INSPIRATORY MUSCLE TRAINING

ADJUNCT IN THE TREATMENT OF WEANING FAILURE?

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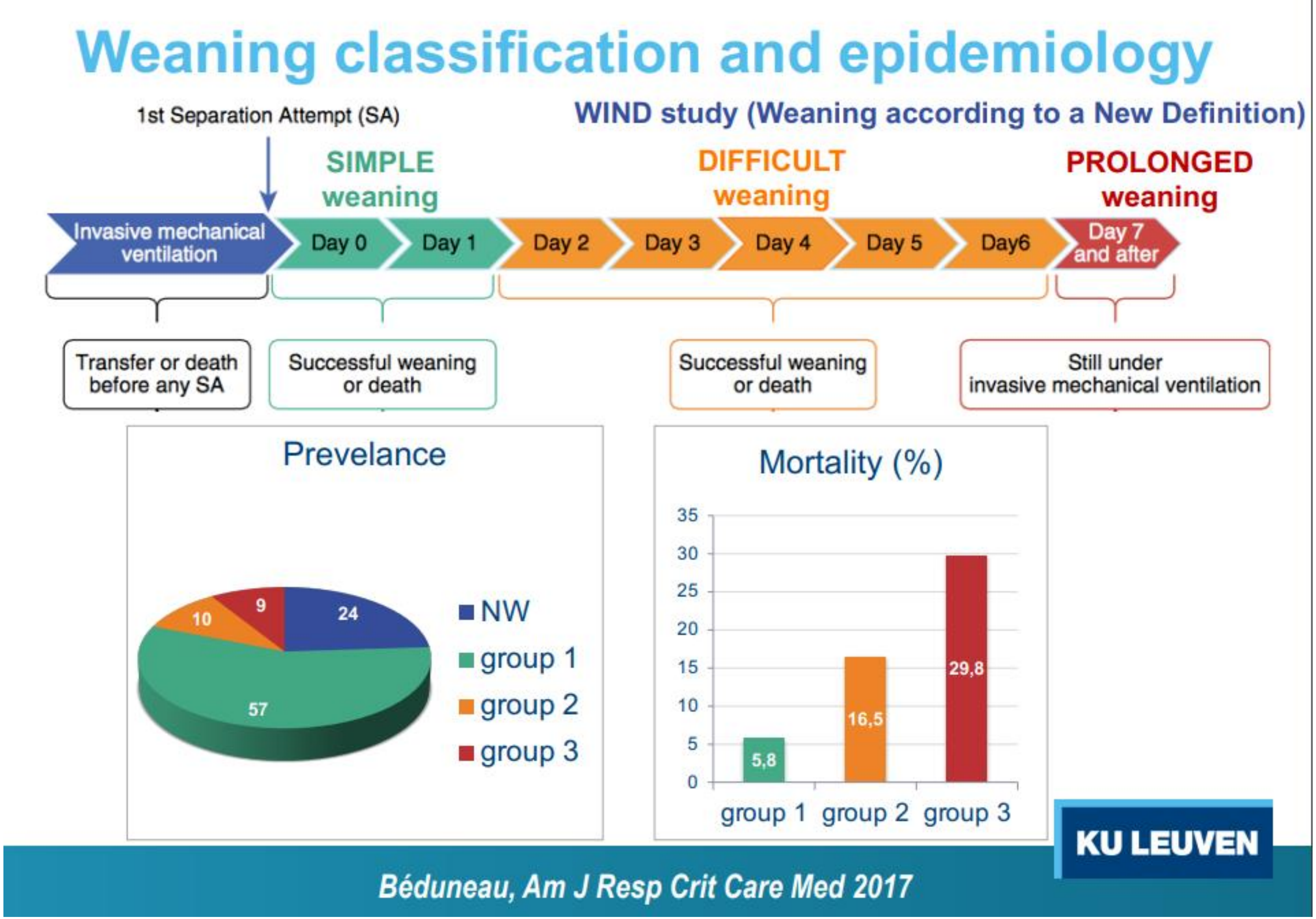
KATHOLIEKE UNIVERSITEIT LEUVEN

réanimation 2025
PARIS 11-13 JUIN



Slide: Greet Hermans

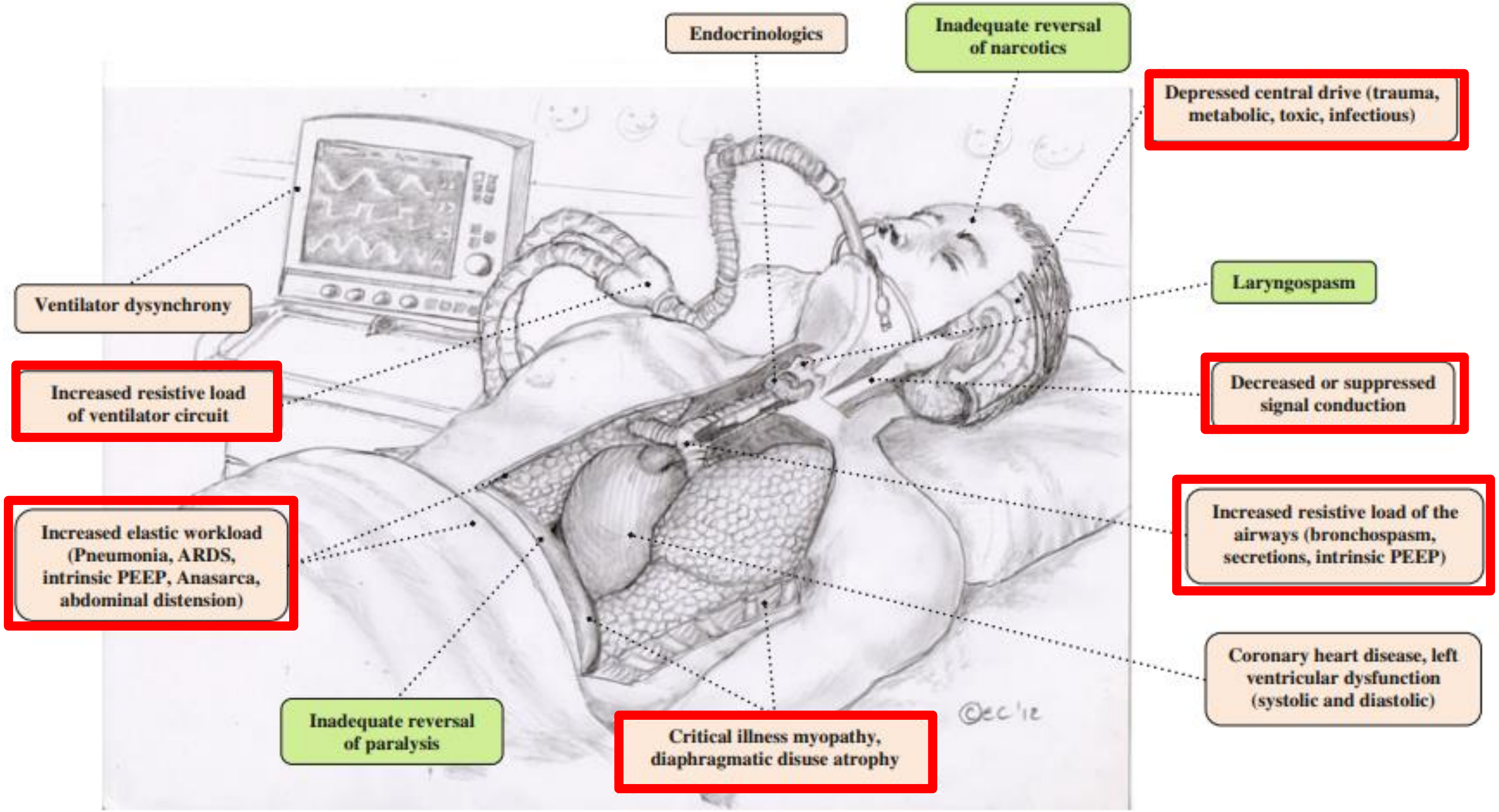


Fig. 1 Synoptic illustration of reasons contributing to weaning/extubation failure in anaesthetized and critically ill patients. ▢ anaesthetized, ▢ critically ill

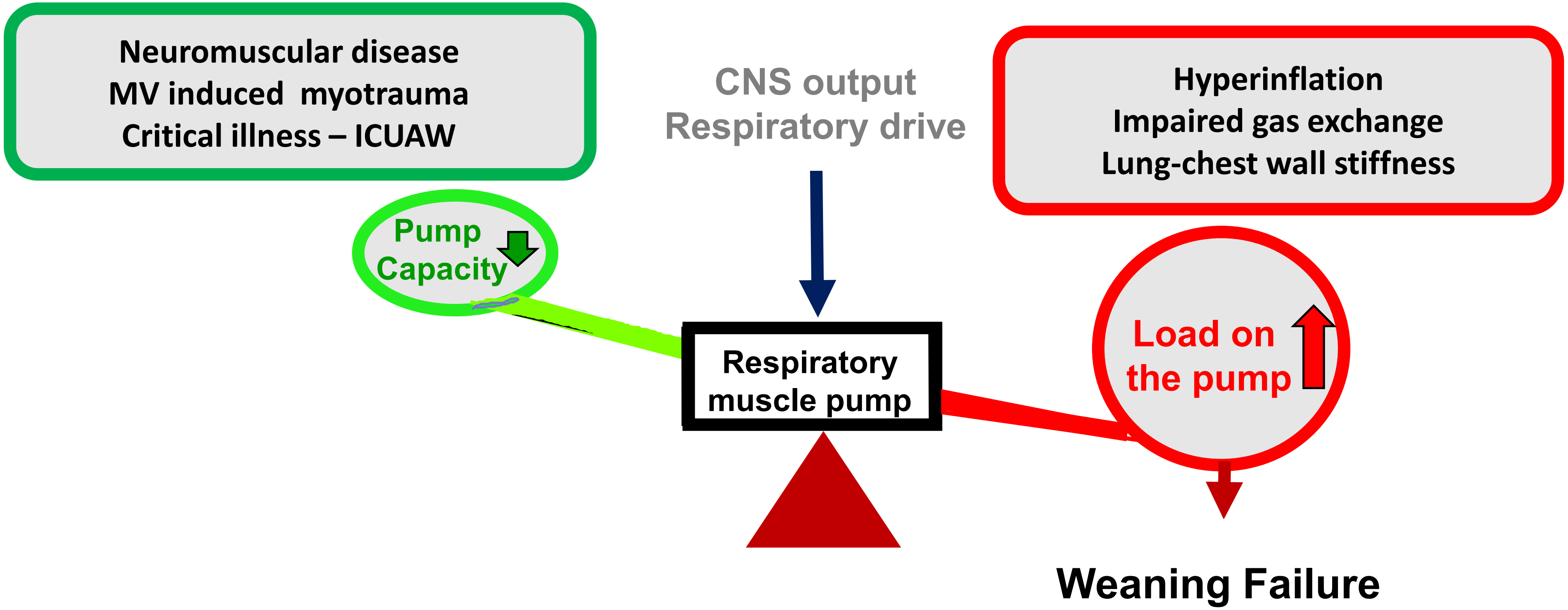
Perren A, Brochard L. **Managing the apparent and hidden difficulties of weaning from mechanical ventilation.**
Intensive Care Med. 2013 Nov;39(11):1885-95. doi: 10.1007/s00134-013-3014-9. Epub 2013 Jul 18. PMID: 23863974.

Table 1 Most frequent reasons for weaning failure according to the three groups of the weaning classification: consequences for daily practice

Simple weaning	Delayed awakening due to accumulation of sedative drugs Lack of screening Excessive level of ventilatory assist making weaning assessment unreliable Lack of systematic discussion during rounds Lack of personnel
Difficult weaning	Accumulation of sedative drugs Fluid overload Left heart failure Respiratory muscle weakness (myopathy) Excessive workload due to infection, secretions, unresolved sepsis, etc.
Prolonged weaning	Severe chronic heart failure Severe chronic respiratory insufficiency Prolonged respiratory muscle weakness (neuro-myopathy) Depression Poor sleep quality, severe constipation, persistent sepsis, etc.

Perren A, Brochard L. **Managing the apparent and hidden difficulties of weaning from mechanical ventilation.** Intensive Care Med. 2013 Nov;39(11):1885-95. doi: 10.1007/s00134-013-3014-9. Epub 2013 Jul 18. PMID: 23863974.

DIFFICULT WEANING



Adapted from Moxham J.

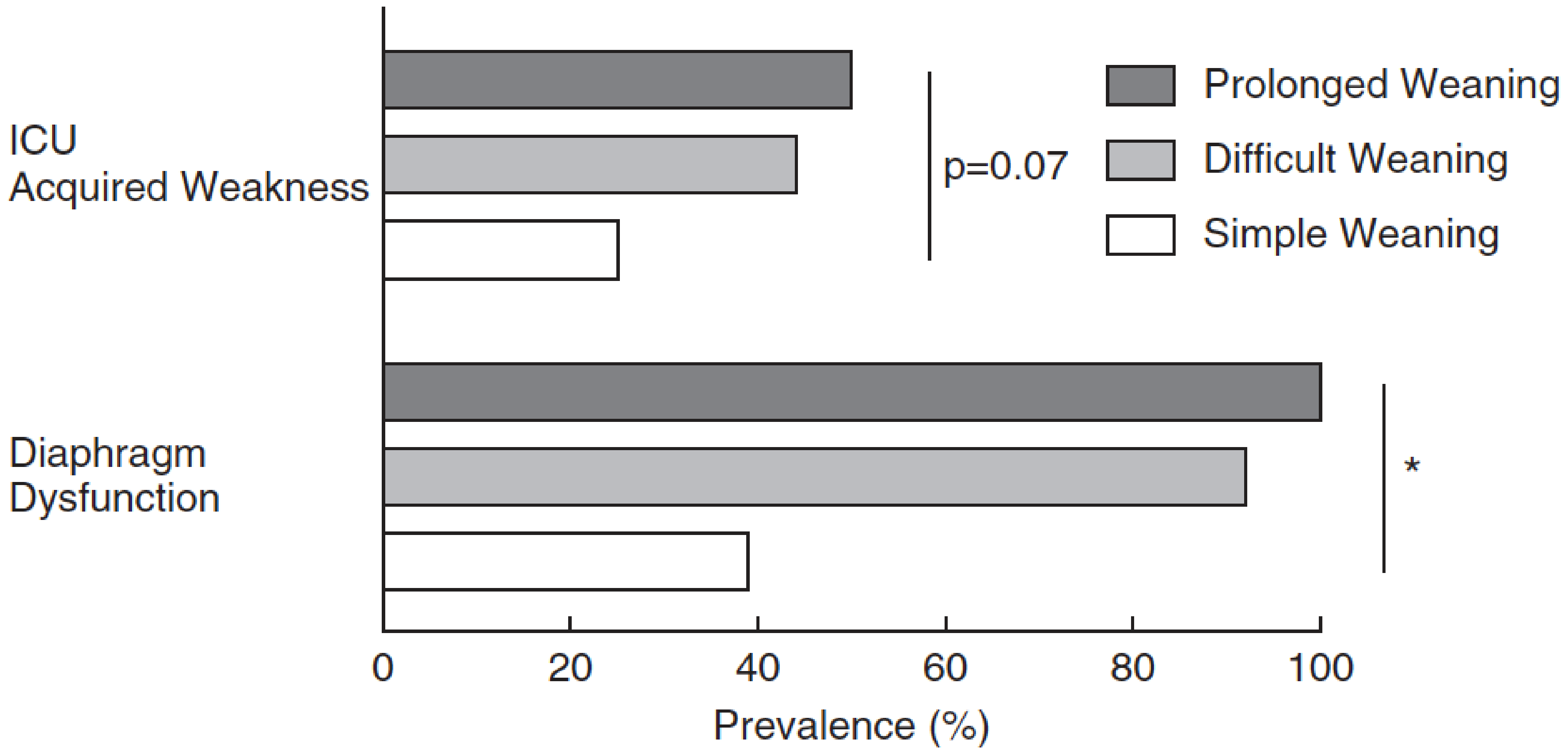
Recovery from ICU-acquired weakness; do not forget the respiratory muscles!

Rik Gosselink, Daniel Langer

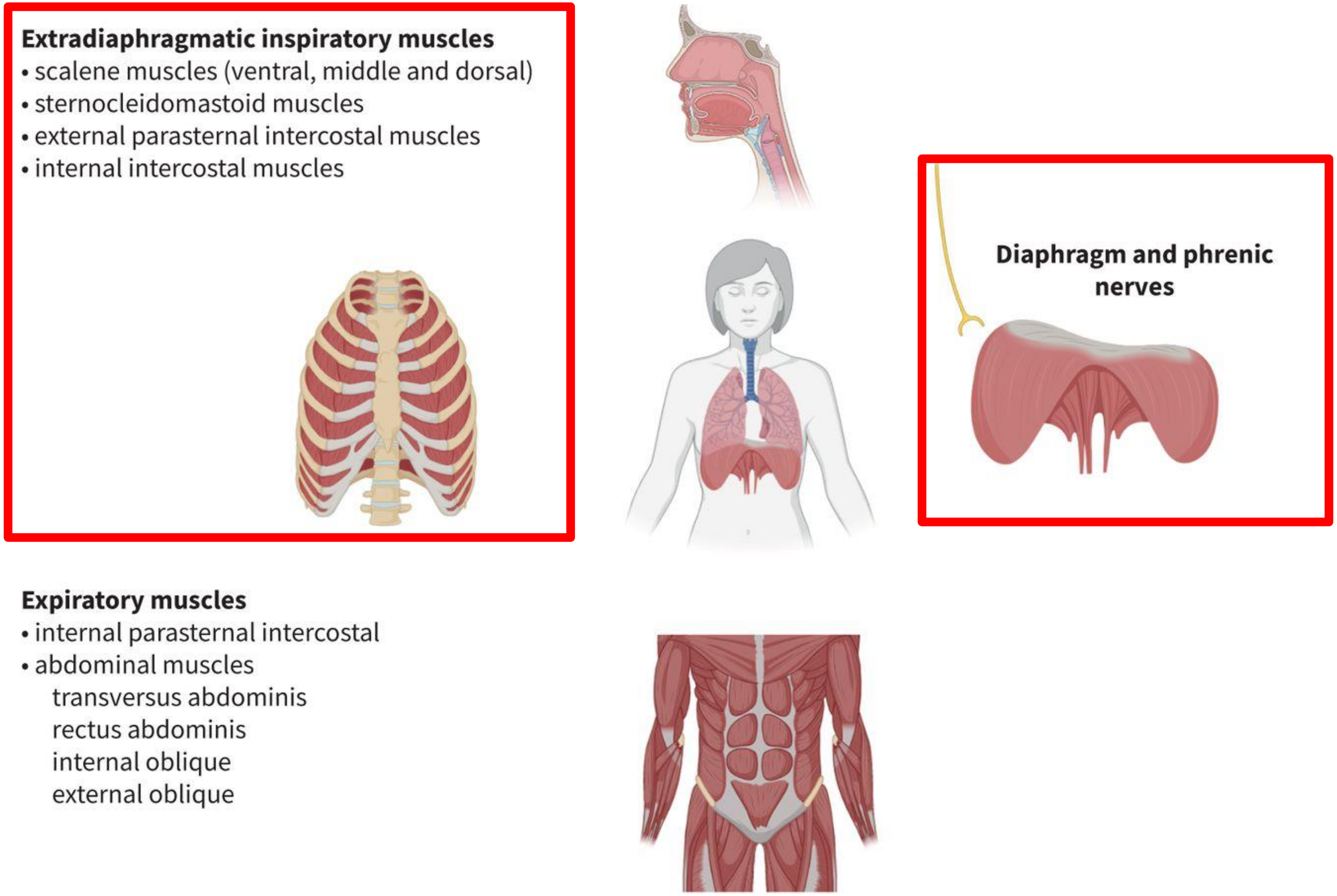
Thorax 2016;**71**:779-

Coexistence and Impact of Limb Muscle and Diaphragm Weakness at Time of Liberation from Mechanical Ventilation in Medical Intensive Care Unit Patients

Martin Dres[1,2*], Bruno-Pierre Dubé[1,3*], Julien Mayaux[2], Julie Delemazure[2], Danielle Reuter[2], Laurent Brochard[4,5], Thomas Similowski[1,2], and Alexandre Demoule[1,2]



Dres et al. Am. J. Resp. Crit. Care Med. 2017



Bureau C, Van Hollebeke M, Dres M. **Managing respiratory muscle weakness during weaning from invasive ventilation.** Eur Respir Rev. 2023 Apr 5;32(168):220205. doi: 10.1183/16000617.0205-2022. PMID: 37019456; PMCID: PMC10074167.

Preventive strategy

Prevention of atrophy: lung and diaphragm protective ventilation

Limit duration and degree of respiratory muscle inactivity: maintaining inspiratory efforts with spontaneous breathing

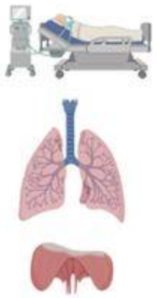
Optimising diaphragm effort and synchrony:

- Injurious efforts: insufficient assists, high effort, high drive
- Eccentric injury: expiratory dysynchrony
- Longitudinal atrophy: excessive positive expiratory pressure
- Disuse atrophy: excessive assist, low effort, low drive

Utilisation of proportional modes

Prevent myotoxic drugs

Phrenic nerve pacing (experimental and clinical data; not in routine)



Therapeutic strategy

Early whole-body mobilisation

Respiratory muscle endurance training

Respiratory muscle strength training

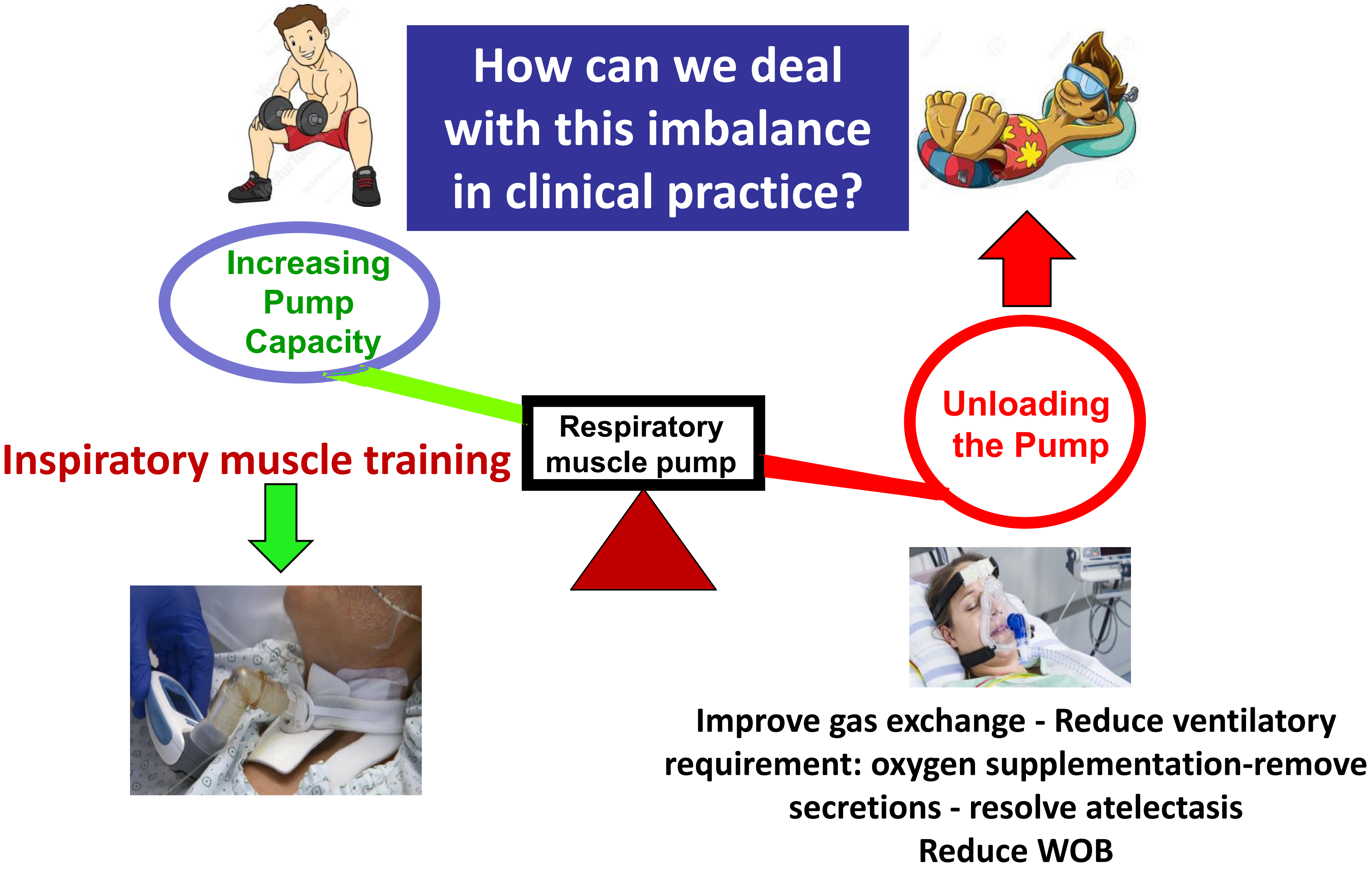
Inspiratory muscle training

Progressive threshold loading (clinical data): specific population of long-term ventilation

Restoring progressive diaphragm function (experimental and clinical data; not in routine)

Electrical muscle stimulation: with phrenic nerve pacing

Bureau C, Van Hollebeke M, Dres M. **Managing respiratory muscle weakness during weaning from invasive ventilation.** Eur Respir Rev. 2023 Apr 5;32(168):220205. doi: 10.1183/16000617.0205-2022. PMID: 37019456; PMCID: PMC10074167.


How can we deal with this imbalance in clinical practice?
Increasing Pump Capacity
Respiratory muscle pump
Unloading the Pump
Inspiratory muscle training
Improve gas exchange - Reduce ventilatory requirement: oxygen supplementation-remove secretions - resolve atelectasis
Reduce WOB

INSPIRATORY MUSCLE TRAINING

ADJUNCT IN THE TREATMENT OF DIFFICULT WEANING?

NO:

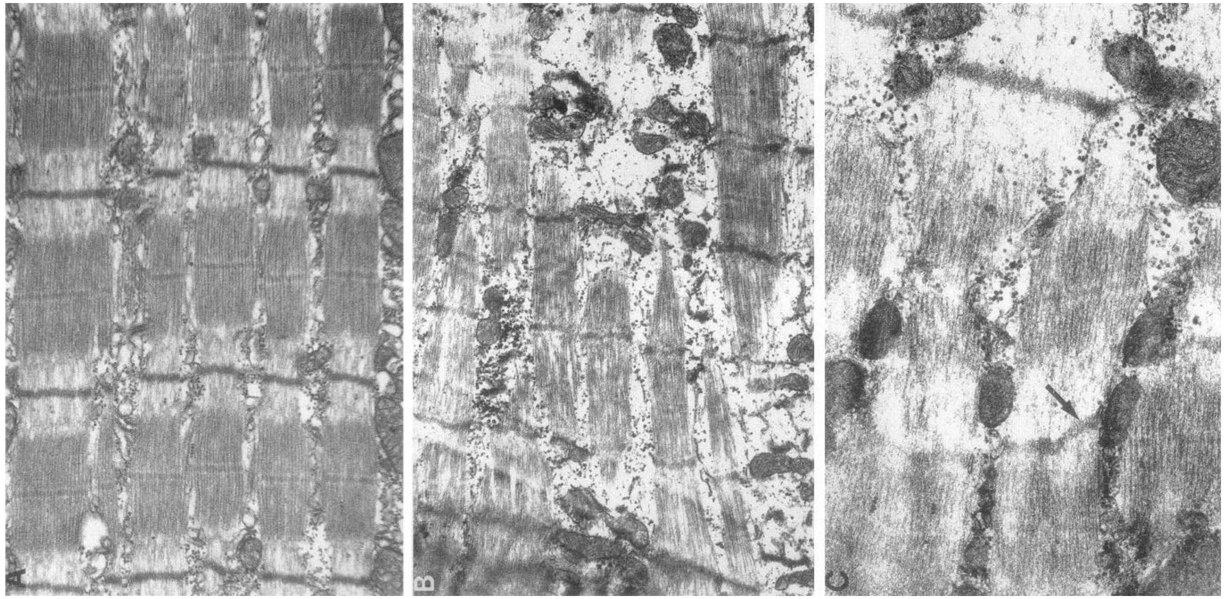
'RESISTIVE BREATHING' CAUSES *DAMAGE* TO THE INSPIRATORY MUSCLES

Diaphragm injury and myofibrillar structure induced by resistive loading

W. D. REID, J. HUANG, S. BRYSON, D. C. WALKER, AND A. N. BELCASTRO
School of Rehabilitation Sciences, University of British Columbia Pulmonary Research Laboratory, and School of Human Kinetics, University of British Columbia, Vancouver, British Columbia V6T 2B5, Canada

J.Appl.Physiol. 1994

6 days of ***tracheal binding*** resulting in tidal breathing Pes: ~20% Pesmax



	Normal Muscle	Abnormal Muscle and Inflammatory Cells	Connective Tissue
Costal			
C	0.901±0.018	0.040±0.010*	0.060±0.012
TB	0.808±0.034	0.133±0.033	0.049±0.007
Crural			
C	0.960±0.008*	0.012±0.003*	0.027±0.006
TB	0.902±0.021*	0.069±0.020	0.029±0.004

Values are means ± SE. * Significantly different between C and TB hamsters ($P < 0.05$).

Diaphragm Muscle Fiber Injury After Inspiratory Resistive Breathing

ERCHENG ZHU, BASIL J. PETROF, JOAGUIN GEA, NORMAN COMTOIS, and ALEJANDRO E. GRASSINO

Hôpital Notre-Dame, Universite de Montréal; Respiratory Division, Royal Victoria Hospital, McGill University; Respiratory Muscle Biology Group, Meakins-Christie Laboratories, McGill University, Montréal, Québec, Canada

Am J Respir Crit Care Med Vol 155. pp 1110–1116, 1997

INTERVENTION:

Uninterrupted Inspiratory **Resistive Breathing** during **2h/day** for 4 consecutive days at Ptr between **-30 to -50 cm H_2O** and $PaCO_2$ between 30-50 mmHg.

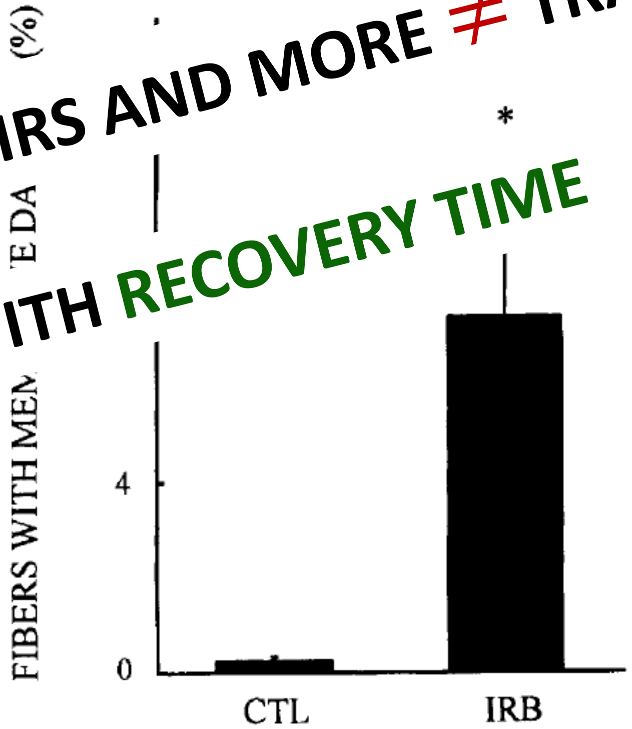
DIAPHRAGM INJURY WITH INSPIRATORY RESISTIVE BREATHING

Electron microscopic views

HIGH INTENSITY RESISTIVE LOADING FOR 2 HRS AND MORE ≠ TRAINING

TRAINING: INTERMITTENT LOADING WITH RECOVERY TIME

BEFORE **AFTER**



We conclude that resistive breathing of a magnitude similar to that seen in some respiratory diseases, or used in respiratory muscle training programs induces muscle membrane and sarcomere injury.

Zhu et al. AJRCCM 1997; 155:1110-16

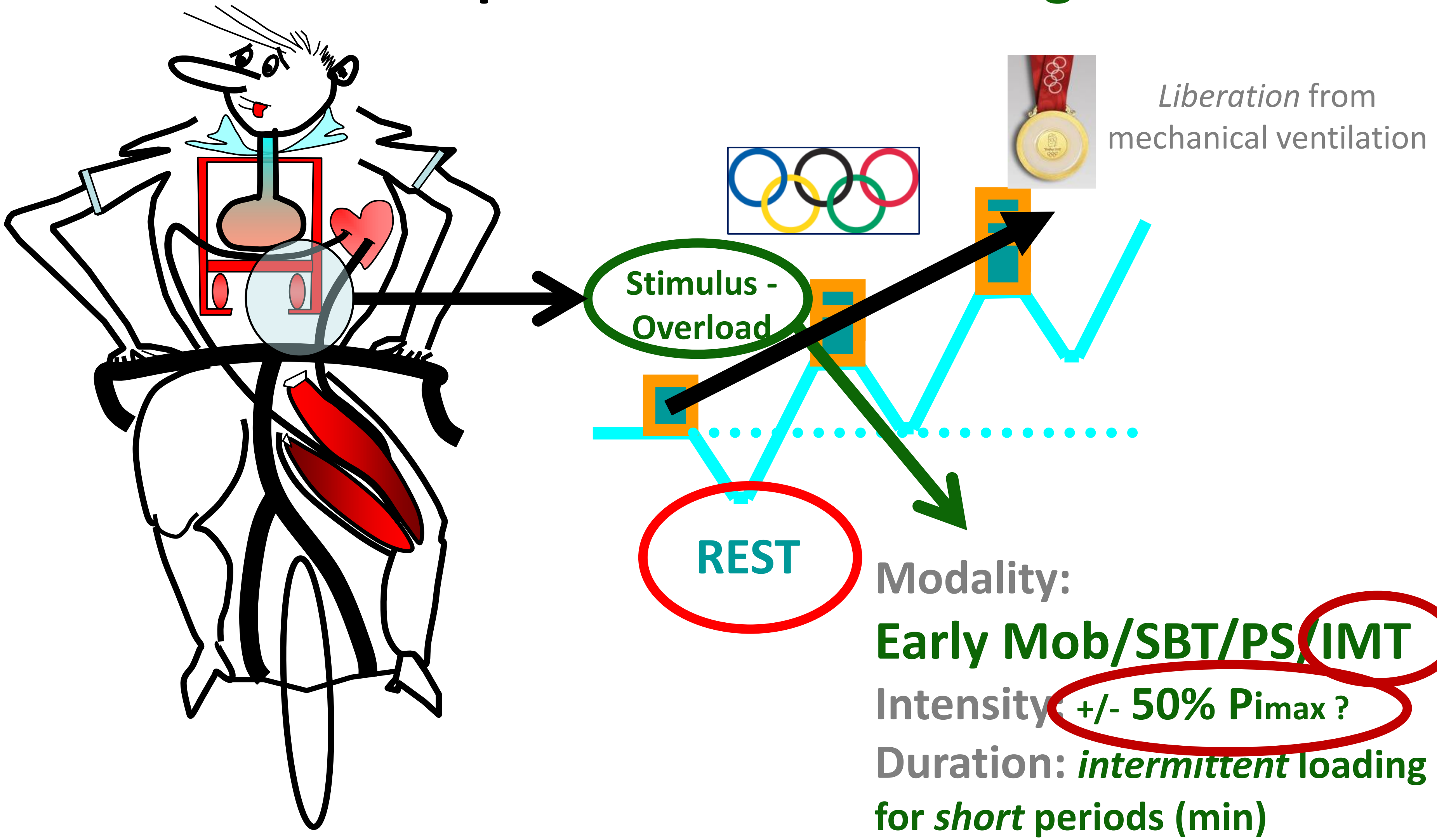
INSPIRATORY MUSCLE TRAINING

ADJUNCT **IN THE TREATMENT OF DIFFICULT WEANING?**

YES:

INSPIRATORY MUSCLE LOADING PREVENTS DECONDITIONING **INSPIRATORY MUSCLE FUNCTION**

Principles of Muscle Training



Modality:

Early Mob/SBT/PS/IMT

Intensity: +/- 50% Pimax ?

Duration: *intermittent* loading for *short* periods (min)

WHAT IS THE EVIDENCE FOR INSPIRATORY MUSCLE TRAINING IN WEANING ?

Inspiratory Muscle Rehabilitation in Critically Ill Adults

A Systematic Review and Meta-Analysis

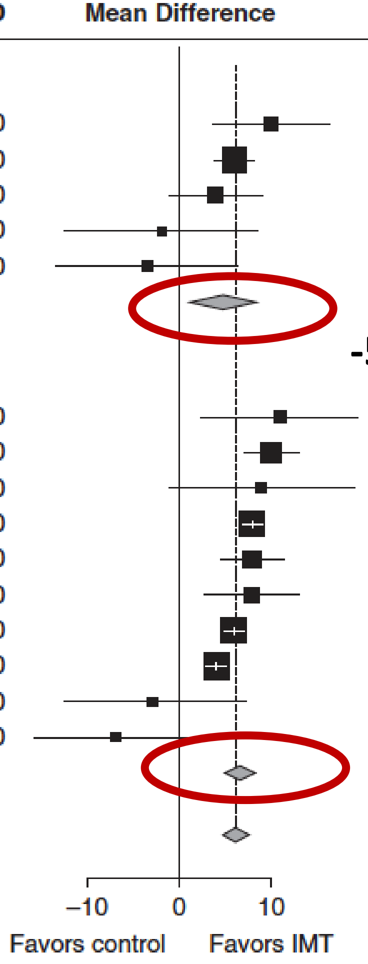
Stefannie Vorona[1], Umberto Sabatini[1], Sulaiman Al-Maqbali[1], Michele Bertoni[1], Martin Dres[2,3], Bernie Bissett[4,5], Frank Van Haren[5,6,7], A. Daniel Martin[8], Cristian Urrea[1], Debbie Brace[1], Matteo Parotto[9,10,11], Margaret S. Herridge[1,9,12], Neill K. J. Adhikari[9,13,14], Eddy Fan[1,9,12,15], Luana T. Melo[16], W. Darlene Reid[9,16], Laurent J. Brochard[2,9,12], Niall D. Ferguson[1,9,12,14,15], and Ewan C. Goligher[1,9,15]

AnnalsATS Volume 15 Number 6 | June 2018

Respiratory muscle endurance and strength

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 ($p = 0.35$)



-5 cmH_2O

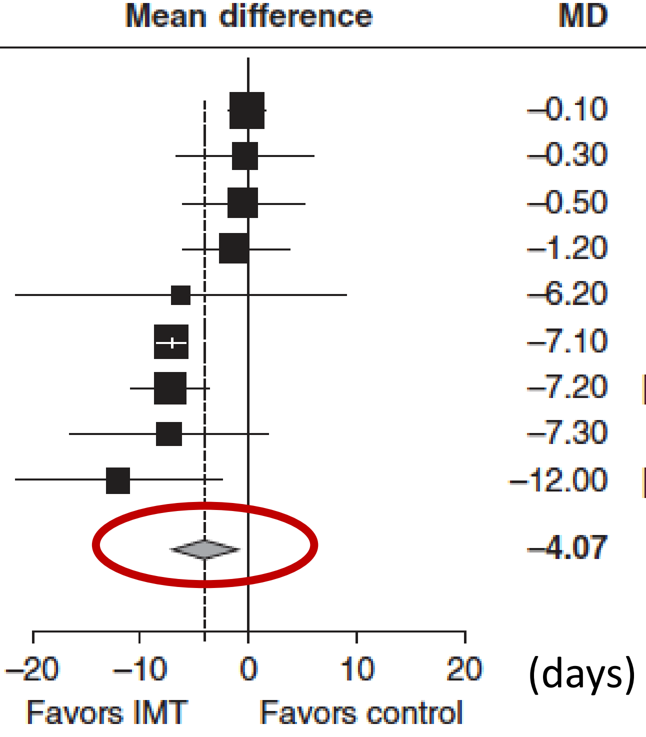
-6 cmH_2O

Vorona S, Sabatini U, Al-Maqbali S, Bertoni M, Dres M, Bissett B, Van Haren F, Martin AD, Urrea C, Brace D, Parotto M, Herridge MS, Adhikari NKJ, Fan E, Melo LT, Reid WD, Brochard LJ, Ferguson ND, Goligher EC. **Inspiratory Muscle Rehabilitation in Critically Ill Adults. A Systematic Review and Meta-Analysis.** Ann Am Thorac Soc. 2018 Jun;15(6):735-744. doi: 10.1513/AnnalsATS.201712-961OC. PMID: 29584447; PMCID: PMC6137679.

Duration of mechanical ventilation

Study	Experimental Total	Experimental Mean	Experimental SD	Control Total	Control Mean	Control SD	MD	95% CI	Weight
Condessa 2013	45	9.1	4.0	47	9.2	3.3	–0.10	[–1.60; 1.40]	16.4%
Shimizu 2014	8	17.8	6.8	5	18.1	4.7	–0.30	[–6.56; 5.96]	10.5%
Chang 2011	8	6.4	4.0	5	6.9	5.3	–0.50	[–5.91; 4.91]	11.6%
Caruso 2005	12	8.6	3.6	13	9.8	8.0	–1.20	[–6.00; 3.60]	12.5%
Martin 2011	35	57.3	29.5	34	63.5	34.0	–6.20	[–21.24; 8.84]	3.7%
Mohamed 2014	20	3.3	1.6	20	10.4	2.5	–7.10	[–8.40; –5.80]	16.6%
Yosef-Brauner 2015	9	9.0	5.0	9	16.2	2.0	–7.20	[–10.72; –3.68]	14.2%
Tonella 2017	11	14.5	10.0	8	21.8	9.8	–7.30	[–16.30; 1.70]	7.4%
Holliday 1990	20	20.6	8.9	16	32.6	17.6	–12.00	[–21.46; –2.54]	7.0%
Random effects model	**168**			**157**			**–4.07**	**[–7.35; –0.80]**	**100.0%**

Heterogeneity: $I^2 = 86\%$, $\tau^2 = 16.41$, $p < 0.01$



-4.6 days

Vorona S, Sabatini U, Al-Maqbali S, Bertoni M, Dres M, Bissett B, Van Haren F, Martin AD, Urrea C, Brace D, Parotto M, Herridge MS, Adhikari NKJ, Fan E, Melo LT, Reid WD, Brochard LJ, Ferguson ND, Goligher EC. **Inspiratory Muscle Rehabilitation in Critically Ill Adults. A Systematic Review and Meta-Analysis.** Ann Am Thorac Soc. 2018 Jun;15(6):735-744. doi: 10.1513/AnnalsATS.201712-961OC. PMID: 29584447; PMCID: PMC6137679.

Only one study on IMT to improve weaning outcome used a sham intervention as controlled condition

Pressure Threshold loading

	Intervention	Sham
Frequency	Daily, 5d/week	Daily, 5d/week
Intensity	The highest pressure setting that the subject could consistently open during inspiration. **≥15%** Maximal inspiratory pressure	Largest opening of a resistive training device
Time	4 sets of 6-10 **forceful inspirations**	4 sets of 6-10 **long, slow inspirations**
Mean difference post-pre in PImax	**+10 cmH_2O**	**+2 cmH_2O**

Elkins M & Dentice R. J Physiother. 2015

Martin AD et al. 2011. Crit Care

Martin et al. Critical Care 2011, 15:R84
http://ccforum.com/content/15/2/R84

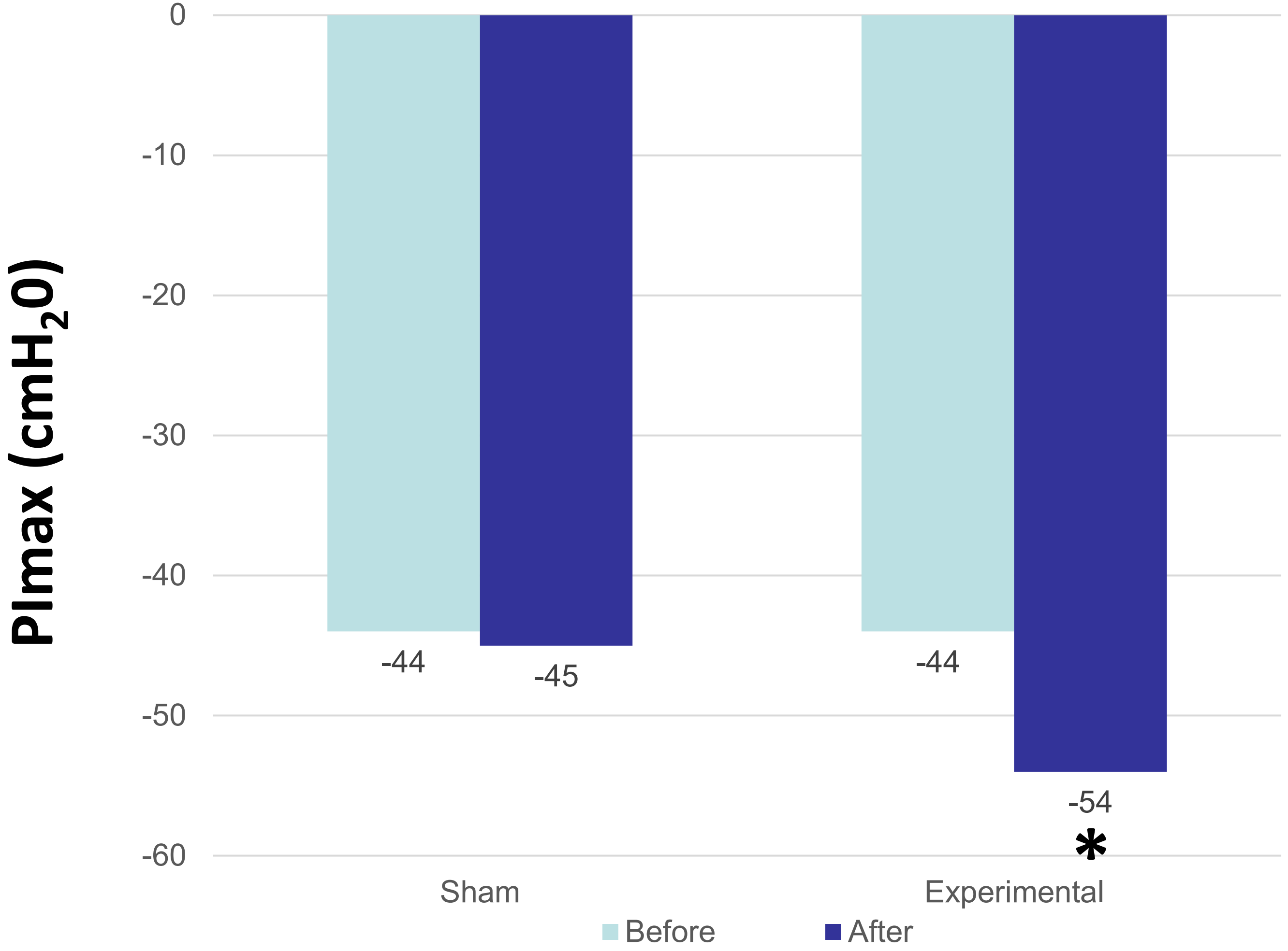
CRITICAL CARE

RESEARCH Open Access

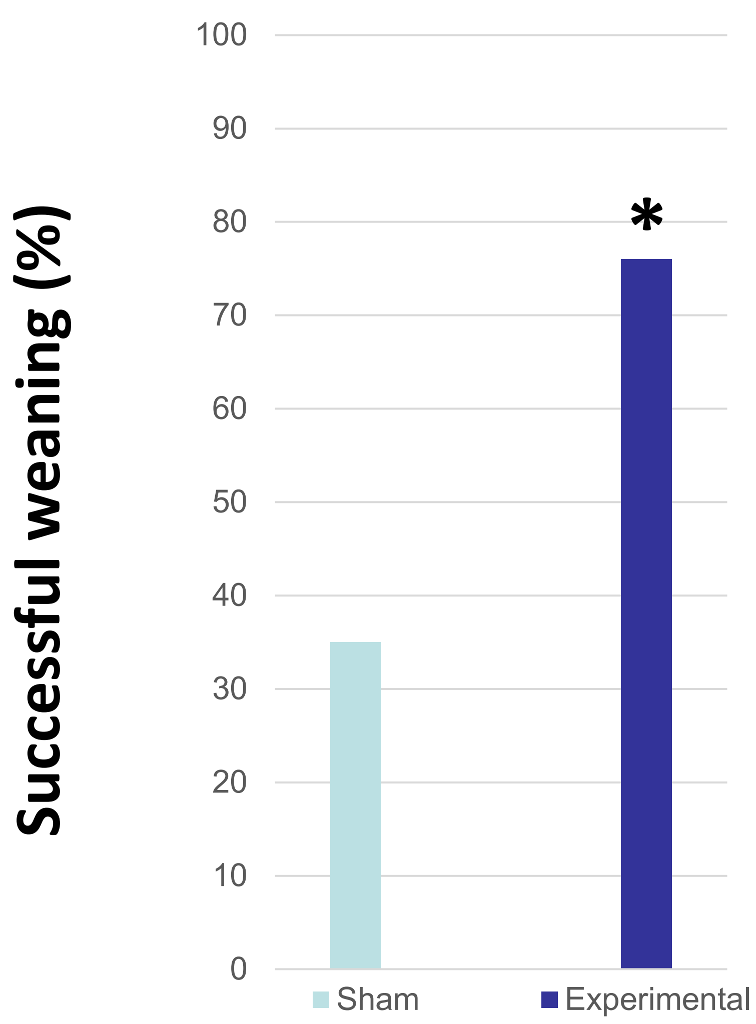
Inspiratory muscle strength training improves weaning outcome in failure to wean patients: a randomized trial

Table 3 Demographic and medical data

	IMST *n* = 35	SHAM *n* = 34	*P* value
Age (years)	65.6 ± 11.7	65.1 ± 10.7	0.86
Gender (male/female)	16/19	15/19	0.42
Number of smokers	12	11	0.86
Pack * years smoking history	54 ± 28	50 ± 30	0.72
Pre-albumin at study start (mg/dL)	15.3 ± 6.6	15.4 ± 6.3	0.96
MV support days to start of study intervention	41.9 ± 25.5	47.3 ± 33.0	0.36
Total MV support days from hospital admission until end of study participation	57.3 ± 29.5	63.5 ± 34.0	0.46
Total study days	14.4 ± 8.1	18.0 ± 8.8	0.10
SAPS II at study start	33.5 ± 8.6	33.0 ± 8.6	0.83



Martin et al. Crit. Care 15, R84 2011



Martin et al. Crit. Care 15, R84; 2011

Nava and Fasano *Critical Care* 2011, 15:153
http://ccforum.com/content/15/2/153

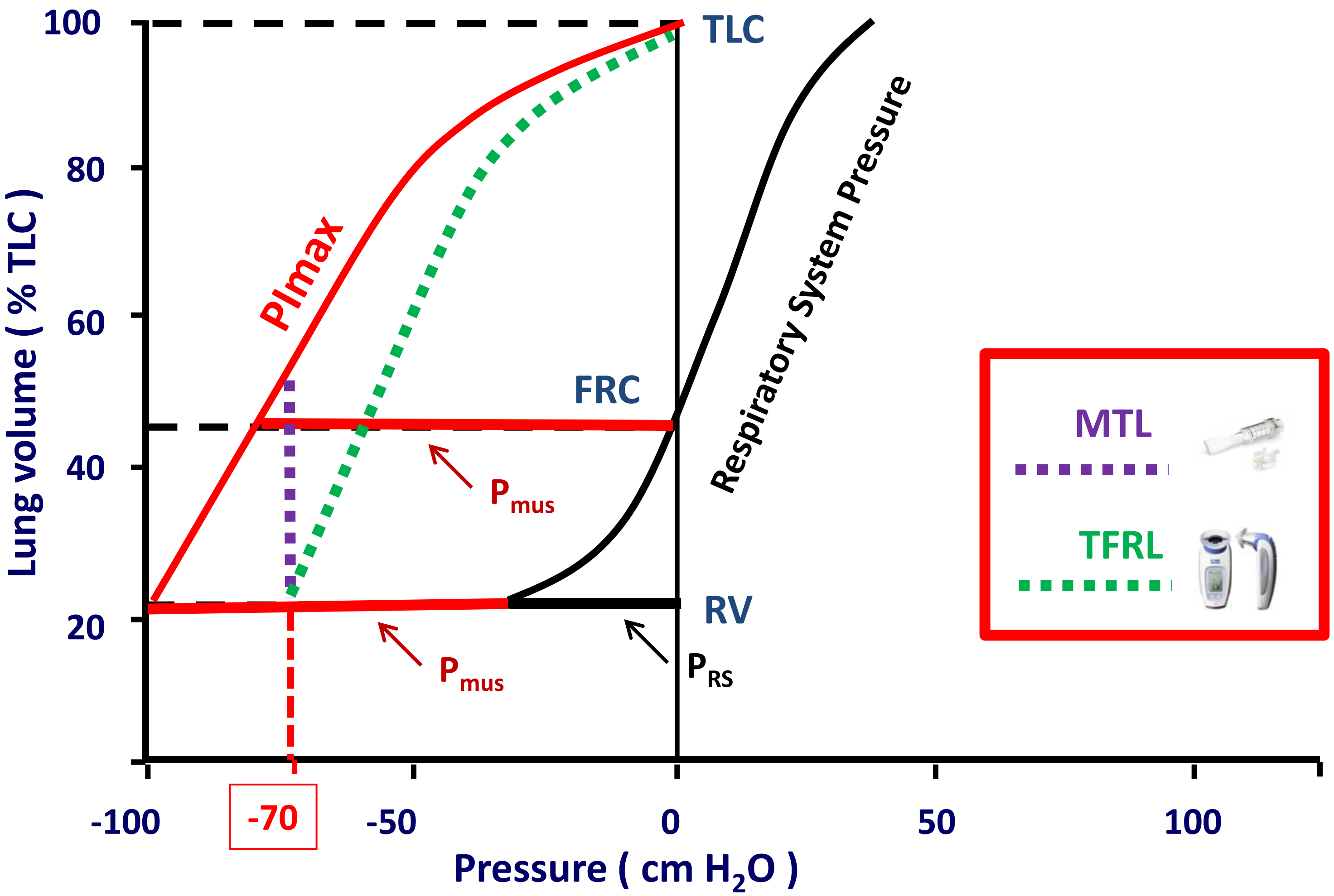
CRITICAL CARE

COMMENTARY

Inspiratory muscle training in difficult to wean patients: work it harder, make it better, do it faster, makes us stronger

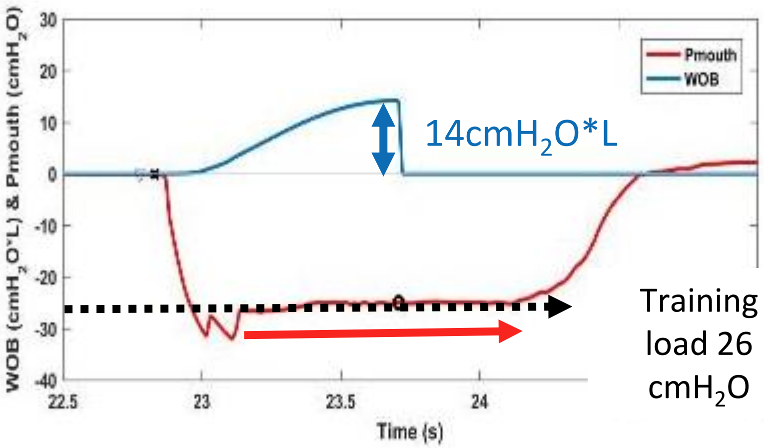
What is the best IMT schedule for these patients?

Pressure and lung volume

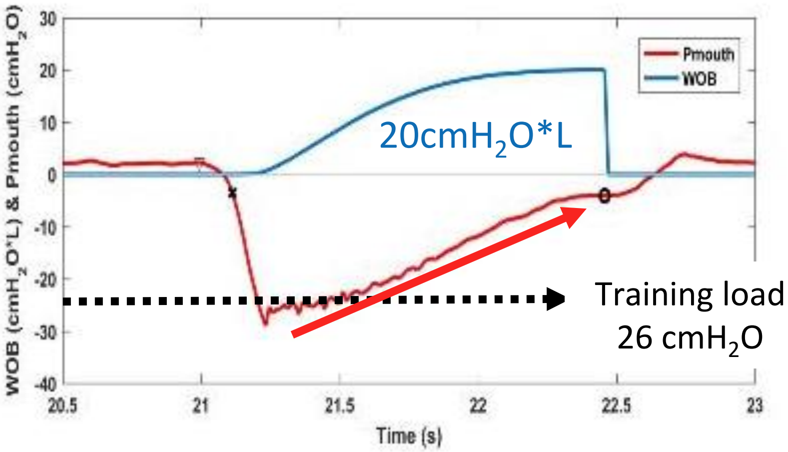


Adapted from: J. T. Sharp et al. Clin Chest Med 1983, 4: 421- 432.

Mechanical Threshold Loading



Tapered Flow Resistive Loading



Official Publications of the American Thoracic Society

ORIGINAL ARTICLE

Similar Weaning Success Rate with High-Intensity and Sham Inspiratory Muscle Training

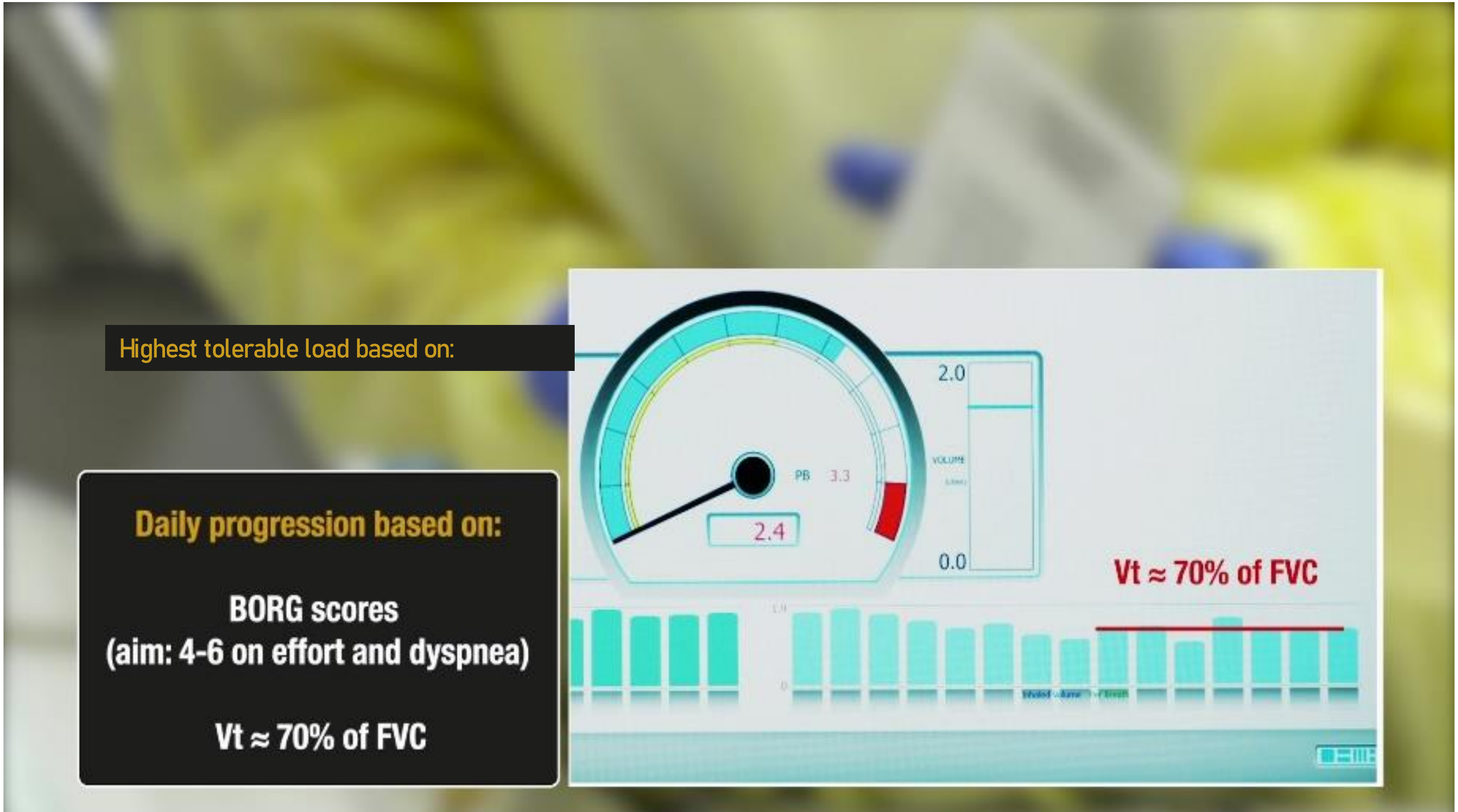
A Randomized Controlled Trial (IMweanT)

Marine Van Hollebeke[1,3*], Diego Poddighe[1,3*], Mariana Hoffman[5,6,7], Beatrix Clerckx[3], Jan Muller[3], Zafeiris Louvaris[1,3], Greet Hermans[2,4], Rik Gosselink[1,3], and Daniel Langer[1,3]

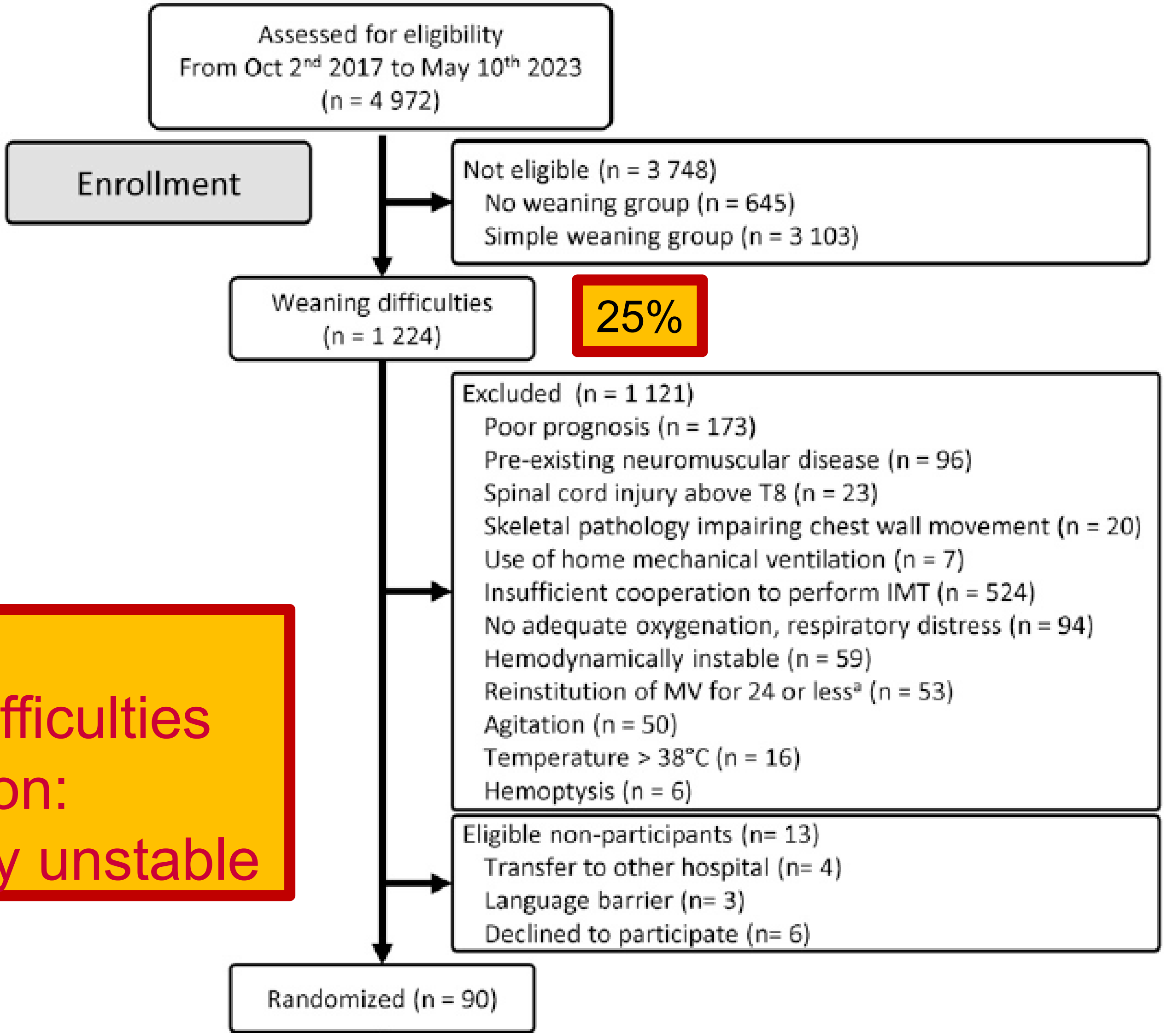
[1]Faculty of Movement and Rehabilitation Sciences, Department of Rehabilitation Sciences, Research Group for Rehabilitation in Internal Disorders, and [2]Department of Cellular and Molecular Medicine, Catholic University of Leuven, Leuven, Belgium; [3]Department of Intensive Care Medicine and [4]Medical Intensive Care Unit, University Hospitals Leuven, Leuven, Belgium; [5]Department of Immunology, School of Translational Medicine, Monash University, Melbourne, Victoria, Australia; [6]Department of Physiotherapy, Alfred Health, Melbourne, Victoria, Australia; and [7]Institute for Breathing and Sleep, Melbourne, Victoria, Australia

https://doi.org/10.1164/rccm.202405-1042OC **PubMed:** 39565276

Received: May 24, 2024 Accepted: November 14, 2024



Hoffman M, et al. BMJ Open 2018



Eligible patients:

±10% patients with weaning difficulties

Main reasons for exclusion:

Unable to cooperate or medically unstable

Patient characteristics

Baseline characteristics	High-intensity IMT group (n=44) mean		SD	Sham low-intensity IMT group (n=46) mean		SD
Sex (Male), n (%)	27 (61)			24 (52)		
Age, years	57	±	15	60	±	12
BMI, kg/m^2	25.1	±	6.6	24.3	±	5.2
Reason for admission to the ICU						
Medical, n (%)	16 (36)			13 (28)		
Surgical, n (%)	28 (64)			31 (67)		
Poly-trauma, n (%)	0 (0)			1 (2)		
COPD, n (%)	6 (14)			7 (15)		
APACHE-II score	21	±	7	21	±	7
Respiratory function at inclusion						
PImax, % predicted	35	±	14	38	±	16
FVC, % predicted	23	±	10	28	±	13
Timing and mechanical ventilation at inclusion						
Tracheostomy at start IMT, n (%)	36 (82)			43 (93)		
MV before 1st SA, days	15	±	19	14	±	13
MV before start IMT, days	27	±	19	31	±	19

Abbreviations: BMI: body mass index, FVC: forced vital capacity, SA: separation attempt

Design

Open access | Protocol

BMJ Open Can inspiratory muscle training improve weaning outcomes in difficult to wean patients? A protocol for a randomised controlled trial (IMweanT study)

Mariana Hoffman,[1,2,3] Marine Van Hollebeke,[2,3] Beatrix Clerckx,[2,3] Johannes Muller,[3] Zafeiris Louvaris,[2,3] Rik Gosselink,[2,3] Greet Hermans,[4,5] Daniel Langer[2,3]

90 patients with difficult weaning
Inclusion period: 10/2017 to 05/2023

Stratification:
COPD
APACHE II score (cut-off=18)

	Intervention (High intensity IMT)	Sham (Low intensity IMT)
Frequency	Daily	Daily
Intensity	**≥30%** Maximal inspiratory pressure (PImax)	**<10%** Maximal inspiratory pressure (PImax)
Time	4 sets of 6-10 full vital capacity inspirations	4 sets of 6-10 full vital capacity inspirations
Type	Tapered Flow Resistive Loading	Tapered Flow Resistive Loading or no resistance if baseline MIP < 25cmH_2O

Both groups received early mobilization and respiratory muscle endurance training!

Hoffman M et al. BMJ Open. 2018

Did we actually train the patients in the sham group?

	High-intensity IMT group (n= 43)						Sham low-intensity group (n= 45)						
	Before IMT		After IMT		Mean difference (After - Before)		Before IMT		After IMT		Mean difference (After - Before)		Between group
	Mean	SD	Mean	SD	Mean	95%CI	Mean	SD	Mean	SD	Mean	95%CI	p-value
PImax, cmH_2O	35	± 14	50	± 19	+15	(9 – 20)*	36	± 16	52	± 21	+14	(9 – 19)*	0.72
FVC, L	0.87	± 0.38	1.21	± 0.56	+0.33	(0.22 – 0.43)*	0.87	± 0.45	1.11	± 0.52	+0.16	(0.07 – 0.25)*	0.04

Abbreviations: Pimax: maximal inspiratory pressure, FVC: forced vital capacity.

Van Hollebeke et al. AJRCCM 2024, in press

Breathing characteristics during IMT

Breathing characteristics	High-intensity IMT group (n= 43) First session Mean ± SD	Last session Mean ± SD	Mean difference (Last-First) Mean	95%CI	Sham low-intensity IMT group (n= 45) First session Mean ± SD	Last session Mean ± SD	Mean difference (Last-First) Mean	95%CI	Between group p-value
External Load, $\%PImax_{baseline}$	33 ± 8	56 ± 26	23	(17 – 30)*	7 ± 4	7 ± 3	0	(-1 – 0)	<0.01
External Load, cmH_2O	11 ± 5	18 ± 8	7	(5 – 9)*	3 ± 1	3 ± 1	0	(0 – 0)	<0.01
Inspiratory tidal volume, %FVC *	62 ± 26	58 ± 26	-4(-15 ; 6)		61 ± 28	66 ± 25	4(-5 ; 14)		0.32
Peak inspiratory flow, L/s	0.93 ± 0.39	1.10 ± 0.42	0.17	(0.06 – 0.28)*	0.94 ± 0.35	1.00 ± 0.40	0.05	(-0.04 – 0.15)	0.26
External WOB / session, Joules	14.7 ± 13.8	31.8 ± 36.8	17	(8 – 27)*	7.8 ± 13.0	7.2 ± 5.3	-0.6	(-4.8 – 3.5)	<0.01

Abbreviations: FVC: forced vital capacity, Pimax: maximal inspiratory pressure, WOB: work of breathing

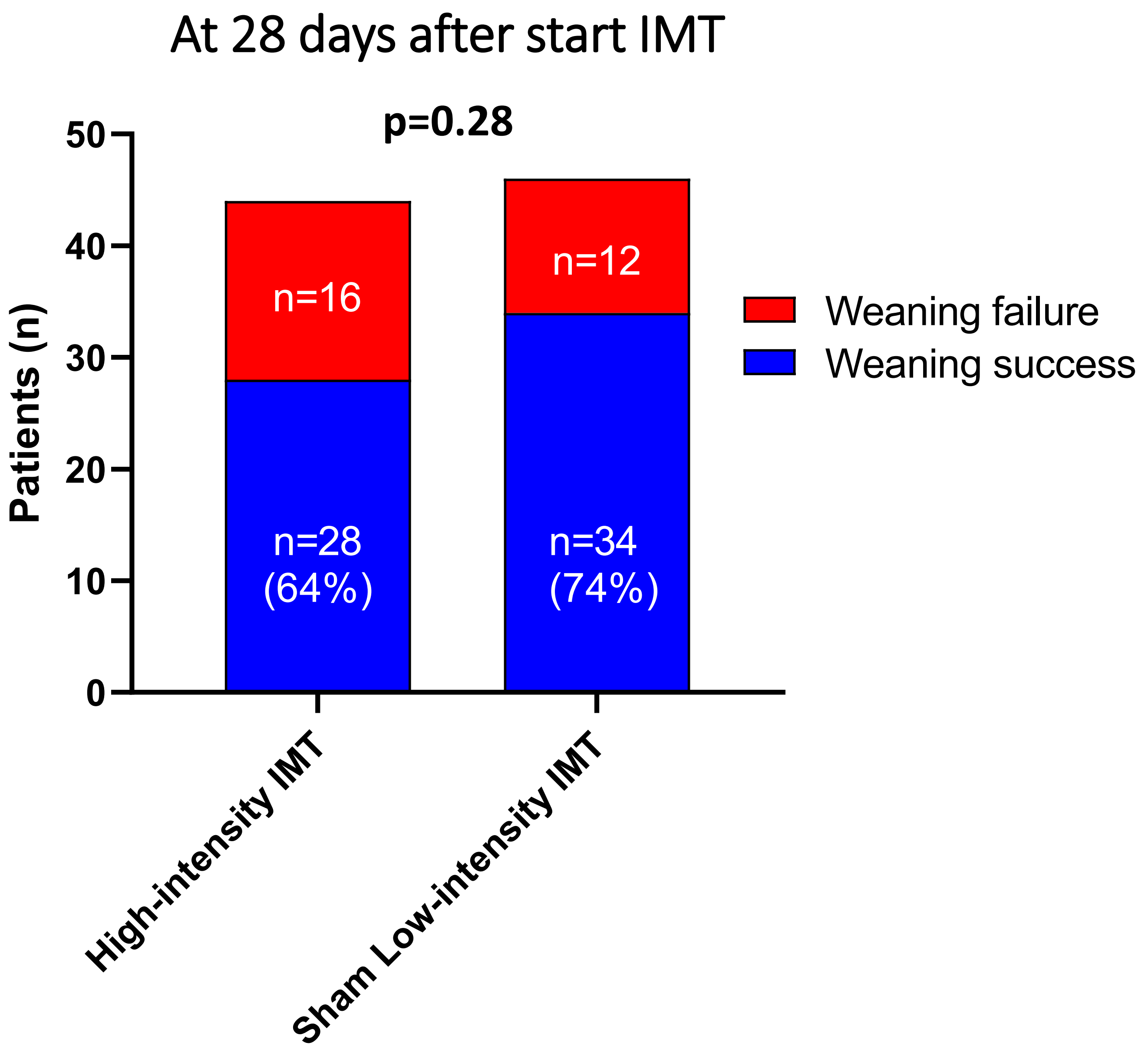
Van Hollebeke et al. AJRCCM 2024, in press

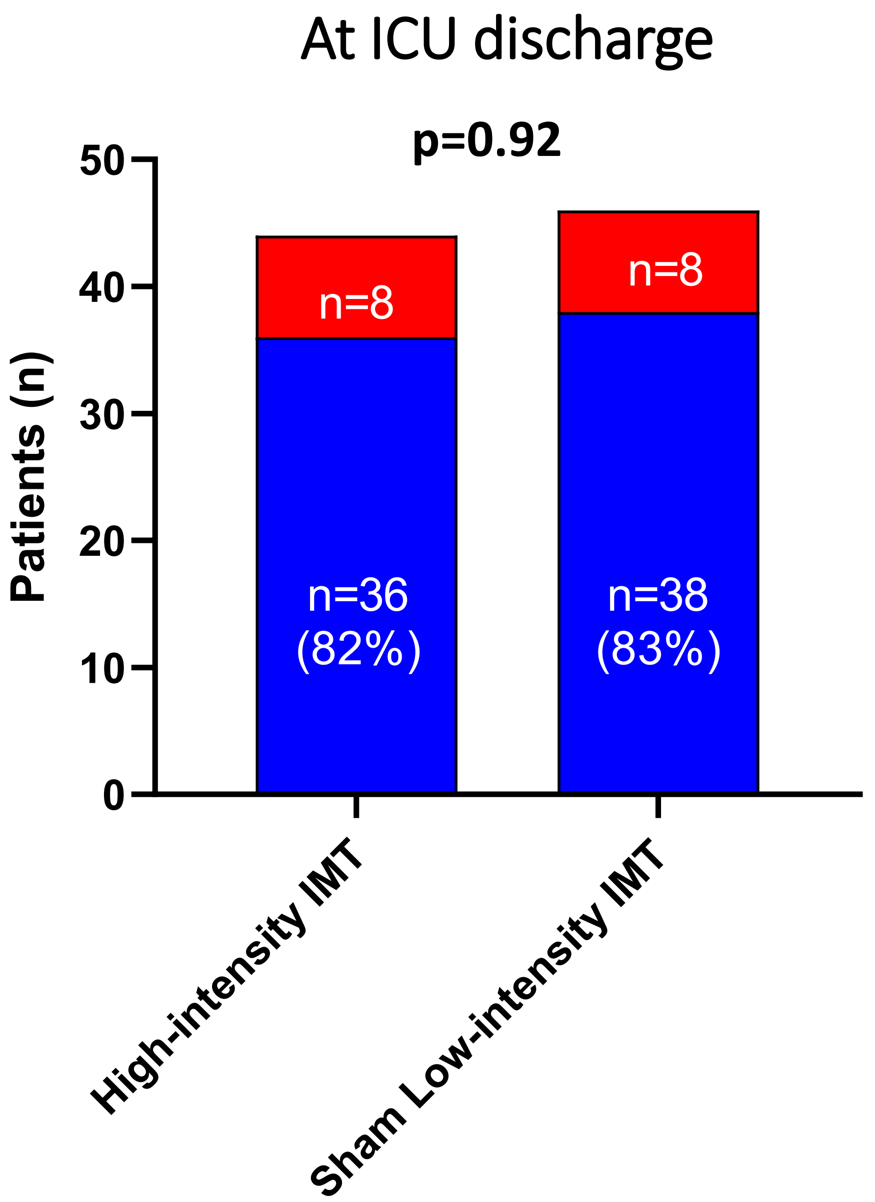
Perceived respiratory symptoms were not different between groups

Perceived respiratory symptoms	High-intensity IMT group (n= 43)						Sham low-intensity IMT group (n= 45)						
	First session		Last session		Mean difference (Last-First)		First session		Last session		Mean difference (Last-First)		Between group
	Mean	SD	Mean	SD	Mean	95%CI	Mean	SD	Mean	SD	Mean	95%CI	p-value
Effort, /10	5.2	± 1.8	4.3	± 1.6	-0.9	(-1.6 – 0.1)*	4.8	± 2.1	3.6	± 2.0	-1.2	(-2.0 – -0.5)*	0.13
Dyspnea, /10	4.8	± 2.1	3.4	± 1.6	-1.4	(-2.0 – -0.7)*	4.3	± 2.3	3.3	± 2.2	-1.0	(-1.8 – -0.1)*	0.57

Van Hollebeke et al. AJRCCM 2024, in press

No significant difference in weaning success rate





Van Hollebeke et al. AJRCCM 2024, in press

Conclusions IMweanT study

High and Low Intensity IMT result in **similarly high weaning success rate**
(82% after High-Intensity IMT vs. 83% after Low-Intensity IMT at ICU discharge)

In control groups of previous studies: 44%, 47%, 55%

Both High and Low Intensity IMT result in **similar and large increases in respiratory muscle strength**
(+15cmH_2O after High-Intensity IMT vs. 14cmH_2O after Low-Intensity IMT)

Mean difference post-pre in Pimax in study Martin et al.	**+10 cmH_2O Intervention**	**+2 cmH_2O Control**
Average increase in PImax in all previous studies	**+7cmH_2O**	**+2cmH_2O**

Martin AD et al. 2011. Crit Care; Elbouhy MS et al. 2014. Egypt J Chest Dis Tuberc; da Silva Guimares B et al. 2021. Crit Care Med

Check for updates

Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients

An important question is whether there is a physiological rationale to improve inspiratory muscle strength in the patients recruited. Yes!

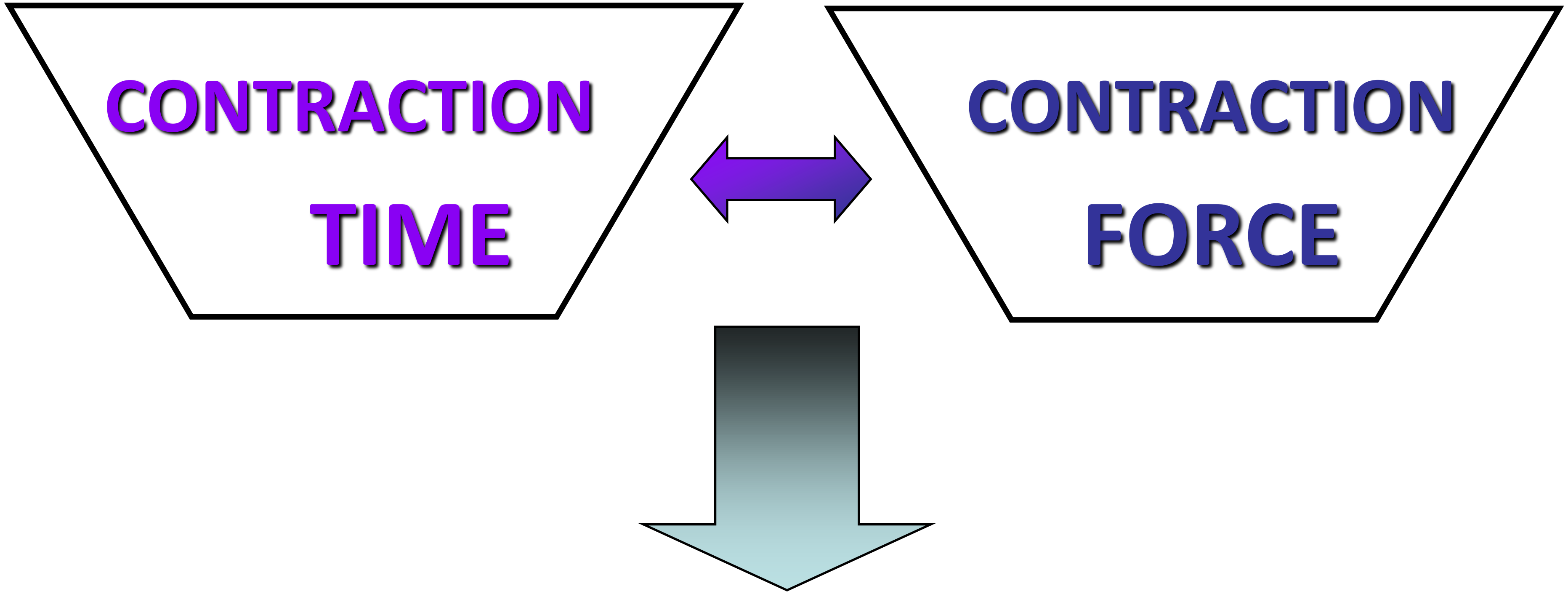
It has been demonstrated that the tension time index (TTI) is one of the main determinants underlying the transition from weaning failure to weaning success.

The TTI is determined as follows by pressure generated during tidal breathing (Pi), Pimax, inspiratory time (Ti), and inspiratory + expiratory time (Ttot):

$$TTI = \frac{Pi}{Pi, max} * \frac{Ti}{Ttot}$$

"Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients." *American Journal of Respiratory and Critical Care Medicine*, 211(3), pp. 311–313

TENSION-TIME INDEX



MUSCLE FATIGUE / ENDURANCE

TENSION-TIME INDEX

FATIGUE

P_I/P_{IMAX}

CONTRACTION FORCE (%MAX)

T_I/T_{TOT}

INSPIRATORY (CONTRACTION) TIME / TOTAL BREATH DURATION

The Tension–Time Index and the Frequency/ Tidal Volume Ratio Are the Major Pathophysiologic Determinants of Weaning Failure and Success

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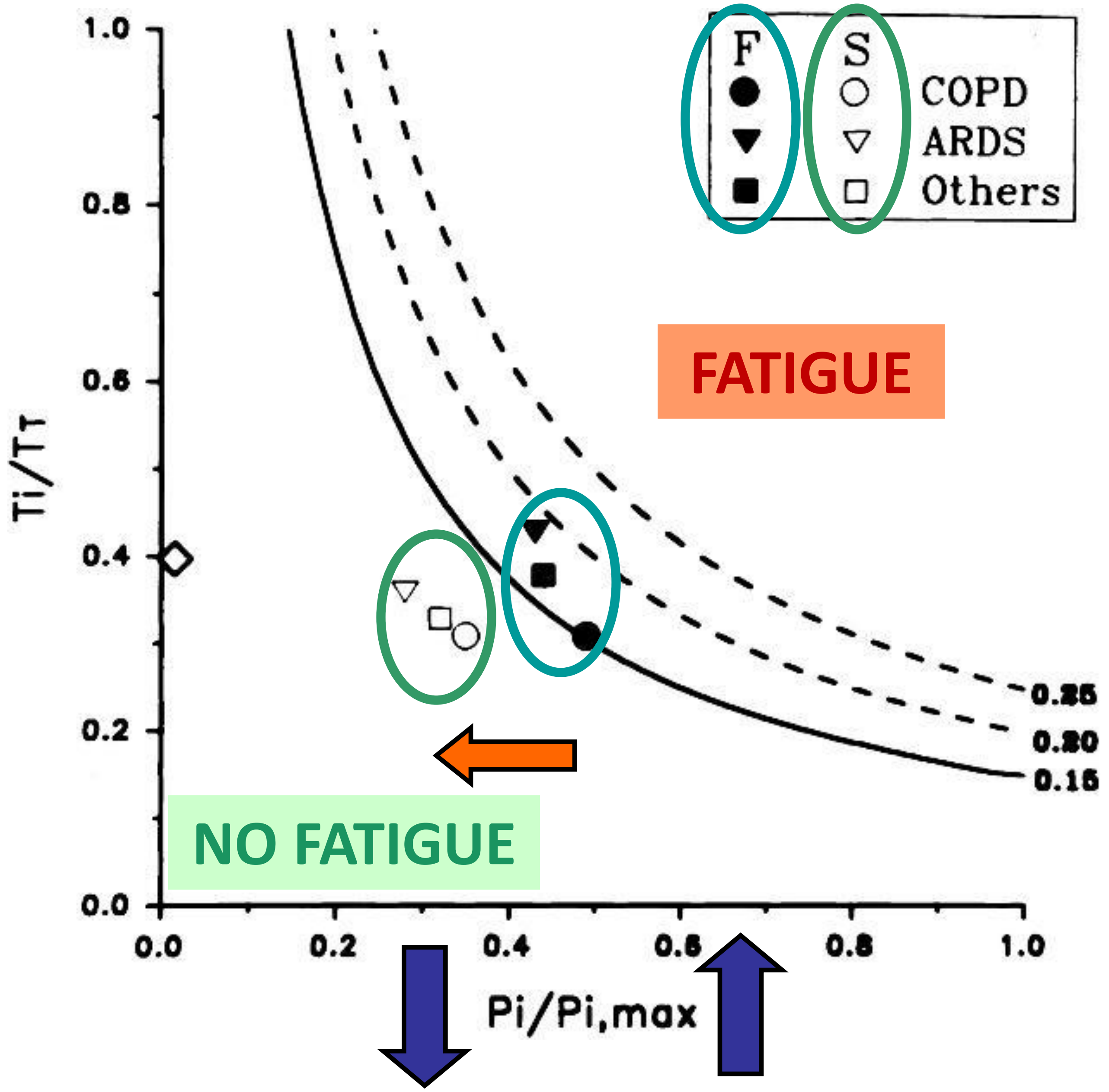
Department of Critical Care and Pulmonary Services, University of Athens Medical School, Evangelismos Hospital, Athens, Greece

AM J RESPIR CRIT CARE MED 1998;158:378–385.



Vassilakopoulos et al. Am J Respir Crit Care Med. 1998; 158:378-385.

TABLE 4

RESPIRATORY MUSCLE STRENGTH AND TENSION–TIME INDEX

Variable	Phase	COPD ($n = 10$)	ARDS ($n = 10$)	Other ($n = 10$)	Combined ($n = 30$)	p Value
MIP, cm H_2O	F	33.8 ± 10.5	52.9 ± 13.8†	40.0 ± 9.1‡	42.3 ±12.7	< 0.0001
	S	46.8 ± 4.7	67.3 ± 15.4*†	46.5 ± 15.1‡	53.8 ± 15.1	
PI_{max}, cm H_2O	F	42.0 ± 9.4	57.4 ± 15.8†	45.6 ± 9.2‡	48.4 ± 13.3	0.0001
	S	53.5 ± 6.3*	69.5 ± 15.7*†	49.1 ± 11.8‡	57.6 ± 14.6	
PI/PI_{max}	F	0.49 ± 0.09	0.43 ± 0.08	0.44 ± 0.11	0.46 ± 0.1	< 0.0001
	S	0.35 ± 0.05*	0.26 ± 0.09*	0.31 ± 0.09*	0.31 ± 0.08	
TTI	F	0.149 ± 0.024	0.178 ± 0.027	0.164 ± 0.035	0.162 ± 0.032	< 0.0001
	S	0.108 ± 0.009	0.094 ± 0.031*	0.103 ± 0.023*	0.102 ± 0.023	

Definition of abbreviations: MIP = maximum inspiratory pressure; PI_{max} = MIP + $PEEP_i$; PI/PI_{max} = the ratio of the mean inspiratory pressure to PI_{max}; TTI = tension–time index calculated from the equation: TTI = $PI/PI_{max} \times TI/Ttot$; NS = not significant; COPD = chronic obstructive pulmonary disease; ARDS = adult respiratory disease syndrome.

* Significantly different between weaning success and failure ($p < 0.05$).

† Significantly different from COPD ($p < 0.05$).

‡ Significantly different from ARDS ($p < 0.05$).

AM J RESPIR CRIT CARE MED 1998;158:378–385.

Research

Open Access

Determinants of weaning success in patients with prolonged mechanical ventilation

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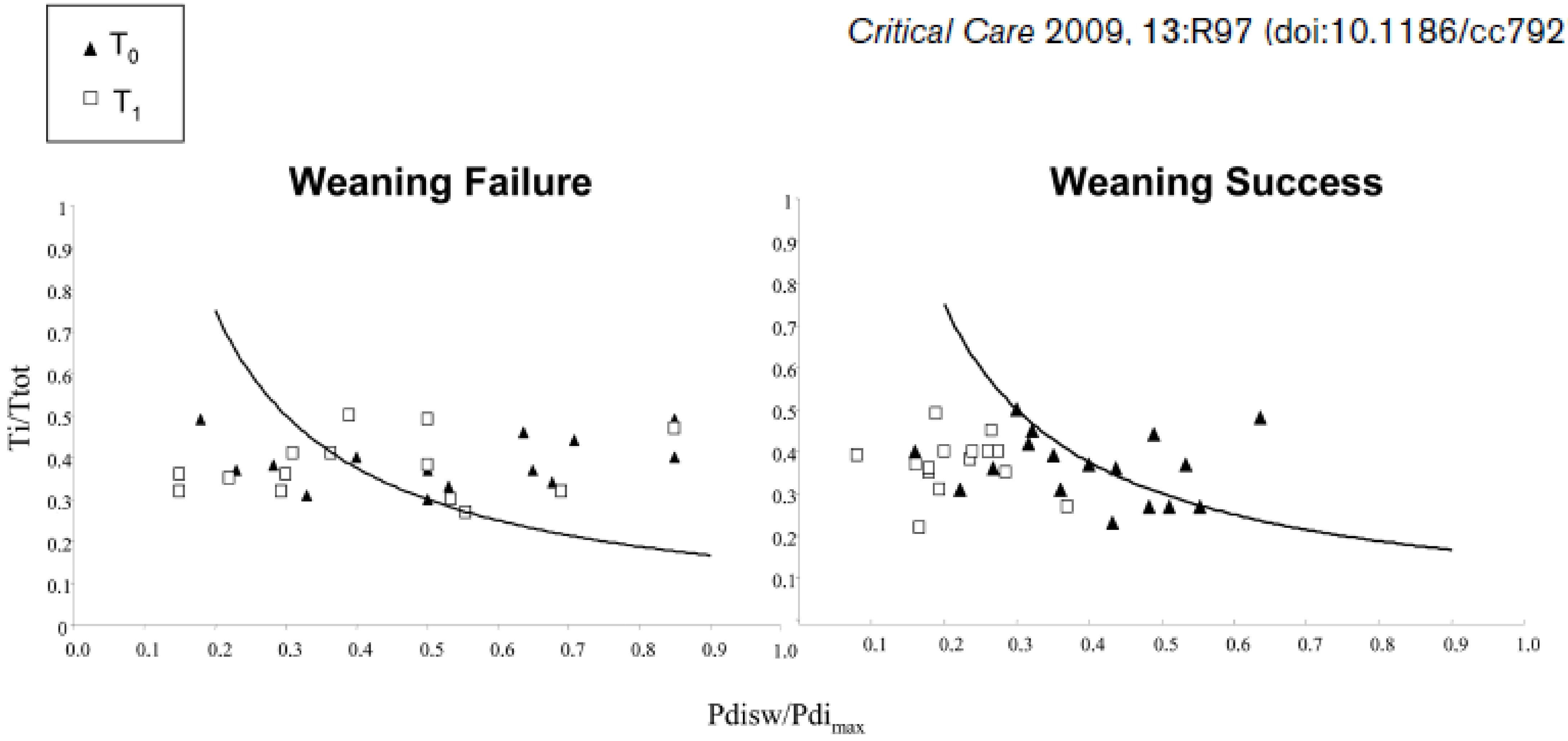
This article is online at: http://ccforum.com/content/13/3/R97

Conclusions The recovery of an inadequate inspiratory muscle force could be the major determinant of 'late' weaning success, since this allows the patients to breathe far below the diaphragm fatigue threshold.

Critical Care 2009, 13:R97 (doi:10.1186/cc7927)



Tension-time diaphragmatic index at T_0 (black triangles) and T_1 (white squares) in the weaned and unweaned groups. $Pdisw/Pdi_{max}$, ratio of tidal diaphragmatic pressure to maximum transdiaphagmatic pressure. Ti/Ttot, inspiratory time expressed as a fraction of the total respiratory cycle duration.

Critical Care 2009, 13:R97 (doi:10.1186/cc7927)

Table 4

Inspiratory muscle function and effort in weaned and unweaned patients

Group	MIP, cm H_2O	Pdi_{max}, cm H_2O	Pdisw/Pdi_{max}, percentage	TTdi
Successful weaning				
T_0	45.2 ± 19.5	34.9 ± 18.9[a]	36.0 ± 15.8[a]	0.13 ± 0.065[b]
T_1	57.3 ± 18.2[b]	43.0 ± 20.04[a]	23.1 ± 7.9[a,b]	0.08 ± 0.029
Failed weaning				
T_0	32.7 ± 18.2	25.4 ± 17.3	54.4 ± 25.5	0.21 ± 0.122[a,b]
T_1	38.6 ± 13.5[b]	27.7 ± 12.5	42.5 ± 22.9[b]	0.14 ± 0.054[a]

[a]$P < 0.05$ differences for each variable within groups; [b]$P < 0.05$ differences for each variable between groups. MIP, maximum inspiratory pressure; Pdi_{max}, maximum transdiaphragmatic pressure; Pdisw, tidal diaphragmatic pressure; TTdi, tension-time index of diaphragm.

Check for updates

Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients

A TTI >0.15 for the diaphragm cannot be sustained long and eventually results in fatigue. Accordingly, both reducing respiratory load (reducing Pi) and improving Pimax are expected to improve weaning success.

Because Pimax increased in the present study (from 35 cm H_2O to 50 cm H_2O), it can be calculated that TTI decreased from 0.18 to 0.12, which is expected to increase weaning success rate.

TTI Before: PI (~16 cm H_2O) / PImax (35 cm H_2O) = 0.46 * TI/Ttot ~0.39 = 0.18

TTI After: PI (~16 cm H_2O) / PImax (50 cm H_2O) = 0.32 * TI/Ttot ~0.39 = 0.12

But: same improvement in Pimax in control group...

"Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients."
American Journal of Respiratory and Critical Care Medicine, 211(3), pp. 311–313

Check for updates

Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients

The authors reason that sham training may provide a training stimulus as a result of high “internal” loads because of reduced respiratory compliance.

However, this seems less likely because the groups performed spontaneous breathing trials up to 10.9 hours per day, where they already face these high “internal” loads.

"Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients."
American Journal of Respiratory and Critical Care Medicine, 211(3), pp. 311–313

We hypothesized that…

1) Total inspiratory effort was probably similar for deep and fast inspirations against both low and high IMT external loads (our intervention and control groups)

2) Deep and slow inspirations against a low IMT external load would result in lower total inspiratory effort and muscle activation

3) Inspiratory effort during both low and high IMT should be much higher than during spontaneous breathing

Characterize the training stimulus during different breathing conditions in difficult to wean patients

Martin AD et al. 2011. Crit Care; Elbouhy MS et al. 2014. Egypt J Chest Dis Tuberc; da Silva Guimares B et al. 2021. Crit Care Med

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Brief research report

Inspiratory effort and respiratory muscle activation during different breathing conditions in patients with weaning difficulties: An exploratory study

Diego Poddighe, PT, MSc [a,b,*], Marine Van Hollebeke, PT, PhD [a,b], Beatrix Clerckx, PT, MSc [b], Luc Janssens, MSc [c], Geert Molenberghs, PhD [d,e], Lisa Van Dyck, MD, PhD [b], Jan Muller, MD [b], Jan Gunst, MD, PhD [b,f], Philippe Meersseman, MD, PhD [g], Marijke Peetermans, MD, PhD [g], Greet Hermans, MD, PhD [f,g], Rik Gosselink, PT, PhD [a,b], Daniel Langer, PT, PhD [a,b]

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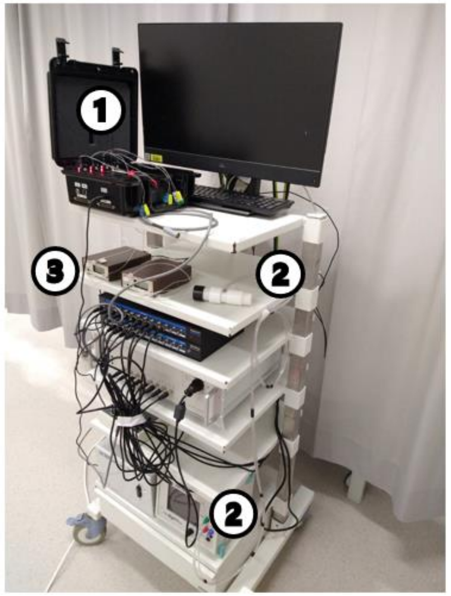
Exploratory assessments

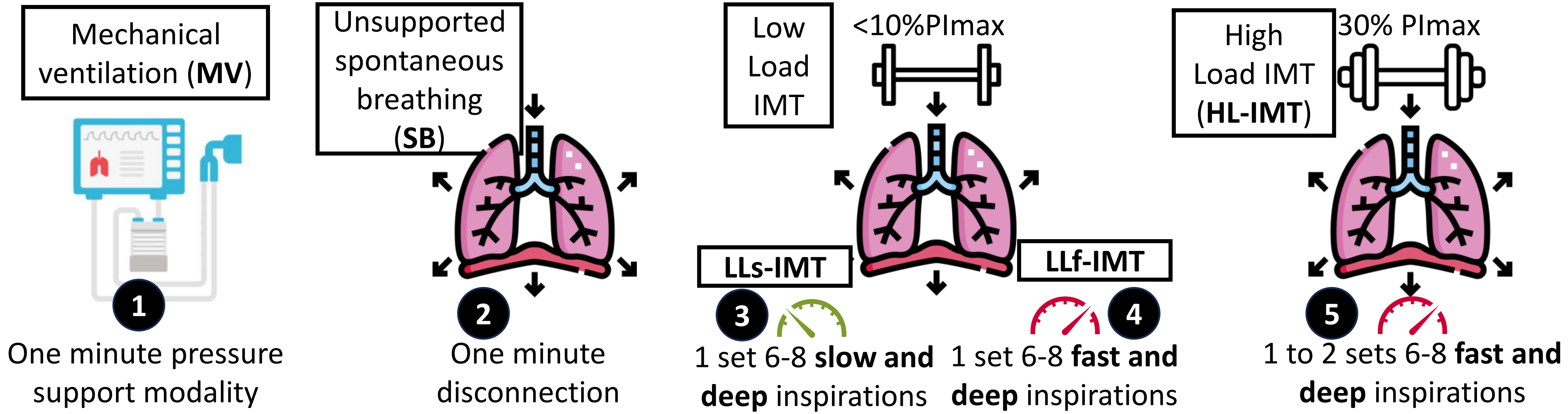


Working station

1. **System for surface EMG (sEMG) recording** (Delsys Trigno Wireless EMG system, Delsys, Boston MA)
2. **Pneumotachograph** (PNT digital platform, MEC electronics)
3. **Digital manometers** (Valydine PS309) for acquisition of esophageal pressure signals with **Nutrivent catheter**

- **Activation of scalene (EMGsca), sternocleidomastoid (EMGscm) and parasternal intercostal (EMGpi) muscles** (Root Mean Square amplitude, %EMGmax)
- **Airway pressure swings (ΔPaw), inspiratory volume (VT)**, and **peak inspiratory flow (PIF)**
- **Esophageal pressure swings (ΔPes) and pressure-time product (PTPes)** = index of inspiratory effort

Breathing conditions



Results of exploratory assessments

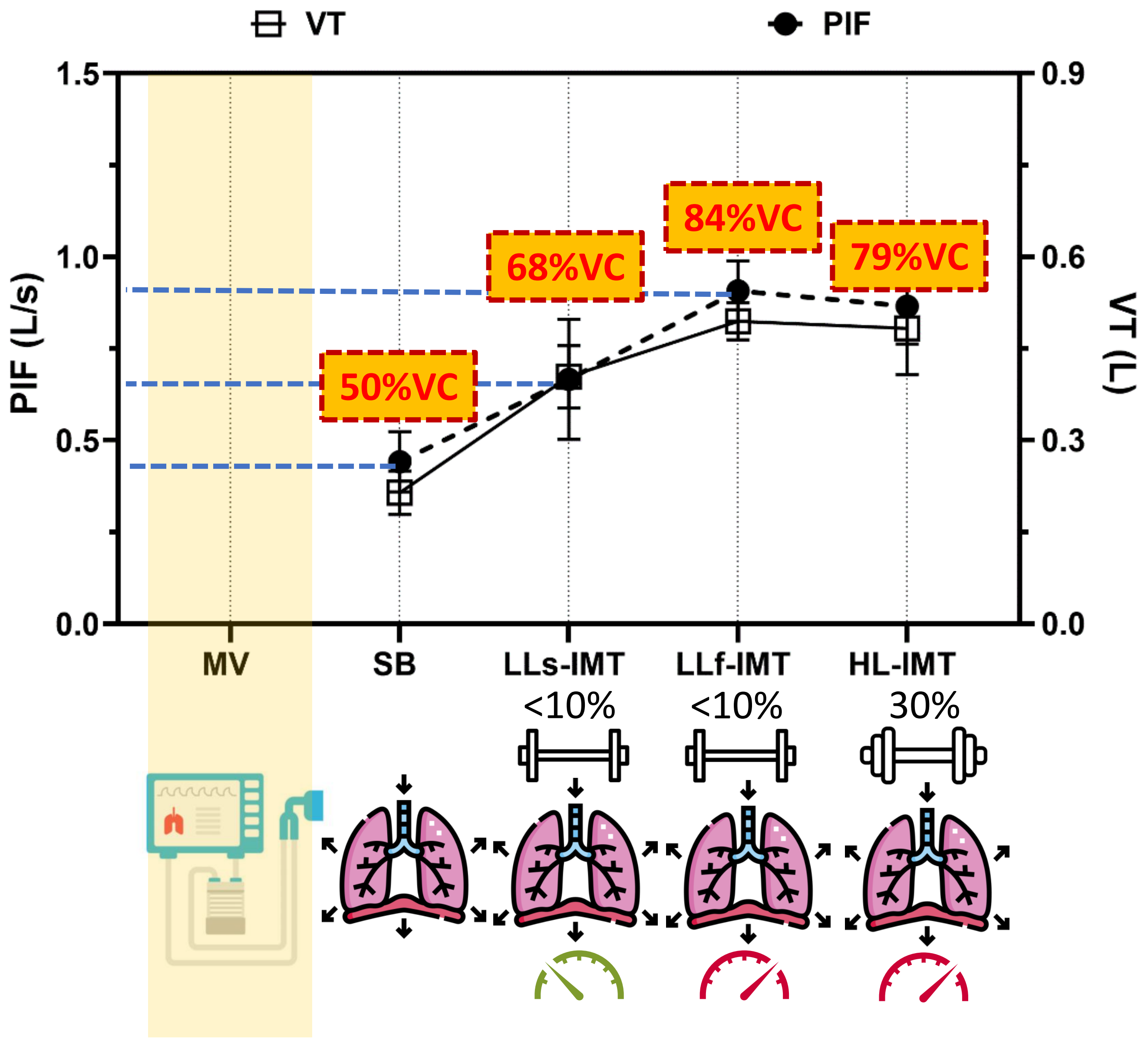
N= 5 patients
Age:68±1y; 20%male; PImax:37±7cmH_2O

Diagnosis at admission:

- Double lung transplantation (N=1)
- COPD exacerbation (N=2)
- Cardiac surgery (N=1)
- Pneumonia (N=1)

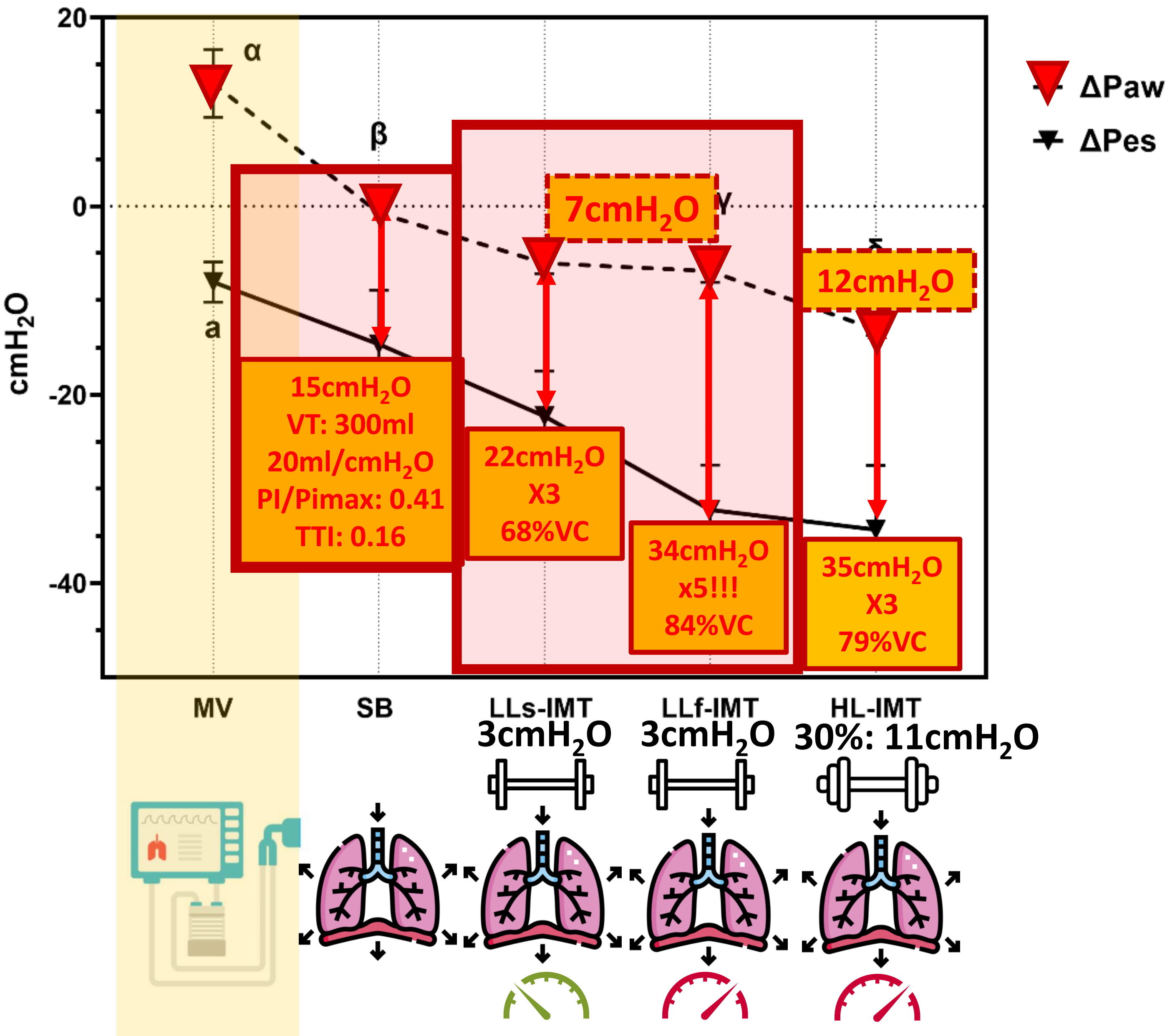
Instructing patients to perform deep and fast (i.e. more powerful) inspirations against low external load significantly increased their end inspiratory volume as compared to slow and deep breathing (**control group study Martin et al.**)

Similar volume inhaled during powerful inspirations against a low or high external load, slightly less with high load.



Poddighe D et al. ACC 2025

Results of exploratory assessments



Against low external load total inspiratory effort was much lower when IMT was executed with slow and deep inspirations **(similar to sham condition in study *Martin et al. Of note: their pressure recorded at airway opening was only 3cmH$_2$O!*)** as compared to powerful and deep inspirations **(higher EILV, IMWeanT control group)**

Total inspiratory effort 3-5x higher than what would be estimated based on external load

Total inspiratory effort was similar when IMT was executed with fast and deep inspirations against both a low or high external load **(Intervention and sham condition in our RCT)**
Borg effort also similar: 4.8 vs 5.4!

IMT (Low and High) resulted in more than 2x higher inspiratory effort as compared to spontaneous breathing!!

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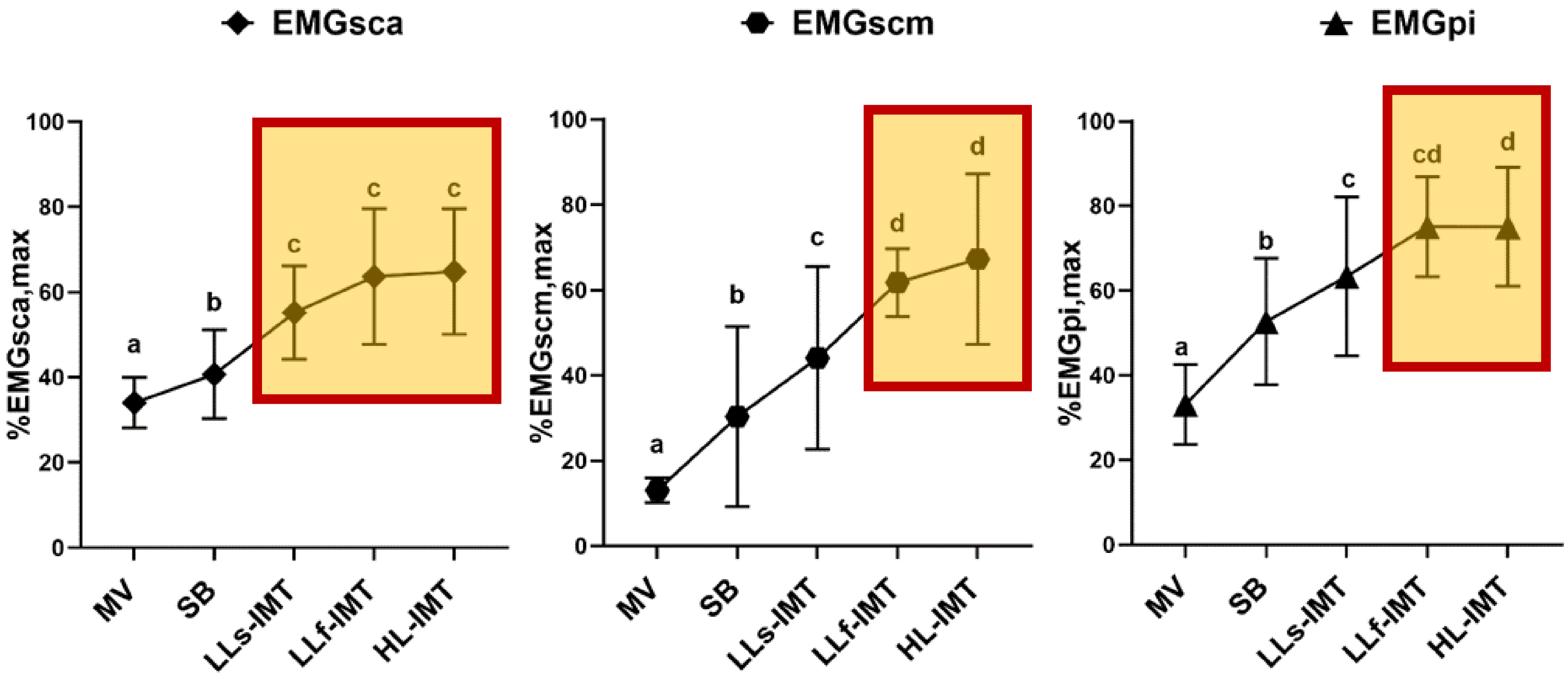
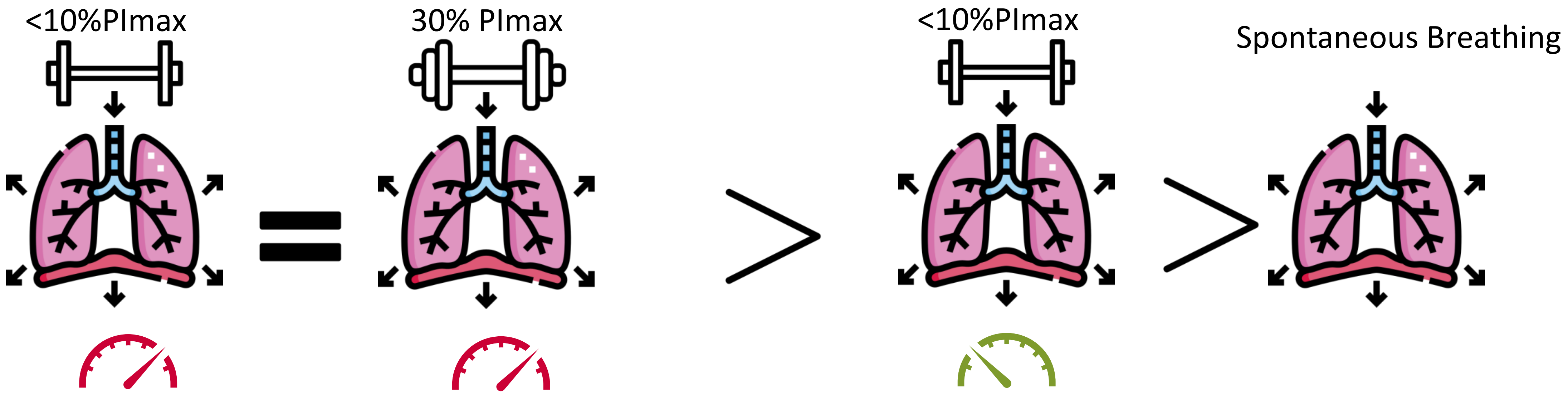
Results of exploratory assessments



Poddighe D et al. ACC 2025

Conclusions exploratory assessments



- External load set on training devices during IMT in weaning failure is not an accurate indicator of the total training load!
- Breathing instructions have a major impact on total training load!
- Results have important implications for designing IMT programs (intervention and control!) in future randomized controlled trials but also for clinical practice!
- Using specific breathing instructions and training parameters (numbers of sets and repetitions) an effective initial respiratory muscle training can be provided to many of these patients (at least in beginning of weaning period) without using external loads and training devices (use Borg effort scores to guide intensity!)

Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients

Remarkably, the increase in Pimax in the sham group of the present study is higher than in control groups in previous studies.

This could however also be a result of patient selection (48% post–lung transplant) and excellent standard of care in this ICU, including rehabilitation practices, sedation practices, infection control, and feeding. These factors may positively influence (respiratory) muscle function.

Based on current study not possible to draw definitive conclusions.

Large (multicenter) RCT with control group receiving no IMT is needed to confirm whether IMT is a useful adjunct to the treatment of weaning failure.

"Blowing in the Wind: The Uncertain Impact of Inspiratory Muscle Strength Training in ICU Patients."
American Journal of Respiratory and Critical Care Medicine, 211(3), pp. 311–313

How do these results affect our clinical practice in patients with weaning failure?

- Inspiratory muscle weakness is associated with weaning failure: ***Assess muscle strength***
- When ***weakness is present***: discuss its potential ***importance in the weaning failure*** and the ***application of IMT***
- Apply IMT ***strength*** training: ***limited number of higher intensity contractions***, control of ***cardiorespiratory response***, ***symptoms***, ***rest period*** between series allows continuation of mode of ventilatory support
- High intensity does not only depend on external load but also on breathing instructions!
- In the beginning of weaning period no or minimal external loads are probably sufficient
- ***Support and feedback*** to the patient during the training session is essential and the basis for progressing the training over time.
- Challenge: can we offer IMT to more patients and earlier during weaning process?

THANK YOU FOR YOUR ATTENTION!

If you have any questions please share your thoughts and ideas!

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