제308회 대한결핵 및 호흡기학회 심포지엄 (2025.05.26)

Inspiratory muscle training in pulmonary rehabilitation

가톨릭의과대학교 성빈센트병원

재활의학과 윤미정

Pulmonary rehabilitation

- **Pulmonary rehabilitation (ERS, ATS)**

: Comprehensive intervention based on a thorough patient assessment
followed by patient-tailored therapies, which include, but are not limited to
Exercise training/ Education/ Behavior change
designed to improve the physical and psychological condition of people with chronic respiratory disease
and to promote the long-term adherence of health-enhancing behaviors

- **Exercise training (cornerstone of PR)**

- Endurance training (whole-body exercise)
- Resistance/Strength training (local muscle exercise)
- Flexibility training
- Neuromuscular electrical stimulation
- Inspiratory muscle training

Am J Respir Crit Care Med Vol 188, Iss. 8, 2013

Muscles involved respiration

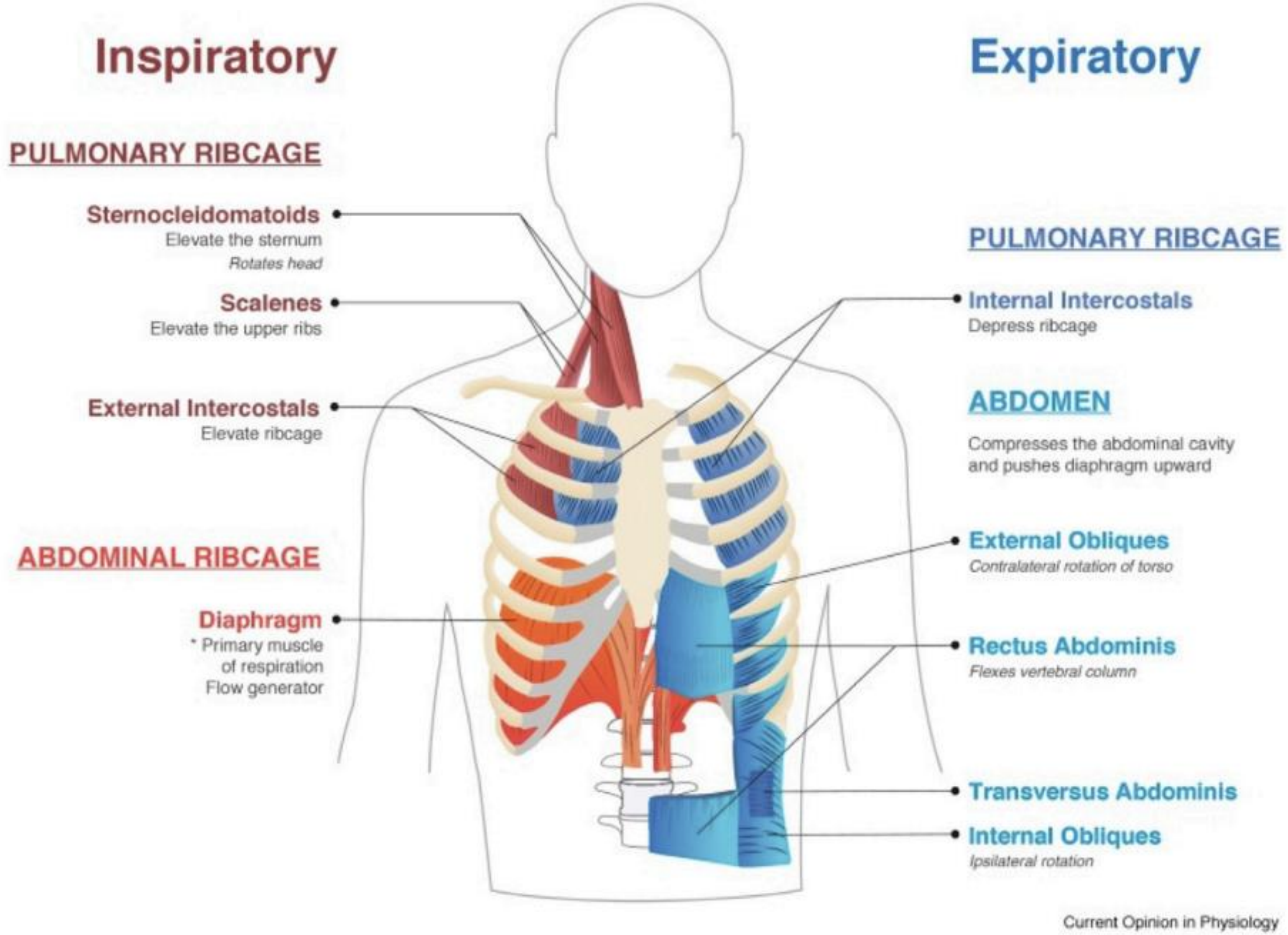


FIGURE 1 | Muscles involved in normal inspiration and expiration. From Welch et al., 2019.

Front. Physiol., 14 June 2022

Inspiratory muscle training

- **Training protocol**
- **Device**

Inspiratory muscle training

- **Inspiratory muscle training** : repetitive breathing exercise against an external load
  - controlled by time, intensity, frequency (FITT)

    Frequency: 3-5 sessions/week, 8-12 weeks

    Intensity: as a proportion of the maximal inspiratory pressure

    (30~50% of MIP → 75~100% MIP)

    (using RPE 12-14. progressively increasing intensity within tolerable range

    Time : interval training, 2min- work, 1min-rest. 7 repeats

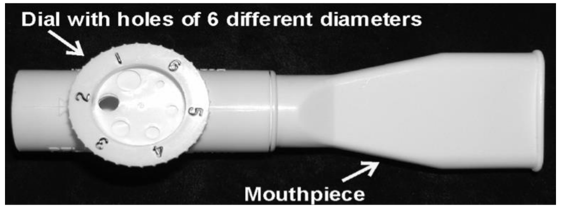
    Type

- **Muscle training (2 type)**
  - Strength training: high intensity and short duration >> 2가지 종류의 device
  - Endurance training: low intensity and long duration >> endurance training device

  : Muscle fiber → overload → structural, neurogenic adaption

Inspiratory muscle training

- **Three types of IMT devices** : how the load is generated
  - ■ threshold loading device: adjustable spring-loaded valve to set the resistance, 9-41cmH_2O



  - ■ passive flow resistive device: contain holes of different diameters

cf) electronic resistive device: similar of passive resistive trainer

dynamically adapting the flow resistance

  - ■ isocapnic hyperpena device: low load and high respiratory flow (60-90% of MVV)

    contain rebreathing bag to maintain physiological rates of CO_2

Inspiratory muscle training

- **Inspiratory muscle device**

  - inspiratory resistive trainer : resistance 가 inspiratory flow rate에 dependent

  - inspiratory threshold trainer: inspiratory flow에 independent

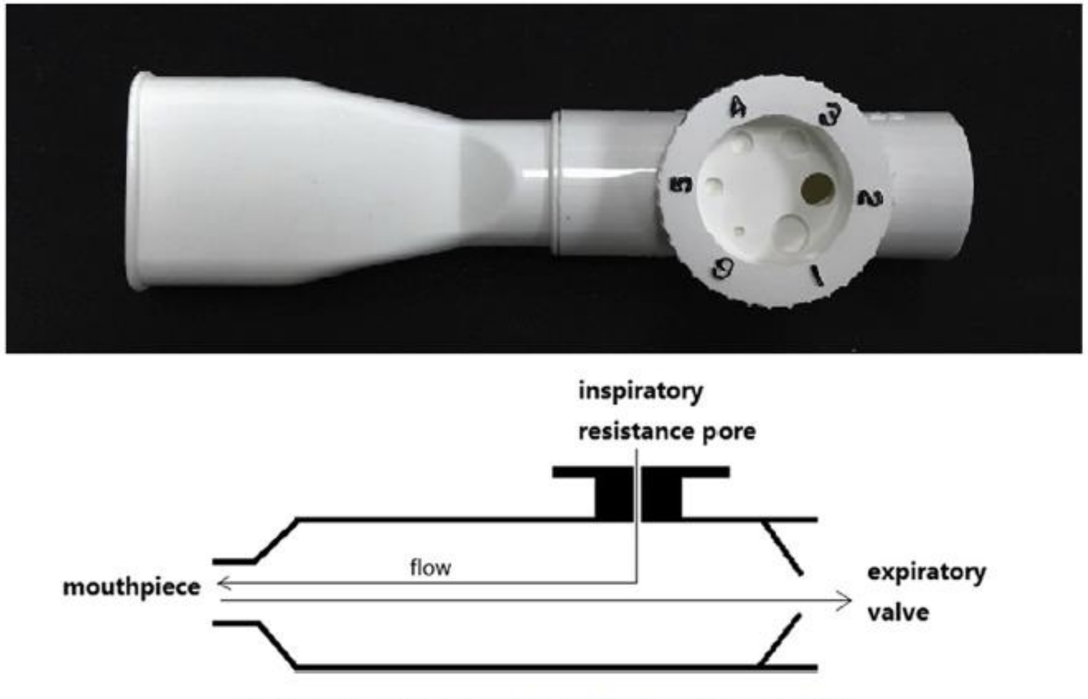


Fig. 1. Respiratory resistance device (PFLEX, Respironics Inc,USA).

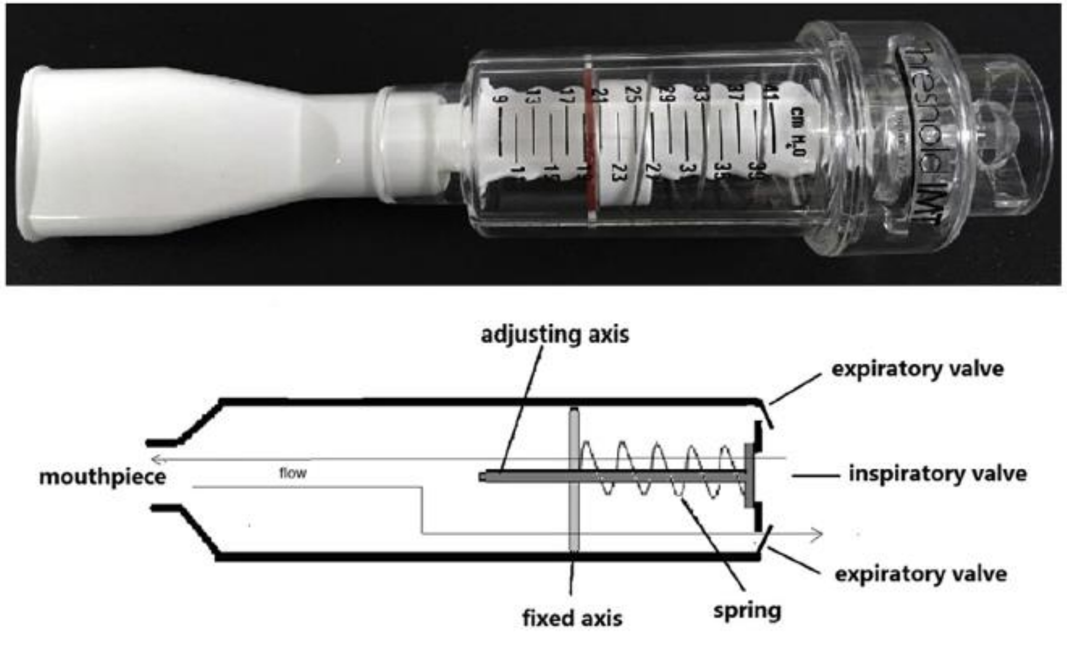


Fig. 2. Respiratory threshold load device (Threshold Inspiration Muscle Trainer, Respironics Inc,USA).

Respiratory Medicine, Vol 132, 84-91 2017

Inspiratory muscle training

Resistive Breathing Training in Patients with Chronic Obstructive Pulmonary Disease*

Michael J. Belman, M.D., F.C.C.P.; Scott G. Thomas, Ph.D.; and Michael I. Lewis, M.D., F.C.C.P.

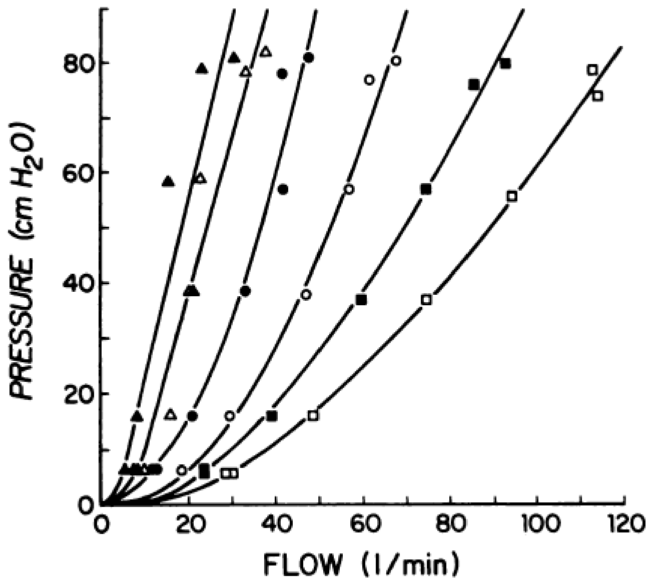


FIGURE 2. Flow characteristics of resistive training device. Each regression line represents pressure required to produce flow at each of six orifices. By decreasing flow, it is possible to maintain pressure relatively low, even though smaller orifice is used. Regression lines from left to right represent orifices 6 (diameter, 0.17 cm) through 1 (diameter, 0.54 cm), respectively.

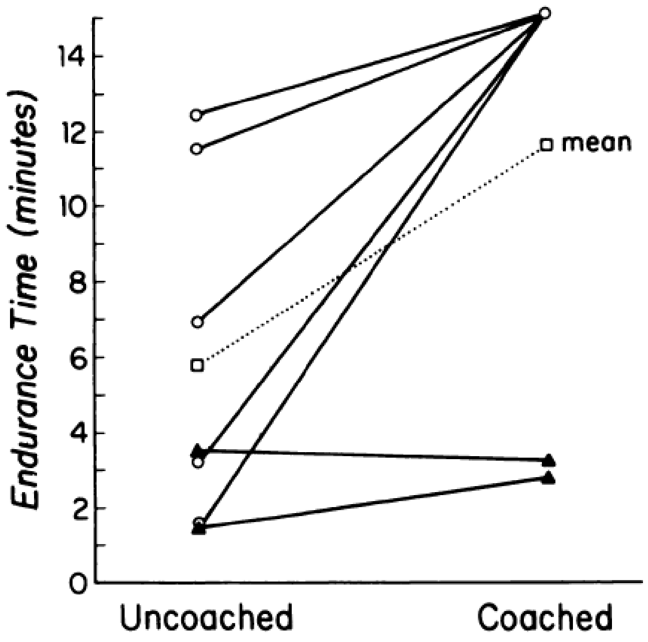


FIGURE 5. Endurance time for seven patients while breathing through orifice one smaller than critical orifice in uncoached and coached manner. There was significant increase in endurance time (5.78 ± 4.59 minutes to 11.56 ± 5.86 minutes) ($p<0.05$). Five patients who improved their endurance time to 15 minutes are shown as *open circles*. Two patients who did not improve are shown as *closed triangles*.

CHEST. Vol 90 (5) 1986

Inspiratory muscle training

- **Contraindication**

- Hx of recurrent spontaneous pneumothorax
- Large bullae
- Marked osteoporosis with Hx of spontaneous rib fracture

- **Safety**

- The first training session must be supervised
- Monitoring SaO2 (modest decrease, onset of hypoventilation as a strategy)

- **Maintenance**

- Training related gains are lost within 12 months
- Maintenance: 2 sessions each week
- During acute AE, cease training

Arch Phys Med Rehabil Vol 91, September 2010

Inspiratory muscle training in various condition

- COPD
- Interstitial Lung Disease
- ICU (mechanical ventilation)
- Post-operation (major surgery)
- Spinal cord injury
- Neuromuscular disorder (myopathy, ALS)

Inspiratory muscle training in

Chronic obstructive pulmonary disease

Pathophysiology of COPD

- **Inspiratory muscle function in COPD**

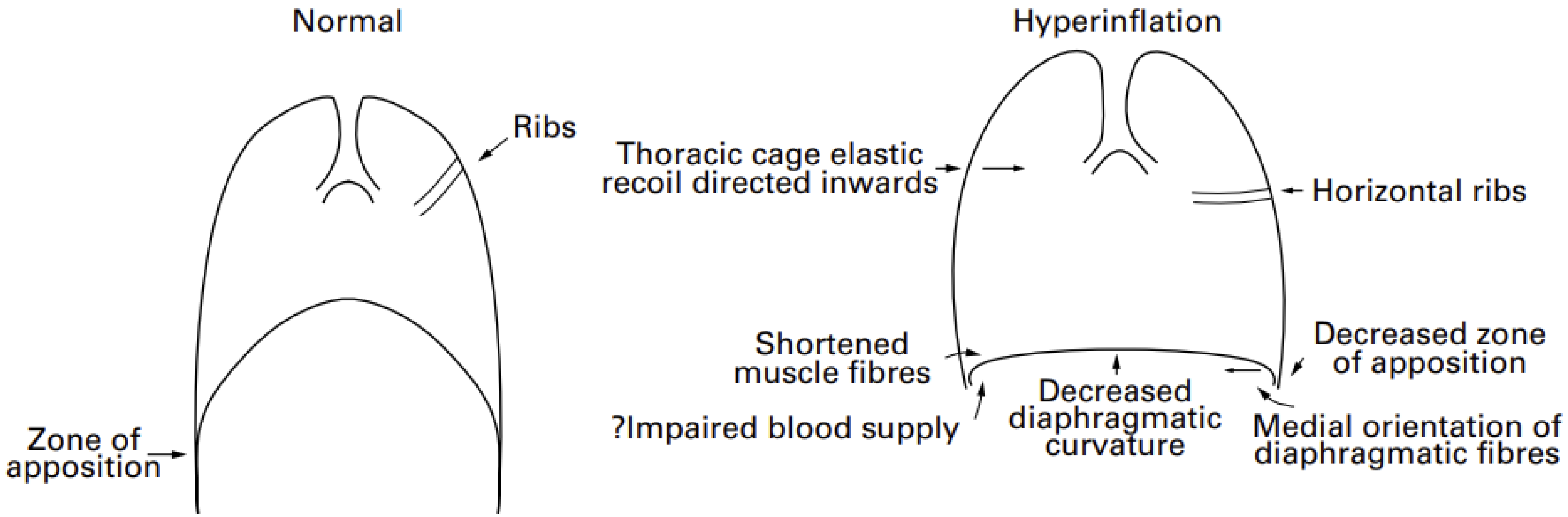


Figure 3 Summary of detrimental effects of hyperinflation on respiratory muscle function. Modified from Tobin.[74]

Hyperinflation

- Altered shape and geometry of chest wall : decreased apposition zone of diaphragm
- Flattening of diaphragm : reduction of force-generating capacity
- Shortening of diaphragm sarcomere length (esp. dynamic hyperinflation)

→ weakness of inspiratory muscle (diaphragm)

Thorax 54:458-465, 1999

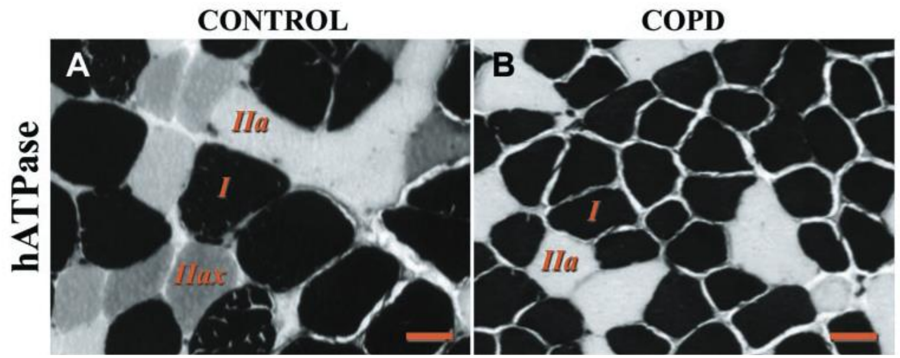
Pathophysiology of COPD

- **Inspiratory muscle function in COPD**

- increased inspiratory muscle load from hyperinflation and high airway resistance

- early stage: adaptation of inspiratory muscle

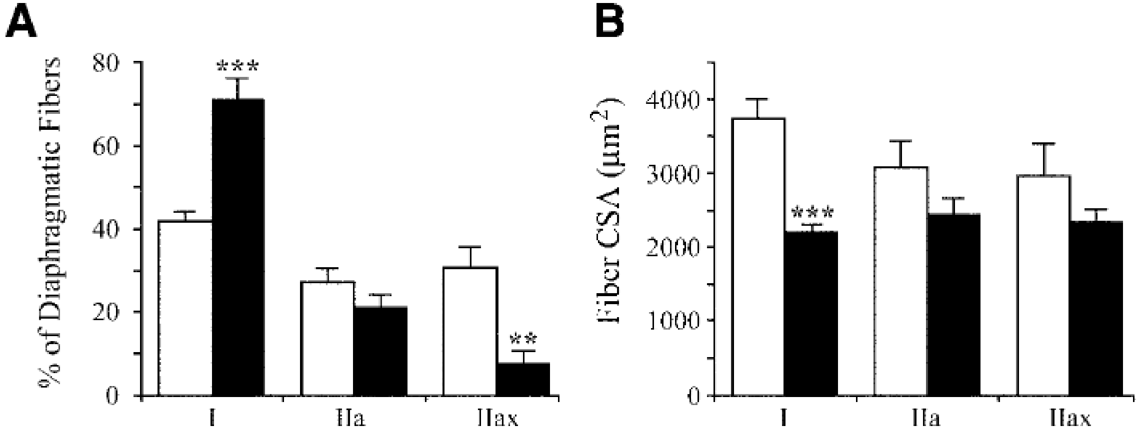
ex) diaphragm: type II fiber → type I fiber

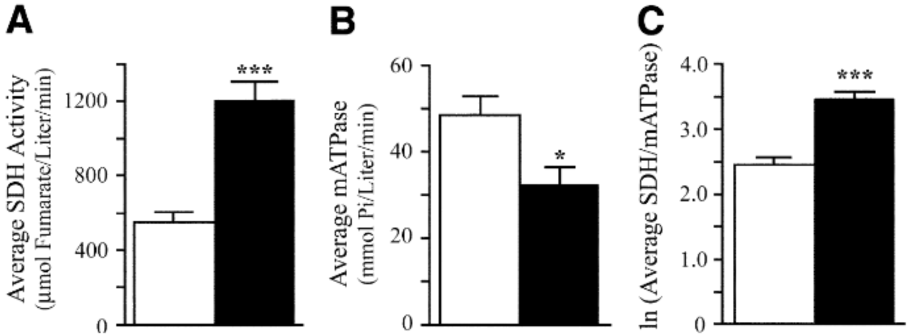


COPD diaphragm adaptation

: Type I fiber > Type IIx fiber

- Higher mitochondrial oxidative capacity





J Appl Physiol 92: 1205–1213, 2002.

Pathophysiology of COPD

- **Inspiratory muscle function in COPD**

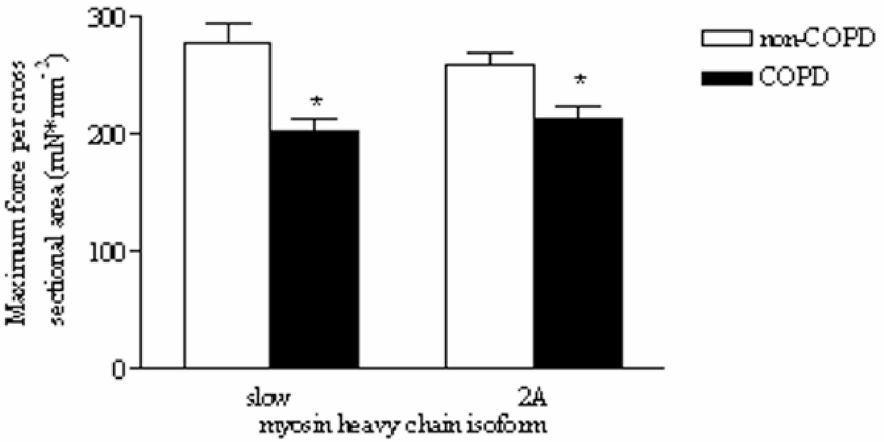
- Advanced stage: imbalance, ineffective function of inspiratory muscle

- Decreased MIP in COPD

MIP (kPa)	healthy	COPD (FEV1, 44%, FEV1/FVC, 37%)
Male	11.0 (3.3)	8.2 (2.6)
female	8.8 (2.7)	6.2 (1.4)

CHEST, 107 (3); 652, 1995

- Decreased trans-diaphragmatic pressure (severe COPD: ~65% of control)
- Reduced force generation of diaphragm fiber
- Inspiratory muscle weakness is related to dyspnea



Respiratory Research 2008, 9:12

>> **Inspiratory muscle training:** potential target for training**!**

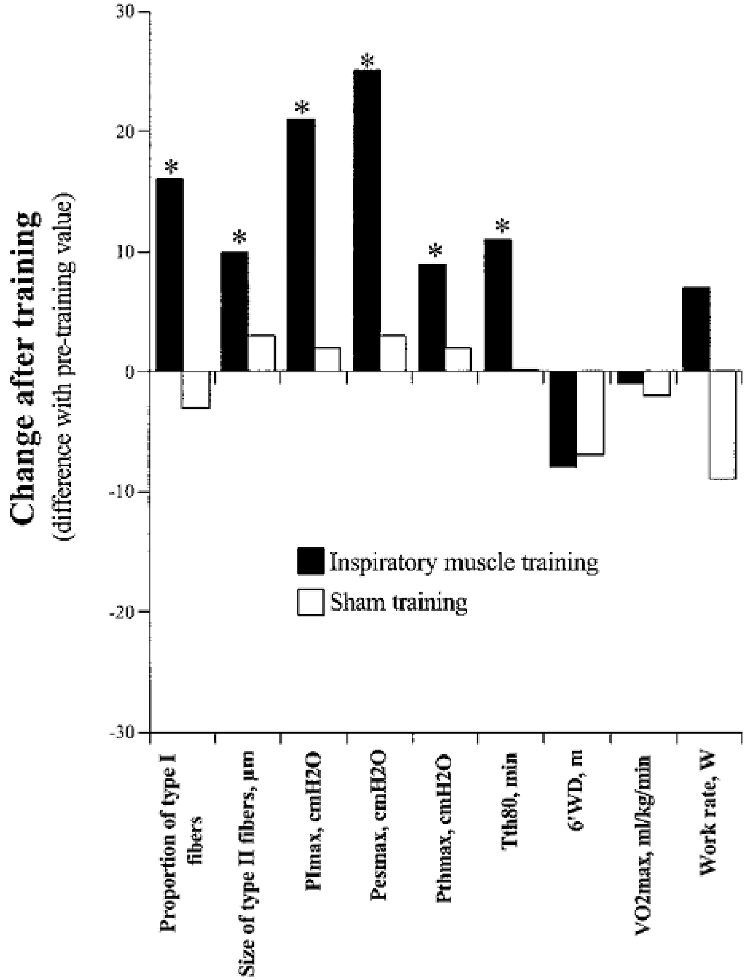
: reducing compromising dynamic hyperinflation

reduce inspiratory time

Effects of IMT in COPD

Inspiratory Muscle Training in Patients with Chronic Obstructive Pulmonary Disease

Structural Adaptation and Physiologic Outcomes



Pre-post change

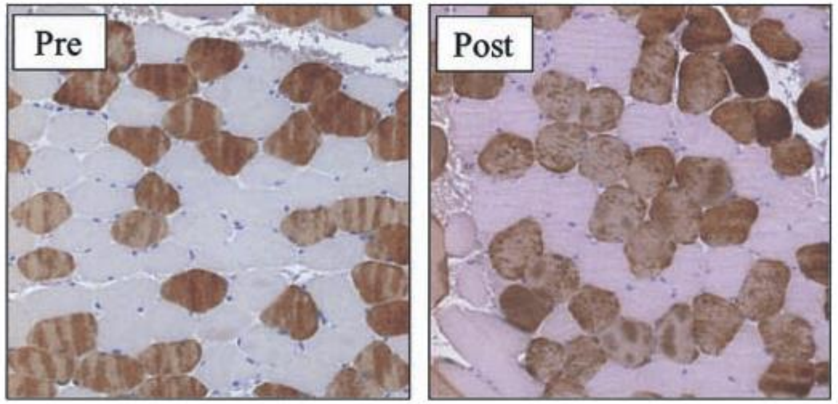
- Function : MIP, endurance 증가

  cf) exercise capacity는 차이 없음

- Structure (external intercostal muscle)

  : type I fiber 비율 증가

  type II fiber의 크기 증가



Am J Respir Crit Care Med, Vol 166, 1491-1497, 2002

Effects of IMT in COPD

Inspiratory muscle training improves breathing pattern during exercise in COPD patients

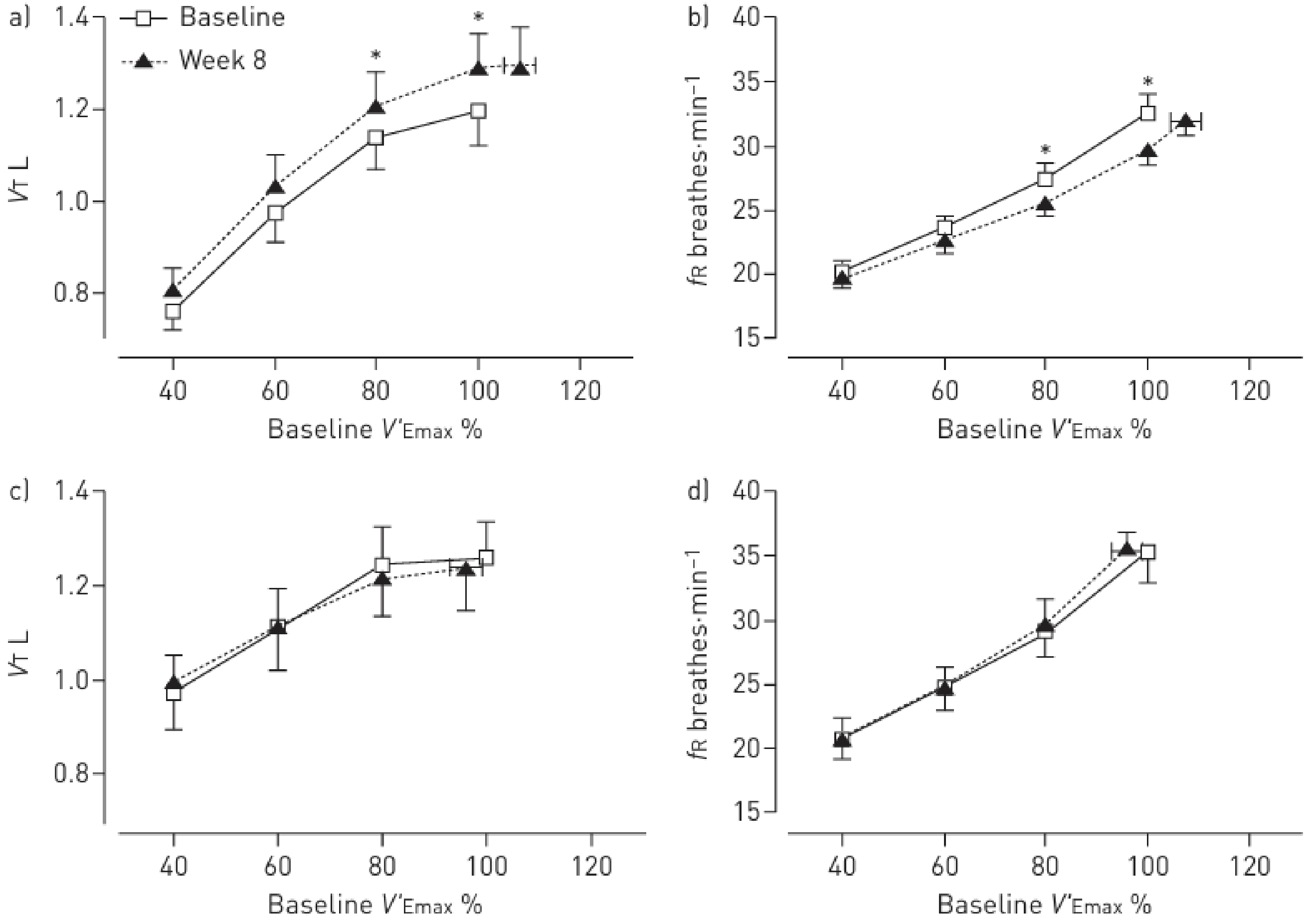


FIGURE 1 Changes in tidal volume (V_T) and respiratory frequency (f_R) at comparable percentages of baseline maximal ventilation (V'_{Emax}) (40, 60, 80, 100 and peak ventilation) at baseline and after training in a) and b) the inspiratory muscle training group and c) and d) the control group. *: $p<0.05$ (baseline *versus* week 8) based on *post hoc* tests from mixed model analysis, values represented as mean±SEM.

Eur Respir J 2016; 47: 1261–1264

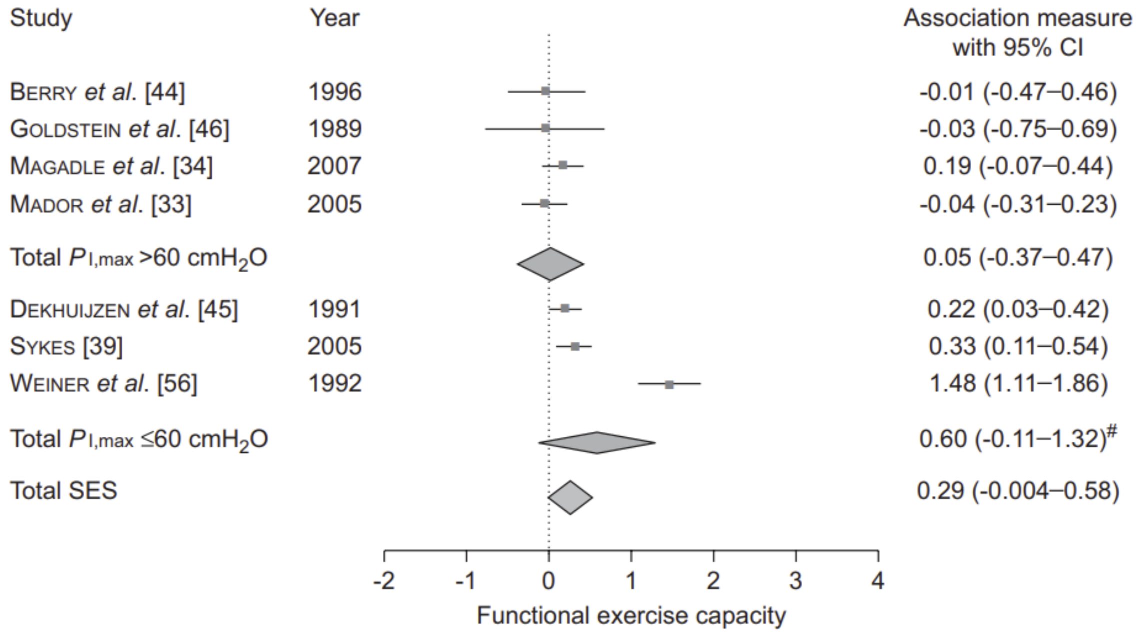
Effects of IMT in COPD

Impact of inspiratory muscle training in patients with COPD: what is the evidence?

- Diaphragmatic fatigue was not demonstrated after exhaustive exercise in COPD

- Adaption of the diaphragm, resistance to fatigue

- Inspiratory muscle strength training > endurance training (MIP, 6MWT, dyspnea)
- IMT vs control: improvement in MIP, 6MWD, dyspnea
- GE vs GE+IMT: improvement in only MIP (6MWD: in inspiratory muscle weakness, MIP<60cmH2O)



European Respiratory Journal 2011 37(2): 416-425

Thorax 2018 73: 942-950

Effects of IMT in COPD

- **COPD patients with inspiratory muscle weakness**

- Subject: MIP<60cmH2O or <50% of predicted normal

- Intervention: GET vs GET + IMT, PowerBreathe K

Table 3 Changes in respiratory muscle function

Variables	Intervention group Pre training	Intervention group Post training	Control group Pre training	Control group Post training	Adjusted difference (95% CI) at post training	P values*
PImax (cm H_2O)	53 (14)	75 (19)†	52 (11)	61 (13)†	14 (10 to 18)	<0.001
PEmax (cm H_2O)	110 (40)	127 (52)†	104 (30)	117 (35)†	3 (−7 to 14)	0.531
Endurance breathing (s)	240 (108)	593 (270)†	251 (96)	413 (236)†	189 (114 to 265)	<0.001
Ti/Ttot (%)	31 (17)	21 (14)†	34 (19)	28 (17)†	−5.6 (−9.3 to −1.9)	0.003
Total work (J)	78 (83)	258 (153)†	79 (97)	159 (162)†	100 (57 to 142)	<0.001
Average power (W)	1.8 (1.4)	3.1 (1.7)†	1.5 (1.5)	2.1 (1.6)†	0.8 (0.4 to 1.1)	<0.001

Dyspnoea post CPET	6.7 (2.6)	6.3 (2.7)	5.9 (2.3)	6.4 (2.1)	−0.5 (−1.4 to 0.5)	0.324
Leg effort post CPET	5.8 (2.9)	6.0 (2.4)	5.9 (2.2)	6.1 (2.1)	−0.1 (−1.0 to 0.8)	0.836
Endurance exercise capacity						
Work rate (W)	42 (16)		44 (18)			
Endurance cycle time (s)	271 (126)	496 (309)†	303 (163)	466 (292)†	75 (1 to 149)	0.048
Dyspnoea post cycle test	6.1 (2.2)	6.0 (2.1)	6.1 (2.2)	5.9 (2.3)	−0.3 (−1.0 to 0.4)	0.405
Leg effort post cycle test	6.0 (1.9)	5.2 (2.1)†	5.5 (2.3)	5.5 (2.3)	−0.4 (−1.2 to 0.3)	0.216
Dyspnoea score at isotime	6.1 (2.2)	3.7 (1.3)†	5.9 (2.0)	4.4 (1.9)†	−0.7 (−1.5 to −0.01)	0.049
Leg effort score at isotime	6.1 (1.9)	4.2 (1.7)†	4.9 (2.3)	4.5 (2.2)	−0.9 (−1.7 to 0.01)	0.052

- MIP, endurance breathing, endurance exercise capacity 증가, dyspnea at isotime 감소

- Exercise capacity (CPET, 6MWD)에서는 차이가 없었음 (insp function gain did not translate to improvement 6MWD)

Effects of IMT in COPD

Effects of inspiratory muscle training on dyspnoea in severe COPD patients during pulmonary rehabilitation: controlled randomised trial

- Subject: severe or very severe COPD, (FEV1<50%)
- Intervention: PPR vs PPR + IMT, PowerBreathe (threshold)

	IMT group	Control group	p-value
Subjects n	74	75	
Dyspnoea scales			
Borg scale	−1.4±2.0	−1.0±1.9	0.160
mMRC	−0.9±1.2	−0.8±1.3	0.508
Functional parameters			
P_{Imax} cmH_2O	14.8±14.9	9.9±13.8	0.041#
IC at rest L	0.1±0.5	0.2±0.4	0.404
IC at end of 6MWT L	0.0±0.5	0.0±0.7	0.796
IC at end of 6MWT – at rest L	−0.1±0.6	−0.2±0.7	0.525
6MWD m	23.4±51.2	36.2±44.9	0.111

Addition of IMT did not improve dyspnea, 6MD, QOL, but increased MIP

Eur Respir J 2018; 51: 1701107

Inspiratory muscle training, with or without concomitant pulmonary rehabilitation, for chronic obstructive pulmonary disease (COPD) (Review)

55 RCT, ~ 2022

		PR vs PR+IMT		IMT vs control/sham	
Outcome	**MCID**	**Mean difference**	**95%CI**	**Mean difference**	**95% CI**
Dyspnea (Borg) -at submax exercise	-1	0.19	-0.42, 0.79 (m)	-0.94	-1.36, -0.51 (v.l)
Dyspnea (mMRC)	-0.5~-1	-0.12	-0.39, 0.14 (v.l)	-0.59	-0.76, -0.43 (l)
6MWD	26	5.95	-5.73, 17.63 (v.l)	35.71	25.68, 45.74 (m)
SGRQ	-4	0.13	-0.93, 1.20 (l)	-3.85	-8.17, 0.48 (v.l)
CAT	-1.6	0.13	-0.80, 1.06 (v.l)	-2.97	-3.85, -2.10 (m)
MIP (PImax)	17.2	11.46	7.42, 15.50 (m)	14.57	9.85, 19.29 (l)
Adverse effect		Minor, self-limited		none	

certainty evidence: m, moderate; l, low; v,l, very low

Cochrane Database of Systematic Reviews, Jan 6;1(1) 2023

Current recommendation and guideline of IMT in COPD

- **British Thoracic Society Guideline in pulmonary rehabilitation in adults (2013)**

- Inspiratory muscle training (IMT) is not recommended as a routine adjunct to pulmonary rehabilitation. (Grade B)

- **An official STS / ERS statement: Key concepts and advances in pulmonary (2013)**

- IMT might be useful when added to whole-body exercise training in individuals <u>with marked inspiratory muscle weakness or those unable to participate in cycling or walking</u>

- **Global Strategy for the Diagnosis, Management, and Prevention of COPD (GOLD report 2025)**

- Inspiratory muscle training increased strength of inspiratory muscles, but this not consistently translate to better performance, reduced dyspnea or improve health related quality of life when added to a comprehensive pulmonary rehabilitation program

→ **IMT, a treatment option for people who <u>are unable to participate fully in whole-body exercise training because of comorbid conditions such as severe musculoskeletal problems or claudication</u>**

Am J Respir Crit Care Med Vol 188, Iss. 8, pp e13–e64, 2013

Inspiratory muscle training in Interstitial lung disease

Respiratory muscle function in ILD

- ILD: lower lung compliance – limit capacity to respond to an increase in respiratory demand
- Inspiratory muscle weakness in ILD? controversial

TABLE 3 Muscle function

	ILD	Controls	p-value
P_{Imax} kPa	9.3±3.4	8.7±2.8	0.51
P_{Emax} kPa	14.2±5.5	15.8±4.7	0.30
$P_{0.1}$ kPa	0.3 (0.3–0.5)	0.2 (0.1–0.3)	0.01
$P_{0.1}/P_{Imax}$ %	4.0 (2–7)	2.0 (0–3)	0.006
f_R L·min^{-1}	21±6[#]	18±5	0.04
V_T L	0.73±0.28[#]	0.75±0.27	0.80
$P_{0.1} \times t_i/V_T$ kPa·s·L^{-1}	0.56 (0.4–0.61)[#]	0.38 (0.28–0.51)[¶]	0.049
SnP_{na} kPa	8.6 (7.3–9.8)	8.3 (6.3–10.3)	0.99
TwP_{mo} kPa	0.86±0.4	1.32±0.4	<0.001
TwP_{oes} kPa	0.92±0.4[+]	1.15±0.3[§]	0.17
TwP_{ga} kPa	-0.47±0.3[+]	-0.77±0.2[§]	0.01
TwP_{di} kPa	1.32±0.6[+]	1.88±0.5[§]	0.02
$t_{trig-max}$ ms	129±16	139±11	0.049
Hand-grip force			
Right kPa	107±20[ƒ]	116±40[##]	0.66
Left kPa	103±25[ƒ]	108±35[##]	0.76

- impaired MIP in mild-to-moderate ILD

- MIP, sniff nasal pressure: 차이 없음
- respiratory drive (P0.1) : ILD 증가
- mouth and trans-diaphragmatic P during bilateral magnetic phrenic nerve stimulation: ILD 감소

European Respiratory Journal 42(1): 211-219.2013
Chest 96: 824–830. 1989

IMT in ILD

Does inspiratory muscle training provide additional benefits during pulmonary rehabilitation in people with interstitial lung disease? A randomized control trial

- Subject: ILD of any etiology, MIP<60cmH2O
- Intervention: 3/week, 8weeks, PR vs PR + IMT (30% of MIP→ 60%)
  SaO2 <88% → O2 Tx

Table 3. Effects of IMT during PR and PR alone at the end of 8 – week.

	PR + IMT Group	PR Group	Mean difference between Groups (95% CI)	Effect size	*p*-value
Partcipants, n	26	25			
Respiratory muscle strength					
PI_{max} cmH_2O	68.40 ± 7.98	57.29 ± 6.53	11.11 (6.90 to 15.31)	1.5	< .001*
Functional capacity					
6 MWD (m)	383.36 ± 40.32	335.46 ± 55.65	47.90 (20.05 to 75.74)	.98	.001*
HRQoL					
SGRQ-S	25.48 ± 6.13	30.08 ± 12.93	−4.59 (−10.25 to 1.06)	.45	.109
SGRQ-A	17.97 ± 11.74	27.80 ± 9.01	−9.83 (−15.74 to −3.92)	.93	.002*
SGRQ-I	25.10 ± 11.43	25.71 ± 12.10	−.61 (−7.23 to 6.01)	.05	.853
SGRQ-T	23.03 ± 6.36	27.04 ± 7.04	−4.00 (−7.78 to −.23)	.59	.038*
PFT					
FEV_1, % predicted	56.84 ± 18.48	57.67 ± 18.83	−.82 (−11.55 to 9.90)	.04	.877
FVC, % predicted	59.80 ± 18.69	58.00 ± 19.22	1.80 (−9.09 to 12.69)	.09	.741
FEV_1/ FVC % predicted	108.64 ± 10.71	108.71 ± 10.14	−.06 (−6.07 to 5.93)	.00	.982
TLC, % predicted	62.60 ± 20.36	60.25 ± 23.42	2.35 (−10.25 to 14.95)	.10	.709
RV, % predicted	73.32 ± 24.32	63.96 ± 25.93	9.36 (−5.08 to 23.80)	.37	.199
RV/TLC, % predicted	117.88 ± 23.41	110.13 ± 21.00	7.75 (−5.04 to 20.55)	.34	.229
DL_{CO},% predicted	41.96 ± 14.06	44.04 ± 13.56	−2.08 (−10.02 to 5.86)	1.5	.601
Dyspnea perception					
mMRC score	1 (1)	2 (1)		0.64	< .001*

Inclusion of IMT to PR may have superior benefits as compared to PR alone in ILD accompanied with IMW.

Physiotherapy Theory and Practice, 39:3, 518-528.2022

IMT in ILD

Effects of home-based telerehabilitation-assisted inspiratory muscle training in patients with idiopathic pulmonary fibrosis: A randomized controlled trial

- Subject: idiopathic pulmonary fibrosis, MIP<60cmH2O
- Intervention: 7/week, 8weeks, sham IMT vs resistance IMT (50% of MIP→ tolerable range)

TABLE 2 Mean difference of values of clinical parameters, by intervention.

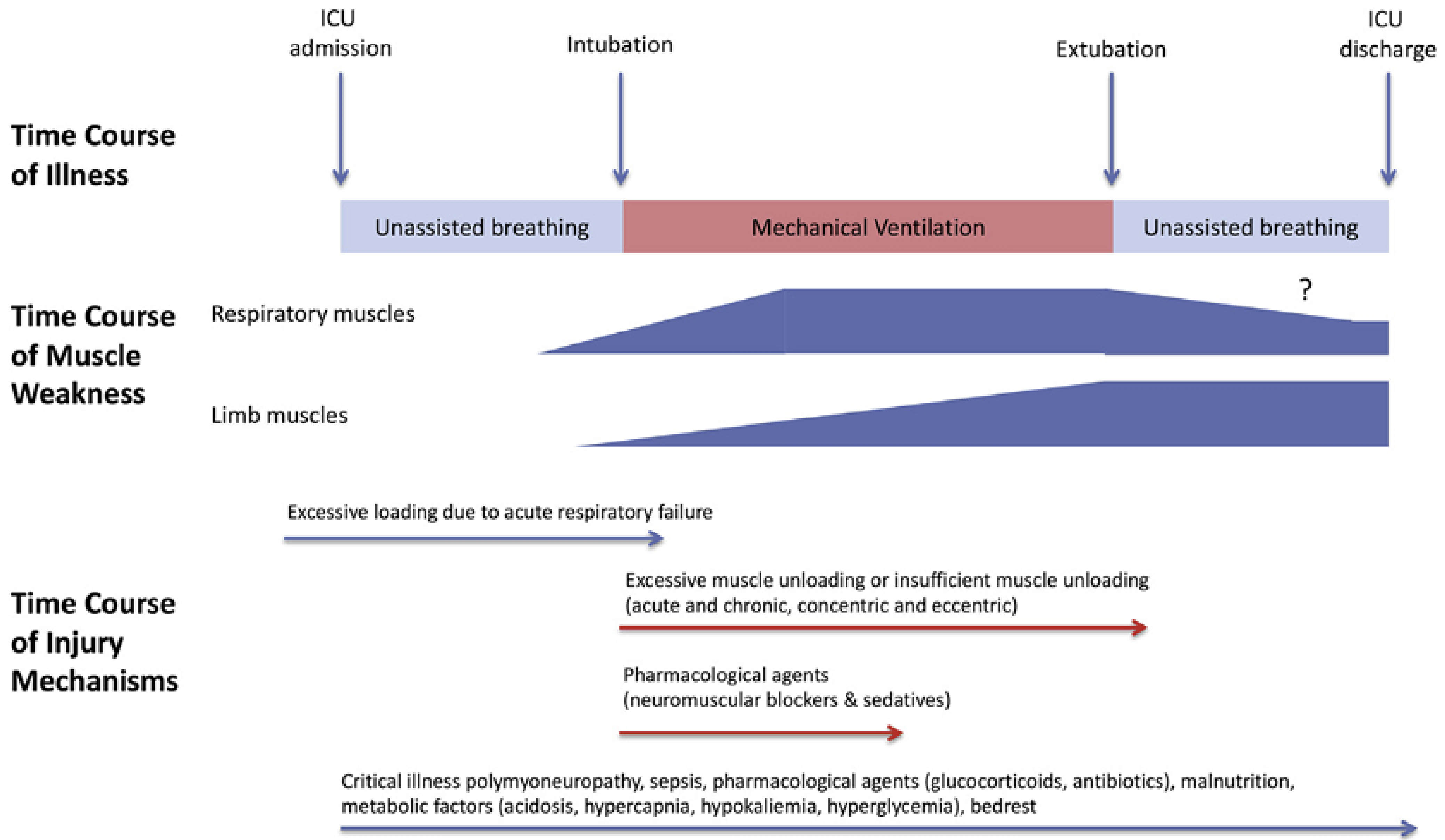
	Intervention group (n = 14)		Control group (n = 14)		Group differences		
Parameters	Post-intervention	95% CI	Post-intervention	95% CI	Mean difference (95% CI)	Effect size (η^2)	p-value[a]
mMRC score	1.13 ± 0.20	0.71–1.54	2.52 ± 0.20	2.10–2.94	−1.39 (−1.99 to −0.80)	*0.48*	<0.001
6MWD, m	460.3 ± 6.0	448.0–472.5	423.7 ± 6.0	411.4–435.9	36.6 (19.2 to 53.9)	*0.43*	<0.001
FEV_1, % predicted	85.5 ± 2.8	82.6–94.2	88.4 ± 2.8	82.6–94.2	−2.9 (−11.1 to 5.4)	*0.02*	0.482
FVC, % predicted	81.9 ± 2.6	76.4–87.3	81.6 ± 2.6	76.1–87.0	0.31 (−7.4 to 8.1)	*0.00*	0.935
DL_{CO}, % predicted	45.3 ± 6.8	31.2–59.4	55.7 ± 6.8	41.6–69.8	−10.4 (−30.4 to 9.6)	*0.04*	0.295
MIP, cmH_2O	72.9 ± 5.9	60.9–84.9	48.1 ± 5.9	36.0–60.1	24.9 (7.9 to 41.9)	*0.27*	0.006
MIP, % predicted	101.7 ± 8.8	83.7–119.8	66.0 ± 8.8	47.9–84.1	35.7 (10.1 to 61.3)	*0.25*	0.008

home-based tele-rehabilitation-assisted IMT intervention produced improvements in MIP, leading to improvements in functional exercise capacity and dyspnea

Respirology ;29:1077–1084. 2024

Inspiratory muscle training in ICU or mechanical ventilation

Respiratory muscle weakness during mechanical ventilation



Crit Care Clin 34 (2018) 357–381

IMT in ICU/MV

Inspiratory Muscle Rehabilitation in Critically Ill Adults

A Systematic Review and Meta-Analysis

28 studies (N=1,185patients)

- heterogenous timing of IMT initiation: after 24hr ventilation/ transition to partially assisted ventilation/ rediness-to-weaning/ failed to attempting weaning/ after liberation from ventilation

Study	Experimental Total	Experimental Mean	Experimental SD	Control Total	Control Mean	Control SD	MD	95% CI	Weight
Regimen = Endurance									
Özyürek 2014	15	35.00	9.0000	16	25.00	9.0000	10.00	[3.66; 16.34]	4.1%
Holliday 1990	20	12.00	4.0000	16	6.00	2.0000	6.00	[3.99; 8.01]	12.1%
Porta 2005	32	9.00	12.0000	34	5.00	9.0000	4.00	[−1.14; 9.14]	5.5%
Caruso 2005	12	5.00	9.0000	13	7.00	19.0000	−2.00	[−13.52; 9.52]	1.5%
Chang 2011	8	10.00	8.0000	5	14.00	10.0000	−4.00	[−14.37; 6.37]	1.9%
Random effects model	87			84			4.75	[1.28; 8.22]	25.2%
Regimen = Strength									
Bissett 2016	33	16.00	19.0000	36	5.00	17.0000	11.00	[2.46; 19.54]	2.6%
Condessa 2013	45	7.00	8.0000	47	−3.00	6.0000	10.00	[7.10; 12.90]	9.8%
Pascotini 2014	7	5.00	13.0000	7	−4.00	4.0000	9.00	[−1.08; 19.08]	2.0%
Cader 2010	14	10.00	2.0000	14	2.00	1.0000	8.00	[6.83; 9.17]	14.1%
Dixit 2014	15	15.00	6.0000	15	7.00	3.0000	8.00	[4.61; 11.39]	8.7%
Martin 2011	35	10.00	11.0000	34	2.00	11.0000	8.00	[2.81; 13.19]	5.5%
Mohamed 2014	20	8.00	2.0000	20	2.00	1.0000	6.00	[5.02; 6.98]	14.5%
Ibrahiem 2014	15	5.00	1.0000	15	1.00	2.0000	4.00	[2.87; 5.13]	14.2%
Tonella 2017	11	7.00	12.0000	8	10.00	11.0000	−3.00	[−13.41; 7.41]	1.8%
Shimizu 2014	8	−5.00	7.0000	5	2.00	11.0000	−7.00	[−17.79; 3.79]	1.7%
Random effects model	203			201			6.62	[4.82; 8.43]	74.8%
Random effects model	**290**			**285**			**6.22**	**[4.71; 7.72]**	**100.0%**

Heterogeneity: $I^2 = 72\%$, $\tau^2 = 3.8396$, $p < 0.01$
Test for subgroup differences: $\chi^2_1 = 0.88$, df = 1 ($p = 0.35$)

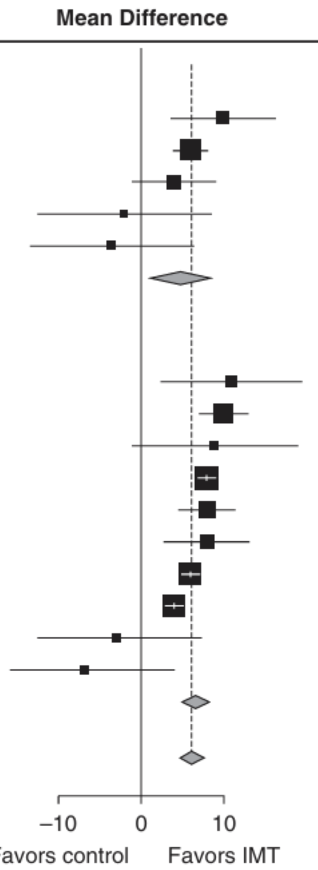


Figure 2. Effect of inspiratory muscle training (IMT) on the change in maximal inspiratory pressure from baseline to the completion of the treatment course.

IMT improved MIP, MEP compared with control

AnnalsATS Volume 15(6); 735, 2018

IMT in ICU/MV

Inspiratory Muscle Rehabilitation in Critically Ill Adults
A Systematic Review and Meta-Analysis

Study	Experimental Total	Experimental Mean	Experimental SD	Control Total	Control Mean	Control SD	MD	95% CI	Weight
Condessa 2013	45	2.2	1.8	47	2.5	2.5	–0.30	[–1.19; 0.59]	14.1%
Caruso 2005	12	1.0	0.5	13	1.3	0.9	–0.30	[–0.87; 0.27]	14.4%
Melo 2017	6	4.9	1.2	4	6.4	1.8	–1.50	[–3.51; 0.51]	12.0%
Shimizu 2014	8	3.4	1.3	5	4.9	2.0	–1.50	[–3.47; 0.47]	12.1%
Cader 2010	14	3.6	1.5	14	5.3	1.9	–1.70	[–2.97; –0.43]	13.5%
Dixit 2014	15	4.3	1.5	15	6.3	1.7	–2.00	[–3.15; –0.85]	13.7%
Tonella 2017	11	3.5	1.6	8	9.4	6.5	–5.90	[–10.50; –1.30]	6.8%
Mohamed 2014	20	3.3	1.6	20	10.4	2.5	–7.10	[–8.40; –5.80]	13.4%
Random effects model	**131**			**126**			**–2.30**	**[–3.94; –0.67]**	**100.0%**

Heterogeneity: $I^2 = 93\%$, $\tau^2 = 4.724$, $p < 0.01$

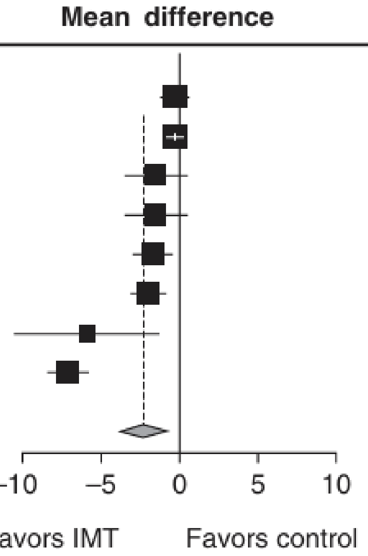


Figure 4. The impact of inspiratory muscle training (IMT) on the duration of weaning from mechanical ventilation. After exclusion of studies at serious risk of bias, the effect remained significant (3.2 d; 95% CI, 0.6–5.8 d; $I^2 = 95\%$). Weight refers to the contribution of each study to the meta-analysis estimate of effect. CI = confidence interval; MD = mean difference; SD = standard deviation.

IMT was associated with reduced duration of ventilation and reduced duration of weaning

not associated with ICU length of stay or increased risk of death in ICU

AnnalsATS Volume 15(6); 735, 2018

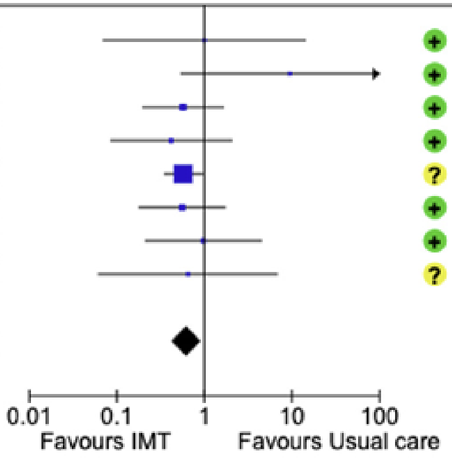
IMT in ICU/MV

The Effects of Inspiratory Muscle Training in Critically ill Adults: A Systematic Review and Meta-Analysis

18 studies, threshold device

Study or Subgroup	IMT Events	IMT Total	Usual care Events	Usual care Total	Weight	Risk ratio M-H, Random, 95% CI	Risk of Bias A	B	C	D	E
Benli 2024	1	13	1	13	2.1%	1.00 [0.07 , 14.34]	+	+	+	+	?
Bissett 2016	4	34	0	36	1.8%	9.51 [0.53 , 170.33]	+	+	+	+	+
Bissett 2023	4	29	9	37	13.0%	0.57 [0.19 , 1.66]	+	?	+	+	+
Condessa 2013	2	45	5	47	5.9%	0.42 [0.09 , 2.04]	+	+	+	+	?
da Silva Guimaraes 2021	14	48	27	53	56.7%	0.57 [0.34 , 0.96]	?	−	+	+	+
Khodabandeloo 2023	4	40	7	39	11.4%	0.56 [0.18 , 1.75]	+	+	+	+	?
Martin 2011	3	35	3	34	6.4%	0.97 [0.21 , 4.48]	+	+	?	+	?
Roceto Ratti 2022	1	34	2	44	2.7%	0.65 [0.06 , 6.84]	?	+	+	+	?
Total		**278**		**303**	**100.0%**	**0.62 [0.42 , 0.91]**					
Total events:	33		54								

Test for overall effect: Z = 2.44 (P = 0.01)
Test for subgroup differences: Not applicable
Heterogeneity: Tau² = 0.00; Chi² = 4.47, df = 7 (P = 0.72); I² = 0%



Risk of bias legend
(A) Risk of bias arising from the randomization process
(B) Risk of bias due to deviations from the intended interventions (effect of adhering to the intervention)
(C) Risk of bias due to missing outcome data
(D) Risk of bias in measurement of the outcome
(E) Risk of bias in selection of the reported result

Figure 5. Forest plot of the risk ratio of mortality. IMT = inspiratory muscle training; SD = standard deviation; CI = confidence interval; IMV = invasive mechanical ventilation; M-H = Mantel-Haenszel; + = low risk of bias; ? = some concerns for risk of bias; − = high risk of bias.

Hospital mortality risk was reduced in IMT group

: IMT initiation during MV was associated with lower mortality

Journal of Intensive Care Medicine 2025 Feb

IMT in ICU/MV

■ **Practical guide for IMT in ICU**

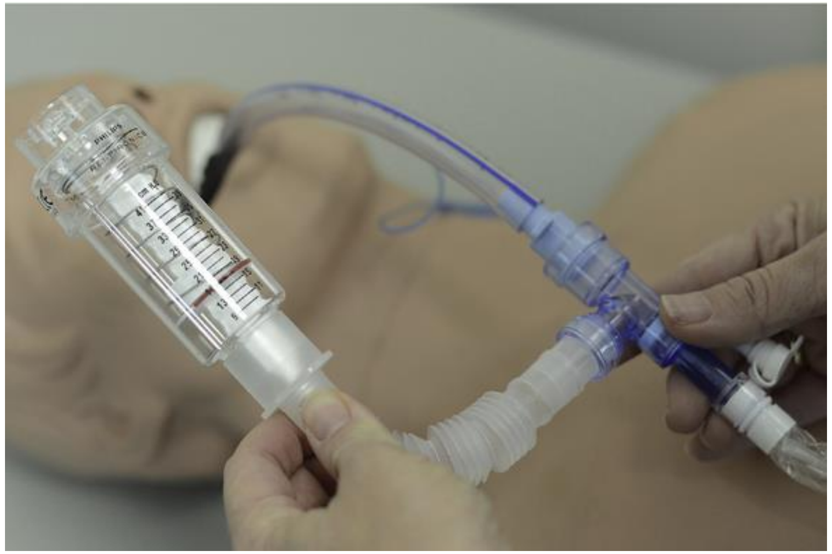
- Indication for IMT in ICU :

  MV>7 days, ventilator-dependent

- Equipment: threshold device (9-41 cmH2O)

  connector to ETT or T-tube

  suction circuit, respiratory pressure meter



ICU PATIENT INVASIVELY VENTILATED > 7 days:

Consider Inspiratory Muscle Training if

VENTILATOR-DEPENDENT:

- Alert and co-operative
- PEEP ≤10 cmH_2O
- FiO_2 <0.60
- RR <25
- Able to trigger spontaneous breaths on ventilator

RECENTLY WEANED* FROM INVASIVE VENTILATION:

- Alert and co-operative
- Capable of lip seal around mouth piece OR have a tracheostomy in situ
- FiO_2 <0.60
- RR <25

Australian Critical Care 32 (2019) 249e255

IMT in ICU/MV

■ **Practical guide for IMT in ICU**

- **Training protocol**

: high-intensity low repetition – maximize benefit and minimize distress

intensity: 50% of MIP ->titration to the maximal tolerated level (complete the 6^{th} breath/set)

frequency: 5 days/ week, 5 sets daily

- supervision: give normal ventilator support between sets, allow rest and recovery before next set (about 1-2min)
- Progression : 1-2 cmH20 every 1-2 days
- Pneumonia: reduce intensity or cease training for a few days

Australian Critical Care 32 (2019) 249e255

Inspiratory muscle training for major surgery patients

Postoperative pulmonary complication

- **Postoperative pulmonary complication (PPC)**

 - atelectasis, pneumonia, bronchospasm, embolus, ARDS, respiratory failure

 → hospital length of stay, functional performance, readmission, mortality

- **Risk factors of PPC**

 - age, smoking

 - cardiopulmonary exercise capacity (peak oxygen uptake)

 - pulmonary disease (forced expiratory volume in 1 second [FEV1]

 - muscular weakness, including that of the respiratory muscles

 → modifiable through pulmonary rehabilitation

IMT for major surgery

Preoperative inspiratory muscle training for postoperative pulmonary complications in adults undergoing cardiac and major abdominal surgery

12 trials (695 participants)

Subject: cardiac surgery / major abdominal surgery

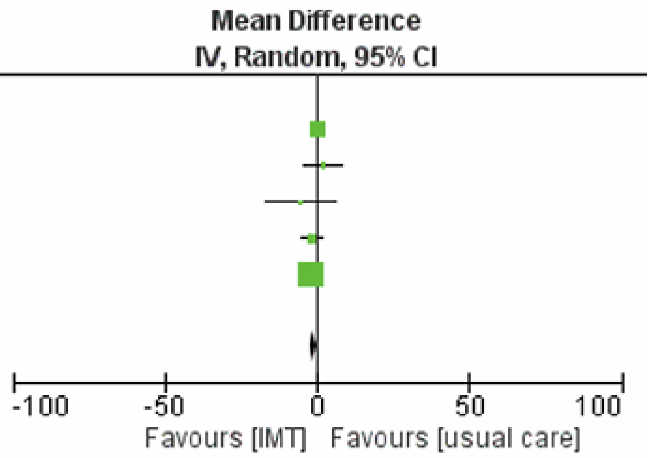
Intervention: preoperative IMT vs control

Figure 7. Forest plot of comparison: 1 Preoperative inspiratory muscle training (IMT) versus usual care, non-exercise intervention, outcome: 1.8 Duration of hospital stay.

	IMT			usual care				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Barbalho-Moulim 2011	2	0	15	2.11	0.33	17		Not estimable
Carvalho 2011	8	3.1	16	8	2.9	16	29.2%	0.00 [-2.08, 2.08]
Da Cunha 2013	9	4.9	7	7	7.6	9	3.7%	2.00 [-4.15, 8.15]
Dronkers 2010	16.2	11.5	22	21.6	23.7	20	1.1%	-5.40 [-16.84, 6.04]
Hulzebos 2006a	7.93	1.94	14	9.92	5.78	12	11.7%	-1.99 [-5.41, 1.43]
Hulzebos 2006b	7.89	2.17	139	9.94	8.27	137	54.3%	-2.05 [-3.48, -0.62]
Total (95% CI)			**213**			**211**	**100.0%**	**-1.33 [-2.53, -0.13]**

Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 4.29$, df = 4 (P = 0.37); $I^2 = 7\%$

Test for overall effect: Z = 2.17 (P = 0.03)



- Preoperative IMT was associated with a reduction of postoperative <u>atelectasis and pneumonia</u>
- The effect of IMT on all-cause postoperative mortality is uncertain
- Preoperative IMT was associated with <u>reduced length of hospital stay</u>

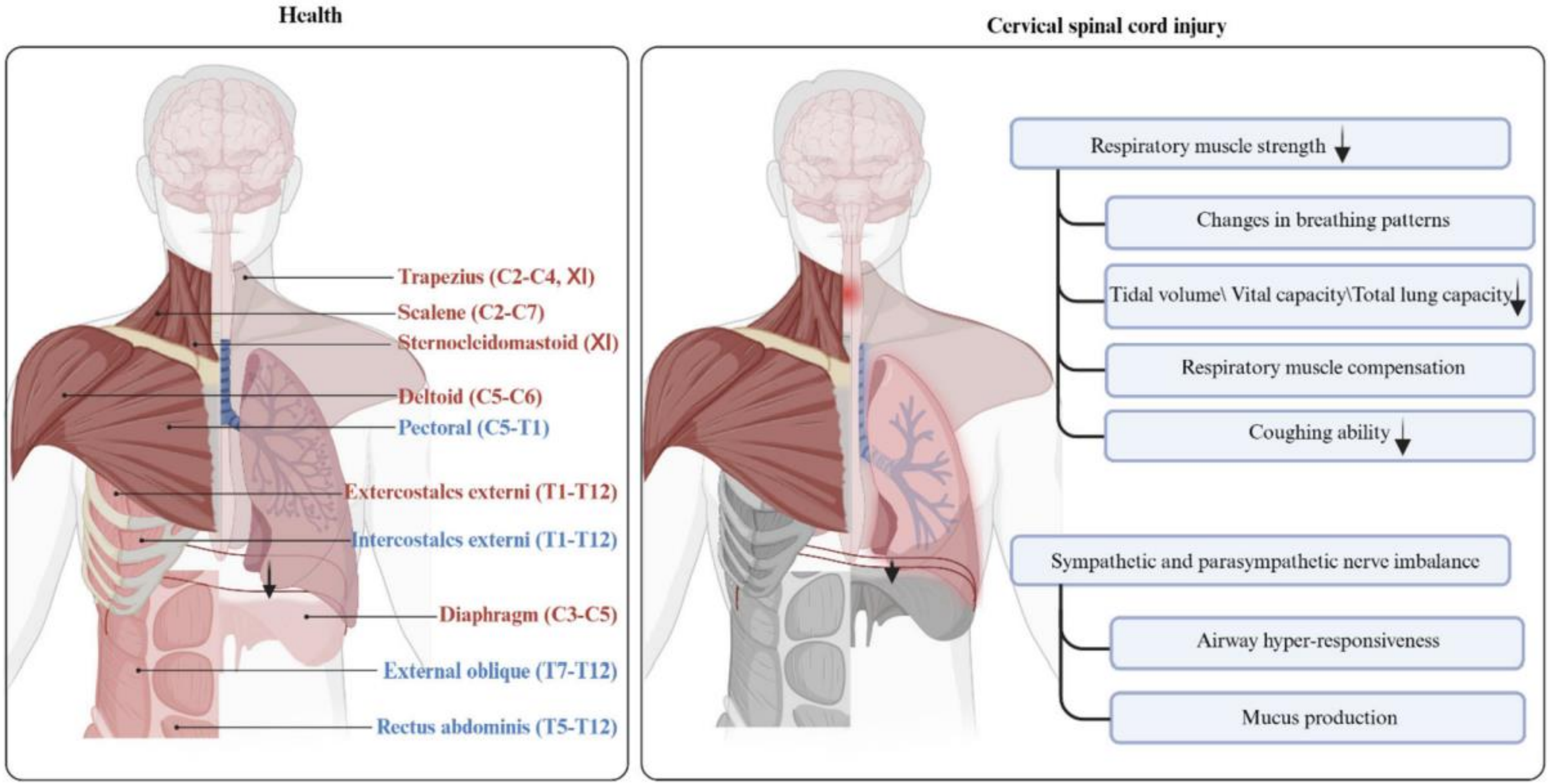
Cochrane Database of Systematic Reviews 2015, Issue 10

Inspiratory muscle training for

Spinal cord injury

Respiratory impairment in spinal cord injury

- **Cervical cord injury**: denervation and loss of coordination of respiratory muscles
  - → Weak respiratory muscle → ventilation, lung volume, cough → pneumonia, atelectasis
  - → leading cause of death in SCI



- Cord injury severity
- Injury level: C4
- Complete, incomplete

Front. Neurol., 14 October 2023

IMT in SCI

Impact of respiratory muscle training on respiratory muscle strength, respiratory function and quality of life in individuals with tetraplegia: a randomised clinical trial

- Subject: SCI induced tetraplegia (C4-C8 level), ASIA scale A-C
- Intervention: IMT (threshold) vs sham-IMT. 3-5 set (12 breaths), 5/weeks, 6 weeks

Table 3 Outcome measures at baseline, after 6 weeks of RMT and after 1 year of unsupervised training

	Sham RMT group			Active RMT group				
	Baseline (n=32)	6 weeks (n=31)	1 year (n)*	Baseline (n=30)	6 weeks (n=29)	1 year (n)*	P value at 6 weeks	P value at 1 year
Primary outcome								
PImax (cmH_2O)	51.5±19.7	54.9±21.3	63.0±29.0 (15)	48.4±22.6	63.7±24.0	70.2±32.2 (19)	**<0.001**	0.081
Secondary outcomes								
PEmax (cmH_2O)	33.2±14.0	37.4±17.8	36.2±16.5 (15)	32.8±18.2	38.4±21.7	44.6±20.5 (18)	0.799	0.075
Lung function								
FEV_1 (L)	1.9±0.7	1.9±0.8	2.0±1.0 (16)	1.8±0.8	1.8±0.8	2.1±0.8 (19)	0.385	0.674
FVC (L)	2.5±0.9	2.6±1.0	2.9±1.4 (16)	2.3±1.0	2.5±1.1	2.8±1.0 (19)	0.349	0.600
Inspiratory capacity (L)	2.1±0.7	2.1±0.8	1.6±0.7 (7)	2.0±0.7	2.0±0.8	2.2±0.5 (11)	0.979	0.077
PEFc (L/s)	4.6±1.6	4.7±1.8	4.2±1.8 (8)	4.6±1.5	4.7±1.6	5.4±1.8 (11)	0.893	0.659
Vital capacity (L)	2.6±0.9	2.7±1.1	2.8±1.4 (7)	2.3±0.8	2.5±1.0	3.0±0.9 (11)	0.126	0.391
Total lung capacity (L)	4.8±1.3	4.9±1.2	4.3±1.8 (4)	5.0±1.1	5.1±1.3	5.0±1.0 (7)	0.402	0.689
Respiratory complications (n)	0	6	10 (19)†	0	2	3 (22)†	0.257	**0.017**

Improvement of MIP, Borg scale, QOL and fewer respiratory complication (after 1 yrs) in RMT group.

Thorax 2020;75:279–288

IMT in SCI

The effects of inspiratory muscle training on inspiratory muscle strength, lung function and quality of life in adults with spinal cord injuries: a systematic review and Meta-analysis

- 6RCT
- Subject: ASIA A-D, acute-chronic
- IMT vs control

	IMT			Control				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Derrickson et al (1992)	58.17	12	6	43.4	13	5	19.2%	14.77 [−0.13, 29.67]
Liaw et al (2000)	58.6	16.7	10	63.1	17.9	10	18.9%	−4.50 [−19.67, 10.67]
Mueller et al (2013)	35.38	29.43	8	8.88	15.21	8	12.7%	26.50 [3.54, 49.46]
Postma et al (2014)	82.7	29.7	19	70.7	28.1	21	16.4%	12.00 [−5.97, 29.97]
Soumyashree & Kaur et al (2018)	110	14.6	15	78.3	27.5	12	17.0%	31.70 [14.48, 48.92]
West et al (2013)	135	15	5	116	15	5	15.9%	19.00 [0.41, 37.59]
Total (95% CI)			**63**			**61**	**100.0%**	**15.72 [5.02, 26.41]**

Heterogeneity: $Tau^2 = 97.70$; $Chi^2 = 11.20$, df = 5 ($P = 0.05$); $I^2 = 55\%$
Test for overall effect: $Z = 2.88$ ($P = 0.004$)

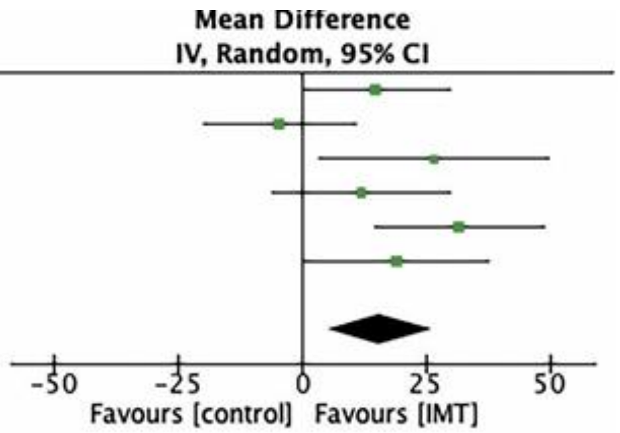


Figure 3. Mean difference (95% CI) in maximal inspiratory pressure (cmH_2O) due to inspiratory muscle training, estimated by pooling data from six studies ($n = 124$).

Improvement in only MIP

No benefit for QOL, FEV1, MEP

Inspiratory muscle training for Neuromuscular disease

Neuromuscular disease (NMDs)

- **Neuromuscular disease (NMDs)**

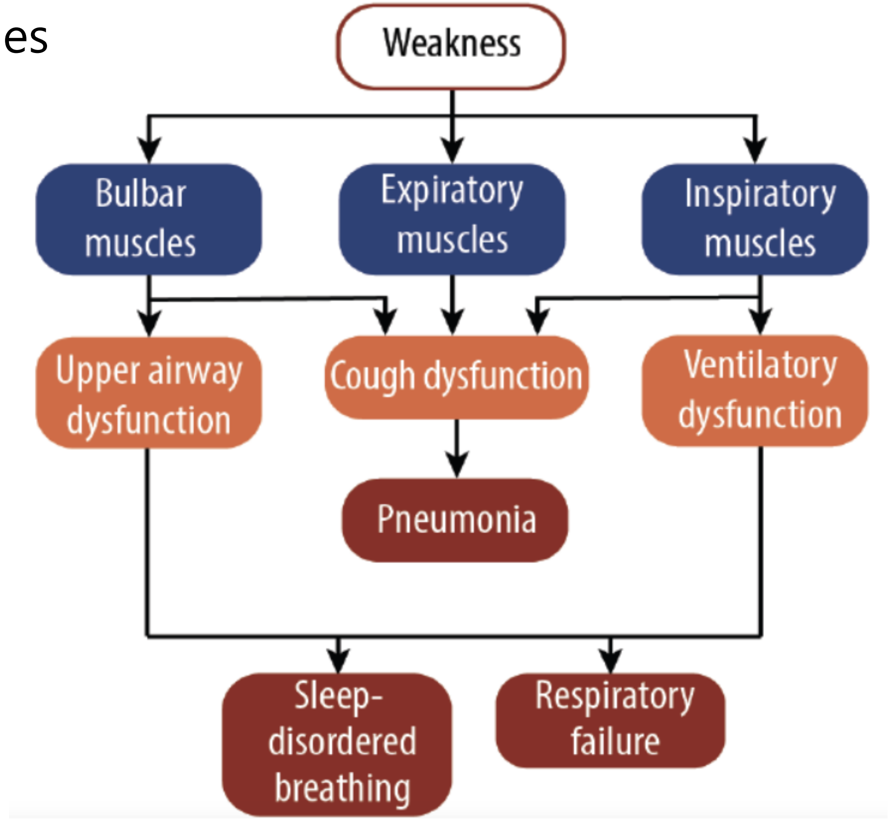
: heterogeneous group of conditions that impair muscle function through pathologies of the anterior horn cell of spinal cord, neuromuscular junction, peripheral nerves and muscles

→ muscle weakness, muscle atrophy including respiratory muscles

- **Respiratory impairments in NMDs**

- ventilator difficulty
- decreased vital capacity
- reduced chest wall expansion
- difficult coughing, impairment in mucus control
- risk of fluid aspiration d/t bulbar palsy

→ respiratory failure



JULY/AUGUST 2022 PRACTICAL NEUROLOGY 53

IMT in NMD

Respiratory muscle training in children and adults with neuromuscular disease

11 studies, 250 participants

- Subject: children+ adults, motor neuron disease (ALS), myopathy (DMD), NMJ disorder (M. gravis)
- IMT vs control

<Amyotrophic lateral sclerosis>

- The mean difference (MD) in FVC% after four months' treatment was 10.86% in favour of IMT (95% CI -4.25 to 25.97; 1 trial, N = 24; low-certainty evidence)
- no benefit in physical function or QOL
- no adverse effects

<Duchenne muscular dystrophy>

- 6-week intervention, TLC favored RMT in DMD (MD 0.45 L, 95% CI -0.24 to 1.14; 1 trial, N = 16; low-certainty evidence)
- 18 days intervention, FVC showed no clear difference in DMD

Cochrane Database of Systematic Reviews 2019, Issue 9

IMT in NMD

Respiratory muscle training in neuromu
systematic review and meta-analysis

Subject: NME with impaired respiratory mu
(spinal cord injury, Guillain-Barre syndrome
risk of bias and the small sample sizes

- Improvement in RMT: VC, MIP, MEP
- No benefit: cough, dyspnea, physical activity, QoL

The quality of evidence: low or very low d/t the overall high

Study or subgroup	Respiratory training Mean	SD	Total	Control Mean	SD	Total	Weight (%)	SMD IV, random, 95% CI
Inspiratory training								
Derrickson *et al.* [16]	2.6	0.73	6	1.68	0.32	5	2.7	1.44 (0.03–2.84)
Fregonezi *et al.* [17]	2.8	0.8	14	3	0.8	13	5.6	−0.24 (−1.00–0.52)
Fry *et al.* [18]/Pfalzer *et al.* [31]	0.2	0.29	20	0.01	0.29	21	6.4	0.64 (0.01–1.27)
Kim *et al.* [22]	0.15	0.06	12	0.03	0.01	12	3.5	2.69 (1.54–3.85)
Liaw *et al.* [24]	0.6	0.31	10	0.4	0.31	10	4.7	0.62 (−0.28–1.52)
Mohamed *et al.* [52]	0.08	0.07	15	0.03	0.03	15	5.6	0.90 (0.15–1.66)
Mueller *et al.* [30]	0.4	0.37	16	0.32	0.45	8	5.0	0.19 (−0.66–1.05)
Postma *et al.* [34]	0.42	0.55	19	0.41	0.55	21	6.5	0.02 (−0.60–0.64)
Reyes *et al.* [35]	2.76	0.92	11	3.03	1.25	5	3.9	−0.25 (−1.31–0.81)
Topin *et al.* [42]	1.78	0.31	8	1.76	0.79	8	4.3	0.03 (−0.95–1.01)
Vural *et al.* [50]	0.41	0.4	9	−0.01	0.06	7	3.7	1.30 (0.19–2.42)
Wanke *et al.* [44]	1.62	0.9	15	1.48	0.71	15	5.8	0.17 (−0.55–0.89)
Subtotal (95% CI)			**155**			**140**	**57.8**	**0.54 (0.14–0.94)**
Heterogeneity: Tau²=0.30; Chi²=28.88, df=11 (p=0.002); I²=62%								
Test for overall effect: Z=2.62 (p=0.009)								
Expiratory training								
Gounden *et al.* [20]	0.5	0.42	20	−0.1	0.55	20	6.1	1.20 (0.52–1.88)
Reyes *et al.* [35]	3.27	1.38	10	3.03	1.25	5	3.9	0.17 (−0.91–1.24)
Roth *et al.* [38]	0.28	0.43	16	0.34	0.53	13	5.7	−0.12 (−0.85–0.61)
Sapienza *et al.* [39]	3.65	0.96	30	3.23	0.78	30	7.2	0.47 (−0.04–0.99)
Westerdahl *et al.* [46]	3.6	1	23	3.6	1	25	6.9	0.00 (−0.57–0.57)
Subtotal (95% CI)			**99**			**93**	**29.8**	**0.36 (−0.10–0.83)**
Heterogeneity: Tau²=0.16; Chi²=9.43, df=4 (p=0.05); I²=58%								
Test for overall effect: Z=1.52 (p=0.13)								
Combined training								
Aslan *et al.* [2]	0.09	0.2	14	−0.2	0.7	10	5.1	0.59 (−0.24–1.42)
Roswell-Ruys *et al.* [48]	2.5	1.1	30	2.6	1	32	7.4	−0.09 (−0.59–0.40)
Subtotal (95% CI)			**44**			**42**	**12.5**	**0.16 (−0.49–0.82)**
Heterogeneity: Tau²=0.11; Chi²=1.92, df=1 (p=0.17); I²=48%								
Test for overall effect: Z=0.49 (p=0.6)								
Total (95% CI)			**298**			**275**	**100.0**	**0.43 (0.16–0.70)**
Heterogeneity: Tau²=0.20; Chi²=42.37, df=18 (p=0.0010); I²=58%								
Test for overall effect: Z=3.11 (p=0.002)								
Test for subgroup differences: Chi²=0.99, df=2 (p=0.61); I²=0%								

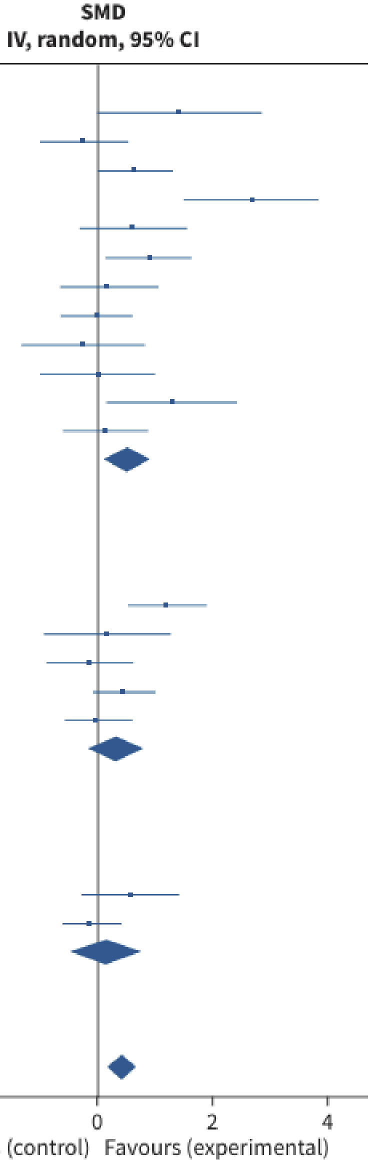


FIGURE 3 Forest plot for (forced) vital capacity. df: degrees of freedom; IV: inverse variance; SMD: standardised mean difference