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CLINICAL FOCUS: PULMONARY AND RESPIRATORY CONDITIONS IN THE ATHLETE
REVIEW

The role of inspiratory muscle training in the management of asthma and exercise-induced bronchoconstriction

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ABSTRACT

Asthma is a pathological condition comprising of a variety of symptoms which affect the ability to function in daily life. Due to the high prevalence of asthma and associated healthcare costs, it is important to identify low-cost alternatives to traditional pharmacotherapy. One of these low cost alternatives is the use of inspiratory muscle training (IMT), which is a technique aimed at increasing the strength and endurance of the diaphragm and accessory muscles of respiration. IMT typically consists of taking voluntary inspirations against a resistive load across the entire range of vital capacity while at rest. In healthy individuals, the most notable benefits of IMT are an increase in diaphragm thickness and strength, a decrease in exertional dyspnea, and a decrease in the oxygen cost of breathing. Due to the presence of expiratory flow limitation in asthma and exercise-induced bronchoconstriction, dynamic lung hyperinflation is common. As a result of varying operational lung volumes, due in part to hyperinflation, the respiratory muscles may operate far from the optimal portion of the length-tension curve, and thus may be forced to operate against a low pulmonary compliance. Therefore, the ability of these muscles to generate tension is reduced, and for any given level of ventilation, the work of breathing is increased as compared to non-asthmatics. Evidence that IMT is an effective treatment for asthma is inconclusive, due to limited data and a wide variation in study methodologies. However, IMT has been shown to decrease dyspnea, increase inspiratory muscle strength, and improve exercise capacity in asthmatic individuals. In order to develop more concrete recommendations regarding IMT as an effective low-cost adjunct in addition to traditional asthma treatments, we recommend that a standard treatment protocol be developed and tested in a placebo-controlled clinical trial with a large representative sample.

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Introduction

Asthma is a multi-faceted pathological condition generally characterized by a variety of symptoms including airway inflammation, bronchial hyper-responsiveness, and airway obstruction that is transient and reversible.[1] Typical clinical presentations include wheezing, coughing, resting and/or exertional dyspnea, and chest tightness.[2,3] The prevalence of asthma is increasing in many countries, and affects individuals over a wide range of ages.[4] Asthma is increasingly recognized as a public health concern due to its high prevalence [5] and associated healthcare costs.[6] It is therefore important to identify lower-cost alternatives to traditional asthma treatments as well as adjunct therapies to supplement traditional treatment strategies for managing asthma and modifying its severity. Exercise-induced bronchoconstriction (EIB) is a distinct, but clinical phenotype of asthma, in which a brief period of exercise or an increase in ventilation causes the airways to constrict both more easily and more forcefully than normal airways in response to bronchoconstrictor stimuli, resulting in airway obstruction.[7] While EIB may be present in athletes without a diagnosis of asthma, evidence suggests that

almost all asthmatic patients may experience bronchial obstruction and clinical symptoms in response to exercise.[8]

At present, the mechanisms underlying EIB are uncertain, but multiple mechanistic pathways are thought to be involved. Hyperventilation during exercise causes a large volume of air to be quickly warmed and humidified as it passes through the conducting airways.[8] During this process, water loss in the airways may result in airway dehydration and a consequent increase in the osmolarity of the airway-lining fluid.[7–10] This may trigger airway inflammatory cells to release mediators, such as histamine, cysteinyl leukotrienes, and prostaglandins.[7,11] These mediators promote contraction of smooth muscles lining the airways, as well as airway edema.[7] Alternatively, it has been suggested that airway cooling primarily affects the bronchial vasculature, such that rapid rewarming of the airways following exercise may lead to reactive hyperemia and airway edema, which would further contribute to the airway narrowing.[8]

The heterogeneity and varying clinical presentations of asthma have made it difficult to identify the specific pathophysiology of asthma. Most clinicians, however, agree that a fundamental cause of asthma is airway inflammation.[12] The

inflammatory response in the airways of patients with asthma involves an orchestrated interplay of the respiratory epithelium, innate immune system, and adaptive immunity that initiates and drives a chronic inflammatory response.[13] Fundamental to this process is an interaction between genes and environment, resulting in an abnormal immune response to allergens and other environmental triggers in genetically susceptible individuals.[14] The interaction between airway epithelial cells, allergic cells, inflammatory leukocytes, cytokines, and eicosanoids are central to the disease progression, and result in the clinical expression of a lower airway obstruction that is usually reversible.[15]

Lung hyperinflation (or an increase in the end-expiratory lung volume) is also a common feature of asthma, resulting from expiratory flow limitation, premature closing of the small airways, reduced pulmonary compliance, and increased activity of the inspiratory muscles at the end of expiration.[16] The severity of hyperinflation likely varies with changes in the duty cycle (ratio of inspiratory time compared to total breath time) throughout the course of daily living, with some periods through the day impacted more than others. Despite the likelihood of periods of less hyperinflation, it is still probable that hyperinflation contributes to the symptoms observed in asthma. Hyperinflation can be detrimental since it reduces the length of the diaphragm and accessory muscles of inspiration, forcing these muscles to operate farther from the optimal portion of their length-tension curve.[17] Lung hyperinflation may also physically distort the diaphragm by flattening it from its normal dome-shape,[17] which can cause the diaphragm to pull the ribs horizontally, limiting the expansion of the thoracic cage, and thereby reducing the ability to inspire.[17] Furthermore, hyperinflation increases the work of breathing, placing additional stress on the respiratory musculature.[18] Each of these factors, which are associated with hyperinflation, have been shown to contribute to the perception of dyspnea, and it is postulated that the neuro-mechanical dissociation that occurs with hyperinflation is perceived as 'unsatisfied inspiration'. [18] Moreover, the level of voluntary central drive to respiratory muscles in strong efforts may be higher in asthmatics compared to non-asthmatics. Therefore, any strategy that can reduce the degree of lung hyperinflation may be helpful in mitigating these deleterious effects.

The majority of pharmacological treatments for asthma are therefore aimed at reducing airway inflammation and promoting airway smooth muscle relaxation to lessen airway narrowing. Common current clinical therapies for management of asthma include the prescription of short-acting β_2 -agonists (SABA), long-acting β_2 -agonists (LABA), and inhaled corticosteroids (ICS).[4] EIB is commonly managed similarly with short-term bronchodilators such as ICS, SABA, LABA, and leukotriene (LT) modifiers.[7,8,19,20] However, the clinical response to asthma therapy, such as LT modifiers and corticosteroids are heterogeneous, and even with optimum treatment, there is a substantial burden of unaddressed disease.[4] LT modifiers provide only modest protection against symptoms and prolonged use of a number of medications can result in reduced effectiveness or tachyphylaxis. For example, the daily use of long-acting β_2 -agonists in the management of asthma has been questioned, and reversal of an asthma attack, such as

EIB, may be ineffective when short-acting β_2 -agonists are used on a daily basis.[21] Therefore, the combination of traditional pharmacological treatments with low-cost adjunct therapies may allow for better management of asthma. Although the treatment of asthma/EIB mainly encompasses pharmacological intervention, there is now evidence that non-pharmacological interventions may also play an important role in modifying the severity of asthma and EIB.[19,20] A promising approach to managing these conditions is IMT, which may be an effective method for off-setting the lung hyperinflation, and increased dyspnea and medication use that is common in individuals with asthma and EIB. This may be an effective means of modifying the severity of asthma and EIB in conjunction with traditional pharmacological treatments. It is important to note however, that IMT does not impact the inflammatory, hyperventilation, and airway cooling cascades, rather it is aimed at improving the strength and endurance of the inspiratory muscles and improving respiratory muscle function.

Studies were identified by searching the following electronic databases: PubMed and Google Scholar. The keywords: 'IMT' and 'respiratory muscle training' were combined with 'asthma' or 'exercise-induced bronchoconstriction'. Studies were excluded if subject populations had chronic or neuromuscular disease, or if IMT was coupled with supplementary ventilatory muscle strengthening exercises. Whereas a previous review [16] referenced only those studies that used a randomized control design, the current review also included those studies that balanced groups for sex, age, and/or pulmonary function.

IMT

IMT is a technique aimed at increasing the strength or endurance of the diaphragm and accessory muscles activated during inspiration.[22] Since dynamic hyperinflation of the lung increases inspiratory muscle work, strengthening the inspiratory muscles may reduce the intensity of dyspnea in asthmatics. This is likely a result of the increase in inspiratory muscle strength resulting from IMT, which allows for the generation of a given pressure with less respiratory motor drive. [23] Similar to training in any peripheral skeletal muscle group, the training stimulus imposed on the inspiratory muscles by IMT must be adequate to induce structural and biochemical adaptations within the inspiratory muscles.[24] The specific loading protocols for IMT, as a potential adjunct to managing asthma, are varied and are comprised of three distinct categories: flow-resistive loading, pressure threshold loading, and normocapnic hyperpnea.

Flow-resistive loading consists of a protocol which requires an individual to breathe through a device with a variable-diameter orifice which increases the inspiratory pressure required to generate a given airflow.[16] This is typically performed in a laboratory with an inspiratory-resistance training device several times a week.[25] While specific protocols are varied, an archetypal example involves three training sessions per week, which begin with three maximal inspiratory maneuvers from residual lung volume to total lung capacity against an inspiratory resistance. For example, a commonly

used flow-resistive device contains a fixed leak via a 2-mm diameter orifice, which sets a maximum flow during the inspiratory effort proportional to the pressure achieved.[25,26] These maneuvers are recorded on a computer screen and the area under the curve is calculated. This may be termed either the area under the curve or sustained maximal inspiratory pressure (SMIP). The best of the three maneuvers (i.e. SMIP) is selected and used to create a training template. Computer software interfaced with the training device then calculates a curve referring to 80% of the SMIP for training, and subjects are required to match or exceed the training template during the training session. While some protocols simply require subjects to reproduce the training template for a fixed number of repetitions,[27] others utilize a progressively increasing work–rest ratio.[26,28,29] With a progressive work–rest ratio protocol, subjects complete six inspirations followed by a 1-min rest period. After completing these six breaths, the rest period is decreased to 45-s for the next six breaths, then 30-, 15-, 10-, and finally 5-s every six breaths. Subjects cease training if they fail to achieve at least 90% of the training template, or if they complete all 36 breaths. A typical control group will perform the same training, except with the resistance set to 30% SMIP, rather than 80% SMIP.

Pressure-threshold-loading consists of breathing through a device with a one-way valve that remains closed until a pre-determined amount of inspiratory pressure is generated, whereupon the valve opens and airflow is allowed.[16] As with flow-resistive loading, protocols vary significantly. A representative protocol, however, involves training for 30 breaths twice daily set to 50% of maximal inspiratory mouth pressure (MIP).[24,30–33] This training is conducted for 6 weeks with portable hand-held devices, which subjects may take with them, thus eliminating the need to regularly visit the laboratory for training during the intervention period. A typical control group for this type of training will perform sham IMT at the same frequency and duration with the resistance set to 15% of MIP instead of 50% MIP.[30,32]

Finally, normocapnic hyperpnea consists of a volume loading protocol, rather than a resistive protocol. With this intervention, individuals are asked to maintain a high level of minute ventilation relative to their maximum voluntary ventilation with rebreathing to stabilize carbon dioxide levels.[16] A typical loading protocol for volitional normocapnic hyperpnea involves 20 training sessions lasting 30 min each, with 1 day of rest following two consecutive days of training.[34–40] During these training sessions, subjects perform voluntary normocapnic hyperpnea with a duty cycle (ratio of time of inspiration to total breath time) of 0.5 and a specific target tidal volume (V_T) and breathing frequency (f_b). Minute ventilation is initially set at 60% of the subject's maximal voluntary ventilation, with V_T set at 50–60% of vital capacity and f_b adjusted accordingly. After 25 min of training, subjects are asked whether they felt they would be exhausted after 30 min of training. If not, they are instructed to increase f_b by 5 breaths·min⁻¹ for the last 5 min of training. If subjects increase f_b during a session, the subsequent training session starts with an f_b of 2 breaths·min⁻¹ higher than the f_b of the previous session. Otherwise, the subsequent training session only increases the f_b by 1 breaths·min⁻¹. If after 25 min, subjects feel they are unable

to continue for another 5 min at the same target f_b , they are allowed to decrease f_b by 5 breaths·min⁻¹. If this is the case, the subsequent training session begins with identical settings as the previous session.

Several mechanisms could account for the observed increases in strength and endurance of the inspiratory muscles.[22] IMT has been shown to promote hypertrophy of the diaphragm and external intercostal muscles,[16] allowing them to produce more force for a given level of respiratory muscle drive. Specifically, IMT has been shown, using both human and animal models, to increase diaphragm thickness [40–43] and the proportion of type II muscle fibers in the external intercostal muscles,[44] which are accessory muscles of inspiration. Increases in muscle fiber cross-sectional area are generally associated with increased muscle strength.[45,46] Furthermore, an increase in GLUT-4 membrane proteins and enzymes crucial to oxidative phosphorylation, have been shown to occur with IMT in the sheep diaphragm, describing, in part, the increase in respiratory muscle endurance performance observed with IMT.[47–49]

Since the aforementioned specific loading protocols for IMT each vary significantly from one another, it is reasonable to postulate that they may not produce uniform results when utilized as a management strategy for asthma control. Despite the wide variation, these typical protocols have been developed through an iterative process and have been shown to be effective in enhancing the strength and endurance of the respiratory muscles. Furthermore, the complex nature of asthma and EIB, combined with the heterogeneity in their pathogenesis and varying levels of severity, may make assessing the efficacy of IMT as an asthma management strategy challenging. To date, there have been only a limited number of investigations examining the impact of IMT on asthma and EIB.

IMT and asthma

As stated above, training of the respiratory muscles must be a significant stress in order to induce adaptation. Therefore, the frequency, intensity, volume, duration, and mode of the training are important factors to consider. Moreover, IMT likely does not impact some of the underlying causes of asthma, such as airway cooling and inflammation, rather it could reduce functional limitations associated with asthma, such as hyperinflation and dyspnea. Table 1 presents the relevant studies examining IMT and its impact on outcomes related to asthma. Differences in study population, training mode, intervention duration, and specific loading protocols are summarized in the table. The discrepancies between studies make navigating the equivalencies difficult, and have led some to label the efficacy of IMT as yet unresolved.[16,50] Ritz and Roth concluded that the benefits of IMT lack clarity,[50] while Silva et al. determined that evidence either to support or refute IMT as a technique for treatment of asthma is incomplete.[16] One possible explanation for these assessments is that the variation in methodologies and study populations may confound any conclusions that could be reached regarding the efficacy of IMT for the management of asthma. Indeed, methodological discrepancies have been previously examined

Table 1. Summary of select studies examining IMT and respiratory measures in asthmatics.

Study	Reference	Population	Intervention	IMT outcomes
Turner et al. (matched for MIP)	[33]	Mild-to-moderate asthma, FEV _{1.0} >70% predicted <i>n</i> = 15, 24 ± 1 years, eight females/seven males, sham group included	Pressure threshold: 50% MIP 30 breaths, 2× day, 6 weeks	↑:MIP, Tlim; less ↓ in MIP during exercise ↓:Exertional dyspnea No Δ: FVC, FEV _{1.0}
McConnell et al. (FVC/sex matched)	[51]	Mild-to-moderate asthma, no FEV _{1.0} data given <i>n</i> = 18, no age reported, 8 females/10 males, sham group	Pressure threshold: 50% MIP 30 breaths, 2× day, 3 weeks	↑:MIP, PEF, motivation to exercise ↓:Exertional dyspnea No Δ: FVC, FEV _{1.0}
Weiner et al. (‘high’ β ₂ -agonist use) (randomized control)	[52]	Mild, stable asthma, FEV _{1.0} >80% predicted <i>n</i> = 76, 36.3 ± 3 years, 34 females/42 males, sham group	Pressure threshold: ≤60% MIP 0.5 h, 6× week, 3 months	↑:MIP, ease breathing against resistance ↓:β ₂ agonist usage
Sampaio et al. (randomized control)	[53]	Clinical diagnosis of asthma by pneumologist <i>n</i> = 30, 22.6 ± 3 years, 24 females/6 males, non-intervention group	Flow resistive, 40% of daily MIP 10 min, 3× week, 6 weeks	↑:MIP, MEP
Weiner et al. (randomized control)	[54]	Mild-to-moderate asthma, FEV _{1.0} >60% predicted <i>n</i> = 22, 36.2 ± 3.1 years, females only, sham group	Pressure threshold: ≤60% MIP 0.5 h, 6× week, 20 weeks	↑:MIP ↓:Dyspnea, β ₂ agonist usage No Δ: FEV _{1.0}
Weiner et al. (randomized control)	[55]	Moderate-to-severe asthma, FEV _{1.0} ~57% predicted <i>n</i> = 30, 40.5 ± 6.7 years, 12 females/18 males, sham group	Pressure threshold: ≤80% MIP 0.5 h, 5× week, 6 months	↑:MIP, FEV _{1.0} , FVC, respiratory endurance ↓:Asthma symptoms
Weiner et al. (randomized control)	[56]	Mild-to-moderate asthma, FEV _{1.0} >60% predicted <i>n</i> = 30, 38.4 ± 4.9 years, 13 females/17 males, sham group	Pressure threshold: ≤60% MIP 0.5 h, 6× week, 16–25 weeks	↑:MIP ↓:Dyspnea, β ₂ agonist usage No Δ: FEV _{1.0} , FVC
Lima et al. (randomized control)	[57]	Asthma severity not reported <i>n</i> = 50, 9.7 ± 1.2 years, 34 females/16 males Non-intervention group	Breath exercises and pressure threshold: 40% MIP, 50 min, 2× week, 7 weeks	↑:MIP, MEP, PEF ↓:Asthma symptoms
Shaw and Shaw ^a (age/sex matched)	[58]	Mod-persistent asthma, FEV ~2.85 L (no % given) <i>n</i> = 66, 21.9 ± 3.9 years, female and male, non-intervention group	Flow resistive, varying inspir: expir ratio 9 sets, 5–20 reps, 3× week, 8 weeks	↑:FEV _{1.0} , FVC, PEF, IVC No Δ: MVV, posture
Shaw and Shaw ^a (age/sex matched)	[59]	Mod-persistent asthma, FEV _{1.0} , FVC, or PEF = 60–80% <i>n</i> = 88, 21.9 ± 4 years, 32 females/56 males, non- intervention group	Flow resistive, varying inspir: expir ratio 9 sets, 5–20 reps, 3× week, 8 weeks	↑:FEV _{1.0} , FVC, PEF ↓:FEV _{1.0} /FVC; Improved chest dimensions

FEV_{1.0}, forced expiratory volume in 1 s; MIP, maximal inspiratory pressure; BMI, body mass index (kg/m²); m, meters; h, hour; Tlim, time limit of exercise tolerance; MEP, maximal expiratory pressure; FVC, forced vital capacity; PEF, peak expiratory flow rate; IVC, inspiratory vital capacity; MVV, maximal voluntary ventilation; *n*, number of participants in IMT group.

^aNo external IMT device. Resistive flow performed with 10-cm long and 10-cm diameter tube.

by Silva et al. [16], who discussed differences in control characteristics, aims, outcomes, biases, and study design. The authors identified a paucity in the number of randomized control intervention studies.[16] These considerations, in combination with the small number of studies, make interpretation of data difficult. Therefore, data from these studies [16] should be interpreted in light of these inconsistencies, and standardized approaches to IMT should be encouraged.

Studies measuring static and dynamic lung volumes in asthmatics pre- and post-IMT have demonstrated mixed results, as some studies have shown increases in forced expiratory volume in 1.0 s (FEV_{1.0}),[55,58,59] forced vital capacity (FVC),[55,58,59] and peak expiratory flow,[57–59] while others observed no changes in FEV_{1.0} or FVC.[33,51,54,56] These discrepancies may depend on duration and type of IMT, as well as participant population.

However, despite the mixed results regarding lung volume data and lack of uniformity in study design, examination of other outcomes may still prove valuable as common themes do arise. In fact, the studies examining the impact of IMT on asthma almost uniformly demonstrated an improvement in inspiratory muscle strength (as assessed by MIP) and endurance,[33,51–57] decreased dyspnea at rest [54,56] and exercise,[33,51] decreased β₂-agonist usage,[52,54,56] as well as

decreased asthma symptoms.[55,57] The findings presented in Table 1 suggest that increases in inspiratory muscle strength may mediate the reduction in dyspnea and asthma symptoms. Improvements in inspiratory muscle performance are likely the result of an increase in the cross-sectional area of the inspiratory muscles [42] as previously discussed, as well as an improvement in inspiratory muscle economy.[60] The increase in inspiratory muscle strength may partially alleviate the increased effort of respiration associated with lung hyperinflation, thus reducing the perception of dyspnea and the need for β₂-agonist usage. Figure 1 displays a proposed schematic of the mechanisms by which IMT may impact asthma and exercise-induced bronchoconstriction.

These improvements in inspiratory muscle strength, dyspnea, medication use, and asthma symptoms were observed across a wide spectrum of populations with varying degrees of asthma severity.[33,51–58] Moreover, the interventions themselves were also varied. It therefore appears that, despite the fact that inspiratory muscles could adapt differently depending on the techniques and type of demands placed upon them, the variability in methods may not be important as long as the stress on the respiratory muscle is sufficient. This supports the efficacy of IMT as a management strategy for asthma that could reduce the severity of the disease and be a

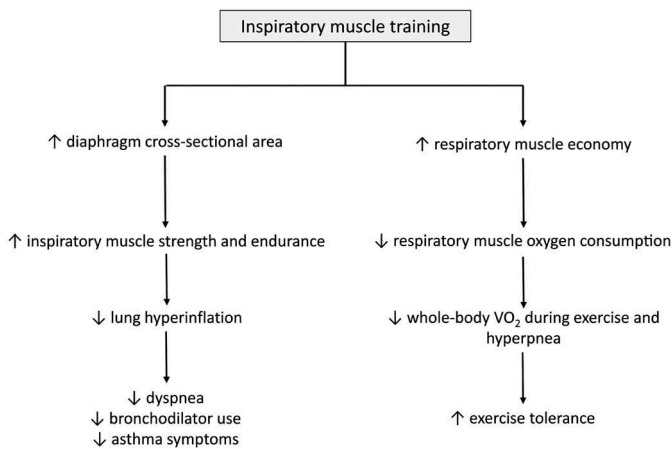


Figure 1. Proposed schematic depicting how IMT may impact asthma and exercise-induced bronchoconstriction.

complementary strategy to traditional treatments. Therefore, a simple but effective protocol for applying IMT as a management strategy for asthma is required. High-quality data from randomized, placebo-controlled clinical trials could aid greatly in establishing such a standardized protocol. This would be in the best interest of the patient since excessively long or complicated interventions may discourage patients from undertaking such training, as well as hinder compliance to IMT.

IMT and asthma: impact on exercise

Asthmatics typically exhibit a reduction in exercise capacity, which may be a consequence of expiratory flow limitation and dynamic lung hyperinflation.[61] Importantly, none of these factors are associated with the occurrence of EIB in these asthmatic patients.[61] Therefore, it is likely that stable asthma itself is related to the genesis of expiratory flow limitation, dynamic hyperinflation, and the consequent reduction in exercise capacity.

Expiratory flow limitation observed in highly trained athletes is typically reflective of ventilatory demands, which are high enough to approach or exceed their ventilatory capacity.[62–64] In contrast, however, it is likely that the pathological occurrence of expiratory flow limitation in asthmatics reduces the ventilatory capacity of these subjects, and the ‘abnormal’ ventilatory response to exercise in asthmatics occurs as a result of the acute requirement for airflow regardless of administration of β_2 -agonists.[65] Reductions in ventilatory capacity may impact the ability of the respiratory system to maintain arterial blood gas concentrations, and ultimately compromise exercise tolerance. In addition to the reductions in exercise capacity related to expiratory flow limitation, exercise capacity may be further compromised by the increases in elastic work of breathing and elevated O_2 cost of ventilation associated with dynamic hyperinflation.[66]

Increased elastic work of breathing and elevated oxygen cost of ventilation, which have been observed with dynamic hyperinflation,[66] may contribute to respiratory muscle

fatigue. Consequently, there may be an increase in the accumulation of vasoactive metabolites, which activate type IV phrenic afferent fibers.[67] This increases sympathetic vasoconstrictor activity, and has been termed the respiratory metaboreflex.[68–70] This reflex is thought to reduce limb perfusion [68,71–73] and has been shown to compromise exercise performance.[74,75] However, the link between asthma and respiratory muscle fatigue is not well described. It is possible that asthmatics do not reach an exercise capacity where limb perfusion is limited and thoracic pressure is so increased that the blood flow to the diaphragm is restricted enough to activate the respiratory metaboreflex. Further, some evidence suggests that dynamic hyperinflation may not be associated with large changes in inspiratory endurance performance,[76] and that asthma may in fact increase inspiratory and expiratory muscle endurance in asthmatic subjects.[77] Therefore, it is important to note that while the occurrence of respiratory muscle fatigue in asthma is still contentious, training the respiratory muscles may have the potential to alleviate some of the deleterious effects of dynamic hyperinflation on exercise performance. In fact, IMT has been shown to attenuate the respiratory muscle metaboreflex in healthy subjects,[78] likely by reducing the activity of chemosensitive afferents.

Surprisingly, to date, only one study has examined how IMT impacts exercise tolerance in asthmatic individuals. In patients with mild-to-moderate asthma, 6 weeks of pressure-threshold IMT improved exercise tolerance and reduced the perception of dyspnea during cycling exercise at $\sim 70\%$ $\dot{V}O_{2max}$ to exhaustion.[33] The authors found that patients who undertook 6 weeks of pressure-threshold IMT reduced the extent of hyperinflation that occurred during exercise, and may have reduced the elastic work of breathing and associated oxygen cost of ventilation.[33] Furthermore, these subjects also demonstrated a reduction in the whole-body oxygen consumption following 6 weeks of pressure-threshold IMT, which may be due in part to improved respiratory muscle economy.[33] In fact, more recent data confirms that 6 weeks of pressure threshold IMT does indeed reduce the oxygen cost of ventilation, with no change in the oxygen cost of ventilation in a sham-controlled group, suggesting that the reduction in whole-body oxygen consumption may be due in part to a lower respiratory metabolic demand and/or reduction in neuro-motor drive to the respiratory musculature.[60] Reductions in the perception of dyspnea may also be important, as recent evidence suggests that muscle fatigue (in the legs) could be linked to the perception of dyspnea [79] Interestingly, despite increases in inspiratory muscle strength, FVC and $FEV_{1.0}$ were unchanged following 6 weeks of pressure-threshold IMT. This was in contrast to other findings that 3–6 months of IMT increased FVC and $FEV_{1.0}$ in individuals with moderate to severe asthma.[55] The disparity in these findings may be due in part to differences in population (mild-to-moderate vs. moderate-to-severe asthma), pulmonary system changes with age (24 vs. 40 years), and/or intervention duration (6 weeks vs. 3–6 months).

IMT and exercise-induced bronchoconstriction

Similar to stable asthma, EIB also results in constrained airflow, and may increase respiratory muscle work, promote ventilation-perfusion mismatches, and increased perception of dyspnea and effort.[80] The specific impact of EIB on exercise performance was recently discussed in a systematic review.[80] The authors reported that while it is reasonable to conclude that these factors could compromise exercise capacity, presently there is insufficient evidence to definitively describe the impact of EIB on exercise performance.[80] In light of this, it is not surprising that presently there are no data available to describe the impact of IMT on exercise tolerance in individuals with EIB. Accordingly, it is first necessary to better describe the specific impacts of EIB on exercise capacity, before asking if IMT can play a role in altering exercise performance in subjects with EIB. Subsequently, if strong evidence comes to light linking EIB to compromised exercise capacity, examining whether IMT could ameliorate those detriments would be warranted.

The lack of studies examining the impact of IMT on exercise capacity in asthmatics, and those with EIB, represents a fertile area for future investigations. Specifically, future work should aim to develop a standardized training regimen based on comparisons of the varying IMT protocols, and to identify whether sub-populations of asthmatics, and those with EIB, respond differently to IMT. Consequently, a guide of best practices, which can be recommended to practitioners and patients, could be developed.

Conclusion

In summary, an examination of the current evidence on the application of IMT as a complementary management strategy in conjunction with traditional treatments for asthma suggests that, despite disparities in IMT protocols and study populations, there is emerging evidence suggesting that IMT may be beneficial for reducing both resting and exertional dyspnea, as well as reducing medication use. These positive changes have been linked to increases in inspiratory muscle strength and endurance. However, the limited number of studies and incongruent methodologies do warrant further investigation to better develop protocols for maximum efficacy of IMT for alleviating symptoms of asthma. Furthermore, the specific impact of IMT on exercise tolerance in individuals with asthma and EIB requires additional investigation. Future investigations should also aim to discover whether IMT can improve EIB as well as asthma. It is recommended that a standard treatment protocol be developed and tested in a randomized, placebo-controlled clinical trial with a large and representative sample in order to develop more concrete guidelines.

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