THE POWER AND POTENTIAL OF RESPIRATORY MUSCLE TRAINING

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INTRODUCTION

Respiratory muscle weakness is the primary reason for the inability of respiratory muscles to meet the increased demands of breathing during physical activity, with important secondary consequences. These include dyspnoea, exercise intolerance, sleep disturbances, speech and swallowing problems, as well as musculoskeletal and posture problems due to the loss of the stabilising function of the respiratory musculature. Despite the fact that a wide range of pulmonary, cardiovascular, metabolic and neuromuscular diseases shows characteristic respiratory muscle weakness, the acceptance and application of respiratory muscle training (RMT) as an effective intervention to reverse or mitigate this condition is low. Increasing evidence supporting the effectiveness of RMT in the treatment of disorders associated with respiratory muscle weakness calls for enhanced awareness, education and application of this therapy. Recent integration of RMT into guideline recommendations for pulmonary rehabilitation further exemplifies this need (figure 1) [1, 2].

RESPIRATORY MUSCLE DISORDERS

The "cardiorespiratory" system comprises two tightly connected circuits: 1) the lungs, airways and pulmonary vasculature as the respiratory circuit; and 2) the heart and systemic circulation as the cardiac circuit. Regulatory elements ensure adequate blood oxygenation during rest and exercise, while integrating systemic and pulmonary circulations. Respiratory muscle disorders include those primarily affecting the respiratory system, such as chronic obstructive pulmonary disease (COPD), asthma and bronchiectasis, as well as those associated with primary bellows failure, such as diverse types of neuromuscular diseases (NMD). Other disorders associated with secondary respiratory muscle dysfunction include congestive heart failure, obstructive sleep apnoea, diabetes, obesity, renal failure and glottic dysfunction [3].

Therefore, respiratory muscle disorders comprise a surprisingly

Figure 1. Respiratory muscle training slows progression of respiratory muscle disorders. (Image courtesy of PNMedical, Orlando, FL, USA).

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heterogeneous group with different pathophysiology, unified by the common symptoms of dyspnoea, exercise intolerance or reduced exercise capacity, and reduced quality of life (QoL). As the affected components of the respiratory system may vary between disorders, the disease manifestations may differ as well. For example, loss of elastic recoil of the lungs and increased flow resistance lead to hyperinflation, further contributing to respiratory muscle stress in COPD, whereas ventricular dysfunction leads to generalised and respiratory myopathy in heart failure, causing reduced muscle endurance [3, 4]. Additionally, when all muscle groups are affected, such as in NMD or spinal cord injury, both inspiratory and expiratory muscle groups can be impaired [1]. Furthermore, respiratory muscle weakness is associated with and contributes to worse prognosis after abdominal, thoracic and cardiac surgery, mechanical ventilation and intense cancer or stem cell treatment [5, 6]. These are some examples of disease states in which respiratory system dysfunction and respiratory muscle weakness are intricately associated.

RESPIRATORY MUSCLE TRAINING

Since respiratory muscle weakness is a common denominator of respiratory muscle disorders, RMT may be an effective adjunct therapy. The principle of RMT is similar to that of peripheral muscle strength and/or endurance training. In order to improve muscle strength, short bouts of muscle utilisation with high intensity are applied, akin to a few moves at near maximal power during weight lifting or bouldering. Muscle endurance on the other hand is improved by repetitious exercise at low intensity, such as long distance running or low grade, long range alpine climbing. As in skeletal muscles, respiratory muscles will predominantly show type II fibre growth in response to strength training and type I fibre growth after endurance training. RMT schemes may improve both respiratory muscle strength and endurance. However, the more effectively and widely applied RMT methods aim to predominantly improve respiratory muscle strength.

TRAINING RESPIRATORY MUSCLE STRENGTH

RMT protocols depend on the device used and the underlying disorder. They should be tailored to the specific needs and lifestyle of the patient. In general, improving respiratory muscle strength requires regular RMT for at least 3 weeks in order to observe a significant effect. Training intensity should be moderate to high; patients should train at 50–70% of their maximal inspiratory or expiratory pressure. Training frequency is typically once or twice per day, on at least 5 days per week. In chronic disease such as COPD, long-term RMT will be most beneficial, as improvements are still observed after 12 months of training [1, 7]. Conditions such as heart failure require lower training intensities (at around 30–60% of maximal inspiratory pressure) at the same frequency to optimise training benefit with consideration given to patient's baseline parameters and extent of respiratory muscle weakness [8]. The RMT protocol should therefore be patient tailored, and integrated into the patient's lifestyle for long-lasting benefits.

RESPIRATORY MUSCLE TRAINING METHODS

Depending on the RMT device and application, training can strengthen inspiratory muscles, expiratory muscles or both by using a combined method. Table 1 gives an overview

TABLE 1. Evidence for effectiveness of inspiratory and/or expiratory muscle training in different patient groups

Patient group	Inspiratory	Expiratory	Reference
COPD	Yes	Yes	[9]
Asthma	Yes		[10, 11]
Heart failure	Yes	Yes	[12]
NMD	Yes	Yes	[13, 14]
Spinal cord injury	Yes	Yes	[15, 16]
Hypertension	Yes	Yes	[17, 18]
Sleep apnoea	Yes		[19, 20]
Dysphagia	Yes	Yes	[14, 21, 22]
Vocal cord dysfunction	Yes	Yes	[14, 21, 22]
Prevention of post-operative pulmonary complications	Yes		[23]
Weaning from ventilation	Yes		[24]
Back pain	Yes		[25]
Stroke	Yes	Yes	[26–28]

COPD: chronic obstructive pulmonary disease; NMD: neuromuscular disease.

of evidence for the effectiveness of inspiratory muscle training (IMT) and/or expiratory muscle training (EMT) in specific patient groups. Please note that lack of evidence does not imply that other RMT methods are unsuitable.

Inspiratory muscle training

RMT during which resistance is added to inspiratory flow will specifically train inspiratory muscles, especially the diaphragm, which generates negative intrathoracic pressure and enlarges the thoracic cavity during inspiration. Other inspiratory muscles include the external intercostal muscles, essential for rib cage flexibility, while scalene and sternocleidomastoid muscles lift the rib cage during inspiration. The diaphragm and intercostal muscles are naturally slow to fatigue due to their high content of oxidative type I and type IIA muscle fibres. Moderate-to-high intensity IMT (~60% of maximal inspiratory pressure) will increase muscle strength, maximal shortening velocity and maximal power of the inspiratory muscles. In addition, inspiratory muscle strength training will also improve muscle endurance and delay diaphragm fatigue, thus increasing exercise tolerance and performance [1]. As diaphragm motion also supports stabilisation of the spine, IMT contributes to improved posture control [25]. Devices for IMT provide some form of resistance that has to be overcome during inhalation, while expiration is unloaded. The two dominant groups are resistive and threshold devices. Threshold devices usually contain a spring valve, which will open once a threshold pressure is applied, leading to strong resistance in the early part of the inspiratory flow, while the remaining volume is unloaded. Examples for threshold devices include POWERbreathe (PowerBreathe International Ltd, Southam, UK) and Threshold IMT (Philips Respironics, Murrysville, PA, USA).

Resistive IMT devices decrease the opening through which air can flow, creating a constant resistance throughout the entire volume of the breath. Examples for resistive IMT devices can be found in table 2.

While the modes of action differ slightly between threshold and resistive devices, the benefits are comparable. Head-to-head comparisons have not identified superiority of either method for improving inspiratory muscle strength and endurance, exercise capacity, dyspnoea or health-related QoL. While threshold devices might elicit more pronounced improvements in respiratory muscle strength, resistive devices are more effective in improving all four cornerstones of health-related QoL in COPD: dyspnoea, fatigue, emotional well-being and mastery of disease [29, 30].

Expiratory muscle training

While expiration during resting is passively mediated by the recoil of the lung and thorax, forced expiration or expiration during exercise requires

Table 2. Commercially available respiratory muscle trainers for inspiratory and expiratory muscle training and a combination of inspiratory and expiratory muscle trainers

Device	Manufacturer/distributor	Inspiratory	Expiratory	Combination
Breather	PNMedical (Orlando, FL, USA)	Yes	Yes	Resistive
Threshold PEP	Philips Respironics (Murrysville, PA, USA)	Yes	Yes	Resistive and threshold
Eolos	Aleas Europe (Miami, FL, USA)	Yes	Yes	Resistive
Threshold IMT	Philips Respironics (Murrysville, PA, USA)	Yes		Threshold
Pflex	Philips Respironics (Murrysville, PA, USA)	Yes		Resistive
POWERbreathe	POWERbreathe (Southam, UK)	Yes		Threshold
Trainair	Project Electronics Ltd (Erith, UK)	Yes		Resistive
Respifit S	Biegler GmbH (Mauerbach, Austria)	Yes		Resistive
Ultrabreathe	Tangent Healthcare Ltd (Basingstoke, UK)	Yes		Resistive
Portex IMT	Smiths Medical (St Paul, MN, USA)	Yes		Resistive
EMST-150	Aspire Products (Atlanta, GA, USA)		Yes	Threshold

expiratory muscle activation. This includes muscles of the abdominal wall, in particular the transloc abdominis and the internal and external oblique muscles, as well as internal intercostals. Expiratory muscles, especially upper airway musculature, play essential roles during phonation, airway clearance and expectoration. Expiratory muscles in the trunk also support rotation and flexion [1].

EMT elicits similar responses to IMT in the expiratory muscle system, although much less data is available to date, compared to evidence on the effect of IMT. Akin to IMT, improvement of the maximal expiratory pressure is the hallmark parameter of successful EMT. Interestingly, EMT alone also leads to improved maximal inspiratory pressure, demonstrating involvement of the inspiratory muscles in the process of expiration, whereas IMT does not improve maximal expiratory pressure [1]. Due to the importance of expiratory muscles in speech and swallow functions, EMT is of particular interest for patients with dysphonia, dysphagia and reduced ability for airway clearance, such as those with Parkinson's or other NMDs.

The design of customary devices for EMT is again dominated by threshold and resistant methods, following principles identical to those of the respective IMT devices, but loading the expiratory phase of breathing with free inspiration. Examples for threshold EMT devices are listed in table 2.

Combined inspiratory/expiratory muscle training

While benefits of either IMT or EMT alone are clearly demonstrated in the literature, combinations of IMT and EMT have not been widely reported. However, a few important studies highlight the possibly overlooked potential of combined IMT and EMT. Combined IMT and EMT in patients with Duchenne muscular dystrophy or spinal muscular atrophy improved inspiratory and expiratory muscle strength, and led to a sustained reduction of respiratory load perception, thus improving patient comfort and health-related QoL [31]. In patients with multiple sclerosis, combined IMT/EMT improved maximal inspiratory and expiratory pressure, and significantly reduced fatigue [13]. Most importantly, direct comparison of IMT, EMT or a combination thereof showed that in COPD patients maximal inspiratory and expiratory pressure improved by 33% when inspiratory and expiratory muscles were trained simultaneously, but only by 20–25% if only one set of muscles was strengthened [9]. These findings clearly indicate that a combination of IMT and EMT may at least be equally effective to either method alone, and might be indicated in respiratory muscle disorders in which training of both muscle groups is of greater benefit, such as COPD and NMDs.

Currently, there are few devices on the market that provide both IMT and EMT; examples are listed in table 2. These devices differ in their applied RMT method: while the Threshold PEP (Philips Respironics) combines threshold IMT with resistive EMT, inspiratory and expiratory muscles are both trained by resistance with the Breather (PNMedical, Orlando, FL, USA).

RESPONSES TO RMT IN PATIENTS

While increased maximal respiratory pressure presents the most commonly reported response to RMT, several other physiological changes have been observed which grant RMT a much wider therapeutic target range than anticipated. Increased respiratory muscle strength directly correlates with observed improvement in exercise tolerance and capacity, which is assessed by distance covered in the 6-min walk test as well as with forced expiratory volume in 1 s (an indicator of pulmonary function) [32]. The impact of RMT on exercise tolerance and capacity is also evident in healthy people and athletes, where it has been shown to improve performance by 1.7% to 4.6% [1].

An extensive list of additional RMT-mediated benefits has been observed in a variety of disorders and disease backgrounds, and the examples here are by no means exhaustive. In COPD patients, inspiratory capacity, inspiratory fraction, respiratory endurance and, most importantly, the prognostic factor hyperinflation improved after RMT [33]. Direct responses to RMT in the diaphragm include increased thickness and increased velocity of movement, indicating significant functional improvements in stroke patients [26, 34]. RMT directly influences cardiac activity, improving heart rate variability and sympathetic nerve activity. An important finding with potential widespread implications is the ability of RMT to lower both systolic and diastolic blood pressure in hypertensive and normotensive adults [8, 17, 19]. Improved circulation includes enhanced blood flow to the limbs, which has been shown in chronic heart failure patients. Reduced vasoconstriction in the calf muscle and delayed metaboreflex, which are responsible for regulating blood flow to exercising limbs, allow greater exercise tolerance in response to RMT [35].

Obstructive sleep apnoea (OSA) is a growing health concern associated with daytime sleepiness, hypertension, heart disease, obesity and increased mortality. RMT significantly improves sleep quantity and quality by reducing apnoea, hypopnea and desaturation during rapid and non-rapid eye movement sleep. Strengthening the pharyngeal muscles during RMT further reduces snoring, extending RMT benefits to the partners of people affected by OSA [36].

The strengthening effect of RMT on upper airways is also influential in its impact on speech

TABLE 3. Specific benefits of respiratory muscle training in different patient groups

Patient group	Specific benefits of respiratory muscle training#	Reference
COPD	Increased inspiratory capacity	[9, 33, 37]
	Increased peak inspiratory flow	
	Reduced hyperinflation	
Asthma	Reduced β_2-agonist consumption	[10, 11]
Heart failure	Improved heart rate variability	[8, 34, 35]
	Reduced sympathetic nerve activity	
	Improved diaphragm function	
	Increased blood flow to limbs	
NMD	Reduced relative load perception	[13, 14, 21, 22, 31]
	Reduced fatigue	
	Improved cough and swallow function	
	Improved phonation	
Spinal cord injury	Improved orthostatic stress-mediated respiratory response	[15, 16]
	Improved cardiovascular function	
	Improved autonomic responses	
Hypertension	Lower blood pressure	[17]
	Reduced sympathetic activity	
Sleep apnoea	Improved sleep quality	[19, 20]
	Reduced number of arousals	
	Fewer periodic limb movements	
	Fewer awakenings	
	Improved apnoea/hypopnoea	
	Decreased desaturation in REM sleep	
Dysphagia	Improved cough and swallow function	[21, 22, 27]
	Reduced penetration/aspiration	
	Decreased compression phase duration	
	Increased cough volume acceleration	
	Shorter expiratory rise time	
Vocal cord dysfunction	Improved voice quality	[14]
	Improved vowel phonation	
Prevention of post-operative pulmonary complications	Reduced incidence of post-operative pulmonary complications	[23]
	Reduced duration of post-operative hospitalisation	

(*Continued*)

Table 3. Continued

Patient group	Specific benefits of respiratory muscle training#	Reference
Mechanical ventilation liberation	Higher successful weaning rate	[24]
Back pain	Reduced lower back pain intensity	[25]
	Improved relative proprioceptive weighting	
Stroke	Decreased diaphragm asymmetry	[26–28]
	Improved swallow function	

COPD: chronic obstructive pulmonary disease; NMD: neuromuscular disease; REM: rapid eye movement. #: only benefits other than the generally observed increase in maximal inspiratory pressure with inspiratory and expiratory muscle training, maximal expiratory pressure with expiratory muscle training, improved quality of life, reduced perception of dyspnoea and increased exercise capacity are listed.

and swallowing function observed in patients with NMD, such as Parkinson's and multiple sclerosis. Here, RMT results in improved penetration/aspiration scores, compression phase duration and expiratory rise time, as well as swallow function, cough function, vowel phonation and perceived speech quality [14, 21, 22].

The importance of RMT in the acute care environment comes from its ability to significantly reduce post-operative pulmonary complications after thoracic and abdominal surgery, a major cause for morbidity, mortality and increased hospitalisation rates. Preoperative RMT reduces the risk of post-operative pulmonary complications by almost 50%, and shortens hospital stay [23]. For patients who fail to wean from mechanical ventilation after surgery, RMT significantly increases the chance of successful liberation from 47% to 71% [24].

Other independent findings demonstrate that RMT improves posture control due to the involvement of respiratory muscles in trunk stability and core strength, as well as the intensity of lower back pain [25]. Table 3 provides an overview of the specific benefits of RMT observed in different patient groups.

In addition to the direct effects of RMT, the therapy can also serve to enhance pharmacological interventions. For example, RMT may improve lung deposition of inhaled medication through enhancement of peak inspiratory flow, which may serve to reduce frequency of bronchodilator use [10, 37].

CONCLUSION

This article aims to highlight the increasing range of benefits provided by RMT. While the sheer diversity of possible applications and target patient groups is impressive by itself, the real power of RMT might be the holistic approach it has to offer. Akin to general exercise, RMT may result in systemic improvements to the cardiorespiratory and circulatory systems. The recent finding that RMT has the ability to reduce hypertension and improve posture control adds to its therapeutic potential. As patients, such as those with COPD, often present with multiple comorbidities, OSA or asthma–COPD overlap syndrome, medical treatment can be complex [38]. For this population, RMT may offer a unique approach to safe and effective relief of a number of symptoms, predominantly dyspnoea, sleep apnoea, hypertension and exercise intolerance. Consequently, RMT might lead to increased exercise capacity, starting a "therapeutic domino effect". In contrast to general exercise, RMT also offers benefits and health improvements for those with reduced mobility, in intensive care or on mechanical ventilation.

Furthermore, RMT adds significantly to general exercise regimes routinely recommended for patients with cardiorespiratory disorders. Compared to exercise alone, it has been reported that RMT is much more efficient in improving oxygen uptake and ventilation, maximal inspiratory pressure, exercise performance and QoL [39–41]. It is also noteworthy that RMT in combination with exercise has proven far superior to any pharmacological intervention in improving exercise capacity [42]. The effect of RMT is even more pronounced for the alleviation of dyspnoea, which accompanies all respiratory muscle disorders. Neither exercise nor long-acting bronchodilators were as effective as RMT alone in reducing perception of dyspnoea [43]. These findings demonstrate the unique position of RMT among both pharmacological and nonpharmacological interventions in the treatment of dyspnoea and exercise intolerance, the greatest contributors to health-related QoL.

While a range of RMT devices are currently available, the next generation is already in development. In step with current technological possibilities, remote monitoring of pulmonary parameters has been tested to identify the onset of acute exacerbations of COPD. These events of sudden worsening of symptoms greatly contribute to hospitalisation, impaired QoL, healthcare costs and mortality. In a pilot study, remote monitoring of breath sounds predicted 76% of acute exacerbations of COPD events [44]. Beyond proof of concept, the next generation of the Breather (Breather 2) will remotely report a variety of pulmonary parameters from each RMT session to the clinician, giving them the opportunity to intervene at the onset of pulmonary function decline, and prevent imminent acute exacerbations of COPD events.

The remote monitoring of RMT along with measures of lung function is anticipated to contribute to the reduction of hospitalisation associated with exacerbation of COPD, as well as improve patient adherence to prescribed therapy. Based on increasing evidence, RMT is a safe, effective and inexpensive therapeutic option with immense clinical potential, without any recorded adverse events. The integration of this simple therapy into pulmonary rehabilitation, or as an adjunct in the management of primary or secondary respiratory disorders, or in the prevention or treatment of a host of many cardiopulmonary disorders, should be strongly considered.

CONFLICT OF INTEREST

N. Bausek is an employee of PNMedical and has received personal fees from PNMedical during the conduct of this article and outside the submitted work. T. Berlin is an unpaid consultant for PNMedical working to develop and test a newly designed muscle training and monitoring device. S. Aldarondo is the Chief Medical Officer for PNMedical which manufactures, develops and distributes The Breather, one of the devices mentioned in this article.

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