

Northumbria Research Link

Citation: Gloeckl, R., Zwick, R.H., Furlinger, U., Jarosch, I., Schneeberger, T., Leidl, D., Koczulla, A.R., Vonbank, K., Alexiou, Charikleia, Vogiatzis, Ioannis and Spruit, M.A. (2023) Prescribing and adjusting exercise training in chronic respiratory diseases – Expert-based practical recommendations. *Pulmonology*, 29 (4). pp. 306-314. ISSN 2531-0437

Published by: Elsevier

URL: <https://doi.org/10.1016/j.pulmoe.2022.09.004>
<<https://doi.org/10.1016/j.pulmoe.2022.09.004>>

This version was downloaded from Northumbria Research Link:
<https://nrl.northumbria.ac.uk/id/eprint/50450/>

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.)



ORIGINAL ARTICLE

Prescribing and adjusting exercise training in chronic respiratory diseases – Expert-based practical recommendations



R. Gloeckl^{a,b,*}, R.H. Zwick^c, U. Füllinger^c, I. Jarosch^{a,b}, T. Schneeberger^{a,b}, D. Leitl^{a,b}, A.R. Koczulla^{a,b,d}, K. Vonbank^e, C. Alexiou^f, I. Vogiatzis^f, M.A. Spruit^{g,h,i}

^a Institute for Pulmonary Rehabilitation Research, Schoen Klinik Berchtesgadener Land, Schoenau am Koenigssee, Germany

^b Department of Pulmonary Rehabilitation, Philipps-University of Marburg, Marburg, Germany

^c Therme Wien Med, Ludwig Boltzmann Institute for Rehabilitation Research, Vienna, Austria

^d Teaching Hospital, Paracelsus Medical University Salzburg, Salzburg, Austria

^e Clinical Division of Pulmonology, Department of Medicine II, Medical University of Vienna, Vienna, Austria

^f Department of Sport, Exercise, and Rehabilitation; Faculty of Health and Life Sciences, Northumbria University, Newcastle, UK

^g Department of Research and Development, CIRO+, Center of Expertise for Chronic Organ Failure, Horn, The Netherlands

^h NUTRIM, School of Nutrition and Translational Research in Metabolism, Faculty of Health, Medicine and Life Sciences, Maastricht, The Netherlands

ⁱ Department of Respiratory Medicine, Maastricht University Medical Center, Maastricht, The Netherlands

Received 14 July 2022; accepted 5 September 2022

Available online 20 October 2022

KEYWORD

COPD;
Endurance training;
Guideline;
Pulmonary
rehabilitation;
Resistance training;
Strength training

Abstract

Background: International guidelines recommend endurance (ET) and strength training (ST) in patients with chronic respiratory diseases (CRDs), but only provide rough guidance on how to set the initial training load. This may unintentionally lead to practice variation and inadequate training load adjustments. This study aimed to develop practical recommendations on tailoring ET and ST based on practices from international experts from the field of exercise training in CRDs.

Methods: 35 experts were invited to address a 64-item online survey about how they prescribe and adjust exercise training.

Results: Cycling (97%) and walking (86%) were the most commonly implemented ET modalities. Continuous endurance training (CET, 83%) and interval endurance training (IET, 86%) were the frequently applied ET types. Criteria to prescribe IET instead of CET were: patients do not tolerate CET due to dyspnoea at the initial training session (79%), intense

Abbreviations: AACVPR, American Association of Cardiovascular and Pulmonary Rehabilitation; ACCP, American College of Chest Physicians; ATS, American Thoracic Society; BTS, British Thoracic Society; CET, continuous endurance training; CRD, chronic respiratory disease; ERS, European Respiratory Society; ET, endurance training; IET, interval endurance training; PR, pulmonary rehabilitation; RCT, randomized, controlled trial; ST, strength training.

* Corresponding author at: Institute for Pulmonary Rehabilitation Research, Schoen Klinik Berchtesgadener Land, Malterhoeh 1, 83471 Schoenau am Koenigssee, Germany.

E-mail address: rgloeckl@schoen-klinik.de (R. Gloeckl).

<https://doi.org/10.1016/j.pulmoe.2022.09.004>

2531-0437/© 2022 Sociedade Portuguesa de Pneumologia. Published by Elsevier España, S.L.U. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

breathlessness during initial exercise assessment (76%), and/or profound exercise-induced oxygen desaturation (59%). For ST, most experts (68%) recommend 3 sets per exercise; 62% of experts set the intensity at a specific load that patients can tolerate for a range of 8 to 15 repetitions per set. Also, 56% of experts advise patients to approach local muscular exhaustion at the end of a single ST set.

Conclusions: The experts' practices were summarized to develop practical recommendations in the form of flowcharts on how experts apply and adjust CET, IET, and ST in patients with CRDs. These recommendations may guide health care professionals to optimize exercise training programs in patients with CRDs.

© 2022 Sociedade Portuguesa de Pneumologia. Published by Elsevier España, S.L.U. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Patients with chronic respiratory diseases (CRDs) perceive various limitations of exercise capacity, which go far beyond (exertional) breathlessness. Peripheral muscle weakness and associated physical inactivity accelerate physical deconditioning and amplify exercise-induced breathlessness and peripheral muscle discomfort.¹ The beneficial effects of exercise training (either as a stand-alone intervention or as part of a pulmonary rehabilitation (PR) program) have been well documented in patients with CRDs.^{2–4} Thus, exercise training has been established as a key component of non-pharmacological treatment options in CRDs.^{5,6} However, when it comes to practical recommendations on how to prescribe exercise training in patients with CRDs, there is only scarce information available in the international respiratory societies' official statements and guidelines (Tables 1–2).^{5,7,8} This lack of information is even more noticeable regarding how exercise training should be adjusted and progressed during an ongoing exercise training program. Therefore, we collected the experiences of multiple international experts from the field of exercise training in CRDs on how they initially set and subsequently adjust exercise training workloads in patients with CRDs.

Methods

We initially developed a 64-item online survey to understand international expert practices on the delivery of exercise training in the setting of PR in patients with CRDs like chronic obstructive pulmonary disease, asthma, or interstitial lung disease. Peers checking for plausibility and consistency proofread the survey before its dissemination. The survey consisted of mixed open-ended questions and multiple-choice questions. Most of the questions afforded multiple answers – no question was mandatory to be addressed. The survey was built by using SurveyMonkey Software.

Dissemination of the survey

The survey was sent by email to 45 international experts from the field of exercise training in CRD patients and was available from 18 January 2022 to 18 February 2022. Participants for the survey were selected from contributor lists of previous international surveys and statements on PR^{5,9} and were partly

expanded by experts based on the experiences and judgment of the authors. Only one expert per center was invited to participate in the survey to avoid a center-based bias. Participation in the survey was voluntary and participants were asked if they agreed that their names would be disclosed in the section of acknowledgments.

Data analysis

Quantitative data were reported as percentages of answers for each question of the survey.

Results

Thirty-five out of 45 invited experts from 21 countries across 5 continents (e-Figure 1) completed the survey (response rate: 78%). The professional background of the experts was multidisciplinary, consisting of physiotherapists (66%), pulmonologists (20%), and clinical exercise physiologists (14%). Most experts provide outpatient programs (71%) of 8 to 12 weeks, including 2 to 3 training sessions per week or inpatient exercise programs (37%) for 3 to 4 weeks applying 5–7 exercise sessions per week (e-Figures 2–4). All experts (100%) provide endurance training and 94% apply strength training. The online supplement includes all survey questions and the experts' responses.

Tables 1–2 summarise the findings from the survey relevant to CET, IET and ST recommendations reported within international respiratory society statements, and guidelines as well as evidence from the literature.

Endurance training

Cycling (97%) and walking (ground floor 86% or treadmill 77%) were the most common endurance training modalities, and continuous endurance training (CET, 83%) or interval endurance training (IET, 86%) were the most used modes (e-Figures 8–9). Criteria to prescribe IET instead of CET were: when patients do not tolerate CET due to dyspnoea at the initial training session (79%), intense breathlessness during the initial exercise assessment (76%), or profound exercise-induced oxygen desaturation (59%). The following measurements are usually performed during CET and IET: 10-point Borg scale rating of breathlessness (94%) and leg discomfort (86%), oxygen saturation (87%), and heart rate (80%) (e-Figures 20 and 33).

Table 1 Overview of recommendations to prescribe and adjust continuous and interval endurance training in patients with chronic respiratory diseases including experts' practices from the current survey.

Continuous endurance training (CET)	ACCP/AACVPR 2007 ⁸	BTS 2013 ⁷	ATS/ERS 2013 ⁵	Evidence from the literature (n=13 studies) 1 Meta-analysis ¹⁰	Expert-based practices from the current survey 2022
Modality	Walking or cycling	Walking or cycling	Walking (treadmill or ground-based) or cycling (cycle ergometer)	Stationary cycling	Walking (treadmill or ground-based) or cycling (cycle ergometer)
Frequency	Not stated	2-3 days per week (minimum)	3-5 days per week	2-6 days per week	2-3 days per week (outpatient) 5-7 days per week (inpatient)
Intensity	60-80% of peak work rate	>60% of peak work rate	>60% of peak work rate	50-80% of peak work rate	60-70% of peak work rate
Duration	Not stated	30-60 minutes per session	20-60 minutes per session	20-47 minutes per session	30-40 minutes per session
Dyspnoea/Leg discomfort (10-point Borg scale)	Not stated	Not stated	4-6	4-5	4-6
Criteria for workload progression	Not stated	Not stated	Not stated	- Mainly when symptoms on the Borg scale are <3-4 - increase the intensity by 5-10% of baseline workload - total workload increments weekly or monthly	When symptoms on the Borg scale are ≤3: 1) Increase intensity and 2) Increase duration, both according to symptoms When symptoms on the Borg scale are >4: Increase duration up to 30-40 minutes, if tolerated Increase intensity, according to symptoms <i>See the flowchart for detailed information (Figure 1)</i>
Interval endurance training (IET)	ACCP/AACVPR 2007 ⁸	BTS 2013 ⁷	ATS/ERS 2013 ⁵	Evidence from the literature (n=13 studies) 1 Meta-analysis ¹⁰	Expert-based practices from the current survey 2022
Modality	Not stated	Walking or cycling	Typically stationary cycle based	Stationary cycling	Typically cycle based
Frequency	Not stated	2-3 days per week (minimum)	3-5 days per week	2-6 days per week	2-3 days per week (outpatient) 5-7 days per week (inpatient)
Intensity	Not stated	Not stated	Not stated	80-100% of peak work rate for the active period and typically complete rest in the passive period	80-100% of peak work rate
Duration	Not stated	30-60 minutes per session, interval duration not stated	20-60 minutes per session; interval duration not stated	20-45 minutes per session, most common rate 1:1 with 30 seconds per interval	20-40 minutes per session; The most common mode is 1:1 with 30-60 seconds per interval
When to apply interval instead of continuous endurance training (CET)	Not stated	The choice of interval or continuous training will be down to the patient and/or therapist's preference	Not stated	When CET is not tolerated due to dyspnoea	- CET is not tolerated due to dyspnoea - intense breathlessness during the initial exercise assessment - profound exercise-induced oxygen desaturation during CET
Criteria for workload progression	Not stated	Not stated	Not stated	- Mainly when symptoms for the BORG scale are <3-4 - increase the intensity by 10-20% from the baseline workload - total workload increment weekly	When symptoms on the Borg scale are ≤3: Increase intensity Reduce the duration of the recovery period When symptoms on the Borg scale are >4: Increase total duration up to 20-40 minutes, if tolerated - Increase intensity, according to symptoms

Abbreviations: ACCP – American College of Chest Physicians, AACVPR – American Association of Cardiovascular and Pulmonary Rehabilitation, BTS – British Thoracic Society, ATS – American Thoracic Society, ERS – European Respiratory Society, CET – continuous endurance training.

Table 2 Overview of recommendations to prescribe and adjust strength training in patients with chronic respiratory diseases including experts' practices from the current survey.

Strength Training (ST)	ACCP/AACVPR 2007 ⁸	BTS 2013 ⁷	ATS/ERS 2013 ⁵	Evidence from the literature (n=11 RCTs) 2 Meta-Analyses ^{11 12}	Expert-based recommendations from the current survey 2022
Modality	Machine weights, free weights, elastic resistance bands, and lifting the body against gravity	Not stated	Not stated	Strength training machines, dumbbells, elastic tubes, or bodyweight	Strength training machines, dumbbells, elastic tubes, or bodyweight
Frequency	2-3 days per week	2 days per week (minimum)	2-3 days per week	2-3 days per week	2-3 days per week (outpatient) 5-7 days per week (inpatient)
Load	Not stated	Not stated	60-70%1RM or 8-12 RM	40-90% 1RM	8-15 RM at an intensity that evolves 'local muscular exhaustion'
Duration	Not stated	2-4 sets of 10-15 repetitions	1-3 sets of 8-12 repetitions	2-4 sets of 5-15 repetitions	3 sets à 8-15 repetitions
Criteria for work-load progression	Not stated	The load chosen should be individualized and progressed once all sets can be completed with the selected weight	When an individual can perform the current work-load for 1 or 2 sets over the desired number of 6 to 12 repetitions, on 2 consecutive training sessions the load should be increased	<ul style="list-style-type: none"> - Reassessment with 1RM test when required sets and/or repetitions are achieved without difficulty or - improvements based on 1RM tests every 2 weeks or - based on Borg scale when scores <4 for muscle discomfort at a given fixed number of repetitions or can increase number of repetitions for a given set 	<p>When patient discontinued strength training exercise <8 repetitions:</p> <ol style="list-style-type: none"> 1) Decrease the load until patients reach 'momentary muscular failure' between 8 to 15 repetitions 2) Decrease the number of total sets according to the patient's tolerance <p>When patient completed strength training exercise >15 repetitions:</p> <ol style="list-style-type: none"> 1) Increase the load until patients reach 'momentary muscular failure' between 8 to 15 repetitions 2) Increase the number of total sets according to the patient's tolerance

Abbreviations: ACCP – American College of Chest Physicians, AACVPR – American Association of Cardiovascular and Pulmonary Rehabilitation, BTS – British Thoracic Society, ATS – American Thoracic Society, ERS – European Respiratory Society, RM – repetition maximum, RCT – randomized controlled trial.

Setting initial CET load

To set initial training intensity, 82% of experts start CET at 60-70% of peak work rate and 77% use the 10-point Borg scale to set exercise intensity aiming for a dyspnoea score between 4 and 6. Seventy-four percent prescribe a total duration of 10 to 20 minutes during the first training session (Table 1).

Adjusting CET load during an ongoing training program

To advance the training load, 57% of experts initially increase the duration of exercise, aiming for a total CET duration of 30 to 40 minutes per session (71% of experts, e-Figure 21). As a second step, the intensity is increased. The rate of intensity progression is variable, as 71% increase the intensity depending on the patients' symptoms (breathlessness and/or leg discomfort, e-Figure 25). Fig. 1 provides an overview on experts' practices, when patients need to interrupt a CET session due to various reasons.

Setting initial IET load

Most experts (59%) use a ratio of 1 to 1 alternating exercise with active or complete recovery periods. Work to recovery ratios of 1 to 2 (29%) or 2 to 1 (26%) are also used (e-Figure 35). Periods of 30 to 60 seconds are usually (69%) implemented as the length of time for the interval (exercise or recovery) phases (e-Figure 36). The initial intensity for the work interval is mostly (78%) set between 80% to 100% of baseline peak work rate with an initial total exercise duration of 10 to 20 minutes (61%) during the first training session (e-Figures 37 and 41).

Adjusting IET load during an ongoing training program

All experts (100%) agreed that it is necessary to progressively adjust the load during IET (e-Figure 43) with 76% allowing a total IET duration ranging between 20 and 40 minutes per session based on the patients' tolerance (e-Figure 42). Also,

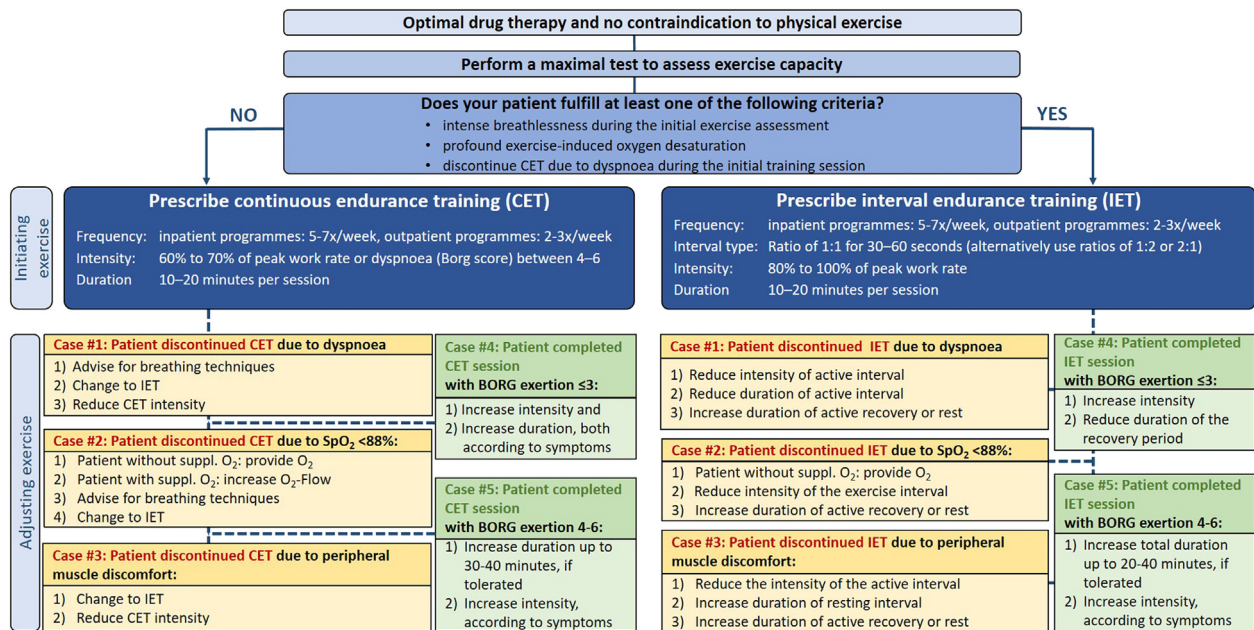


Fig. 1 Summary of expert-based practices for prescribing and adjusting continuous and interval endurance training in patients with chronic respiratory diseases.

76% of experts progressively increase the intensity of exercise during IET based on the patients' symptoms (e-Figure 45). Fig. 1 provides an overview on experts' practices when patients discontinue a IET session due to various reasons.

Strength training (ST)

Experts used various ST apparatus, such as regular weight training machines (79%), elastic tubes (56%), dumbbells (53%), or bodyweight only (53%) (e-Figure 52). The following muscle groups were seen as a minimum standard for ST: knee extensors (91%), chest muscles (59%), arm flexors (59%), arm elevator muscles (56%), hip extensors (56%), and upper back muscles (50%) (e-Figure 53). Fifty-one percent of experts do not perform a 1-repetition maximum test at the beginning of a ST program (e-Figure 54).

Setting initial load for ST

Most experts (68%) perform 3 sets per exercise (e-Figure 58). 62% of experts set the intensity at a specific load that patients can tolerate for a range of 8 to 15 repetitions per set, whereas 56% of experts use a range of around 60% to 70% from the 1-repetition maximum test to determine the initial ST intensity (e-Figure 55). Also, 56% of experts advise patients to reach local muscular exhaustion (or close to it) at the end of a single ST set (e-Figure 59).

Adjusting ST load during an ongoing training program

When patients can complete all sets during an exercise workout without significant exhaustion, experts increase the load to the next higher tolerated workload (41%), increase the weight by 5 to 10% of the 1-repetition maximum (35%) or increase the training load until patients reach local muscular

exhaustion (or close to it) at the end of a single set (35%) (e-Figure 63). 53% of experts also extend the total number of exercises, according to the patients' tolerance to further progress training volume (e-Figure 64).

Exercise prescription flowcharts

Exercise flowcharts were developed (Figs. 1 and 2) to facilitate tailoring of exercise training prescription to the individual patient's needs and capabilities. The expert practices on adjusting exercise training for the presented cases, were derived on the basis of the most prevalent responses to the survey questions (see online supplement).

Discussion

We conducted a survey to capture the practices of international experts in delivering exercise training for patients with CRDs. Based on the expert clinical practice, exercise flowcharts were developed including suggestions on prescribing and adjusting continuous, interval, and strength training in patients with CRDs. International experts from 35 different centres across 21 countries completed the survey. This reflects the largest collection of multiple expertise within this field and provides an update and extension of previously published practical recommendations on exercise training in patients with COPD.¹³ Interestingly, there was considerable heterogeneity amongst experts on how they apply and adjust exercise training. This shows that there are several ways to reach the same aim for improving physical performance.

International guidelines and statements on PR provide recommendations on how exercise training in patients with CRDs should be prescribed (Tables 1-2). Our survey indicates that exercise training practices closely align with these guidelines. However, guidance on how to further adjust exercise training

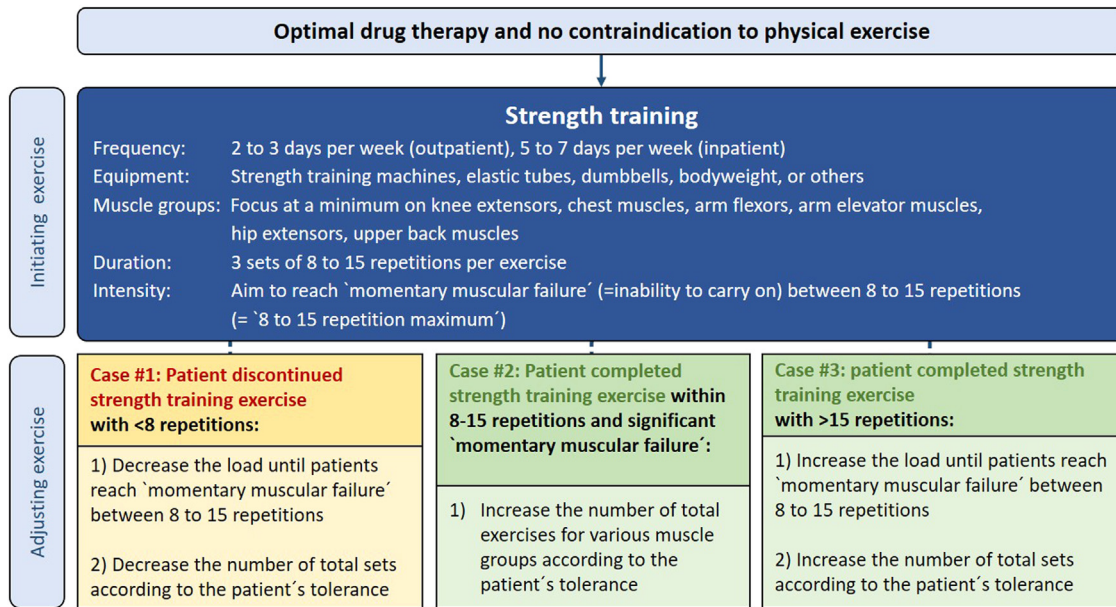


Fig. 2 Summary of expert-based practices for prescribing and adjusting strength training in patients with chronic respiratory diseases.

workload during an ongoing exercise training program and how to deal with situations when patients need to discontinue a session of exercise training due to various limitations, is scarce. Former surveys about exercise prescription also focussed more on exercise programme structures and modalities rather than on practical advice on tailoring exercise training workload.^{14,15} However, these aspects are highly relevant to the delivery of exercise training, and as such our flowcharts may provide further practical guidance on prescribing and adjusting exercise training according to the individual patient's needs and capabilities.

Endurance training (CET or IET) is consistently considered a fundamental component of exercise training in patients with CRDs.^{5,16–18} Most endurance training programmes are based on the CET method, in which exercise is performed at a constant intensity for an extended period without interruption. However, patients with severe CRDs are usually unable to sustain CET at relatively high intensities for an extended period due to increased respiratory distress.^{19,20} IET, which consists of repeated bouts of maximal/high-intensity exercise, alternated with short intervals of rest or low-intensity exercise, is a suitable alternative to CET.²¹ Several systematic reviews have consistently concluded that CET and IET demonstrate comparable efficacy in improving exercise capacity, exercise-induced dyspnoea sensations, muscle fiber structure and function, and quality of life.^{10,22} However, there is also some evidence, that especially patients with advanced CRDs perceive less dyspnoea during IET compared to CET.^{20,23} Underlying physiological reasons include a lower reliance on anaerobic glycolysis associated with lower ventilatory requirement and degrees of dynamic hyperinflation during IET.^{24,25} This explains the greater tolerance to IET compared to CET in patients with advanced CRDs. In our flowchart we presented practical indications from the experts' experiences on when to consider IET instead of CET. Furthermore, practical cases are presented, that show how experts proceed, when patients need to interrupt CET or IET due to various reasons.

Studies have shown, that endurance training combined with strength training results in significantly greater improvements in muscle strength, muscle hypertrophy, and quality of life compared to endurance training alone in patients with COPD.^{11,12,26,27} Therefore, when patients with COPD have the capacity to perform a combined endurance and strength training program, this may provide the optimal exercise prescription.

One of the most important considerations concerning strength training is intensity. The general use of the term 'intensity' in the strength training literature, including the ACSM statement,²⁸ refers to the load used (i.e. the fraction of 1 repetition maximum, %1RM). However, the expression of %1RM only represents the training load given as a fraction of maximal effort. The %1RM does not explicitly imply how hard an individual is working *during* a set of strength exercises. Therefore, Fisher and colleagues proposed that 'intensity' in its truest sense is the level of a subjects effort applied to a given load.²⁹ The inability to perform additional concentric contractions at a given load without significant changes in posture or movement speed was defined as 'momentary muscular failure'.²⁹ It has been shown that training to 'momentary muscular failure' maximizes muscle fibre recruitment (especially to the higher threshold fast-twitch muscle fibres), and increases the secretion of growth-promoting hormones compared to not reaching 'momentary muscular failure'.³⁰ Both are important factors for the capability of producing the greatest increases in muscle strength and hypertrophy.

To date, many studies have investigated the benefits of strength training and the different approaches to determine the optimal strength training intensity/load. Several systematic reviews have consistently concluded that muscle hypertrophy can be equally achieved across a wide spectrum of loads (30%1RM to 90%1RM).^{29,31,32} This evidence suggests that reaching 'momentary muscular failure' at the end of a strength training set (i.e. within a range of 8 to 15 repetitions) is the most important aspect for maximizing muscle

hypertrophy. Therefore, it is not necessary to perform a 1RM effort for prescribing strength training intensity at a certain fraction of 1RM, because the fraction of 1RM alone is not relevant for improving muscle hypertrophy.²⁹ Instead, it is the effort that a subject perceives as strenuous.

We are aware that the requirements for exercise training programmes in patients with CRDs vary widely across the world within different healthcare systems and local infrastructure. However, different types of exercise training apparatus (e.g. regular strength training machines, free weights, elastic tubes, etc.) can potentially increase exercise performance, when appropriate exercise training principles and intensity progression to reach 'momentary muscular failure' are applied.^{33,34} Recent studies have shown that an exercise training program using minimal equipment can be equally effective in increasing muscle strength and exercise performance compared to using sophisticated exercise apparatus.^{33,34} Therefore, what is much more relevant is *how* adequately patients exercise and not what kind of apparatus they use. Hence, our flowchart suggestions are also transferable to different exercise training settings.

Some limitations need also to be addressed. First, there is no direct proof of the benefits of the training recommendations included in our flowcharts. A clinical validation is needed. However, we suggest that the meaningful benefits shown in numerous exercise training studies might also apply to our expert-based recommendations since there is a substantial overlap in several basic training principles between the experts' practices and scientific evidence.

Second, there was no official panel discussion involving all experts like a Delphi consensus process. Third, we did not ask for safety issues related to the experts' experiences with exercise training. However, exercise training is usually accepted as a safe intervention for patients with CRDs following a baseline patient assessment to rule out any contraindications for physical exercise.⁵ Fourth, we provided general recommendations for a range of CRDs and did not take disease-specific considerations into account (i.e. an interval warm-up phase of 10-15 minutes in patients with asthma to prevent exercise-induced bronchoconstriction during a subsequent endurance training).³⁵

Finally, the current flowcharts do not take into account non-invasive ventilation during exercise training,³⁶ or other types of lower-limb muscle training, such as neuromuscular electrical stimulation,³⁷ single-leg cycling,³⁸ and whole-body vibration.³⁹

A strength of this survey is the large collection and consolidation of international experts' experiences for adjusting exercise training in patients with CRDs during an ongoing training program.

During the process of this survey, we have also identified important questions for future research like what patient/modality combinations are the best to safely achieve the largest training effects? What are the underlying changes in exercise performance, including intramuscular changes⁴⁰ and oxygen uptake kinetics.⁴¹ Furthermore, is there a valid approach to optimise walking speed during ground-based walking training? Future studies should include a larger number of rehabilitation experts and should collect more data with a more detailed description of the expert responses, in order to standardize procedures at a world level in the area of exercise training in CRDs.

In conclusion, based on these experts' experiences, exercise prescription flowcharts were developed. These flowcharts are meant to guide healthcare professionals in prescribing and adjusting continuous, interval, and strength training in patients with chronic respiratory diseases.

Acknowledgments

Guarantor

RG had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

Other contributions

The authors thank all the participants who completed the survey, allowing the high response rate. We thank the participants for sharing their knowledge and experiences, which may support healthcare professionals worldwide by providing exercise training to patients with chronic respiratory diseases. The following experts answered the survey and agreed to be named here (in alphabetical country order):

Christian Osadnik (Melbourne, Australia), Vinicius Cavalheri (Perth, Australia), Ralf Zwick (Vienna, Austria), Chris Burtin (Hasselt, Belgium), Daniel Langer (Leuven, Belgium), Heleen Demeyer (Ghent, Belgium), Carlos A. Camillo (Londrina, Brazil), Alberto Neder (Kingston, Canada), Linette Kofod (Hvidovre, Denmark), Isabelle Vivodtzev (Paris, France), Rainer Gloeckl (Schönau am Königssee, Germany), Janos Varga (Budapest, Hungary), Stefano Belli (Veruno, Italy), Guido Vagheggini (Volterra, Italy), Akita Tamaki (Kobe, Japan), Atsuyoshi Kawagoshi (Akita, Japan), Enock Chisati (Blantyre, Malawi), Steffi Lemmens-Janssen (Basalt, Netherlands), Maurice Sillen (Horn, Netherlands), Anita Grongstad (Jessheim, Norway), Bente Frisk (Bergen, Norway), Alda Marques (Aveiro, Portugal), Catarina Santos (Lisbon, Portugal), Elena Gimeno-Santos (Barcelona, Spain), Karin Wadell (Umea, Sweden), Gilbert Büsching (Barmelweid, Switzerland), Thomas Riegler (Heiligenschwendi, Switzerland), Spencer Rezek (Winterthur, Switzerland), Melda Saglam (Ankara, Turkey), Ioannis Vogiatzis (Newcastle, UK), Rachael Evans (Leicester, UK), Don S Urquhart (Edinburgh, UK), Rebecca Crouch (Durham, USA)

Financial/nonfinancial disclosures

All authors declare that they have no conflicts of interest.

Role of sponsors

This study did not receive any funding.

Funding information

This study did not receive any funding.

Declaration of Competing Interest

All authors declare that they have no conflicts of interest.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:[10.1016/j.pulmoe.2022.09.004](https://doi.org/10.1016/j.pulmoe.2022.09.004).

References

- Maltais F, Decramer M, Casaburi R, Barreiro E, Burelle Y, Debigare R, et al. An official American thoracic society/European respiratory society statement: update on limb muscle dysfunction in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med*. 2014;189:e15–62.
- McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y. Pulmonary rehabilitation for chronic obstructive pulmonary disease. *Cochrane Database Syst Rev*. 2015;2:CD003793.
- Hansen ESH, Pitzner-Fabricsius A, Toennesen LL, Rasmussen HK, Hostrup M, Hellsten Y, et al. Effect of aerobic exercise training on asthma in adults: a systematic review and meta-analysis. *Eur Respir J*. 2020;56:2000146.
- Dowman L, Hill CJ, May A, Holland AE. Pulmonary rehabilitation for interstitial lung disease. *Cochrane Database Syst Rev*. 2021;2:CD006322.
- Spruit MA, Singh SJ, Garvey C, ZuWallack R, Nici L, Rochester C, et al. An official American thoracic society/European respiratory society statement: key concepts and advances in pulmonary rehabilitation. *Am J Respir Crit Care Med*. 2013;188:e13–64.
- Holland AE, Cox NS, Houchen-Wolloff L, Rochester CL, Garvey C, ZuWallack R, et al. Defining modern pulmonary rehabilitation. An official American thoracic society workshop report. *Ann Am Thorac Soc*. 2021;18:e12–29.
- Bolton CE, Bevan-Smith EF, Blakey JD, Crowe P, Elkin SL, Garrod R, et al. British Thoracic Society guideline on pulmonary rehabilitation in adults. *Thorax*. 2013;68(Suppl 2). ii1–30.
- Ries AL, Bauldoff GS, Carlin BW, Casaburi R, Emery CF, Mahler DA, et al. Pulmonary rehabilitation: joint ACCP/AACVPR evidence-based clinical practice guidelines. *Chest*. 2007;131:4S–42S.
- Spruit MA, Pitta F, Garvey C, ZuWallack RL, Roberts CM, Collins EG, et al. Differences in content and organisational aspects of pulmonary rehabilitation programmes. *Eur Respir J*. 2014;43:1326–37.
- Alexiou C, Ward L, Hume E, Armstrong M, Wilkinson M, Vogiatzis I. Effect of interval compared to continuous exercise training on physiological responses in patients with chronic respiratory diseases: a systematic review and meta-analysis. *Chron Respir Dis*. 2021;18:14799731211041506.
- Li N, Li P, Lu Y, Wang Z, Li J, Liu X, et al. Effects of resistance training on exercise capacity in elderly patients with chronic obstructive pulmonary disease: a meta-analysis and systematic review. *Aging Clin Exp Res*. 2020;32:1911–22.
- Yu B, Tong S, Wu Y, Abdelrahim MEA, Cao M. Effects of resistance training on exercise ability in chronic obstructive pulmonary disease subjects: a systematic review and meta-analysis. *Int J Clin Pract*. 2021;75:e14373.
- Gloeckl R, Marinov B, Pitta F. Practical recommendations for exercise training in patients with COPD. *Eur Respir Rev*. 2013;22:178–86.
- Garvey C, Fullwood MD, Rigler J. Pulmonary rehabilitation exercise prescription in chronic obstructive lung disease: US survey and review of guidelines and clinical practices. *J Cardiopulm Rehabil Prev*. 2013;33:314–22.
- Garvey C, Casaburi R, Spruit MA, De Brandt J. Survey of exercise prescription in US pulmonary rehabilitation programs. *J Cardiopulm Rehabil Prev*. 2020;40:116–9.
- Zainuldin R, Mackey MG, Alison JA. Optimal intensity and type of leg exercise training for people with chronic obstructive pulmonary disease. *Cochrane Database Syst Rev*. 2011:CD008008.
- Vogiatzis I, Terzis G, Nanas S, Stratakis G, Simoes DC, Georgiadou O, et al. Skeletal muscle adaptations to interval training in patients with advanced COPD. *Chest*. 2005;128:3838–45.
- Simoes DCM, Vogiatzis I. Can muscle protein metabolism be specifically targeted by exercise training in COPD? *J Thorac Dis*. 2018;10:S1367–76.
- Kortianou EA, Nasis IG, Spetsioti ST, Daskalakis AM, Vogiatzis I. Effectiveness of interval exercise training in patients with COPD. *Cardiopulm Phys Ther J*. 2010;21:12–9.
- Gloeckl R, Halle M, Kenn K. Interval versus continuous training in lung transplant candidates: a randomized trial. *J Heart Lung Transplant*. 2012;31:934–41.
- Vogiatzis I, Nanas S, Roussos C. Interval training as an alternative modality to continuous exercise in patients with COPD. *Eur Respir J*. 2002;20:12–9.
- Beauchamp MK, Nonoyama M, Goldstein RS, Hill K, Dolmage TE, Mathur S, et al. Interval versus continuous training in individuals with chronic obstructive pulmonary disease—a systematic review. *Thorax*. 2010;65:157–64.
- Wickerson L, Brooks D, Granton J, Reid WD, Rozenberg D, Singer LG, et al. Interval aerobic exercise in individuals with advanced interstitial lung disease: a feasibility study. *Physiother Theory Pract*. 2021;37:1034–42.
- Sabapathy S, Kingsley RA, Schneider DA, Adams L, Morris NR. Continuous and intermittent exercise responses in individuals with chronic obstructive pulmonary disease. *Thorax*. 2004;59:1026–31.
- Vogiatzis I, Nanas S, Kastanakis E, Georgiadou O, Papazhou O, Roussos C. Dynamic hyperinflation and tolerance to interval exercise in patients with advanced COPD. *Eur Respir J*. 2004;24:385–90.
- Liao WH, Chen JW, Chen X, Lin L, Yan HY, Zhou YQ, et al. Impact of resistance training in subjects with COPD: a systematic review and meta-analysis. *Respir Care*. 2015;60:1130–45.
- De Brandt J, Spruit MA, Hansen D, Franssen FM, Derave W, Sillen MJ, et al. Changes in lower limb muscle function and muscle mass following exercise-based interventions in patients with chronic obstructive pulmonary disease: a review of the English-language literature. *Chron Respir Dis*. 2018;15:182–219.
- Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, 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. *Med Sci Sports Exerc*. 2011;43:1334–59.
- Fisher J, Steele J, Bruce-Low S, Smith D. Evidence-based resistance training recommendations. *Medicina Sportiva*. 2011;15:147–62.
- Willardson JM. The application of training to failure in periodized multiple-set resistance exercise programs. *J Strength Cond Res*. 2007;21:628–31.
- Schoenfeld BJ, Grgic J, Ogborn D, Krieger JW. Strength and hypertrophy adaptations between Low- vs. High-Load resistance training: a systematic review and meta-analysis. *J Strength Cond Res*. 2017;31:3508–23.
- Lacio M, Vieira JG, Trybulski R, Campos Y, Santana D, Filho JE, et al. Effects of resistance training performed with different loads in untrained and trained male adult individuals on maximal strength and muscle hypertrophy: a systematic review. *Int J Environ Res Public Health*. 2021;18:11237.
- Patel S, Palmer MD, Nolan CM, Barker RE, Walsh JA, Wynne SC, et al. Supervised pulmonary rehabilitation using minimal or

- specialist exercise equipment in COPD: a propensity-matched analysis. *Thorax*. 2021;76:264–71.
34. de Lima FF, Cavalheri V, Silva BSA, Grigoletto I, Uzeloto JS, Ramos D, et al. Elastic resistance training produces benefits similar to conventional resistance training in people with chronic obstructive pulmonary disease: systematic review and meta-analysis. *Phys Ther*. 2020;100:1891–905.
35. Parsons JP, Hallstrand TS, Mastrorade JG, Kaminsky DA, Rundell KW, Hull JH, et al. An official American Thoracic Society clinical practice guideline: exercise-induced bronchoconstriction. *Am J Respir Crit Care Med*. 2013;187:1016–27.
36. Gloeckl R, Andrianopoulos V, Stegemann A, Oversohl J, Schneeberger T, Schoenheit-Kenn U, et al. High-pressure non-invasive ventilation during exercise in COPD patients with chronic hypercapnic respiratory failure: a randomized, controlled, cross-over trial. *Respirol*. 2019;24:254–61.
37. Sillen MJ, Franssen FM, Delbressine JM, Vaes AW, Wouters EF, Spruit MA. Efficacy of lower-limb muscle training modalities in severely dyspnoeic individuals with COPD and quadriceps muscle weakness: results from the DICES trial. *Thorax*. 2014;69:525–31.
38. Evans RA, Dolmage TE, Mangovski-Alzamora S, Romano J, O'Brien L, Brooks D, et al. One-legged cycle training for chronic obstructive pulmonary disease. A pragmatic study of implementation to pulmonary rehabilitation. *Ann Am Thorac Soc*. 2015;12:1490–7.
39. Gloeckl R, Jarosch I, Bengsch U, Claus M, Schneeberger T, Andrianopoulos V, et al. What's the secret behind the benefits of whole-body vibration training in patients with COPD? A randomized, controlled trial. *Respir Med*. 2017;126:17–24.
40. Vogiatzis I, Terzis G, Stratakis G, Cherouvim E, Athanasopoulos D, Spetsioti S, et al. Effect of pulmonary rehabilitation on peripheral muscle fiber remodeling in patients with COPD in GOLD stages II to IV. *Chest*. 2011;140:744–52.
41. Buekers J, P DEB, Theunis J, Houben-Wilke S, Vaes AW, Franssen FME, et al. Physiological changes differ between responders and nonresponders to pulmonary rehabilitation in COPD. *Med Sci Sports Exerc*. 2021;53:1125–33.