in the MTL group were analyzed. One participant in the MTL group dropped out of the study during the final week of the intervention after a

hospitalization due to an acute exacerbation. Baseline characteristics of the participants are presented in Table 1. Groups were well matched for sex, age, inspiratory muscle function, and pulmonary function. Participants in the TFRL group had a normal average weight, whereas those in the MTL group, on average, were overweight. Participants in both groups had comparable impairment of baseline P_{imax}. Symptom limitation and relative intensity (%P_{imax}) of the endurance breathing task also were comparable between groups (Tab. 1).

Training Progression

A mean of 95% (SD=7%) of the training sessions in the TFRL group (based on data stored by the electronic device) and 93% (SD=6%) of the training sessions in the MTL group (based on data from written patient diaries) were completed. Duration of the supervised training sessions ranged from 3 to 5 minutes, corresponding to a daily training duration for both groups ranging from 6 to 10 minutes. Progression of training intensity in both groups is illustrated in Figure 3. Participants in the TFRL group increased their training load from a mean of 45% (SD=8%) of their baseline P_{imax} in the first week of training to 84%

Table 1.

Baseline Characteristics^a

Variable	TFRL Group (n=10)	MTL Group (n=10)	P
Sex (F/M)	5/5	5/5	
Age (y)	64±5	67±8	.428
BMI (kg/m ²)	22.6±6.6	27.7±6.0	.088
FEV ₁ (%pred)	60±17	54±15	.441
FVC (%pred)	91±16	79±22	.243
FRC (%pred)	132±35	138±36	.991
P _{imax} (cm H ₂ O)	67±17	70±19	.840
P _{imax} (%pred)	67±10	71±15	.435
Tlim (s)	219±71	208±139	.380
Intensity endurance test (%P _{imax})	50±11	50±13	.825

^a Values are expressed as mean ± standard deviation. TFRL=tapered flow resistive loading, MTL=mechanical threshold loading, F=female, M=male, BMI=body mass index, %pred=percentage predicted, FEV₁=forced expiratory volume in 1 second, FVC=forced vital capacity, FRC=functional residual capacity, P_{imax}=maximal inspiratory pressure, Tlim=time that patients could sustain the endurance breathing task until symptom limitation.

(SD=16%) in week 8 ($P<.001$). Participants in the MTL group increased their training load from a mean of 38% (SD=11%) of their baseline P_{imax} value to 61% (SD=19%) ($P<.001$). Participants in the TFRL group tolerated a significantly higher training load during the final 3 weeks of the training protocol (all $P<.05$; Fig. 2). Despite the differing training intensities, average Borg CR-10 Scale scores at the end of the supervised

training sessions were similar for both groups for perceived inspiratory effort ($\bar{X}=3.0$ [SD=1.6] versus 3.6 [SD=1.1], respectively; $P=.35$) and perceived dyspnea ($\bar{X}=2.3$ [SD=0.6] versus 2.0 [SD=0.2], respectively; $P=.70$).

Pulmonary Function

There were no significant improvements in pulmonary function in either of the 2 groups (both within-

group $P>.05$) and no differences in improvements between groups (FEV₁ [% predicted]: $\bar{X}=3$ [SD=7] versus $\bar{X}=4$ [SD=9], $P=.662$; forced vital capacity [% predicted]: $\bar{X}=4$ [SD=9] versus $\bar{X}=9$ [SD=16], $P=.495$; and functional residual capacity [% predicted]: $\bar{X}=-14$ [SD=22] versus $\bar{X}=-10$ [SD=20], $P=.714$).

Inspiratory Muscle Strength

Both groups exhibited significant improvements in P_{imax} (both within-group $P<.01$), but participants in the TFRL group showed a significantly larger increase (TFRL group: \bar{X} increase=31 cm H₂O [SD=4], from $\bar{X}=67$ cm H₂O [SD=17] to 99±16 cm H₂O; MTL group: \bar{X} increase=18 cm H₂O [SD=6], from $\bar{X}=70$ cm H₂O [SD=14] to $\bar{X}=89$ cm H₂O [SD=26]; $P=.02$; effect size [Cohen d]=1.21 [95% confidence interval=0.59, 1.82]).

Inspiratory Muscle Endurance

Changes in breathing parameters during the endurance breathing task are summarized in Table 2. Increases in Tlim (effect size [Cohen d]=1.70; 95% confidence interval=0.65,

Table 2.

Breathing Characteristics During the Inspiratory Muscle Endurance Task^a

Measure	TFRL Group (n=10)			MTL Group (n=9)			P
	Preintervention	Postintervention	Change	Preintervention	Postintervention	Change	
Tlim (s)	219±71	751±168	+532±204 ^b	193±124	361±309	+187±233 ^b	.02
Breaths (n)	32±12	95±34	+64±27 ^b	32±18	52±33	+21±33 ^b	.03
Total work (J)	132±73	539±235	+407±230 ^b	157±188	331±466	+193±245 ^b	.03
Avg Ti (s)	2.7±1.3	1.6±0.6	-1.1±0.8 ^b	2.3±1.1	2.0±0.8	-0.2±0.3	.02
Ti/Ttot (%)	37±6	21±8	-16±6 ^b	37±7	33±11	-5±5 ^b	.02
Avg peak V _i /Ti (L/s)	2.1±0.5	3.4±0.7	+1.4±0.6 ^b	1.9±0.5	1.9±0.8	+0.1±0.3	.001
Avg power (W)	1.9±0.6	4.2±1.5	+2.3±1.0 ^b	2.0±0.9	2.5±1.7	+0.5±1.2	.004
Avg inspiratory volume (L)	1.8±0.7	2.2±0.6	+0.4±0.2 ^b	1.6±0.7	1.7±1	+0.1±0.1	.25
Avg work (J)	4.7±3.5	6.4±3.9	+1.7±1.0 ^b	4.6±3.7	5.3±5.2	+0.7±1.1	.27

^a Values are expressed as mean ± standard deviation. Changes are expressed as differences between preintervention and postintervention values. P values are reported for between-group comparisons (TFRL vs MTL) of postintervention values with baseline values entered as covariates (analysis of covariance). TFRL=tapered flow resistive loading, MTL=mechanical threshold loading, Tlim=time that participants could sustain the endurance breathing task, Avg=average per breath, Ti=inspiratory time, Ttot=time of a complete respiratory cycle, V_i/Ti=inspiratory flow.

^b Statistically significant increase from baseline to 8 weeks within groups ($P<.05$).

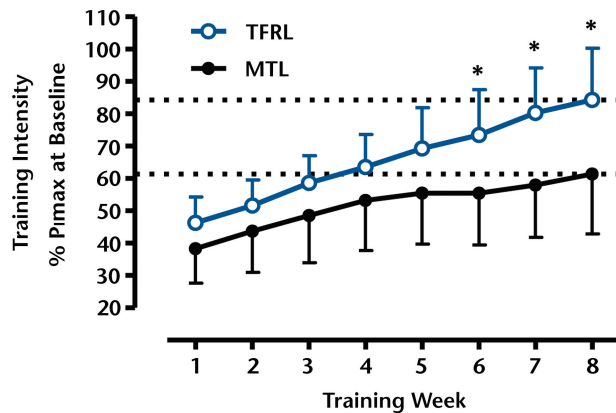


Figure 3.

Progression of training intensity expressed as a percentage of baseline maximal inspiratory pressure (P_{imax}). TFRL=tapered flow resistive loading, MTL=mechanical threshold loading. * $P < .05$ between groups. Dotted lines represent the highest average training intensities reached in the TFRL and MTL groups, respectively.

2.76), number of breaths, and total work were significantly higher in the TFRL group. Participants in this group also were able to achieve larger increases in their peak inspiratory flow during the loaded breathing task, indicating enhanced velocity of shortening of the inspiratory muscles under load. This enhanced velocity of shortening under load resulted in larger, statistically significant improvements in inspiratory muscle power output and a shortening of the duty cycle in the TFRL group. Increases in average inspiratory volume and average work performed per breath were only significantly different from baseline in the TFRL group (Tab. 2). We also performed the analysis of the main outcomes with a 2-way ANOVA for group, time, and group \times time interaction. The results were similar, with the exception of the comparisons of differences in total work and average inspiratory time that did not reach statistical significance in the 2-way ANOVA (data not presented).

Discussion

We studied the effects of a short and largely home-based IMT program in patients with COPD. The participants were adherent to the IMT pro-

tol and achieved significant improvements in inspiratory muscle strength and endurance. Participants in the TFRL group tolerated significantly higher training loads, as well as achieving significantly larger and more comprehensive improvements in inspiratory muscle function (ie, strength, power, shortening velocity, and endurance) compared with those in the MTL group.

Efficacy of the Novel Training Method Compared With Previous IMT Protocols

The average improvements in P_{imax} of 18 cm H₂O (MTL group) and 31 cm H₂O (TFRL group) after 8 weeks of IMT in the current study both exceeded the average increase in P_{imax} of 13 cm H₂O that was reported in the latest meta-analysis of randomized controlled trials of stand-alone IMT.¹ Furthermore, the average increase in breathing endurance time reported in this meta-analysis (261 seconds) was exceeded in the TFRL group (532 seconds) and was approached in the MTL group (187 seconds).¹ These data are encouraging, as all RCTs included in the meta-analysis implemented fully supervised training protocols with daily training durations of 30 min-

utes.¹ Our IMT protocol was largely home-based and consisted of only 2 daily sessions of 30 breaths (~6–10 minutes) of daily training. Despite this short daily training duration, the program resulted not only in improved strength but also in improved endurance capacity of the inspiratory muscles. Improvements in P_{imax} of 25% (MTL group) and 45% (TFRL group) after this home-based program also are similar to findings from a fully supervised IMT protocol that used shorter training durations (29%–32% increases in P_{imax} with 42 minutes of weekly training).^{2,3} This short protocol also resulted in improved endurance capacity.²⁷ These short IMT protocols are similar to those that have been applied successfully in healthy people.¹¹

The current findings support the feasibility and efficacy of a brief, intense, and largely home-based IMT protocol in patients with COPD and demonstrate that this protocol appears to be most efficacious when carried out and supervised with an electronic TFRL device. Reductions in time investment in comparison with previous protocols might help to improve patients' adherence to training and increase motivation of health care providers to prescribe and provide the intervention.

Comparing Effects of MTL IMT and TFRL IMT

One factor that might have contributed to better outcomes in the TFRL group during this home-based IMT program was the ability to objectively monitor unsupervised training sessions. In contrast to the TFRL group, monitoring of the MTL group completely relied on self-reported data of completed IMT sessions, which did not allow us to control the quality of the unsupervised sessions and may have overestimated training adherence. Another explanation for the larger improvements of inspira-

tory muscle function in the TFRL group might be related to the differences in the applied loads (see Method section). Inspiratory effort reported by participants at the end of supervised IMT sessions was comparable between the MTL and TFRL groups, which confirms that both groups were encouraged equally to perform IMT at the highest tolerable intensity.

Changes in Breathing Pattern Characteristics During Loaded Breathing

We observed significantly larger increases in inspiratory flow during the loaded breathing task in the TFRL group, which resulted in larger increases in inspiratory power output and reductions in inspiratory time. Significant enhancement in the velocity of inspiratory muscle shortening during resistive breathing tasks and increases in the size of type 2 muscle fibers following MTL IMT have been observed previously in patients with COPD.^{6,28} These improvements might be of clinical relevance to patients, as the improvements should prepare them for the requirements that increasing ventilatory needs impose on their inspiratory muscles during physical activity. During exercise in people with COPD, functional weakening of inspiratory muscles occurs when they are forced to contract the muscles at shorter lengths (high lung volumes) and higher velocities (shortened time for inspiration). At the same time, these muscles face increasingly higher elastic loads during exercise due to progressive dynamic hyperinflation. These higher loads result in an increase in motor drive to the inspiratory muscles that is associated with an increased sense of respiratory effort and dyspnea.^{29,30} Further studies are warranted to explore whether the improvements in inspiratory muscle power characteristics with TFRL IMT can help to reduce efferent drive to

these muscles and improve the perception of respiratory effort and dyspnea during exercise.

Limitations

A valid concern is that we were assessing the efficacy of our interventions against the background of improvements due to simultaneous exercise training. A limitation of this study, therefore, was the absence of a control group performing a pulmonary rehabilitation program without IMT.³¹ On the other hand, the average improvements in P_{imax} observed after both of our interventions exceeded improvements in P_{imax} of 11 cm H₂O that were reported previously after a similar, but longer, pulmonary rehabilitation program without additional IMT.³²

We further focused exclusively on measurements of inspiratory muscle function and found significantly larger improvements in the TFRL group, which suggests a true training effect. Our study was not designed and sufficiently powered to investigate whether this additional improvement in inspiratory muscle function yielded greater changes in exercise capacity and quality of life. Partly due to the small sample size, the study also cannot be regarded as an effectiveness trial, but rather as an efficacy trial. A large, adequately powered RCT examining the effectiveness of IMT as an adjunct to pulmonary rehabilitation on functional exercise capacity and quality of life is currently addressing this question.⁹

Another shortcoming is that improvements in P_{imax} were assessed only from residual volume and not from functional residual capacity or higher volumes that are more representative of operating lung volumes during rest and exercise in these patients. Length specificity of IMT has been demonstrated previously,³³ and it might be that TFRL has a larger effect on pressure-

generating capacities of inspiratory muscles at shorter muscle lengths (ie, higher lung volumes) than MTL IMT, which should be further studied. Finally, the endurance breathing task was only performed against TFRL and not against MTL. Larger improvements in endurance capacity and more pronounced changes in breathing pattern in the TFRL group, therefore, might have been related to the higher task specificity of the test. Based on the current data, it is unclear whether the observed changes in breathing pattern are restricted to the specific test that we performed or whether these changes will translate to less specific tasks such as breathing during exercise or breathing against a different type of inspiratory resistance. This question should be investigated in future studies.

In conclusion, the presented IMT method required less time investment from both health care providers and patients and resulted in significant improvements in inspiratory muscle function in comparison with previously described fully supervised IMT interventions in patients with COPD. The largely home-based program was most efficient when performed and supervised with an electronic TFRL device. Participants, as in the TFRL group tolerated higher training intensities and achieved significantly larger improvements in inspiratory muscle function than patients using conventional MTL devices for the same perceived effort. Costs and effectiveness of the different approaches need to be weighed against each other when implementing the intervention in clinical practice. Further research should be directed toward assessing the effects of this novel IMT method on inspiratory muscle function and dyspnea perception during whole-body exercise in patients with COPD.

Dr Langer, Dr McConnell, Dr Decramer, and Dr Gosselink provided concept/idea/research design. Dr Langer, Ms Charusisin, Ms Hoffman, Dr McConnell, and Dr Gosselink provided writing. Dr Langer, Ms Charusisin, Ms Jácome, and Ms Hoffman provided data collection and analysis. Dr Langer and Dr Gosselink provided project management. Dr Gosselink and Dr Decramer provided participants and facilities/equipment. Dr McConnell and Dr Decramer provided consultation (including review of manuscript before submission). Dr Langer is a postdoctoral fellow of Research Foundation Flanders. The authors acknowledge the physical therapists Veronica Barbier, Ilse Muylaert, and Iris Coosemans for performing the pulmonary rehabilitation program and all measurements of included patients as blinded outcome assessors. They also thank Dr Hans Scheers, Lung Toxicology and Epidemiology Research Unit, KU Leuven, for providing statistical advice and for his assistance during the data analysis of the endurance breathing task.

The study was approved by the University Hospital Leuven's Institutional Review Board (Approval Number ML7489).

Dr McConnell acknowledges a beneficial interest in the POWERbreathe inspiratory muscle trainers in the form of a share of royalty income to the University of Birmingham and Brunel University. She also provides consultancy services to POWERbreathe International Ltd.

DOI: 10.2522/ptj.20140245

References

- Gosselink R, De Vos J, van den Heuvel SP, et al. Impact of inspiratory muscle training in patients with COPD: what is the evidence? *Eur Respir J*. 2011;37:416–425.
- Hill K, Jenkins SC, Philippe DL, et al. High-intensity inspiratory muscle training in COPD. *Eur Respir J*. 2006;27:1119–1128.
- Sturdy G, Hillman D, Green D, et al. Feasibility of high-intensity, interval-based respiratory muscle training in COPD. *Chest*. 2003;123:142–150.
- Dekhuijzen PN, Folgering HT, van Herwaarden CL. Target-flow inspiratory muscle training during pulmonary rehabilitation in patients with COPD. *Chest*. 1991;99:128–133.
- Wanke T, Formanek D, Lahrmann H, et al. Effects of combined inspiratory muscle and cycle ergometer training on exercise performance in patients with COPD. *Eur Respir J*. 1994;7:2205–2211.
- 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;166:1491–1497.
- Polkey MI, Moxham J, Green M. The case against inspiratory muscle training in COPD. *Eur Respir J*. 2011;37:236–237.
- Langer D, Jacome C, Charusisin N, et al. Measurement validity of an electronic inspiratory loading device during a loaded breathing task in patients with COPD. *Respir Med*. 2013;107:633–635.
- Charusisin N, Gosselink R, Decramer M, et al. Inspiratory muscle training protocol for patients with chronic obstructive pulmonary disease (IMTCO study): a multi-centre randomised controlled trial. *BMJ Open*. 2013;3:e003101.
- Doig GS, Simpson F. Randomization and allocation concealment: a practical guide for researchers. *J Crit Care*. 2005;20:187–191.
- Illis SK, Held U, Frank I, Spengler CM. Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. *Sports Med*. 2012;42:707–724.
- Rahn H, Otis AB. The pressure-volume diagram of the thorax and lung. *Am J Physiol*. 1946;146:161–178.
- McConnell AK, Griffiths LA. Acute cardio-respiratory responses to inspiratory pressure threshold loading. *Med Sci Sports Exerc*. 2010;42:1696–1703.
- Chatham K, Baldwin J, Oliver W, et al. Fixed load incremental respiratory muscle training: a pilot study. *Physiotherapy*. 1996;82:422–426.
- Hsiao SF, Wu YT, Wu HD, Wang TG. Comparison of effectiveness of pressure threshold and targeted resistance devices for inspiratory muscle training in patients with chronic obstructive pulmonary disease. *J Formos Med Assoc*. 2003;102:240–245.
- Harver A, Mahler DA, Daubenspeck JA. Targeted inspiratory muscle training improves respiratory muscle function and reduces dyspnea in patients with chronic obstructive pulmonary disease. *Ann Intern Med*. 1989;111:117–124.
- Borg GAV. Psychophysical basis of perceived exertion. *Med Sci Sports Exerc*. 1982;14:377–381.
- Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Respir Dis*. 1969;99:696–702.
- Rochester DF, Arora NS. Respiratory muscle failure. *Med Clin North Am*. 1983;67:573–597.
- Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J*. 2005;26:319–338.
- Wanger J, Clausen JL, Coates A, et al. Standardisation of the measurement of lung volumes. *Eur Respir J*. 2005;26:511–522.
- Belman MJ, Shadmehr R. Targeted resistive ventilatory muscle training in chronic obstructive pulmonary disease. *J Appl Physiol* (1985). 1988;65:2726–2735.
- Vickers AJ, Altman DG. Statistics notes: analysing controlled trials with baseline and follow up measurements. *BMJ*. 2001;323:1123–1124.
- Twisk J, de Vente W. The analysis of randomised controlled trial data with more than one follow-up measurement: a comparison between different approaches. *Eur J Epidemiol*. 2008;23:655–660.
- Twisk J, Proper K. Evaluation of the results of a randomized controlled trial: how to define changes between baseline and follow-up. *J Clin Epidemiol*. 2004;57:223–228.
- Vestbo J, Hurd SS, Agustí AG, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *Am J Respir Crit Care Med*. 2013;187:347–365.
- Hill K, Jenkins SC, Philippe DL, et al. Comparison of incremental and constant load tests of inspiratory muscle endurance in COPD. *Eur Respir J*. 2007;30:479–486.
- Villafranca C, Borzone G, Leiva A, Lisboa C. Effect of inspiratory muscle training with an intermediate load on inspiratory power output in COPD. *Eur Respir J*. 1998;11:28–33.
- Killian KJ, Jones NL. Respiratory muscles and dyspnea. *Clin Chest Med*. 1988;9:237–248.
- Moxham J, Jolley C. Breathlessness, fatigue and the respiratory muscles. *Clin Med*. 2009;9:448–452.
- Castro M. Placebo versus best-available-therapy control group in clinical trials for pharmacologic therapies: which is better? *Proc Am Thorac Soc*. 2007;4:570–573.
- Troosters T, Gosselink R, Decramer M. Short- and long-term effects of outpatient rehabilitation in patients with chronic obstructive pulmonary disease: a randomized trial. *Am J Med*. 2000;109:207–212.
- Tzelepis GE, Vega DL, Cohen ME, McCool FD. Lung volume specificity of inspiratory muscle training. *J Appl Physiol*. 1994;77:789–794.

Physical Therapy

Journal of the American Physical Therapy Association



Efficacy of a Novel Method for Inspiratory Muscle Training in People With Chronic Obstructive Pulmonary Disease

Daniel Langer, Noppawan Charususin, Cristina Jácome, Mariana Hoffman, Alison McConnell, Marc Decramer and Rik Gosselink

PHYS THER. 2015; 95:1264-1273.

Originally published online April 9, 2015

doi: 10.2522/ptj.20140245

References

This article cites 33 articles, 13 of which you can access for free at:

<http://ptjournal.apta.org/content/95/9/1264#BIBL>

Subscription Information

<http://ptjournal.apta.org/subscriptions/>

Permissions and Reprints

<http://ptjournal.apta.org/site/misc/terms.xhtml>

Information for Authors

<http://ptjournal.apta.org/site/misc/fora.xhtml>
