Chapter 10
Evidence on Exercise Training in Pulmonary Hypertension

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Abstract Pulmonary hypertension (PH) is a chronic, debilitating condition which gravely affects exercise tolerance and quality of life. Though most therapies focus purely on medical intervention, there is a growing body of evidence to suggest the role and benefits of exercise training. This chapter discusses the various physiological basis for exercise intolerance observed in PH and highlights the rationale for exercise training. Recent evidence related to exercise training is summarized and potential pathways to suggest adaptations to exercise training are put forward. While keeping the paper applicable to clinicians, details on evaluating exercise intolerance, prescribing exercise and setting up rehabilitation centers for PH are discussed.

Keywords Exercise • Cardiopulmonary exercise testing • Pulmonary arterial hypertension • Rehabilitation

1 Introduction

Pulmonary hypertension (PH) is a condition that is gaining global attention with the rise in prevalence, thanks to the rise in other diseases such as heart failure (HF) and chronic obstructive pulmonary disease (COPD) [1]. The recent World Symposium on Pulmonary Hypertension at France, has classified PH into five distinct etiological

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groups which are clinically relevant [2]. However, based on haemodynamic parameters, PH can also be classified as pre-capillary, post-capillary, isolated post-capillary and combined post- and pre-capillary PH [3, 4]. The changes in haemodynamics are related to pulmonary vascular remodeling which occurs due to a dysfunction of the pulmonary endothelial cells and vascular smooth muscles [5]. All these changes result in gross limitation to perform exercise as a result of various physiological mechanisms causing symptoms of dyspnea, fatigue and syncope [6–8].

Current therapies have focused on targeting the three main pathways of pulmonary vascular remodeling (i.e., endothelin pathway, nitric oxide pathway and prostacyclin pathway) through either sequential combination therapy or through an initial double or triple combination therapy [9]. With these advancements in medical therapies, survival years have only improved which have resulted in greater survivors of PH having poor functional capacity and quality of life [10, 11]. Thus, there is a need to work towards improving their function and quality of life through various rehabilitative interventions such as exercise training.

This chapter will focus on the various physiological mechanisms limiting exercise performance, the rationale for exercise training, evaluation of exercise capacity and an updated review of recent literature on exercise training in PH. In addition, key information on setting up a PH rehabilitation center will also be described.

2 Exercise Limitations in Pulmonary Hypertension

Exercise intolerance is a major finding across all forms of PH. A complex interaction between the pulmonary, cardiovascular and musculoskeletal systems are responsible for exercise intolerance seen in PH. Early studies by Sun et al., identified various central and peripheral mechanisms in idiopathic PH from cardiopulmonary exercise testing (CPX) [12]. A recent review, described the various limiting factors for various etiologies of PH and postulated possible mechanisms through which the various systems involving the right and left ventricles, pulmonary circulation, respiratory system and skeletal muscles all contribute to poor exercise tolerance in PH [6].

2.1 Haemodynamics and Exercise Limitation

Altered haemodynamics in the pulmonary circulation is a key finding in PH. Changes in pulmonary vascular resistance (PVR) and pulmonary artery pressures (PAP) under normal circumstances, allow for adequate decrease and maintenance to ensure homeostasis within the pulmonary circulation [7]. In a normal healthy individual, the response to exercise causes a drop in PVR secondary to recruitment of the vascular bed. In addition, minimal alteration in the radius of the vessel results in an almost fourfold increase in PVR [7]. These are similar to changes in pulmonary vascular distensibility in which a 2% per mmHg decrease of mean PAP occurs during high cardiac output [13]. However, changes in distensibility by even a meager 0.1% per mmHg, greatly increases the mean PAP resulting in a limitation of exercise. The

impact of the raised PVR is felt on the right ventricle (RV) and this results in uncoupling of the RV and the pulmonary vasculature [14]. A recent study further identified altered resting ventriculo-arterial coupling ratio which failed to increase during exercise thereby advancing the RV dysfunction and limiting exercise [15].

The altered size of the RV in turn compresses the left ventricle (LV) which subsequently affects CO by affecting the distensibility of the LV [16, 17]. This cycle continues with the progression of the uncoupling and consequently affects the RV contractile reserve [18]. In conditions like HF with reduced ejection fraction (HFrEF), there is a gradual increase in PAP due to the prolonged elevation of the PCWP [19]. HF with preserved ejection fraction (HFpEF), however, increases in left atrial pressure leads to remodeling and a decrease in compliance of the pulmonary arterial bed, thereby increasing the oscillatory load on the RV [20].

2.2 Cardiorespiratory Function and Exercise Limitation

Cardiorespiratory function as evaluated from cardiopulmonary exercise testing (CPX), which has now received a Level B, Class IIa recommendation for diagnostic evaluation [21], was initially used to describe two potential pathways resulting in exercise intolerance in PAH, i.e., an increase in ventilatory demand and impaired muscle contraction (which will be described in Sect. 2.3) [12].

These changes are more profound in chronic lung disease and chronic thromboembolic PH (i.e., Group 3 and group 4). Altered diffusion in chronic lung disease occurs as the result of altered biomechanics of the thorax and the hypoxia induced vasoconstriction causing the raised PVR [22] [23]. In addition, CTEPH, as a result of increased dead space ventilation, shows an abnormal decrease in end tidal carbon dioxide ($P_{ET}CO_2$) and abnormal rise in the minute ventilation – carbon dioxide production (V_E/VCO_2) relationship [24]. This has also been observed in other forms of PH like idiopathic PH, PH due to congenital heart disease and connective tissue disorders [25].

2.3 Muscles and Exercise Limitation

In addition to the altered pulmonary haemodynamics and cardiorespiratory system, muscle dysfunctions (both peripheral and respiratory) further contribute to exercise limitations. Poor oxygen delivery at the periphery due to circulatory changes result in lactic acid build up which has been shown to limit exercise [26]. In addition, limited cardiac output could result in overactivation of the sympathetic systems similar to that seen in HF [27]. Both these factors could contribute to the "generalized myopathy" observed [28]. The involvement of the diaphragm, along with the peripheral muscles, has been shown to further contribute to the exercise limitations seen in PH [29]. Changes in respiratory muscle strength have recently been shown to moderately strong relationships with functional capacity (r = 0.40) and physical activity (r = 0,38–0.61 for vigorous and moderate physical activity respectively) [30].

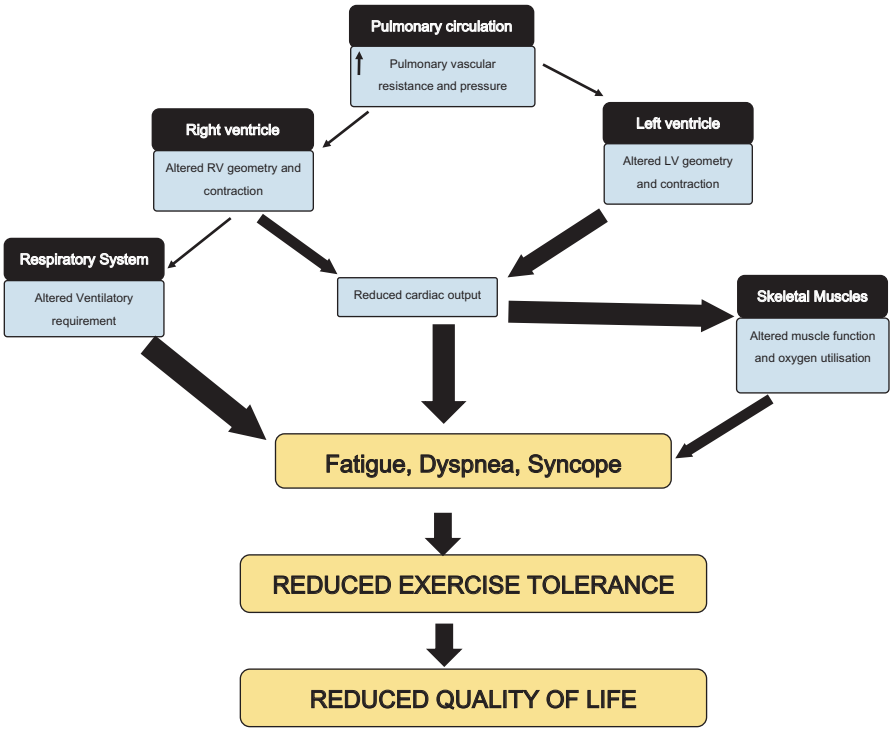

Fig. 10.1 Summary of mechanisms contributing to exercise limitations in pulmonary hypertension

Thus, the contributions of the various systems to exercise limitations in PH are summarized. Figure 10.1 provides a pictorial representation of the complex interplay of the various physiological systems.

3 Rationale for Exercise Training

Exercise training has been found to have numerous benefits on the cardiovascular system [31, 32] and skeletal muscle systems. Patients with HF and COPD have been shown to respond favorably to exercise training with marked improvements in exercise capacity, quality of life and longevity [33]. There exists similarity between limitation to exercise performance in both PH and HF. Both conditions have contributions from central factors, vascular function, respiratory system and peripheral muscles [6, 34]. Studies in HF have suggested potential mechanisms for improvements from the changes in the neurohumoral systems, endothelial function, anti-inflammatory effects, cardiovascular effects and skeletal muscle changes [35]. Considering these effects observed in HF, it is only logical to assume that these

same effects in a patient with PH would no doubt improve outcomes with exercise training. Indeed it was the anti-oxidant effects and improved vascular function of studies in HF that drove the hypothesis for exercise training in PH [36].

Since the publication of the first randomized controlled trial of exercise training study in humans [36], studies have continued to demonstrate significant benefits with exercise training on cardiorespiratory fitness (peak $\dot{V}O_2$), functional capacity (6 min walk distance-6MWD) and peripheral and respiratory muscle function in individuals with PH. In the first review on this topic Desai and Channick (2008) highlighted the rationale for exercise training in 2008 [37]. These authors also hypothesized the benefits of exercise in chronic obstructive pulmonary disease (COPD) and their mechanisms as potential reasons to advocate exercise training. Since then, the recent systematic reviews of the existing literature have supported the benefits of exercise training on various functional outcomes [38–40]. Thus, it appears that exercise training through various mechanisms, which still need to be elucidated, have an impact on clinical and functional outcomes in PH.

4 Evidence on Exercise Training in Pulmonary Hypertension

Evidence on the effects of exercise training in PH were limited till early 2000. However, there has been a steady increase in the number of trails registered in various clinical trial registries across the world [41]. Recently, there have been excellent reviews and meta-analysis on this topic and each one has focused on various aspects [38–40]. Moreover, the results of a Cochrane review on randomized controlled trials, has also recently been published [42].

This section compiles information from all these reviews and further contributes to articles available since the publication of these reviews. Among these three recent reviews, only one has included all forms of study designs [40] while the other two have focused only on randomized controlled trials [38, 39]. From the 15 trials included in the systematic review, there have been an additional four articles that have been published since the last search performed in the review [43–46], thus making a total of 19 observational and randomized controlled trial of exercise training published till date. A summary of these studies are included in Table 10.1.

As observed, most of the studies have observed changes in functional capacity and quality of life. Recent meta-analysis and systematic reviews have reiterated the benefits seen with regard to exercise capacity, functional class and quality of life [38–40, 47]. At present, conclusions from the randomized clinical trials [36, 44, 45, 48–50] suggest significant benefits in terms of exercise capacity (peak $\dot{V}O_2$), 6 min walk distance (6MWD), right ventricular systolic pressure (RVSP), mean PAP, PVR and quality of life. In addition to these studies, a recent paper assessed the use of home based exercises in children with PH [51]. However, in spite of the growing literature, the evidence base for exercise training remains narrow and the quality of the evidence remains low [42]. Furthermore, much of our evidence comes from the same group of authors that used an inpatient training program followed by a home based program.

Table 10.1 Summary of the various studies included in the review

Reference	N	Design	NYHA grade at enrolment	PH cause	Intervention (Intensity)	Duration	Results
[36]	30	RCT	II – IV	CTEPH, PAH	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	85 m increase after 3 weeks and 96 m after 15 weeks for 6MWD ($p < 0.001$)
							Improved QoL in physical function and vitality ($p < 0.005$)
[62]	2	Case report		iPH and PAH due to scleroderma	Cycle ergometry (50% peak workload)	6 weeks – Institution based, 3 days/week	4% and 14% increase in peak VO2
							Improved QoL
[65]	19	Pre-post	II – III	iPH	Cycling and quadriceps muscle training while maintaining SpO2 > 85% and HR <120 bpm	12 weeks – Outpatient based	4% increase in 6MWD ($p = 0.13$)
							Increase in workload of AT from 32 to 46 watt; ($p = 0.003$)
							13% and 34% increase in quadriceps endurance and strength ($p < 0.05$)
[85]	8	Non-randomized controlled trial	II – III	Congenital heart disease	Interval training on bicycle and resistance training	2 days a week for 12 weeks – Outpatient? Based	No significant change in 6MWD and QoL
[63]	5	Case series	II – III	iPH	Aerobic and resisted exercises (60% max workload and 70% MVC)	12 weeks – Outpatient based	58 m improvement in 6MWD ($p = 0.01$)

[64]	22	Non-randomized controlled trial	II – III	iPH and CTEPH	Aerobic and resisted exercises + stair climbing (60–80% HRmax)	12 weeks – Outpatient and home based	32 m and 1.1 ml/kg/min improvement in 6MWD and peak VO2 ($p < 0.05$)
[54]	58	Pre-post	II – IV	iPH	Aerobic and resistance training + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	87 m and 2.1 ml/kg/min improvement for 6MWD and peak VO_2 ($p < 0.001$)
							Improvement in all domains of SF36 ($p < 0.05$)
[56]	183	Pre-post	II – IV	PAH, CTEPH, PH due to lung and heart disease	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	68 m increase after 3 weeks and 78 m after 15 weeks for 6MWD ($p < 0.001$)
							Improved QoL ($p < 0.05$)
[57]	21	Pre-post	II – IV	PAH due to CTD	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	67 m increase after 3 weeks and by 71 m after 15 weeks for 6MWD ($p < 0.05$)
							Improved QoL ($p < 0.05$)

(continued)

Table 10.1 (continued)

Reference	N	Design	NYHA grade at enrolment	PH cause	Intervention (Intensity)	Duration	Results
[55]	35	Pre-post	II – IV	CTEPH	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	61 m increase after 3 weeks and 71 m after 15 weeks for 6MWD
							1.9 ml/kg/min in peakVO2 after 15 weeks
							Improved QoL ($p < 0.05$)
							>20% reduction fot NT-proBNP at 3 weeks
							1,2 and 3 year survival rates of 97%, 94% and 86%

[48]	23	RCT	I – IV	PAH	Education versus exercise training	10 weeks outpatient	56 m increase in 6MWD with exercise training ($p = 0.002$)
							Improvements in both QoL measurements ($p < 0.05$)
[58]	20	Pre-post	II – IV	PAH due to CHD	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	63 m increase after 3 weeks and 67 m increase after 15 weeks for 6MWD ($p < 0.001$)
							Increase in peak VO_2 from 8.3 L/min to 9.02 and 9.25 L/min at 3 and 15 weeks respectively Significant improvement only in bodily pain 100% survival at years 1 and 2. Transplantation free survival 100% and 93% at years 1 and 2

(continued)

Table 10.1 (continued)

Reference	N	Design	NYHA grade at enrolment	PH cause	Intervention (Intensity)	Duration	Results
[49]	20	RCT	II – III	PAH, CTD, CTEPH, portal hypertension	Exercise + respiratory muscle training	3 weeks Inpatient	91 m improvement in the experimental group in 6MWD ($p = 0.008$)
[50]	24	RCT	I – IV	PAH, CTD	Education versus exercise training	10 weeks This is the same study as Chan et al.	53 m increase in 6MWD ($p = 0.003$) with exercise training
							Improved fatigue scores
[61]	7	Case series	III – IV	PAH		3 weeks – Inpatient based and 12 weeks – Home based	92 m increase after 3 weeks and 81 m increase after 15 weeks for 6MWD ($p < 0.001$)
							Improved PImax by 1 kPa ($p = 0.086$), PEmax by 2.3 kPa ($p = 0.021$), SnPna by 1.3 kPa ($p = 0.025$) at 15 weeks
[43]	8	Case series	II – III	CTEPH	Endurance + strength training	12 weeks, home based	33 m improvement in 6MWD
							Improved QoL

[44]	29	RCT	II – III	iPAH, PAH due to CHD, CTD and RA	Inspiratory muscle training	6 weeks	50 m improvement in 6MWD
							Improved mental components on Nottingham health profile
							26 and 10 cmH_2O improvement in MIP and MEP
							Increased FEV1 (6%) and FVC (10%)
[45]	87	RCT	II – IV	PAH, CTEPH	Exercise + respiratory muscle training	3 weeks – Inpatient based and 12 weeks – Home based	41 m improvement on 6MWD
							3.1 ml/kg/min improvement
[46]	27	Non-radomized	II – III	PAH	Exercise + respiratory muscle training + slow breathing + psychological intervention	4 weeks	~32 m improvement on 6MWD

6MWD – Six minute walk distance, *6MWT* – Six minute walk test, *CHD* – Congenital heart disease, *CTD* – connective tissue disorder, *CTEPH* – Chronic thromboembolic pulmonary hypertension, *HR* – Heart rate, *HRmax* – Maximum heart rate, *iPH* – Idiopathic pulmonary hypertension, *MVC* – maximal voluntary contraction, *NR* – Not reported, *PAH* – Pulmonary artery hypertension, *PEmax* – Peak expiratory pressure, *PImax* – Peak inspiratory pressure, *QoL* – Quality of life, *SF36* – Medical outcomes survey short form 36, *RA* – Rheumatoid arthritis, *SF12* – Medical outcomes survey short form 12, *SnPna* – Sniff nasal pressure, *SpO_2* – Oxygen saturation, *peak VO_2* – Peak oxygen consumption

This highly supervised, expensive model of exercise training would be difficult to incorporate into most standard rehabilitation programs around the world [52, 53].

5 Adaptations to Exercise Training

With the evidence supporting the use of exercise training to improve functional capacity and quality of life in PH, there are certain adaptations that could occur as a result of the exercise training programs. Most of the studies have utilized a combination of aerobic and resistance training interventions [36, 45, 54–61] with only a few relying solely on aerobic [62–64], peripheral [65] and respiratory muscle strengthening [44] and home-based exercise training [43].

The effects reported from all the studies have reflected to a certain extent changes in the RV and muscle strength. Few have also reported haemodynamic changes. Single groups studies have not reported significant changes, though there is a minimal decrease by 2–4 mmHg in mPAP at rest when assessed by either echocardiography or right heart catheterisation [36, 45] while some have reported no change at all [43]. Recent meta-analysis have also reported changes in peak systolic pulmonary artery pressure with exercise training (−3.66 mm Hg; 95% CI: -5.45, −1.87; p = 0.694) [39]. Recently, an abstract presented at the recent American Thoracic Society conference (2016) found that supervised exercise training improve RV function (with respect to RV stroke volume and ejection fraction) when evaluated with cardiac MRI [66]. RV function determined from tricuspid annular plane systolic excursion (TAPSE) was also seen to improve from 23 ± 10 mm to 21 ± 3 mm in a single group observational study. This is the only study till date to report improvements in TAPSE following exercise training [46]. Another cardiac MRI study also identified that 3 weeks of exercise training produced a reduction pulmonary artery flow resistance along with an increase in pulmonary perfusion [49]. Figure 10.2 summarizes the various adaptations reported from all the studied till date.

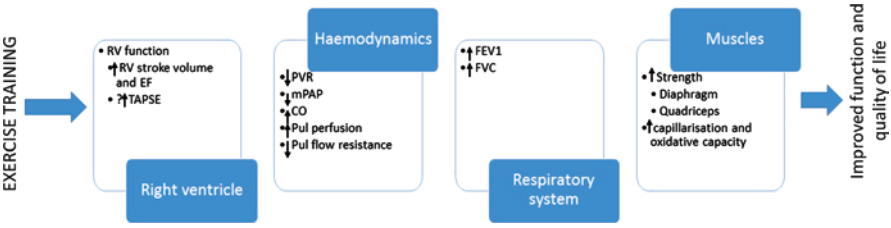

Fig. 10.2 Adaptations to exercise training programs in pulmonary hypertension form published literature

Abbreviations: *RV* – Right ventricle; *EF* – Ejection fraction; *TAPSE* – Tricuspid annulus planar systolic excursion; *PVR* – Pulmonary Vascular resistance; *mPAP* – mean pulmonary artery pressure; *CO* – Cardiac output; *Pul* – Pulmonary; *FEV1* – Forced expiratory volume in 1st second; *FVC* – Forced vital capacity

6 Assessing and Prescribing Exercise in Pulmonary Hypertension

Assessment of exercise capacity in PH has always played an important role. All through the years, the 6 min walk test (6MWT) has been used extensively due to its ease of administration. The importance of evaluating exercise capacity with CPX and 6MWT has been reiterated in the recent ESC-ERS guidelines as well [3]. The use of CPX or other functional tests like the 6 min walk test (6MWT), shuttle walk test, functional walk test or bag and carry test are dependent on setting and expertise [67]. However, CPX and 6MWT are the most commonly used methods for evaluating exercise capacity.

6.1 Cardiopulmonary Exercise Testing

CPX is the gold standard for the evaluation of exercise capacity and currently receives evidence based recommendations for diagnosis, prognostication and evaluation of therapeutic efficacy [21]. CPX is a non-invasive method that estimates the expired ventilation and concentration of oxygen and carbon dioxide through a breath-by-breath gas analyser while the patient exercises on a bicycle or treadmill. Various outcomes like peak $\dot{V}O_2$, peak respiratory exchange ratio (RER), anaerobic/lactate threshold, ventilatory efficiency ($\dot{V}_E/\dot{V}CO_2$ slope), end tidal CO_2 ($P_{ET}CO_2$) and dead space to tidal volume ratio (Vd/Vt) [68, 69]. In addition to these variables, heart rate, blood pressure, oxygen saturation, Borg's rating of perceived exertion and symptoms are further determined during the test. For the evaluation of PH however, peak $\dot{V}O_2$, $\dot{V}_E/\dot{V}CO_2$ slope, $P_{ET}CO_2$, anaerobic threshold and Vd/Vt are the primary variables of interest.

Many of these variables have also been shown to have prognostic importance [21, 67]. High $\dot{V}_E/\dot{V}CO_2$ slope (>45), low peak $\dot{V}O_2$ (<10 ml/kg/min) and low $P_{ET}CO_2$ (no value established as yet) were consistently seen to have poor prognosis in PH with level IIb recommendation for Level B evidence [21]. In addition, CPX has also been found to have a role in determining therapeutic efficacy having a IIb level of recommendation with Level C evidence. This may change in the current years, as to date, nearly all the existing PH research has relied very heavily on the popular 6 min walk test (6MWT).

As with standard exercise testing procedures, pre-testing screening and calibration of equipment is important. Adequate infrastructure and space for the exercise testing lab are crucial considering the amount of equipment that will need to be stored. Presence of emergency resuscitation equipment and personnel trained in both basic and/or advanced resuscitation need to be available. In addition, to life saving skills, competencies in ECG recording and interpretations are highly important [70]. Finally, the level of experience in the individuals is important for CPX testing, with more experienced centres showing greater reliability [71].

6.2 Six Minutes Walk Test

The 6MWT has been widely used in PH studies as a measure of functional outcome and has been used as recommended by the American Thoracic Society and European Respiratory Societies [72, 73]. The recent guidelines continue to emphasis the need for measurement of the 6MWD as an outcome for risk stratification [3]. The 6MWT has been used as an outcome measure in a number of clinical trials and the minimally important difference (MID) well characterized in the PH population [72, 74]. The 6MWT has been found to elicit a maximal cardiovascular response among patients with PH [75]. The test has been found to predict peak VO_2 in both children and adults with PH with varying levels of accuracy ($r = 0.87$; $p < 0.001$ and $r = 0.68$; $p < 0.001$ respectively) [76]. In adults however, ventilatory efficiency was found to be lower during the 6MWT with only a moderate correlation between 6MWD and peak VO_2 from CPX ($r = 0.49$) [75]. Yet, the worsening of 6MWD has been shown to be associated with poor prognosis, though improvements in 6MWD have not been found to be reflective of mortality benefits as yet [77]. However, this is now a topic of controversy as a recent study did not find any changes in 6MWD and between patients on monotherapy and triple therapy despite differences being observed in their VE/VCO_2 and $P_{ET}CO_2$ [25].

Despite the fair amount of inaccuracy of the 6MWT to predict peak VO_2, the fact that the test elicits a maximal cardiovascular response makes it an ideal alternative to test patients with PH [78]. This holds good in low resource settings where the cost for setting up a CPX lab can go higher than USD50000 [67].

The 6MWT though used frequently is not without any risks. There are a few studies that have reported adverse events with the 6MWT which further increases the need for close monitoring during the test [40, 79, 80]. The use of telemetric monitoring systems (where available) during the test or having the supervisor of the test walk behind the individual being tested could be an appropriate safeguard to this group of patients who can experience sudden arrhythmias resulting in cardiac arrest even during a sub-maximal test [72].

7 Setting Up a Pulmonary Hypertension Rehabilitation Center

Rehabilitation centers focusing on PH are limited. Currently, these patients are enrolled along with HF cardiac rehabilitation programs or pulmonary rehabilitation programs. However, there are no dedicated programs for PH per se. The Pulmonary Hypertension Association, USA has initiated a program to establish PH care centers (PHCC) across the various parts of the US (accessed from: http://www.phassociation.org/PHCareCenters). This program accredits centers with expertise in the evaluation and management of PH to improve outcomes of patients with PH [81]. The goal of these centers are to provide evidence based team care to patients with PH, improve access of specialized health care, promote adherence to guidelines to optimize research and clinical services, and promote awareness [82].

Development of centers for comprehensive care require expertise in staff and support services, facilitates and research. Despite these guidelines for PH specific centers, there is limited mention for the need of physiotherapists/exercise physiologists as part of the comprehensive healthcare team. Though referral to cardiac or pulmonary rehabilitation programs are described, this is not considered as a part of the center requirements. This section, expert driven, will provide a framework for the development of a PH rehabilitation center which has been developed and modified from both the cardiac and pulmonary rehabilitation programs (Tables 10.2 and 10.3).

The PH rehabilitation center working along with PH care centers or as a part of them can be developed on the model of both cardiac and pulmonary rehabilitation centers. Table 10.2 provides a list a staff, facilities and services that should be made available at a PH rehabilitation center. Though these are components that would be desirable to have, it should also be kept in mind that even the use of simple cost effective methods are acceptable. The recent model for and consensus statement on low cost cardiac rehabilitation could be used as a source to guide setting exercise training programs in low resource settings [83, 84] even for PH; though this will need to be evaluated 8.

Table 10.2 PH rehabilitation center: Staff, facilities and services

Staff
Physician with expertise in PH
PH nurse
Clinical pharmacist
Physiotherapist
Exercise physiologist
Occupational therapist
Nutritionist
Social worker
Psychologist/Psychiatrist
Facilities
Evaluation labs for assessment of pulmonary function, cardiorespiratory fitness, muscle strength (both peripheral and respiratory), autonomic function (heart rate variability), energy expenditure and body composition
Exercise training areas for aerobic, resistance and respiratory muscle training
Patient education rooms
Counselling areas
Areas of groups discussions and therapy
Work simulation labs
Services
Exercise training
Nutritional counselling
Vocational rehabilitation
Psychological support
Patient education

Table 10.3 Projected requirements for evaluations of patients with PH

Assessment	Team member performing	Baseline	Follow up
Electrocardiogram	Cardiologist	√	√
Echocardiography	Cardiologist	√	√
Right heart catheterisation	Cardiologist	√	
Pulmonary function test	Exercise physiologist/physiotherapist	√	
Diffusion capacity evaluations	Exercise physiologist/physiotherapist	√	
Exercise capacity			
CPX	Exercise physiologist/physiotherapist/physician	√	√
6MWT	Exercise physiologist/physiotherapist/nurse	√	√
Inspiratory muscle strength	Exercise physiologist/physiotherapist	√	
Peripheral muscle strength	Exercise physiologist/physiotherapist	√	
Quality of life	Nurse	√	√
Depression	Nurse/psychologist	√	√

8 Future Recommendations

The future for exercise in PH is bright. There is scope numerous avenues of research in this area. At present, greater good quality studies are required to further systematically assess the effects of exercise training through various models, intensities and modes on cardiovascular and haemodynamic outcomes. In addition, long term studies assessing time to clinical worsening and hard outcomes like mortality need to be addressed. If PH rehabilitation centers can be developed, they will offer valuable evidence through prospective databases and registries on the effects of exercise.

9 Conclusion

Exercise intolerance is a major hindrance to function and poor quality of life among patients with PH. Evaluation of the mechanisms of intolerance are important prior to initiation of rehabilitation. Cardiopulmonary exercise testing and the use of functional tests are useful in the assessment and prognosis of these patients. Exercise training interventions are showing promising results, however, there is a need for more generalizable results and feasible exercise training protocols for patients with PH. Nevertheless, exercise training will have an impact on the various physiological systems of the body and will result in numerous adaptations which will help improve function and quality of life (Table 10.3).

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