Effects of Inspiratory Muscle Training on Dyspnea and Respiratory Muscle Function at Rest and during Exercise in Patients with COPD

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BACKGROUND & RATIONALE

Patients with COPD experience dyspnea during exercise, leading to the limitation in exercise tolerance and activities in daily life. Patients with low inspiratory muscle strength experience more significant dyspnea during exercise due to the mismatch between load and capacity of the respiratory muscles resulting in increases Neural Respiratory Drive (NRD) which is closely related to perceived dyspnea sensation. However, since NRD cannot be directly measured, it was suggested to measure this neural output through activation of respiratory muscles or electromyogram of the diaphragm (EMGdi). It has been demonstrated that inspiratory muscle training (IMT) reduces dyspnea sensation by reducing (EMGdi). However, whether IMT also reduces activation of the extra-diaphragmatic inspiratory muscles is unknown.

OBJECTIVE & HYPOTHESIS

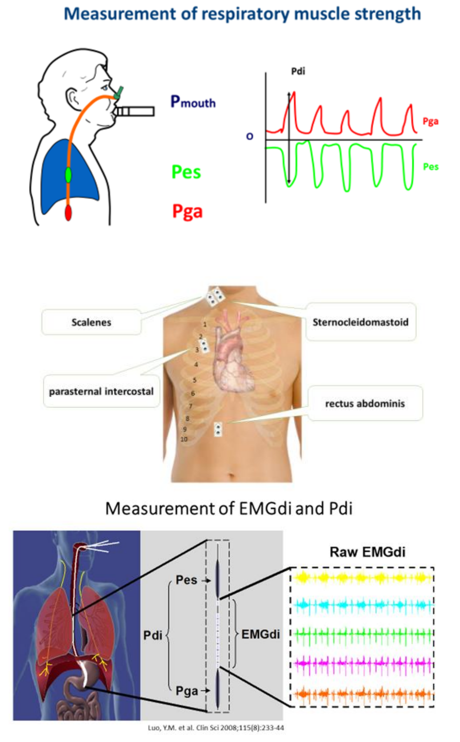
To investigate the effects of either IMT or sham-IMT on a more comprehensive measurement of NRD (EMG activity of the diaphragm, scalene, sternocleidomastoid and rectus abdominis) in relation to dyspnea sensation during constant work rate (CWR) cycling. Also, we aimed to study how these muscles were recruited and activated during IMT sessions in patients with COPD. The hypothesis was that eight weeks of IMT would improve dyspnea sensation during exercise and reduce the neural respiratory drive to the diaphragm and extra-diaphragmatic respiratory muscles.

METHODS

A single-blind, placebo-controlled, randomized clinical trial.

Clinically stable COPD patients with reduced inspiratory muscle strength were included in this study. Patients were allocated into an IMT group or a sham training group and underwent 8 weeks of IMT or sham training. The primary outcome (Borg dyspnea score) and other outcomes were measured during a CWR cycling test (cycling at 75% of maximal work rate) until symptom limitation. Perception dyspnea was rated every minute during CWR cycling test using a modified Borg scale. An esophageal catheter and surface EMG electrodes were used to assess EMGdi, transdiaphragmatic pressures and extra-diaphragmatic respiratory muscle activation. EMG results were presented as a proportion of maximal activation during IC maneuver or force vital capacity for inspiratory and expiratory muscles respectively. After the training, the test was repeated at the same work rate, the comparison of all outcomes was performed at the iso-time (the end time of the shortest cycling test).

Measurement of respiratory muscle strength



Measurement of EMGdi and Pdi

Luo, Y.M. et al. Clin Sci 2008;115(8):233-44

PRE → 8 WEEKS IMT/SHAM IMT → POST

IMT group n = 16

- 7 days/wk, 8 weeks, 2 sessions/day
- 30 breaths, 4-5min
- 1 supervised session/wk
- highest tolerated load , ~50% PImax (Borg 4-5/10)
- **weekly PImax measurement**

Tapered flow resistive loading IMT device

Control group n = 8

- 7 days/wk, 8 weeks, 2 sessions/day
- 30 breaths, 4-5min
- 1 supervised session/wk
- load is not adjusted ,~10% PImax
- **weekly PImax measurement**
- The training is presented to the patients as an endurance training

POWERbreathe®KH2 device (HaB International Ltd., Southam, UK)

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RESULTS

Baseline characteristics

Overall Characteristics	Sham IMT (n=5)	IMT (n=11)
Male:Female, n	2:3	7:4
Age, years	68 ± 9	65 ± 4
Body Mass index, kg/m²	21.6 ± 1.6	27.7 ± 7.1
BDI total score (0-10)	6.3 ± 1.0	6.6 ± 1.9

Table 1 Values are means ± SD. *Abbreviations:* BDI = Baseline Dyspnea Index, total scores range from 0 (most severe activity related dyspnea) to 12 (no activity-related dyspnea); mMRC dyspnea scale = modified Medical Research Council dyspnea scale, scores range from 0 (best) to 4 (worst)

Responses to IMT and sham IMT: main outcome measures

	Sham IMT		IMT		P values Between groups
	Pre	Post	Pre	Post	
FEV$_1$, L (% predicted)	1.32 ± 0.40 (43 ± 33)	1.04 ± 0.51 (49±25)	1.68 ± 0.66 (64 ± 34)	1.65 ± 0.61 (63 ± 3)	0.3765
FRC, L (%predicted)	4.65 ± 1.00 (168 ± 14)	4.80 ± 1.08 (173 ± 16)	5.41 ± 1.83 (166 ± 36)	5.34 ± 2.01 (165 ± 43)	0.2939
IC, (L) (%predicted)	1.49 ± 0.31 (74 ± 30)	1.42 ± 0.66 (70 ± 38)	2.28 ± 0.57 (85 ± 29)	2.24 ± 0.43 (85 ± 29)	0.8600
IC/TLC, %	25 ± 9	23 ± 11	31 ± 9	31 ± 10	0.3720
Inspiratory muscle strength					
Pes, sniff, cmH_2O#	-55 ± 11	-58 ± 15	-65 ± 12	-74 ± 19	0.4312
Pdi, sniff, cmH_2O##	72 ± 10	67 ± 23	94 ± 18	105 ± 18	0.1590
MIP at RV, cmH_2O (%predicted)	-73 ± 7 (98 ± 14)	-77 ± 11 (102 ±5)	-73 ± 17 (77 ± 21)	-93 ± 19 (97 ± 24)*	0.0175ǂ
Inspiratory muscle endurance test					
Inspiratory load, cmH_2O	45 ± 12		49 ± 13		-
Endurance breathing time, min	7.1 ± 4.1	10.3 ± 4.9*	5.9 ± 3.1	10.6 ± 4.4*	0.4059
Inspiratory power/breath, W	3.3 ± 1.2	4.0 ± 1.4	3.3 ± 1.7	5.0 ± 3.0*	0.2381
Total external inspiratory work, J	237 ± 153	283 ± 102	206 ± 151	483 ± 313*	0.6964
Constant work rate cycle ergometer test					
Work Rate, W (% Max)	53 ± 21 (79 ± 6)		65 ± 21 (74 ± 5)		-
Exercise time, min	6.8 ± 4.7	6.8 ± 5.0	6.6 ± 2.3	11.6 ± 7.2	0.1398
Activity-related dyspnea					
mMRC dyspnea scale (1-5)	2.0 ± 0.8	2.0 ± 1.4	1.1 ± 0.6	1.2 ± 0.4	0.7867
TDI total score (-9 to 9)	-	2.3 ± 3.3	-	3.9 ± 3.0	0.3976

Table 2 Values are means ± SD. #=Pes,sniff cut-off below -70 cmH_2O in men and -60 cmH_2O in women for significant inspiratory muscle weakness. ##=Pdi,sniff normal value of Pdi sniff range 82-204 cmH_2O. *Abbreviations*: FEV$_1$ = forced expiratory volume in one second; FRC = plethysmographic functional residual capacity; IC = inspiratory capacity; TLC = total lung capacity; Pes = esophageal pressure; Pdi = diaphragmatic pressure; MIP at RV= maximal inspiratory mouth pressure at residual volume; mMRC = modified Medical Research Council, with dyspnea scale scores ranging from 0 (best) to 4 (worst);TDI, transition dyspnea index, with scores ranging from -9 (maximal worsening of symptoms) to 9 (maximal improvement of symptoms); TLC, total lung capacity. *P < 0.05, within-group difference, pre- vs. post-intervention by paired t-test (or Wilcoxon match-pairs signed rank test). ǂP < 0.05 by unpaired t-test (or Mann-Whitney test compares ranks) comparing treatment differences for IMT vs. sham IMT.

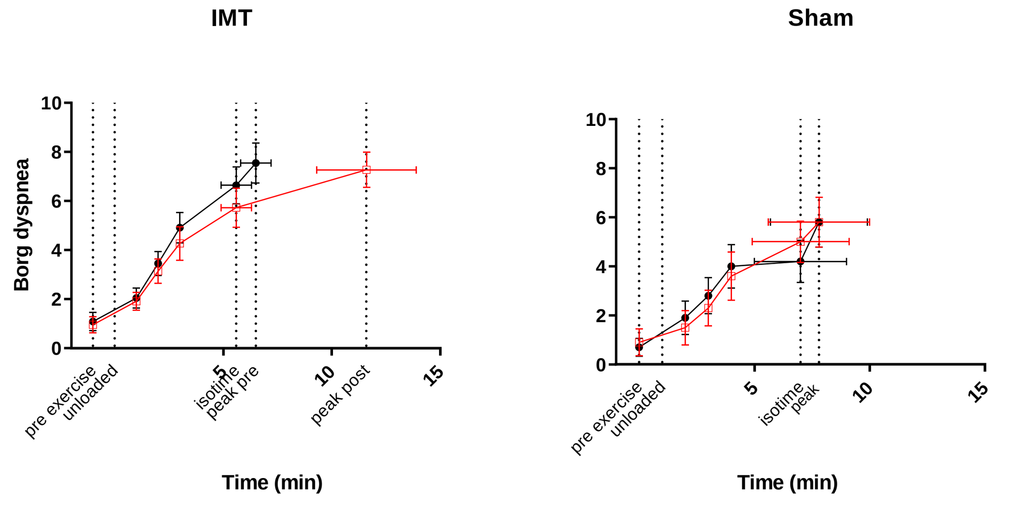

Fig 1 Borg dyspnea scores during rest and every minute of CWR cycling test at pre- and post- measurement of the IMT group and sham group

Responses to IMT during CWR cycle ergometer test at iso-time

Measurements during CWR cycle exercise at iso-time	Sham IMT		IMT		P values Between group
	Pre	Post	Pre	Post	
Work rate, W (% Max)	53 ± 21 (79 ± 6)		65 ± 21 (74 ± 5)		-
Exercise time at Isotime, min	6.0 ± 4.5		5.6 ± 2.2		-
VO_2, L/min	1.15 ± 0.27 (36 ± 13)	1.10 ± 0.30 (35 ± 14)	1.36 ± 0.41 (48 ± 16)	1.26 ± 0.36 (44 ± 13)*	0.4109
Breathing pattern					
Ventilation, L/min	33.9 ± 11.1	37.0 ± 13.4	41.6 ± 7.3	40.9 ± 6.8	0.2339
Vt, L	1.09 ± 0.27	1.15 ± 0.33	1.46 ± 0.38	1.43 ± 0.32	0.0887
BF, breaths/ min	32.9 ± 4.5	32.3 ± 5.9	28.9 ± 5.5	29.5 ± 5.8	0.4595
IC, L§	1.28 ± 0.32	1.28 ± 0.31	1.89 ± 0.38	1.88 ± 0.51	0.9072
IRV, L	1.04 ± 0.28	1.15 ± 0.33	1.32 ± 0.44	1.30 ± 0.37	0.1078
Ti/Ttot, %	37 ± 6	36 ± 5	41 ± 3	41 ± 5	0.7341
Pressures and effort of breathing					
Pes,tidal, cmH_2O	24 ± 5	26 ± 8	32 ± 10	33 ± 10	0.7627
Inspiratory Pes, cmH_2O	-22 ± 2	-21 ± 2	-18 ± 4	-18 ± 6	0.8345
Inspiratory Pes/Pes,sniff, %	39 ± 13	35 ± 13*	29 ± 7	27 ± 12	0.6152
Inspiratory Pdi, cmH_2O	30 ± 2	30 ± 0	26 ± 8	29 ± 12	0.5892
Inspiratory Pdi/Pdi,sniff, %	41 ± 3	40 ± 10	27 ± 6	28 ± 11	0.7764

Table 3 Values are means ± SD. *p<0.05 within-group difference pre vs post intervention by paired t-test (or Wilcoxon match-pairs signed rank test). ǂP < 0.05 by unpaired t-test (or Mann-Whitney test compares ranks) comparing treatment differences for IMT vs. sham IMT. § P < 0.05 by unpaired t-test (or Mann-Whitney test compares ranks) comparing treatment differences for baseline values IMT vs. sham IMT. *Abbreviations*: VO_2 = oxygen consumption; Vt = tidal volume; BF= breathing frequency; IC = inspiratory capacity; IRV = inspiratory reserve volume; Ti/Ttot = inspiratory duty cycle; Pestidal = the tidal swing of Pes; inspiratory Pes = the most negative Pes during a tidal inspiration; inspiratory Pdi = the most positive Pdi during a tidal inspiration

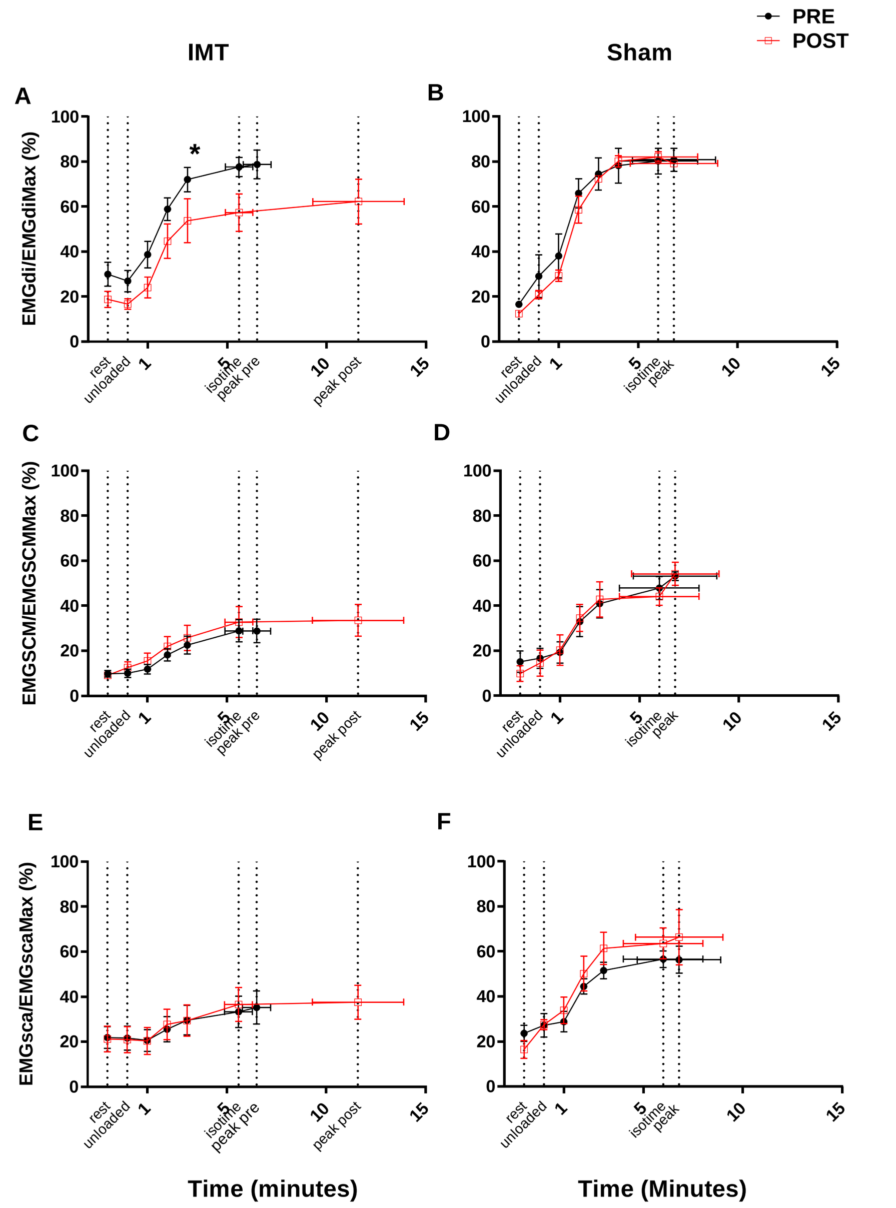

Fig 2 Muscle activation (EMG/EMGMax%) during rest and every minute of CWR cycling test at pre- and post- measurement of the IMT group of diaphragm (A), sternocleidomastoid (C), and scalene (E), and sham group of diaphragm (B), sternocleidomastoid (D), and scalene (F).

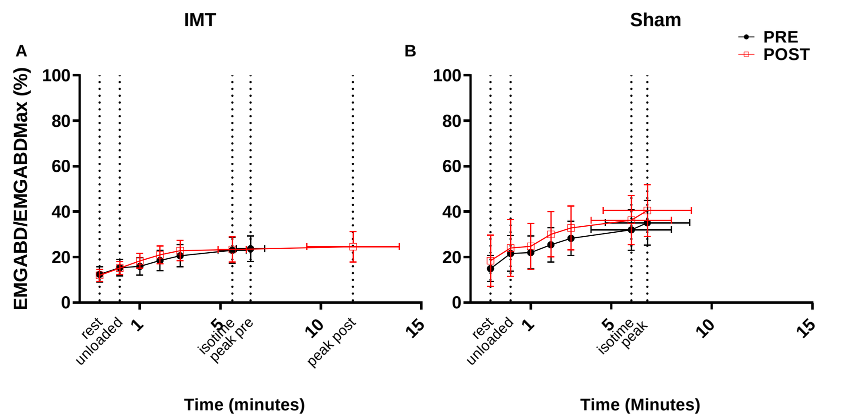

Fig 3 Abdominal (rectus abdominis) muscle activation (EMGABD/EMGABDMax%) during expiration at rest and every minute of CWR cycling test at pre- and post- measurement of the IMT group (A) and the sham IMT group (B).

	Diaphragm	SCM	Scalene	Rectus abdominis
change from baseline Tidal EMG (%)	-22	21	-0.9	-6
change from baseline EMG Max (%)	8	16	1	1
TidalEMG/EMGmax PRE (%)	78	29	33	23
TidalEMG/EMGmax POST (%)	57	33	37	23

Table 3 Percent change from baseline (pre-measurement) of the tidal and maximal activation (during IC maneuver) of the diaphragm, sternocleidomastoid (SCM), scalene and rectus abdominis of the IMT group at iso-time during CRW cycling test.

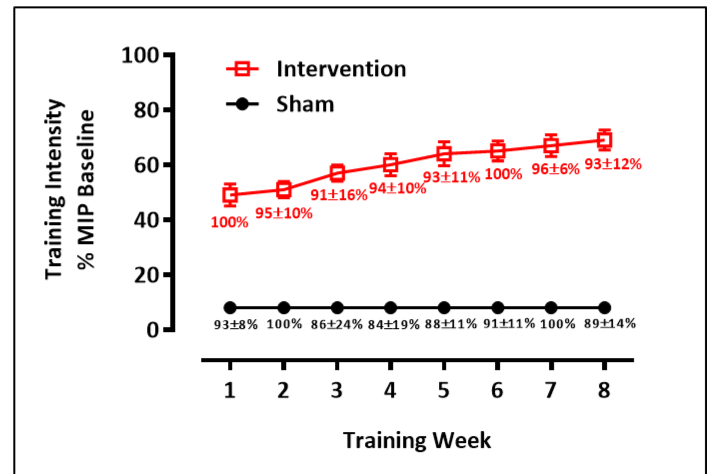

Fig 4 Average inspiratory resistance that had to be overcome by the patients during weekly-supervised inspiratory muscle training (IMT) sessions expressed as percentage of baseline maximal inspiratory mouth pressure (MIP) measured from residual volume. Percentages displayed below weekly averages indicate average compliance of participants with prescribed sessions each week. Values are means ±SD.

	IMT	
	Rest	End
Pressure, cmH_2O (% MIP)	41 ± 11 (53 ± 7)	
Dyspnea, Borg Units	0.7± 1.2	4.9 ± 2.7
breathing effort, Borg Units	0.8 ± 1.1	5.3 ± 2.0
Unpleasantness, Borg Units	1.0 ± 1.4	6.0 ± 2.3
Breathing pattern		
Ventilation, L/min	12.6 ± 2.3	12.2 ± 3.9
Vt, L	0.78 ± 0.27	2.20 ± 0.92
BF, breaths/min	19.1 ± 6.9	6.1 ± 2.3
Inspiratory peak flow, L/s	0.89 ± 0.21	2.32 ± 1.00
Ti, s	1.38 ± 0.48	2.48 ± 0.97
Ti/Ttot, %	38 ± 6	24 ± 8
Muscle activation		
EMGdi/EMGdi,max, %	29 ± 19	66 ± 30
EMGscm/EMGscmmax, %	6 ± 4	63 ± 44
EMGsca/EMGscamax, %§	14 ± 14	67 ± 48
EMGabd/EMGabdmax, %	2 ± 3	6 ± 5
Pressure and effort of breathing		
Pes,tidal, cmH_2O	12 ± 4	38 ± 17
Inspiratory Pes, cmH_2O	-12 ± 5	-62 ± 26
Inspiratory Pes/Pes,sniff, %	19 ± 6	98 ± 16
Inspiratory Pdi, cmH_2O	22 ± 4	73 ± 17
Inspiratory Pdi/Pdi,sniff, %	23 ± 4	78 ± 13

Table 4 Breathing pattern, muscle activation, respiratory pressures and effort of breathing during one IMT session (30 breaths) of the patients in the IMT group. Values are means ± SD. Abbreviations: Vt = tidal volume; Fb= breathing frequency; Ti' inspiratory time; Ti/Ttot = inspiratory duty cycle; EMGdi = electromyogram of the diaphragm measured during tidal inspiration; EMGdimax = the largest value of the diaphragm during a maximum inspiratory maneuver; EMGscm= electromyogram of the sternocleidomastoid measured during tidal inspiration; EMGscmmax= the largest value of the sternocleidomastoid during a maximum inspiratory maneuver; EMGsca= electromyogram of the scalene measured during tidal inspiration; EMGscamax=the largest value of the scalene during a maximum inspiratory maneuver; EMGabd= electromyogram of the abdominal (rectus abdominis) muscles measured during tidal expiration; EMGabd,max= the largest value of the abdominal (rectus abdominis) muscles during a maximum force vital capacity maneuver; Pestidal = the tidal swing of Pes; inspiratory Pes = the most negative Pes during a tidal inspiration; inspiratory Pdi = the most positive Pdi during a tidal inspiration

CONCLUSIONS

These preliminary results suggest that IMT improves inspiratory muscle strength with large effect size, while a trend of dyspnea improvement during potential longer exercise duration with medium effect size was observed. These improvements after IMT during the exercise were accompanied by a potentially better function of the diaphragm (improvement in Pdi,sniff, and reduction of diaphragm activation during exercise with medium effect sizes) and more reliance on the SCM muscle during exercise breathing. The more reliance on the SCM potentially was contributed by higher SCM stimulation during IMT.