10 Respiratory Muscle Training

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Abstract

The respiratory muscles have a key role within the respiratory system allowing air to be pumped in and out the lungs. As other skeletal muscles, they can fatigue and be affected by pathological mechanisms leading to muscle weakness. They can also be trained using specific strategies inducing overloading and adaptations over time. Inspiratory muscle resistive training and respiratory muscle isocapnic hyperpnea training are the two main training methods used to increase respiratory muscle strength and endurance. It has been shown in healthy subjects that these kinds of training improve not only respiratory muscle function but also endurance exercise performance. In several diseases, patients can also benefit from respiratory muscle training which can improve respiratory function, exercise capacities, symptoms, and quality of life. As other training and rehabilitative methods, also respiratory muscle training, to be efficient, requires appropriate modalities, intensity, and duration as well as evaluations of the training effects.

10.1 Introduction

The respiratory muscles have a key physiological role within the respiratory system by allowing movement of air within the lungs to the alveoli. This is critical for gas exchange, especially for oxygen intake and carbon dioxide output. The respiratory muscles drive the ventilatory responses to various stimuli and in particular to physical exercise. An important concept to consider is the balance between the ventilatory demand (or respiratory load) and the respiratory muscle capacity (Fig. 10.1). Any disproportionate increase of the ventilatory demand or respiratory

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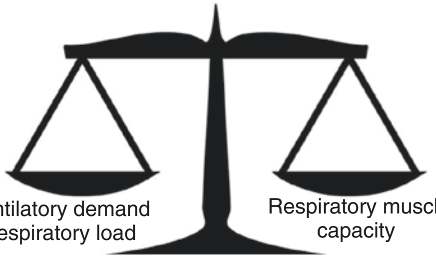

Fig. 10.1 The respiratory balance represented as the results of the respiratory load and the respiratory capacity. Some factors able to influence one side or the other of the balance are also indicated

load compared to the ability of the respiratory muscle output to accommodate this demand/load will result in an altered respiratory balance which will not be sustainable for a long period and which may induce deleterious consequences. An increase in ventilatory demand or respiratory load can be generated in healthy subjects by exercise (and the associated hyperpnea) and by exposure to specific environment such as altitude (and the associated hyperventilatory response). Several diseases can induce an increase in respiratory load, for instance, obstructive and restrictive respiratory diseases, which can enhance the airway resistance and reduce thoracic compliance. The capacity of the respiratory muscles to pump air in and out the lungs can be altered due to transitory (fatigue) or permanent (weakness) reduction in their ability to produce inspiratory and expiratory pressures. This can happen in healthy subjects following fatiguing physical exercise and in several disease conditions affecting the function (structure, metabolism, etc.) of the respiratory muscles and/or overloading the respiratory muscles. The capacity of the respiratory muscles to generate pressure and flow can also be enhanced by using specific training strategies (respiratory muscle training).

10.2 General Concepts

The respiratory muscles should be considered as any other skeletal muscles on many aspects. Muscles have two functions, i.e., to develop force and to shorten. In the respiratory system, force is expressed as changes in pressures, while shortening is expressed as changes in lung volume or displacement of the chest wall. Therefore, the respiratory muscle function is generally performed by measuring the respiratory pressures and lung volumes. Respiratory muscle strength in clinical setting is usually assessed based on maximal voluntary inspiratory or expiratory maneuvers against an occluded airway, leading to the measurement of maximal inspiratory (PI_{max}) or expiratory (PE_{max}) pressures. Additional clinical measurements such as sniff tests and peak expiratory cough flow can also be used. In research setting, electrical or magnetic stimulation of the motoneurons innervating the respiratory muscles (the phrenic nerves for the diaphragm, for instance) can be used to provide a non-volitional and more specific assessment of respiratory muscle force production capacities. Respiratory muscle endurance can also be evaluated by asking the subjects to sustain an increased respiratory load over a prolonged period, e.g., by breathing with an added inspiratory resistance or by performing isocapnic hyperpnea. The time to task failure (i.e., the inability to sustain the respiratory load) is generally the index used to quantify respiratory muscle endurance. The reader is referred to the American Thoracic Society/European Respiratory Society position statement on respiratory muscle testing [1] for more information on this topic.

Based on careful respiratory muscle strength measurements, respiratory muscle fatigue or weakness can be demonstrated. Muscle fatigue is defined as a transient reduction in the ability to generate force (or pressure for the respiratory muscles) following a period of overload (e.g., exercise-induced hyperpnea) followed by progressive recovery of the initial muscle abilities. Muscle weakness is defined as a permanent reduction of the ability to generate strength compared to the expected muscle force capacities. Respiratory muscle fatigue has been demonstrated in healthy subjects, for instance, following intense whole-body exercise (e.g., cycling) by showing reduced maximal voluntary or evoked (by electrical or magnetic stimulations) inspiratory and expiratory muscle pressures after, compared to before exercise [2–5]. Respiratory muscle weakness can be observed in various diseases by comparing PI_{max} and PE_{max}, for instance, to theoretical values that provide expected values for a healthy subject depending on sex, age, and body size.

As other skeletal muscles, respiratory muscles can adapt to repetitive increase in load; in fact, they can increase their capacities in response to specific training program. Therefore, the key principles of physical training apply also to respiratory muscle training. To induce muscle adaptations, training programs should induce overloading, i.e., a significant increase in the total work the muscles have to perform over a prolonged period of time. The training load will depend on the intensity of the work during the exercise training session (e.g., the strength and speed the muscle has to develop and the number of contractions) and the number of training sessions per week. If the intensity of the training session is too low, or the number of training sessions per week is insufficient, the training will not induce significant muscle improvement. Similarly, if the exercise training intensity is too high, or the training sessions are too frequent and do not allow proper recovery, the training will also fail in improving muscle capacities. Therefore, the efficiency of respiratory muscle training will depend on the determination of the appropriate training program and should be evaluated by objective methods such as the assessment of respiratory muscle strength and endurance. In addition to improving respiratory muscle strength and endurance, the ultimate goal of respiratory muscle training is to increase performance of sportsmen and to improve health status, functional capacities, and quality of life of patients. Hence, in addition to the effects of respiratory muscle training on respiratory muscle function (respiratory muscle strength and endurance, for instance), these important outcomes (e.g., exercise endurance, respiratory symptoms, health-related quality of life, etc.) also have to be evaluated to objectivize the potential effect of this kind of training.

10.3 Respiratory Muscle Training in Healthy Individuals

Two main methods of respiratory muscle training have been developed and evaluated by specific studies: inspiratory muscle resistive training and respiratory muscle isocapnic hyperpnea training.

Because the inspiratory muscles are mainly involved in breathing, they have been targeted by training methods consisting in repetitive contractions against a load, either a resistance (which has the disadvantage to be flow-dependent) or more usually a threshold-loading valve, which opens only when the subject produces a certain negative pressure during inspiration. The load during inspiratory resistive training is set based on the target mouth inspiratory pressure to produce, expressed as a percentage of the PI_{max} and on the number of contractions (inspiratory maneuvers) to perform per session. It is also important to consider the lung volume and the respiratory pattern during inspiratory resistive training, because these parameters will influence the length and the speed of the inspiratory muscle contractions and therefore the muscle adaptations induced by training. Depending on studies, inspiratory muscle pressure during inspiratory muscle training varies between 30% PI_{max} (low-intensity training) and 80% PI_{max} (high-intensity training).

In order to mimic heavy breathing as during intense physical exercise, respiratory muscle training methods based on isocapnic voluntary hyperpnea have been developed. During this kind of training, subjects have to increase their ventilation to >60% of their maximal minute ventilation (measured over 10–15 s or calculated theoretically as FEV1 × 35–40) and to sustain this high level of ventilation for 20–30 min per session. With this method, both inspiratory and expiratory muscles are recruited and trained. In order to prevent hypocapnia, induced by hyperventilation, the use of a specific device allowing partial rebreathing is required to maintain a stable CO_2 (isocapnic hyperpnea). The device should also provide feedback on the appropriate tidal volume and breathing frequency to sustain during the training session. As for inspiratory resistive breathing, several devices are commercially available and allow proper training conditions (e.g., POWERbreathe© K-Series for inspiratory resistive training, Spirotiger© for isocapnic hyperpnea training). Other devices do not provide proper feedback and may therefore prevent the subjects to benefit from training, as expected.

Both inspiratory resistive training and isocapnic hyperpnea training programs over 4–8 weeks (five to seven sessions per week) have been shown to improve significantly respiratory muscle function in healthy subjects. Inspiratory resistive training mostly improves inspiratory muscle strength (as shown by increased PI_{max} [6]), while isocapnic hyperpnea training mainly increases respiratory muscle endurance (as demonstrated by an increase in time to exhaustion during a hyperpnea endurance test [7]) (Fig. 10.2). In addition to increasing respiratory muscle strength and endurance,

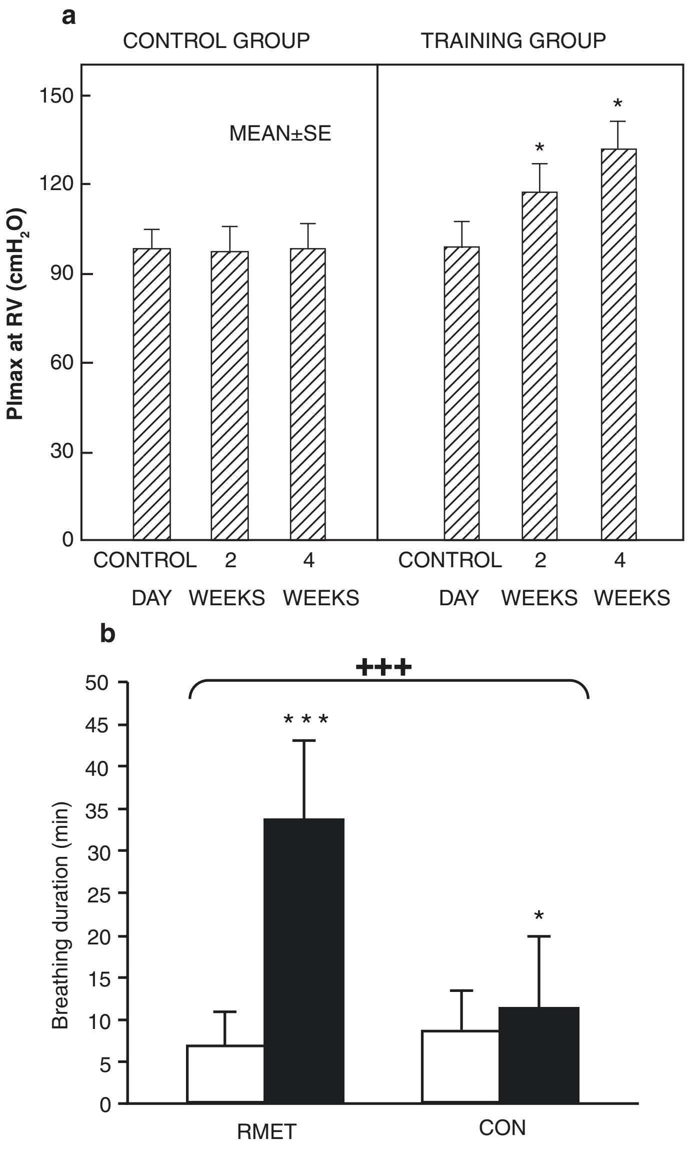

Fig. 10.2 (**a**) The effect of 4 weeks of inspiratory resistive training on maximal inspiratory pressure (PI_{max}, measured at residual volume, RV) [6]; and (**b**) of 4–8 weeks of respiratory muscle isocapnic hyperpnea training (RMET) on breathing endurance [7]. Changes are provided for a training group and for a control (CON) group

respiratory muscle training has been shown to increase performance during various types of exercise in healthy subjects (cycling, running, rowing, etc.). Maximal oxygen consumption and maximal aerobic power output generally did not improve after respiratory muscle training, while submaximal endurance performance (time to exhaustion at submaximal intensity, distance during a time trial, time for a given distance) has been shown to increase in several studies. A systematic review and meta-analysis [8] have assessed the effect of respiratory muscle training on exercise endurance performance and the factors influencing the change in exercise endurance performance in healthy subjects. The conclusions indicated (1) a significant improvement in exercise performance after respiratory muscle training, which was detected by constant load tests, time trials but not by incremental tests; (2) less fit subjects benefit the most from respiratory muscle training; and (3) improvements did not differ between inspiratory resistive training and isocapnic hyperpnea training. Respiratory muscle training can also reduce exercise-induced respiratory muscle fatigue [9, 10], improve respiratory sensations during exercise [7], and reduce blood lactate concentration [11, 12].

10.4 Respiratory Muscle Training in Patients

Respiratory muscle training has been tested in several neuromuscular disorders as an adjunct to other rehabilitation strategies. In patients with multiple sclerosis and lateral amyotrophic sclerosis, for instance, it improves lung function and respiratory muscle strength [13]. In spinal cord injury, respiratory muscle training is recognized as an efficient method to improve vital capacity, PI_{max} and PE_{max}, while the potential positive effects on dyspnea and quality of life remain to be confirmed [14]. The effect of respiratory muscle training in chronic obstructive pulmonary diseases (COPD) has been assessed in numerous clinical trials. Recent systematic review and meta-analysis indicate that inspiratory resistive training improves inspiratory muscle strength, exercise capacity, and quality of life and decreases dyspnea in COPD patients [15, 16]. In asthmatic patients, respiratory muscle training has been proposed as a complementary therapy to the pharmacological treatments. This intervention seems to improve symptoms and quality of life, although the evidence remains modest [17]. Similarly, in cystic fibrosis, respiratory muscle training may contribute to a better respiratory function and quality of life, but further studies are required to provide clear clinical recommendations [18]. In cardiovascular diseases, respiratory muscle training can also be considered as an attractive intervention in addition to standard care. Adding inspiratory resistive training to whole-body exercise training program induces significant improvement in inspiratory muscle strength and quality of life of patients with heart failure, for instance [19]. Respiratory muscle training should also be considered in obese patients [20, 21] and after stroke [22, 23]. There are recent evidences that respiratory muscle training is feasible and safe in ventilated patients and that this kind of intervention can reduce the weaning period and improve weaning success rates [24]. Respiratory muscle training can be used pre- and post-thoracic and upper-abdominal surgery in order to improve lung function and to reduce postoperative respiratory complications [25, 26].

10.5 Recommendations and Remaining Questions

Respiratory muscle training has been proposed as a complementary intervention in the management of a range of diseases. It appears to consistently improve respiratory muscle function and has been associated in several diseases with a clinically important improvement in symptoms such as dyspnea, impaired cough, functional capacity (such as exercise performance), and quality of life. However, its indications and potential contraindications, the type of evaluations, the optimal training modalities (intensity, duration and number of sessions, etc.), and the selection of patients who may benefit the most remain to be better clarified. It seems that patients with respiratory muscle weakness and respiratory symptoms (dyspnea, impaired cough, etc.) could be good candidates.

Inspiratory resistive training should be done with a flow-independent device (by using a threshold-loading valve, for instance) and a controlled pattern of breathing ensuring the patient inspires a sufficient volume of air at an appropriate rate. Hyperpnea training should be done with a device ensuring isocapnia (by partial rebreathing, for instance) and providing feedback to the patients regarding tidal volume and breathing frequency. A sufficient intensity has to be determined for the first training sessions (see Table 10.1). Then, it is critical to increase the intensity at least weekly as the patient's respiratory muscle capacity will progressively increase in order to maintain an appropriate muscle overloading. A sufficient number of sessions per week are also critical (see Table 10.1), and a minimum training program of 4 weeks appears reasonable. Posture and breathing technique, especially if the respiratory muscle training session is supervised by a professional health care, should be optimized since respiratory muscle training is also able to influence and improve these aspects. As for any kind of exercise training, the benefits of respiratory muscle training will progressively disappear after the end of the training program if the overloading of the muscle (i.e., the training load) is not present anymore. Whether inspiratory resistive training and isocapnic hyperpnea training provide

Table 10.1 Respiratory muscle training modalities

	Inspiratory resistive training	Isocapnic hyperpnea training
Description	Repetitive inspiratory maneuvers against a fixed resistance similar to strength training	Heavy breathing without resistance but at high minute ventilation mimicking breathing during intense exercise, similar to muscle endurance training. Partial rebreathing allows isocapnia
Session duration	10–15 min, twice a day	20–30 min
Frequency	Five to seven sessions per week	Five sessions per week
Intensity	30–50% PI_{max} (adjusted weekly)	50–60% of maximum minute ventilation (adjusted weekly), tidal volume close to 50% vital capacity
Device feedback	Information on breathing pattern and inspired volume are important	Information on tidal volume and breathing frequency are important

similar benefits or should be selected for certain types of patients remain unknown. Specific expiratory muscle resistive training may also be considered in some conditions [27].

Key Points

- Respiratory muscle weakness and fatigue have been identified in a variety of conditions.
- They can be responsible for significant functional impairments, symptoms, and impaired quality of life of patients.
- Respiratory muscles can be trained similarly to other skeletal muscles to increase their strength and endurance.
- Respiratory muscle training by either inspiratory resistive breathing or isocapnic hyperpnea induces significant improvement in respiratory muscle function in healthy subjects and several different diseases.
- These increases in respiratory muscle function can be associated with enhanced exercise performance and respiratory function and improvements in symptoms and quality of life.

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