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Cardiorespiratory adaptation of COPD patients to physical training on land and in water

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Cardiorespiratory adaptation of COPD patients to physical training on land and in water. J. Perk, L. Perk, C. Bodén. ©ERS Journals Ltd 1996.
ABSTRACT: Physical training in water might be included in a comprehensive pulmonary rehabilitation programme, but data on the feasibility and safety of this technique in chronic obstructive pulmonary disease (COPD) patients are lacking.

We studied cardiorespiratory parameters of 20 stable COPD patients (10 with forced expiratory volume in one second (FEV_1) <35% of predicted value, and 10 with FEV_1 ≥35% pred) on land and in a temperate-controlled pool (32°C) both at rest and during a 15 min submaximal upper body muscle training programme.

Compared to resting values on land, we found in water a decrease of systolic and diastolic blood pressure (14 and 6 mmHg, respectively), rate-pressure product (7%) and lung function (vital capacity (VC) 12%, FEV_1 14%, peak expiratory flow (PEF) 18%). There were no differences in heart rate, breathing frequency or O_2 saturation. The most strenuous exercise in water resulted in a slightly lower O_2 saturation compared to work on land (95 and 93%, respectively), and an increase of Borg rating for dyspnoea from 4 to 5. In spite of the restriction of lung function in water, all patients (even those with FEV_1 <35% pred) performed the training in the pool well, without clinically relevant desaturation, arrhythmia or discomfort. No training session was discontinued due to dyspnoea.

We conclude that a 15 min session of submaximal physical training in a pool with a water temperature of 32°C is feasible and safe for nonhypoxaemic normotensive COPD patients without cardiac failure.
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The aims of rehabilitation programmes for patients with chronic obstructive pulmonary disease (COPD) have been discussed in several articles in the Journal [1, 2]. Physical training on land, especially training of inspiratory muscles, has been widely applied but remains under debate [3], partly due to the disadvantage of sophisticated equipment [4]. A combination of inspiratory muscle training and general exercise conditioning might significantly improve exercise capacity [5], but follow-up treatment is essential in order to ensure a long-lasting effect [6].

Physical training in water may be an attractive alternative for COPD patients as it combines elements of general exercise training, inspiratory muscle training, psychosocial and low-cost benefits of group training. The physiological effects of exercise in water have been known for decades. Immersion in water leads to a higher stroke volume, a lower heart rate, and an increased work of breathing due to hydrostatic pressure [7–10]. Thus, it would allow for a higher intensity of training at a lower or unchanged circulatory load. Exercise training in water has been recommended for younger asthmatics, but its feasibility, safety and potential benefits for COPD patients have not been evaluated.

Thus, the aims of this study were: 1) to compare cardiorespiratory parameters of stable nonhypoxaemic COPD patients at rest on land and in water; 2) to compare cardiorespiratory parameters during dynamic submaximal upper body exercise on land and in water; and 3) to evaluate the safety and possible benefits of physical training in water for COPD patients.

Material and methods

Study population

Twenty patients regularly attending the COPD outpatients clinic of the Oskarshamn District Hospital were included in the study. All patients had a ratio of FEV_1 to forced vital capacity (FVC) of less than 70%, and all had a change in FEV_1 <15% from baseline after inhalation of 0.5 mg terbutaline [11]. Patients with an acute obstructive attack during the past 3 months were excluded, as were patients with resting hypoxaemia (arterial oxygen tension (P_{a,O_2}) <8.5 kPa). Further exclusion criteria were hypertension, ongoing infectious disease and

Table 1. – Patient characteristics

Sex	Age yrs	VC L	FEV_1/ VC	FEV_1 L	FEV_1 % pred	Therapy
M	62	2.88	0.36	1.05	28	SBM
M	74	2.41	0.34	0.82	27	CIM
M	68	1.96	0.51	1.00	34	SBI
M	71	1.41	0.48	0.67	22	SBM
M	76	1.52	0.37	0.57	20	CIM
M	71	2.07	0.46	0.96	31	SI
M	73	1.89	0.30	0.57	19	BITM
F	70	0.78	0.54	0.42	24	CI
M	75	1.90	0.39	0.74	27	SBM
F	66	2.05	0.27	0.55	25	BT
M	73	4.07	0.59	2.42	65	SB
M	69	2.58	0.52	1.33	43	SB
M	74	2.61	0.50	1.30	45	CSB
M	70	3.10	0.73	2.25	69	SBTM
F	67	1.46	0.57	0.83	37	SI
M	66	2.28	0.56	1.27	45	SB
M	64	1.67	0.61	1.02	39	SB
M	73	1.42	0.73	1.03	40	ST
F	63	2.27	0.49	1.11	48	SB
M	75	3.45	0.48	1.64	52	T

M: male; F: female; VC: vital capacity; FEV_1: forced expiratory volume in one second; % pred: percentage of predicted value; C: oral corticosteroids; S: inhaled steroids; B: $beta_2$-agonists; I: ipatropium bromide; T: theophylline; M: mucolytics.

significant cardiac failure (New York Heart Association (NYHA) III and IV). Patient data and medication are presented in table 1.

Measurement at rest

After instruction and informed consent the patient remained sitting on a chair for 5 min. Arterial O_2 saturation (S_{a,O_2}) and heart rate were registered using a pulse oximeter (Ohmeda Biox 3740) with its probe attached to the patient's earlobe. Breathing frequency was recorded. Systolic and diastolic blood pressure were measured with the cuff attached to the right upper arm, using the Korotkoff sound IV for diastolic pressure, adjusting the level to the nearest 5 mm interval. The arm was placed in a horizontally elevated position during the measurement, to prevent the cuff from being submerged during measurement in the training pool. Thereafter, spirometry was performed using a standard Vitalograph spirometer (Ireland, model S). Vital capacity (VC), FEV_1 and peak expiratory flow (PEF) rate were registered, and the ratio FEV_1/VC was calculated. The highest values of three consecutive measurements were used.

Training protocol

The physical training was conducted by a physiotherapist regularly engaged in the care of COPD patients. It consisted of three periods of submaximal dynamic arm and upper body exercise, each lasting 3 min. After each exercise period, the patient was allowed to rest for 2 min. The following exercises were used: Exercise I involved horizontal weight pulling (as in rowing); Exercise II vertical weight pulling (as in bucket lifting); Exercise III forward horizontal weight pulling (as in curtain closing). Each session, both on land and in water, lasted for 15 min. During the first exercise period the weights were adjusted in order to obtain submaximal working heart rates (75% of maximal heart rate). The method described by Karvonen *et al.* [12] was used to define maximal and submaximal heart rates.

Measurements during exercise

During training, S_{a,O_2} and heart rates were registered continuously with the pulse oximeter, and the values at the end of each exercise and rest period were used in the statistical procedure. The patients were asked to estimate their degree of effort and of breathlessness at the end of each training moment using the new Borg scale [13]. It was decided to stop the training if the S_{a,O_2} fell below 85%, when the patient developed hazardous arrythmia, or whenever the patient felt uncomfortable.

Training protocol and measurements in water

After 10–15 minutes rest on land the patient was placed with a hydraulic lift on a chair in the training basin. By adjusting the chair, the patient was submerged with the water surface reaching the level of the jugular fossa. The water temperature was chosen to be 32°C, which is considered to be thermoneutral [14, 15]. Measurements of S_{a,O_2}, heart rate, breathing frequency and blood pressure at rest were taken as on land.

A physical training programme identical to exercise on land was conducted. Patients used slow movements in order to minimize the influence of water resistance. Special care was taken to obtain corresponding levels of work. Comparable workload was obtained by placing the weights outside the basin and by using ropes and the same number of blocks in both training situations. The same pace of training as on land was maintained by using a metronome. All registrations in water followed the protocol on land.

Subgroup analysis

The study group was chosen in order to obtain 10 patients with FEV_1 <35% of predicted level and 10 patients with FEV_1 ≥35% pred. With the exception of two patients (FEV_1 65 and 69%) the population showed a normal distribution, with FEV_1 levels ranging 19–52% (table 1). The results on land and in water, at rest and during training, within and between these subgroups were compared.

Statistics

The following variables during rest on land and in water were compared: VC, FEV_1, FEV_1/VC ratio, PEF, breathing frequency, heart rate, S_{a,O_2}, blood pressure, and rate-pressure product (systolic blood pressure × heart rate/1,000). The variables during exercise were: heart rate, S_{a,O_2}, new Borg scale estimates, and the difference between resting heart rate before and 5 min after completed exercise. All values were expressed as mean±SD. The variables were checked for normality before testing. Paired Student' t-tests were used in the procedure; two-sided tests were used throughout. The study was performed at the Department of Physiotherapy of the Oskarshamn District Hospital and was approved by the Ethics Committee of the Linköping University, Sweden.

Results

Measurements at rest

There was no significant difference in resting heart rate, breathing frequency and S_{a,O_2} on land or when seated in the training basin (table 2). Blood pressure values decreased, systolic pressure in water by -14±14 mmHg (9%; p<0.001), diastolic pressure by -6±10 mmHg (7%; p=0.01). As a result the rate-pressure product decreased by 7% (p=0.01). A restrictive reduction of lung function parameters was noted. VC in the training basin decreased by 12% (p<0.001), FEV1 by 14% (p<0.001), and PEF by 18% (p<0.001), but the ratio FEV1 /VC remained constant.

Measurements during physical training

During training (table 3), the patients reached the submaximal target heart rates: training heart rates were within 72–75% of predicted maximal values. On land, resting heart rates after training did not return to resting pretraining levels to the same extent as in water (p<0.05). There was a 2% fall in S_{a,O_2} during the vertical pulling exercise in water as compared to land (p<0.05). During the other exercises S_{a,O_2} remained unchanged.

Table 2. – Cardiorespiratory parameters at rest on land and in water (n=20)

Parameter	Land	Water	p-value
HR beats·min^{-1}	82±22	86±18	NS
SBP mmHg	164±17	150±18	<0.001
DBP mmHg	87±10	81±11	0.01
Rate-pressure product	14.0±3.6	13.0±3.3	0.01
Ventilation breaths·min^{-1}	18.5±4.3	18.5±5.2	NS
S_{a,O_2} %	94±4	94±4	NS
VC L	2.19±0.78	1.92±0.79	<0.001
FEV1 L	1.08±0.53	0.93±0.54	<0.001
FEV1/VC	0.51±0.12	0.48±0.13	NS
PEF L·min^{-1}	120±82	99±83	<0.001

Values are presented as mean±SD. HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; PEF: peak expiratory flow; NS: nonsignificant; rate-pressure product: SBPXHR/1,000. S_{a,O_2}: arterial oxygen saturation of haemoglobin. For further abbreviations see legend to table 1.

Table 3. – Parameters during 15 min dynamic submaximal arm exercise on land and in water (n=20)

	Land	Water	p-value
Heart rate (HR) beats·min^{-1}			
Exercise I	111±22	115±20	NS
Exercise II	119±25	116±21	NS
Exercise III	114±24	115±23	NS
ΔResting HR*	13±9	7±6	<0.05
S_{a,O_2} %			
Exercise I	93±5	93±4	NS
Exercise II	95±4	93±3	<0.05
Exercise III	94±4	94±3	NS
Borg rating of effort			
Exercise I	12±2	14±2	0.01
Exercise II	15±2	15±2	NS
Exercise III	14±2	14±3	NS
Borg rating of dyspnoea			
Exercise I	3±1	4±1	<0.01
Exercise II	4±1	5±2	<0.01
Exercise III	4±2	4±1	NS

Values are presented as mean±SD. *: change in heart rate (5 min post exercise - pre exercise). NS: nonsignificant.

The rating of effort according to the Borg scale resulted in higher values (increase from 12–14) during the horizontal pulling exercise in water (Exercise I; p=0.01). Dyspnoea scores were higher both in the horizontal and the vertical pulling exercises in water (Exercises I and II; p<0.01).

Effects in patients with low FEV1

Compared to patients with an FEV1 ≥35% pred, patients with a poorer lung function (FEV1 <35% pred) had a lower systolic blood pressure on land (154±15 *vs* 171±15 mmHg; p<0.05) and a lower diastolic pressure in water (74±9 *vs* 85±10 mmHg; p<0.05). They reported higher ratings for effort and dyspnoea during several training periods in water but they did not develop desaturation. In patients with a better lung function (FEV1 ≥35% pred) the higher rating for effort and dyspnoea was only observed in the vertical weight exercise in water. There were no clinically relevant differences in S_{a,O_2} and Borg scale ratings for effort and dyspnoea between the groups.

Adverse events and safety

One patient with atrial fibrillation at rest developed rapid fibrillation (frequency 160–170 beats·min^{-1}) during training on land. After a few minutes of rest, this returned to the previous lower frequency, and, thereafter, workloads were reduced. Some patients experienced slight initial dyspnoea and fear when submerged in the training basin. This subsided after the first minutes of sitting at rest in the basin. No attacks of acute bronchial obstruction or other adverse events were observed. All patients completed the training sessions without discomfort. No exercises had to be discontinued due to low S_{a,O_2} levels, dyspnoea or any other reason except the single case of atrial fibrillation reported above.

Discussion

The main findings of our study are: 1) comparison of cardiorespiratory parameters at rest in water showed a significant fall in blood pressure values, rate-pressure product, a restrictive type limitation of spirometry values, but no changes in heart rate and breathing frequency; 2) comparison during exercise showed a sensation of increased work of breathing in some training periods in water, but no clinically relevant differences in S_{a,O_2} or heart rate despite the restriction of lung function; and 3) with respect to feasibility and safety, all patients performed the submaximal training reaching their target heart rates, and no adverse effects were observed.

The rationale of physical training for COPD patients is to improve and/or optimize muscle function in order to enhance quality of life. Several models of physical training have been proposed, but few studies have reported sustained effects. We have observed that COPD patients tend to lose interest in activities such as daily stair climbing, ergometer bicycling or the use of different types of inspiratory muscle training devices. There is a need for a larger and more engaging variety of training options. Exercise in a swimming pool may be such an alternative: it could be provided on a low cost basis to groups of patients. It would be suitable for elderly COPD patients, whose corticosteroid related skeletal and muscle wasting may limit training on land.

COPD patients attending our department tend to avoid bathing or swimming as they experience increased breathlessness when entering a bath or pool. However, some patients have reported considerable subjective improvement in physical working capacity and less dyspnoea after a period of two to three times weekly training in a swimming pool. The positive reports of these individual patients and the potential benefits of hydrotherapy were the motivation for this study.

Physical training in water has been shown to provide the same physical adaptation as on land [16], *i.e.* there is no difference in submaximal O_2 consumption [17]. A lower heart rate at submaximal work level in water has been reported [9]. The absence of a reduction of the heart rate in water in our study is in contrast to previous reports [9]. Healthy individuals will compensate the higher stroke volume due to increased venous return through a lower heart rate. We suggest that a higher pressure in the pulmonary circulation, as observed in COPD patients, may limit this compensatory mechanism. The fall in blood pressure can be explained by peripheral arterial dilatation due to the submersion in water at 32°C. The restriction of lung volumes is caused by the hydrostatic pressure of the water on the chest. One might expect that this 12–17% restriction should have limited the patients' performance during the exercises in water, especially in the group of patients with a low FEV_1. Instead, heart rates and S_{a,O_2} responded in the same manner as during the exercise on land. We suggest three possible explanations. Firstly, the hydrostatic pressure prompted the patients to increase their tidal volume. This is supported by the higher Borg scale ratings observed for dyspnoea. Secondly, the lower rate-pressure product at rest may even have been present during exercise; this might represent a lower myocardial oxygen demand when compared to identical work on land. And thirdly, due to hydrostatic pressure the diaphragm was moved upwards, contributing to a more effective ventilation. However, this may be counteracted by airway collapse due to a decrease in functional residual capacity.

In our study, an upright sitting position in 32°C water was chosen. The training was designed as a submaximal interval model engaging mainly the upper body muscles, including the accessory respiratory muscles. As the training was performed in a humid environment the choice of monitoring equipment was restricted due to the risk of contamination and electrical accidents. A more extensive investigation of lung function and the collection of arterial blood gas samples was impossible.

For practical reasons, the training in water was always preceded by the session on land, occurring 10–15 minutes before. This might have had some impact on blood pressure levels. We lack comparable data on cardiorespiratory responses in a healthy population of the same age. However, blood pressure levels and lung function in three young male volunteers exposed to this experimental model decreased to the same extent as the patient population (on average 15% decrease). The exercises in the basin were more strenuous due to friction of the water, especially the vertical pulling exercise. This was partly limited through the use of slow movements, but it may have caused an experience of some increased effort for the same workload.

We suggest that the cardiorespiratory adaptation during physical training in water fully compensated for the restriction of the lung volume due to the hydrostatic pressure, in this stable normotensive and nonhypoxaemic COPD population without signs of advanced cardiac failure. A 15 min session of submaximal upper body muscle training in water could be performed without adverse effects or significant desaturation even in patients with more advanced COPD.

Our study addressed cardiopulmonary parameters, feasibility and safety of hydrotherapy in a low-risk chronic obstructive pulmonary disease group. Further studies are needed to assess its long-term effects in comprehensive rehabilitation, including measurements of maximum inspiratory pressure, exercise tolerance and quality of life.

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