Northumbria Research Link

Citation: Armstrong, Matthew and Vogiatzis, Ioannis (2019) Personalized exercise training in chronic lung diseases. Respirology, 24 (9). pp. 854-862. ISSN 1323-7799

Published by: Wiley-Blackwell

URL: https://doi.org/10.1111/resp.13639 <https://doi.org/10.1111/resp.13639>

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/id/eprint/39893/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

Northumbria University NEWCASTLE

UniversityLibrary

Title: Rehabilitation in chronic respiratory diseases: Personalised exercise training in chronic lung diseases.

Author(s)' full name(s) and degree(s): Matthew Armstrong B.Sc., M.Sc. and Ioannis Vogiatzis M.Sc. Ph.D. FERS

Author(s)' affiliation(s): Department of Sport, Exercise and Rehabilitation, School of Health & Life Sciences, Northumbria University Newcastle

Corresponding author full contact details:

Name: Ioannis Vogiatzis

Address: Northumbria University, School of Health & Life Sciences

Postcode: NE1 8ST

City: Newcastle upon Tyne

Country: United Kingdom

Email: Ioannis.vogiatzis@northumbria.ac.uk

Twitter handle (optional-): @Mattarmstrong95

55Authors' contributing statement:

Short title: *Exercise therapy in chronic lung disease*

Keywords: *Exercise, Chronic Obstructive Pulmonary Disease, Interstitial Lung Disease, Asthma, Pulmonary Arterial Hypertension.*

Abbreviations:

COPD: Chronic Obstructive Pulmonary Disease;

ILD: Interstitial Lung Disease;

PAH: Pulmonary Arterial Hypertension.

QOL: Quality of life

CRDs: Chronic Respiratory Disease’s

CFRD: Cystic Fibrosis Related Diabetes

6MWT: 6-min walk test

CF: Cystic Fibrosis

ABSTRACT:

Chronic respiratory diseases (CRDs) are characterised by exertional dyspnea, exercise limitation and reduced health-related quality of life (Qol). Exercise training is essential for improving symptoms, physical function and QoL. Current research available supports the effectiveness of exercise training in patients with chronic obstructive pulmonary disease (COPD), cystic fibrosis and interstitial lung disease (ILD). However, recent studies have shown safety and effectiveness of exercise training in patients with pulmonary arterial hypertension (PAH) and asthma. Despite the lack of clinical guidelines for exercise training in PAH, a recent Cochrane review has shown improvements in functional capacity and effective reductions in mean pulmonary arterial pressure. In the other CRDs, a number of Cochrane reviews supported by numerous randomised controlled trials have been published outlining the benefits of different types of exercise training.

The aim of this review is to establish the principles and modalities of personalised exercise training and the effects of exercise training across a number of CRDs. In addition, this review provides information on personalised exercise prescription for CRD patients with comorbidities.

Introduction

Chronic respiratory diseases (CRDs) are associated with abnormalities in the airways and other structures of the lung. The most common CRDs are chronic obstructive pulmonary disease (COPD), asthma, cystic fibrosis (CF), interstitial lung disease (ILD) and pulmonary arterial hypertension (PAH) [1, 2]. Major risk factors include tobacco smoke, air pollution, occupational chemicals and dusts, and frequent lower respiratory tract infections. CRDs are not curable, however, various forms of treatment can benefit symptoms and increase the quality of life for people with these diseases [3].

In patients with CRDs exercise intolerance is common and refers to the inability of individuals to conduct physical activity at the same rate that would be expected of an age-matched individual with a relatively stable physical condition [4]. Regardless of the condition, this inability is commonly caused by impairment of several physiological systems, associated with the intensification of the perceptions of breathlessness. Equally important are the added effect of peripheral muscle discomfort.

The physiological mechanisms of exercise intolerance in patients with CRDs include ventilatory constraints, gas exchange inadequacy, central and peripheral hemodynamic limitations and skeletal muscle abnormalities [4].

Ventilatory constraints are caused by a disparity between reduced ventilatory capacity and increased ventilatory requirement secondary to increased metabolic demand of exercise. This leads to a reduced maximal and sustainable voluntary capacity progressively causing the inability to sufficiently increase minute ventilation relative to metabolic demands. The reduced capacity of ventilation during exercise is due to altered mechanics of breathing that affect respiratory muscle function. High inspiratory and expiratory airways resistance and/or abnormal lung compliance (increased in COPD and decreased in ILD), can significantly increase the work of breathing [5].

Gas exchange is commonly impaired in these CRD patients. Gas exchange inadequacy comprises the pulmonary vasculature and the ability of oxygen/carbon dioxide transport between the alveolar-capillary interfaces. Abnormal alveolar-capillary inequalities and impairment of diffusion leads to hypoxemia during exercise. It is therefore no surprise that many CRD patients experience arterial oxygen desaturation during exercise [6].

Central hemodynamic variables which involve the transport of oxygen are often impaired in patients with CRDs, due to the coexisting right or left ventricular dysfunction, thereby adversely affecting cardiac output, reducing oxygen delivery and accelerating the onset of metabolic acidosis. In CRDs which are characterized by pulmonary vascular abnormalities, pulmonary hypertension and right-ventricular dysfunction have marked effects on cardiovascular function. These manifestations can be further impaired by the presence of hypoxemia, elevating pulmonary vascular resistance, causing PAH [7]. A reduction in cardiac output, together with low oxygen content, reduces systemic oxygen delivery to both locomotor and respiratory muscles during exercise [8].

Both structural and metabolic abnormalities of the limb muscles can be associated with early lactic acidosis and task failure during exercise. Due to a lack of regular physical activity in these patients, the peripheral muscles manifest significant muscle weakness as well as altered fibre type distribution, with specific reference to loss of high oxidative type-I fibres. A reduction in oxidative muscle fibre–distribution reduces the oxidative potential of the muscles, making them prone to fatigue during exercise of moderate-high intensity [9].

Considering that different pathophysiological factors limit exercise tolerance across the different CRDs, a brief account of these pathophysiological factors is reported in this review article for a number of disease entities, namely COPD, CF, PAH, ILD and Asthma. To partially mitigate the aforementioned cardiovascular and cellular metabolic abnormalities, regular physical exercise training is recommended by the joint ATS and ERS statement of pulmonary rehabilitation [10].

However due to chronic lung conditions presenting various different comorbidities, the understanding that 'one size fits all' approach does not benefit every patient with CRD [2]. In fact there is evidence suggesting that an important proportion of patients does not sufficiently respond to a given training programme (non-responders) [11]. In addition, individual patient response to training is highly variable, even though published guidelines suggest that any patient with stable respiratory disease and disabling symptoms would benefit from pulmonary rehabilitation[11]. The present review article introduces the principles and different modalities of exercise training and also summarises the effects of various types of exercise training in COPD, CF, PAH, ILD and Asthma.

Principles of exercise training:

For patients suffering from CRDs, the general principles of exercise training are the same as for healthy individuals [12]. To be beneficial, training volume must be based upon an individual's specific requirements and capacities, exceeding in effort activities of daily living and progressing as physiological adaptations occur. Suitable training methods, tailored to the cardiovascular, pulmonary and peripheral muscle metabolic limitations of the individual patient, will be required to inform the programme of exercise conditioning [10, 12]. For such programmes to be effective, the implementation of the fundamental principles of exercise training into clinical practice should be followed [13]. Table 2 provides details on the principles of exercise training and how they are best implemented in different CRDs.

Types of personalised exercise training:

Endurance Training modalities:

Endurance training aims to improve cardiorespiratory fitness and condition the muscles of ambulation in order to increase exercise tolerance and reduce breathlessness and leg discomfort. In order to see improvements in exercise capacity, moderately intense continuous exercise is recommended [10]. However, patients with profound ventilatory limitation are unable to sustain such intensities for sufficiently long periods [14]. This is primarily due to the high levels of breathlessness progressively increasing, thereby compromising exercise tolerance. In these patients, high intensity interval exercise training, consisting of repeated bouts of maximal/high intensity exercise, alternating with short intervals of rest or low intensity exercise levels, constitutes a suitable alternative to continuous exercise [15]. In patients with advanced COPD, high intensity interval training has been associated with relatively lower ventilation and less dynamic hyperinflation compared to continuous exercise training. With interval exercise there is a reduction in symptoms of dyspnea and leg discomfort, thus allowing a significantly greater amount of work to be performed compared to that of continuous exercise [16].

Optimal exercise modalities for endurance training include cycling on a cycle ergometer and/or walking on a treadmill or on a flat surface [10]. The prescription of such modalities should be individualised for each patient’s chronic lung condition. Stationary cycling is commonly implemented as it provides precise implementation of training intensity and a greater load on the locomotor muscles and results in less oxygen desaturation than walking [17]. However for certain individuals walking training (treadmill or flat ground), may have more beneficial effects as it is an activity easily translated into improvements in walking capacity [18]. Alternative forms of exercise are stair climbing, stepping, Nordic walking and water-based exercise training.

One-legged cycling:

One-legged cycling constitutes an alternative modality providing an aerobic stimulus to the leg muscles without placing a high ventilatory load on the respiratory system. The ability to separate the work of leg muscles during exercise, with sufficient metabolic stimulus has resulted in a lower minute ventilation and dyspnea sensations [19]. Studies report that one-legged cycling as a method of exercise training enhances peak oxygen consumption and decreases submaximal heart rate and minute ventilation to a larger extent than commonly implemented endurance cycling [19]. These findings indicate a greater cardiovascular and/or muscular training effect which does not substantially prolong the duration of the training session, as it appears sufficient to train each leg for half of the bi-legged cycling time. However, the practicality of this modality requires modification of a typical cycle ergometer, which may complicate the process of organizing exercise sessions [20, 21].

Resistance/ Strength Training:

Resistance training involves the training of local muscle groups by the repetitive lifting or pushing of moderately heavy weights. This training modality is considered important for both healthy individuals and patients with CRDs [10, 12]. Peripheral muscle dysfunction and muscle weakness are extra pulmonary features commonly associated with a number of CRDs, to which resistance training, in part, is reported to partially reverse these features and thereby reduce the impairment in chronic disease [22]. The characteristics of the prescription of resistance training vary significantly, with a different number of repetitions, intensities and/or the method of strength training reported across the literature [23]. The ATS/ERS guidelines for pulmonary rehabilitation suggest performing two to four sets of six to 12 repetitions, with intensities ranging from 50%-85% of one repetition maximum 2-3 times per week [10].

Upper limb Training:

Patients with CRDs often have difficulty undertaking activities of daily living involving the upper extremities. Therefore upper limb training is commonly integrated into exercise sessions, including aerobic regimens (arm cycle ergometer) and resistance (free weights and elastic bands) regimens. When implementing these exercise modalities, targeted muscles include biceps, triceps, deltoids, latissimus dorsi and the pectorals. A recently published Cochrane review gathering the previous literature available on upper limb training has found benefits of this training modality on symptoms of dyspnea and health related quality of life [24].

Flexibility and Stretching exercises:

Flexibility exercises are a common element of many programmes, performed through both upper and lower body exercises [2]. This includes stretching of major muscle groups such as the calves, hamstrings, quadriceps and biceps, as well as motion exercises for the neck, shoulders and trunk [2]. In patients with CRDs, postural impairment can cause a decline in pulmonary function leading to an increased work of breathing. It can also cause abnormalities associated with body mechanics (i.e. back pain), which alters breathing mechanics. To date, clinical trials demonstrating the effectiveness of flexibility training are scarce. It is suggested that improved thoracic mobility and posture in CRD patients may increase vital capacity [2].

Water-based Rehabilitation:

Implementation of water-based exercise as an option for rehabilitation has been void for many years due to thoughts that immersion in water will increase cardiac and respiratory work due to increased chest wall pressures [25]. However, emerging evidence suggests that water-based training sessions can be performed safely even in those patients with a severe disease [26-28].

Water-based exercise engages the lower extremities with minimal impact on the body [29]. Water-based exercises allow patients to gain the benefits of land-based training, without the overt stress or strain on arthritic joints, due to the buoyancy of water facilitating balance and gait [30]. Evidence is available surrounding aquatic exercise training as a potential means of therapeutic training in COPD patients, including a recently published Cochrane review [27, 28, 31-33]. Exercise capacity and quality of life within these patients has been reported, with the benefits comparable to those of land-based exercise [33]. In patients with COPD, water-based exercise training can provide additional beneficial physiological effects caused by hydrostatic pressure. The hydrostatic pressure exerted during immersion in water can facilitate expiration and thereby reduce the degree of air trapping during exercise [34] . Partial immersion in water has been shown to decrease functional residual capacity by about 54% and expiratory reserve volume by 75% in people with COPD [33].

Tai Chi:

Tai Chi, originating from China, is a systematic callisthenic exercise, involving a series of slow, rhythmic circular motions, highlighting the use of ‘mind’ or concentration to aid the control of breathing and circular body movement [35] [36]. Studies have found Tai Chi obtains improved pulmonary function and exercise capacity in COPD patients compared to usual care [37] [38]. Oxygen consumption during Tai Chi was 63% of peak maximal oxygen consumption and 52% of VO_2 reserve, providing evidence as an exercise of moderate intensity in chronic disease. Specifically, Leung and colleagues found a short form sun-style Tai Chi more effective than usual medical care in improving aspects of exercise tolerance, balance, physical performance and quality of life [38]. Different forms of Tai Chi are available and studies within chronic disease have adopted different approaches, meaning many styles or forms of this exercise modality could be implemented for CRD patients [38].

Yoga:

Yoga is a low-impact complementary therapy which can be used in patients with chronic diseases'. Mainly consisting of movement-coordinated breathing, it is known to improve exercise capacity and quality of life. Many health care professionals see it as a useful adjunct to rehabilitation programs for patients with chronic diseases including; heart disease, stroke and COPD [39]. A systematic review is available assessing the effects of yoga training on the management of COPD patients. Five included studies reported significant improvements in FEV_1 (mean difference: 123.57 mL) and 6MWT distance (mean difference: 38.84) [40].

Whole body vibration training:

Whole body vibration training involves an individual standing on a vibrating platform that produces sinusoidal oscillations. These vibrations at a high intensity induce muscle contractions from the leg through to the trunk. Individuals have no direct influence on muscle activity, removing the voluntary muscle contractions which make up common resistance activities. Instead muscle contractions are caused by stretch reflexes of the muscle fibres. The majority of previous research has concentrated on studies within COPD patients, with a systematic review available [41]. This review article consisted of six studies focusing on very different aspects of whole body vibration training. All studies reported superior benefits on exercise capacity (measured by the 6MWT), thereby providing evidence that whole body vibration training is effective in improving functional capacity in COPD patients [41].

Personalised exercise training in specific CRDs:

Exercise training as an intervention to promote functional independence in CRDs, especially in COPD, has been extensively researched to date. Several studies of supervised aerobic exercise training have confirmed that patients with a wide range of severity of CRD can improve exercise capacity, with improved cardiovascular physiology and skeletal muscle strength and endurance [42]. A number of Cochrane reviews have provided evidence of the effects of exercise training on CRDs, including COPD [43], CF [44], PAH [45], ILD [46] and asthma [47].

COPD

Due to a large pathophysiological heterogeneity of COPD (i.e. emphysema and/or chronic bronchitis) and the added comorbidities associated with this CRD, the fundamental elements of impaired exercise capacity in these patients may vary [48, 49]. Intolerable exertional symptoms, including, increased breathlessness and/or leg discomfort limit exercise tolerance. The physiological limitations are multifactorial, involving ventilatory, pulmonary gas exchange, hemodynamic and peripheral muscle abnormalities, all of which prevent adequate oxygen transfer from the atmosphere to its utilization within the mitochondria [50-52].

The standard recommendations for exercise training include moderate/high intensity aerobic endurance exercise in the form of cycling or walking and upper and lower extremity resistance training [10]. For patients with a greater disease severity, high intensity interval training is an alternative due to the ability to perform high intensities of exercise for short periods of time followed by sufficient rest periods [10]. The benefits of exercise training in COPD patients has been documented in a number of systematic review meta-analyses and in two Cochrane reviews [43, 53]. Data available from those reviews have accepted that exercise training is an essential strategy in the ongoing management of COPD. Specifically, 38 studies within the most recent Cochrane review reported an improvement in 6MWT distance of 44 metres, above the minimum clinically important difference of 30 metres [43]. A further 16 studies used an incremental cycle ergometer test to measure maximal exercise capacity, reporting an increase in mean peak work rate of 6.8 Watts among those patients allocated to pulmonary rehabilitation [43]. These marked improvements in exercise tolerance and functional capacity have been associated with reductions in dynamic hyperinflation and dyspnea sensations during exercise. Exercise also increases muscle function, delaying the onset of peripheral muscle fatigue and resulting in increased exercise tolerance (table 1).

Cystic Fibrosis

Three major factors limit exercise in CF patients, namely pulmonary, metabolic and cardiovascular. Impaired lung function and obstructive lung disease alter the ventilatory responses to exercise, with the majority of patients presenting an FEV_1 less than 50% of predicted values [54]. Significant digestive system impairment leads to low body mass and in particular, less skeletal muscle mass. Given the relationship between muscle size and force output, a lack of lean muscle mass and impaired metabolic function has major associations with impaired exercise response [55]. In addition, it is common to see elevated heart rates at rest in CF patients. Higher resting heart rates limit the reserve of cardiac output to increase during exercise, leading to premature cessation of higher intensity activities [56]. Exercise training has an established role in general disease management [57]. A Cochrane review (total number of 15 studies with 487 participants) has examined the effects of different types of training in cystic fibrosis (aerobic, anaerobic and a combination of both types) [44]. The implementation of aerobic and/or anaerobic physical exercise training was found to have positive effects on exercise capacity (peak oxygen uptake), pulmonary function and health related quality of life [44] (table 1).Exercise training in this patient population requires a program length of at least six weeks for an initially tolerable duration, but progressing to at least 20-30 minutes at an intensity of 55-65% maximum heart rate, for three to five days per week [10, 44] (table 1).

The beneficial effects of exercise are associated with an increase in sputum clearance through a combination of hyperventilation, mechanical vibration, coughing and changes in sputum rheology leading to facilitated and increased sputum expectoration [58]. This indicates that exercise may play a potential role in maintaining bronchial hygiene, a crucial aspect of cystic fibrosis care [58].

Pulmonary Arterial Hypertension

The major limitations to exercise in PAH are breathlessness and leg discomfort. In these patients, cardiac output is lower than healthy age-matched individuals and the relationship between cardiac output and oxygen uptake is reduced. This abnormality has been attributed to increased right ventricular afterload reducing stroke volume and hence cardiac output [59]. Consequently, oxygen delivery to the peripheral muscles is reduced, accelerating the onset of muscle fatigue and leg discomfort, alongside increased ventilatory requirement and dyspnea sensation [60].

The mechanisms by which exercise training improves exercise capacity in patients with PAH is less clear than other CRDs. This was due to exercise training being actively discouraged in people with PAH because it would worsen symptoms and negatively affect cardiac function [45]. A Cochrane review has recently been published considering the effects of exercise-based rehabilitation for PAH patients [45]. The review examined five studies, all reporting a large clinically significant improvement in exercise capacity, measured using both the 6MWT and incremental cardiopulmonary exercise testing. The mean increase in the 6MWT distance of 60.1 metres was well in excess of the minimal important difference of 30 metres. Similarly, increases in peak power of 16.4W were reported. To date there is no minimal important difference for cardiopulmonary exercise testing-derived measures of exercise capacity in PAH, however the improvements in peak power reported are in excess of the minimal important difference reported for COPD of 5 to 10W [61].

Limited knowledge is available of the possible mechanisms of improved exercise capacity following exercise training (table 1). A potential mechanism involved an improvement in pulmonary haemodynamic with a lower mean pulmonary artery pressure and an improvement in submaximal and maximal cardiac output. Authors hypothesised that exercise training may improve right ventricular function [62]. Combined with these central changes, there is evidence that exercise training improves skeletal muscle oxidative capacity and capillary density, similar to the improvements found in other CRD populations [10].

Interstitial Lung Diseases

Patients with ILD during exercise exhibit a rapid, shallow breathing pattern. This causes a small tidal volume and increased respiratory rate, which increases the work of breathing. In addition to the inefficient respiratory mechanics, impairment of gas exchange and circulatory limitation play an important role in exercise limitation [6]. Peak VO_2 measured during cardiopulmonary exercise tests was correlated better with measures of central hemodynamic impairment (measures of heart rate, stroke volume and cardiac output), than with other limitations, providing an understanding that circulatory impairment was the primary limitation to exercise. Circulatory limitations are a result of pulmonary capillary destruction and hypoxic pulmonary vasoconstriction, leading to cardiac dysfunction and potential pulmonary hypertension. Destruction of pulmonary capillary beds and/or thickening of the alveolar-capillary membrane is the main cause of impaired gas exchange in ILD causing a mismatch between ventilation-perfusion [4].

The implementation of exercise training was associated with short-term benefits in patients with ILD [10] (table 1). Training strategies have used aerobic exercise alone or a combination of aerobic and resistance training, however the most effective exercise training strategy for patients has yet to be confirmed. Both exercise durations and frequencies been documented, with longer programmes and more frequent sessions appearing to provide greater benefits [10] (table 1).

The most recent Cochrane review identified nine studies providing improvement in both measures of the 6MWT and incremental cycle ergometer test [46]. Quality of life and sensation of breathlessness were also significantly improved immediately following pulmonary rehabilitation. Mean improvement in the 6MWT following pulmonary rehabilitation was 44.3 metres, which exceeds the minimal important difference for the 6MWT distance among patients with interstitial lung diseases, ranging from 30 to 33 metres [63]. Furthermore, a recent randomised control trial not included in the Cochrane review, concluded that exercise training can be effective across the range of ILD’s, in terms of improving the 6MWT distance (>25m) and health-related quality of life [64]. Larger improvements were reported in 6MWT, CRDQ, SGRQ and dyspnea in asbestosis and Interstitial Pulmonary Fibrosis.

AsthmaAsthma is a common long-term inflammatory disease of the airways of the lungs. It is characterized by variable and recurring symptoms, reversible airflow obstruction, and easily triggered bronchospasms. Symptoms include episodes of wheezing, coughing, chest tightness, and shortness of breath.

During exercise, these symptoms can be provoked or worsened, a contributing factor towards reduced participation in exercise, leading to deconditioning and lower exercise tolerance [65].

The overall impact of exercise training on functional capacity and symptoms of asthma is scarce. The current global strategy for asthma management and prevention has given brief guidelines around physical activity, suggesting that regular physical activity improves cardiopulmonary fitness, however no evidence towards specific exercise training has been documented [65]. A single Cochrane review is available examining exercise training in these patients [47]. Included studies have suggested that exercise improved asthma-related symptoms and cardiopulmonary fitness. Studies have reported that an increase in physical activity through exercise training may lower ventilatory requirement of mild and moderate exercise thereby reducing the likelihood of provoking exercise-induced asthma. In addition, a 12-week aerobic training program demonstrated reductions in bronchial hyperresponsiveness and serum proinflammatory cytokines associated with improvements in quality of life and asthma exacerbations in adults with moderate to severe persistent asthma [66].

Exercise training in patients with comorbidities:

People with COPD often have comorbidities that markedly affect functional capacity [67]. These include chronic heart disease, metabolic syndrome, musculoskeletal or neurological comorbidities and many types of cancer. Regular exercise and physical activity are commonly recommended to benefit patients with many chronic morbidities, with aerobic and resistance training modalities suggested as evidence-based treatment in patients with heart failure and/or type 2 diabetes [3]. Patients with cardiovascular disease should begin supervised exercise training with continuous ECG monitoring and decrease to intermittent or no ECG monitoring after 6-12 sessions. For patients with certain musculoskeletal comorbidities, commonly implemented land-based exercise training may cause adverse events. These patients may benefit from water-based exercise training described earlier .

Over the last two decades, an increased prevalence of obesity as a major comorbidity in patients with asthma has become apparent. A recent study by Freitas and colleagues examined the effect of an exercise training programme alongside a structured weight loss programme [68]. They reported improvements in aerobic capacity and strength, associated with improved symptoms of asthma and weight loss. These results suggest that combining exercise with weight loss programmes allow patients to achieve better asthma control in a shorter period of time [68].

In patients with cystic fibrosis, 20% of adolescents and 40-50% of adults develop cystic fibrosis related diabetes [69] For patients with CFRD, exercise training is still recommended even though it is likely to make activities more difficult. When conducting exercise training in these patients, additional precautions should be used to monitor blood glucose, specifically after exercise has ceased [70].

Conclusion

Available literature demonstrates that in the majority of CRDs whole body exercises consisting of aerobic and resistance exercise training decreases respiratory symptoms, improves cardiovascular and muscle function leading to significant improvements in functional capacity. The benefits of personalised exercise training in COPD and ILD are available in abundance, with both moderate intensity continuous and high intensity interval exercise alongside whole body resistance training frequently incorporated into personalised pulmonary rehabilitation. However, in higher risk diseases such as pulmonary arterial hypertension, the previous notion that exercise would worsen symptoms and negatively affect cardiac function has slowed down the progress of exercise as a beneficial therapy and only recent research has begun to report beneficial effects. The availability of alternative exercise modalities, such as water-based exercise training, Tai Chi and single leg exercises, provide many CRD patients who suffer comorbidities a personalised approach to incorporating exercise training into their disease management.

Future randomised controlled trials are needed to continue to evaluate personalised exercise training in patients with more severe CRDs or with multiple comorbidities, due to the known benefits exercise has on aerobic capacity and muscle strength. Additional studies are needed to determine the optimal exercise training strategy for patients with pulmonary arterial hypertension and asthma, including the modality and intensity of training, length of programme and degree of supervision.

The Authors

Ioannis Vogiatzis is a Professor of Rehabilitation Sciences at Northumbria University Newcastle. His research interests include pulmonary rehabilitation in COPD, interval exercise training, exercise training-induced phenotypic and genotypic muscle fibre adaptations, assessment of exercise-induced dynamic hyperinflation by optoelectronic plethysmography, physical activity promotion and tele-coaching.

Matthew Armstrong is a PH.D. Student at Northumbria University Newcastle. His research interests include pulmonary rehabilitation in COPD, physical activity promotion and incremental exercise testing in chronic lung diseases.

References

1. World Health Organisation. *Chronic respiratory diseases*. 2019; Available from: https://www.who.int/respiratory/en/.
2. Societies, F.o.I.R., *The Global Impact of Respiratory Disease.* European Respiratory Society 2017.
3. Wickerson, L., et al., *Exertional Oxygen Requirements During Exercise Training in Advanced Interstitial Lung Disease.* Journal of cardiopulmonary rehabilitation and prevention, 2018. **38**(6): p. 419-424.
4. Vogiatzis, I. and S. Zakynthinos, *Factors limiting exercise tolerance in chronic lung diseases.* Compr Physiol, 2012. **2**(3): p. 1779-1817.
5. O Donnell, D.E., *Exercise limitation and clinical exercise testing in chronic obstructive pulmonary disease.* Progress in respiratory research, 2002. **32**: p. 138-158.
6. O Donnell, D., D. Ofir, and P. Laveneziana, *Patterns of cardiopulmonary response to exercise in lung diseases.* European Respiratory Monograph, 2007. **40**: p. 69.
7. Carlin, C., *European Respiratory Monograph: Pulmonary Hypertension.* Future cardiology, 2013. **9**(2): p. 187-188.
8. Louvaris, Z., et al., *Blood flow does not redistribute from respiratory to leg muscles during exercise breathing heliox or oxygen in COPD.* American Journal of Physiology-Heart and Circulatory Physiology, 2014.
9. Maltais, F., et al., *An Official American Thoracic Society/European Respiratory Society Statement: Update on Limb Muscle Dysfunction in Chronic Obstructive Pulmonary Disease Executive Summary.* American Journal of Respiratory and Critical Care Medicine, 2014. **189**(9): p. 1121-1137.
10. Spruit, M.A., et al., *An official American Thoracic Society/European Respiratory Society statement: key concepts and advances in pulmonary rehabilitation.* American journal of respiratory and critical care medicine, 2013. **188**(8): p. e13-e64.
11. Troosters, T., R. Gosselink, and M. Decramer, *Exercise training in COPD: how to distinguish responders from nonresponders.* Journal of Cardiopulmonary Rehabilitation and Prevention, 2001. **21**(1): p. 10-17.
12. Garber, C.E., et al., *American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise.* Medicine and science in sports and exercise, 2011. **43**(7): p. 1334-1359.
13. Pollock, M.L., et al., *ACSM position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults.* Journals AZ> Medicine & Science, 1998. **30**: p. 6.
14. Maltais, F., et al., *Skeletal muscle adaptation to endurance training in patients with chronic obstructive pulmonary disease.* American journal of respiratory and critical care medicine, 1996. **154**(2): p. 442-447.
15. Vogiatzis, I., S. Nanas, and C. Roussos, *Interval training as an alternative modality to continuous exercise in patients with COPD.* European Respiratory Journal, 2002. **20**(1): p. 12-19.

16. Vogiatzis, I., et al., *Dynamic hyperinflation and tolerance to interval exercise in patients with advanced COPD.* European Respiratory Journal, 2004. **24**(3): p. 385-390.
17. Man, W.D.-C., et al., *Symptoms and quadriceps fatigability after walking and cycling in chronic obstructive pulmonary disease.* American journal of respiratory and critical care medicine, 2003. **168**(5): p. 562-567.
18. Leung, R.W., et al., *Ground walk training improves functional exercise capacity more than cycle training in people with chronic obstructive pulmonary disease (COPD): a randomised trial.* Journal of physiotherapy, 2010. **56**(2): p. 105-112.
19. Dolmage, T.E. and R.S. Goldstein, *Response to one-legged cycling in patients with COPD.* Chest, 2006. **129**(2): p. 325-332.
20. Dolmage, T.E. and R.S. Goldstein, *Effects of one-legged exercise training of patients with COPD.* Chest, 2008. **133**(2): p. 370-376.
21. Ogita, F., et al., *Oxygen uptake in one-legged and two-legged exercise.* Medicine and science in sports and exercise, 2000. **32**(10): p. 1737-1742.
22. Troosters, T., et al., *Pulmonary rehabilitation in chronic obstructive pulmonary disease.* American journal of respiratory and critical care medicine, 2005. **172**(1): p. 19-38.
23. O'Shea, S.D., N.F. Taylor, and J.D. Paratz, *Progressive resistance exercise improves muscle strength and may improve elements of performance of daily activities for people with COPD: a systematic review.* Chest, 2009. **136**(5): p. 1269-1283.
24. McKeough, Z.J., et al., *Upper limb exercise training for COPD.* Cochrane Database of Systematic Reviews, 2016(11).
25. Arborelius, J.M., et al., *Hemodynamic changes in man during immersion with the head above water.* Aerospace medicine, 1972. **43**(6): p. 592-598.
26. Perk, J., L. Perk, and C. Boden, *Cardiorespiratory adaptation of COPD patients to physical training on land and in water.* European Respiratory Journal, 1996. **9**(2): p. 248-252.
27. Wadell, K., et al., *High intensity physical group training in water—an effective training modality for patients with COPD.* Respiratory medicine, 2004. **98**(5): p. 428-438.
28. McNamara, R.J., et al., *Water-based exercise in COPD with physical comorbidities: a randomised controlled trial.* European Respiratory Journal, 2013. **41**(6): p. 1284-1291.
29. Andrianopoulos, V., et al., *Exercise training in pulmonary rehabilitation.* Clinics in chest medicine, 2014. **35**(2): p. 313-322.
30. Grosse, S., *Aquatic progressions. The buoyancy of water facilitates balance and gait.* Rehab management, 2009. **22**(3): p. 25-27.
31. de Souto Araujo, Z.T., et al., *Effectiveness of low-intensity aquatic exercise on COPD: a randomized clinical trial.* Respiratory medicine, 2012. **106**(11): p. 1535-1543.
32. Lotshaw, A.M., et al., *Quality of life and physical performance in land-and water-based pulmonary rehabilitation.* Journal of cardiopulmonary rehabilitation and prevention, 2007. **27**(4): p. 247-251.
33. McNamara, R.J., et al., *Water-based exercise training for chronic obstructive pulmonary disease.* Cochrane Database of Systematic Reviews, 2013(12).

34. Schoenhofer, B., D. Koehler, and M.I. Polkey, *Influence of immersion in water on muscle function and breathing pattern in patients with severe diaphragm weakness.* Chest, 2004. **125**(6): p. 2069-2074.
35. Lan, C., J.-S. Lai, and S.-Y. Chen, *Tai chi chuan.* Sports Medicine, 2002. **32**(4): p. 217-224.
36. Lan, C., et al., *Tai Chi Chuan to improve muscular strength and endurance in elderly individuals: a pilot study.* Archives of physical medicine and rehabilitation, 2000. **81**(5): p. 604-607.
37. Chan, A.W., et al., *The sustaining effects of Tai chi Qigong on physiological health for COPD patients: a randomized controlled trial.* Complementary therapies in medicine, 2013. **21**(6): p. 585-594.
38. Leung, R.W.M., et al., *Short-form Sun-style t'ai chi as an exercise training modality in people with COPD.* European Respiratory Journal, 2013. **41**(5): p. 1051-1057.
39. Desveaux, L., et al., *Yoga in the management of chronic disease.* Medical care, 2015. **53**(7): p. 653-661.
40. Liu, X.-C., et al., *Effects of yoga training in patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis.* Journal of thoracic disease, 2014. **6**(6): p. 795.
41. Gloeckl, R., I. Heinzelmann, and K. Kenn, *Whole body vibration training in patients with COPD: a systematic review.* Chronic respiratory disease, 2015. **12**(3): p. 212-221.
42. Puhan, M.A., et al., *Pulmonary rehabilitation following exacerbations of chronic obstructive pulmonary disease.* Cochrane Database of Systematic Reviews, 2016(12).
43. McCarthy, B., et al., *Pulmonary rehabilitation for chronic obstructive pulmonary disease.* Cochrane Database of Systematic Reviews, 2015(2).
44. Radtke, T., et al., *Physical exercise training for cystic fibrosis.* Cochrane Database of Systematic Reviews, 2017(11).
45. Morris, N.R., F.D. Kermeen, and A.E. Holland, *Exercise-based rehabilitation programmes for pulmonary hypertension.* Cochrane Database of Systematic Reviews, 2017(1).
46. Dowman, L., C.J. Hill, and A.E. Holland, *Pulmonary rehabilitation for interstitial lung disease.* Cochrane Database of Systematic Reviews, 2014(10).
47. Carson, K.V., et al., *Physical training for asthma.* Cochrane Database of Systematic Reviews, 2013(9).
48. Holguin, F., et al., *Comorbidity and mortality in COPD-related hospitalizations in the United States, 1979 to 2001.* Chest, 2005. **128**(4).
49. Gallagher, C.G., *Exercise limitation and clinical exercise testing in chronic obstructive pulmonary disease.* Clinics in chest medicine, 1994. **15**(2): p. 305-326.
50. O'Donnell, D.E. and K.A. Webb, *The major limitation to exercise performance in COPD is dynamic hyperinflation.* Journal of Applied Physiology, 2008. **105**(2): p. 753-755.
51. Debigaré, R. and F. Maltais, *The major limitation to exercise performance in COPD is lower limb muscle dysfunction.* Journal of Applied Physiology, 2008. **105**(2): p. 751-753.

52. Aliverti, A. and P.T. Macklem, *The major limitation to exercise performance in COPD is inadequate energy supply to the respiratory and locomotor muscles.* Journal of applied physiology (Bethesda, Md.: 1985), 2008. **105**(2): p. 749.
53. Lacasse, Y., et al., *Pulmonary rehabilitation for chronic obstructive pulmonary disease.* Cochrane database of systematic reviews, 2006(4).
54. Cropp, G.J., et al., *Exercise tolerance and cardiorespiratory adjustments at peak work capacity in cystic fibrosis.* American Review of Respiratory Disease, 1982. **126**(2): p. 211-216.
55. Lamhonwah, A.M., et al., *Cystic fibrosis transmembrane conductance regulator in human muscle: dysfunction causes abnormal metabolic recovery in exercise.* Annals of neurology, 2010. **67**(6): p. 802-808.
56. Swisher, A.K., et al., *Exercise and habitual physical activity for people with cystic fibrosis: expert consensus, evidence-based guide for advising patients.* Cardiopulmonary Physical Therapy Journal, 2015. **26**(4): p. 85-98.
57. Yankaskas, J.R., et al., *Cystic fibrosis adult care: consensus conference report.* Chest, 2004. **125**(1): p. 1S-39S.
58. Dwyer, T.J., et al., *Effects of exercise on respiratory flow and sputum properties in patients with cystic fibrosis.* Chest, 2011. **139**(4): p. 870-877.
59. Holverda, S., et al., *Impaired stroke volume response to exercise in pulmonary arterial hypertension.* Journal of the American College of Cardiology, 2006. **47**(8): p. 1732-1733.
60. Agusti, A., J. Cotes, and P. Wagner, *Responses to exercise in lung diseases.* Eur Respir Mon, 1997. **2**: p. 32-50.
61. Sutherland, E.R. and B.J. Make, *Maximum exercise as an outcome in COPD: minimal clinically important difference.* COPD: Journal of Chronic Obstructive Pulmonary Disease, 2005. **2**(1): p. 137-141.
62. Ehlken, N., et al., *Exercise training improves peak oxygen consumption and haemodynamics in patients with severe pulmonary arterial hypertension and inoperable chronic thrombo-embolic pulmonary hypertension: a prospective, randomized, controlled trial.* European heart journal, 2015. **37**(1): p. 35-44.
63. Holland, A.E., et al., *Small changes in six-minute walk distance are important in diffuse parenchymal lung disease.* Respiratory medicine, 2009. **103**(10): p. 1430-1435.
64. Dowman, L.M., et al., *The evidence of benefits of exercise training in interstitial lung disease: a randomised controlled trial.* Thorax, 2017. **72**(7): p. 610-619.
65. *Global Strategy for Asthma Management and Prevention.* Global initiative for Asthma 2019.
66. França-Pinto, A., et al., *Aerobic training decreases bronchial hyperresponsiveness and systemic inflammation in patients with moderate or severe asthma: a randomised controlled trial.* Thorax, 2015. **70**(8): p. 732-739.
67. Hillas, G., et al., *Managing comorbidities in COPD.* International Journal of chronic obstructive pulmonary disease, 2015. **10**: p. 95.
68. Freitas, P.D., et al., *The role of exercise in a weight-loss program on clinical control in obese adults with asthma. A randomized controlled trial.* American journal of respiratory and critical care medicine, 2017. **195**(1): p. 32-42.

69. Moran, A., et al., *Cystic fibrosis–related diabetes: current trends in prevalence, incidence, and mortality.* Diabetes care, 2009. **32**(9): p. 1626-1631.
70. Ruf, K., et al., *Risks associated with exercise testing and sports participation in cystic fibrosis.* Journal of Cystic Fibrosis, 2010. **9**(5): p. 339-345.
71. Donnelly, J. and A.C.o.S. Medicine, *Exercise prescription for populations with other chronic diseases and health conditions.* American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription, 8th ed. Philadelphia: Lippincott Williams & Wilkins, 2009: p. 226-272.
72. Casaburi, R., et al., *Physiologic benefits of exercise training in rehabilitation of patients with severe chronic obstructive pulmonary disease.* American journal of respiratory and critical care medicine, 1997. **155**(5): p. 1541-1551.

Table 1: Training modalities for patients with different chronic respiratory disease entities.

	COPD	Cystic Fibrosis	Pulmonary Hypertension	ILD	Asthma
Modality	Aerobic (continuous or interval) & Resistance [10, 43]	Aerobic or Anaerobic or a combination of both [44]	Aerobic (interval) and Peripheral muscle training [45].	Aerobic & Resistance training [46]	Aerobic conditioning using treadmill/ bicycle ergometer or swimming [47].
Intensity	60-80% of peak work capacity for continuous exercise & 100-120% of peak work capacity for interval exercise [10, 43]	55-65% maximum heart rate [10, 44]	<120bpm, SPO_2>85% and Borg score <5/10 [45].	60-80% of peak work capacity for continuous exercise [10]	50-75% VO_2 max aerobic exercise [71]
Length	8-12 weeks [10, 43]	Minimum of 6 weeks [10, 44]	6-8 weeks [45].	8-12 weeks [2]	8-12 weeks [71]
Duration	20-60 min [10, 43]	20-30 min [10, 44]	30-60 min [10, 43].	20-60 min [10, 43].	30-40 min [71]
Frequency	3-5 days per week [10, 43]	3-5 days per week [10, 44]	2-3 supervised exercise [10, 43].	3-5 days per week [10]	2-3 sessions per week [71]
Outcomes	Improvements in exercise capacity, strength and quality of life[10, 43]	Improvements in exercise capacity, strength, and quality of life; slower rate of decline in lung function [44].	Improved exercise endurance, quality of life, peak Vo_2, increased peak workload and increased peripheral muscle function. [45].	Improved 6MWD, dyspnea and quality of life [46]	Improved physical fitness, asthma symptoms, anxiety, depression and quality of life [47].

Indicative content of training modalities commonly implemented in patients with lung disease as part of pulmonary rehabilitation.
Definition of Abbreviations: bpm= beats per minute, SPO_2= Peripheral capillary oxygen saturation, VO_2= oxygen uptake, 6MWD= six minute walk distance.

Table 2: Principles of training

Principles	Description	Implementation
Overloading	**To achieve a training effect it is necessary to expose the physiological systems to an overload, which presents a stress greater than regularly encountered in daily life [12].**	**Program length:** **The general consensus for CRDs is that longer programs (7-12 weeks) rather than shorter programs (4-6 weeks) produce greater training effects [10].** **Duration:** **30-40 min** **Frequency:** **3-5 training sessions per week** **Intensity:** **Endurance training programs should be set at moderate levels (50-70% peak load). High intensity endurance training produces greater physiological benefits (>80% peak load), however severe symptoms may restrict this intensity [72]. An alternative to overcome increasing symptom limitation is high intensity interval training (80-120% peak load) [15].**
Progressive overloading	**Producing a training effect becomes greater as the course of training progresses, due to an increase in exercise tolerance. Therefore training intensity has to be progressively and continuously increased to achieve further physiological improvements [12].**	**For the majority of CRDs, training overload should be progressed using the modified Borg score (ranged 0 to 10 points), with appropriate training intensities met when dyspnea and leg discomfort are rated between 4-5 [10].** **The appropriate progression of training overload for patients with PAH should be guided by patients' physiological targets of vital signs; HR <120bpm, O2 SATS >85% and Borg score <5/10 [45].**
Specificity of loading	**Physiological adaptations are specific to the exercise type (endurance or resistance training), muscle groups (upper or lower extremities) and the mode of exercise (continuous or interval exercise) [12].**	**For the majority of chronic lung diseases, exercise programs involve lower body aerobic (treadmill walking or ergometer cycling), which improve the capacity of the lower limbs. Upper body aerobic is less frequently incorporated in exercise programs, but can be performed using arm cycle ergometers [10].**
. **Reversibility (De-conditioning)**	**When exercise training stops, established physiological adaptations will be reversed [12]** **.**	**There are studies following patients post-rehab and report that effects are maintained up to 6 months and most of them are lost within 12 months. Find these references from papers investigating maintenance strategies post training compared to usual care post-training [10].**