Inspiratory Muscle Training in Patients With Prior Polio Who Use Part-Time Assisted Ventilation

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ABSTRACT. Klefbeck B, Lagerstrand L, Mattsson E. Inspiratory muscle training in patients with prior polio who use part-time assisted ventilation. Arch Phys Med Rehabil 2000;81:1065-71.

Objective: To evaluate whether inspiratory muscle training in patients with prior poliomyelitis (and with symptoms and signs of hypoventilation) who use part-time assisted ventilation could improve symptoms and respiratory muscle function without adverse effects.

Design: Intervention study with before-after trial.

Setting: Training was performed in the patients' homes; assessments were performed at the hospital.

Patients: Ten prior-polio patients were included. Three of them did not complete the trial, and their data were not included in results of training.

Intervention: Ten weeks of daily inspiratory muscle training.

Main Outcome Measures: Spirometry, maximal inspiratory and expiratory pressures, inspiratory muscle endurance, and questions regarding activities of daily living were performed.

Results: Inspiratory endurance capacity over 5 minutes improved from 10.7 to 16.7cm H_2O ($p < .05$) assessed at 15 on the Borg scale, and most patients improved in activities of daily living. The whole-body endurance capacity remained stable over the studied period.

Conclusion: Inspiratory muscle training and close supervision can increase respiratory muscle endurance and improve well-being in patients with prior polio who use part-time assisted ventilation.

Key Words: Ventilation; Inspiratory muscle training; Poliomyelitis; Physical endurance; Rehabilitation.

IN PATIENTS WITH POLIO, the early recovery of muscle function is partly the result of collateral reinnervation. It has been suggested that the surviving motor units in the postpolio patients undergo a continuous process of denervation and reinnervation of some of the muscle fibers within the motor units.[1-3] It has also been suggested that these motor units are more susceptible to overuse.[4] After a period of 15 to 30 years of stable condition, some of the patients with prior poliomyelitis might develop new symptoms such as pain[4,5] or impaired muscle function, ie, postpolio muscle dysfunction (PPMD).[6]

In patients with prior polio, respiratory muscle weakness and chest wall deformities such as scoliosis can lead to a restrictive ventilatory function[7] and hypoventilation.[8-11] Hypoventilation causes hypercapnia[12,13] and symptoms such as dyspnea and daytime fatigue, which might restrict the level of activity.

That ventilatory muscle strength and endurance can be increased by ventilatory muscle training in normal subjects was first shown by Leith and Bradley.[14] Since then, a number of training studies have also been performed on patients with neuromuscular disorders, predominantly on patients with tetraplegia[15-18] and muscular dystrophy.[19-21] The major outcome of these studies concerning training has been improved ventilatory muscle endurance, but improvement in ventilatory muscle strength is also reported.

In some studies,[22-24] the safety of muscle strengthening exercise in patients with PPMD has been studied with regard to deleterious effects histopathologically, serologically, and electromyographically. In these studies, carefully supervised training programs resulted in increased muscle strength without progressively increased muscle pain. However, training is controversial in progressive neuromuscular diseases, because overtraining may lead to impaired muscle function.[25,26]

Respiratory muscle weakness, leading to hypoventilation in patients with prior polio, is usually treated with assisted ventilation to rest the respiratory muscles[12,13,27-29] and to restore ventilatory control. However, use of assisted ventilation as the only treatment may not be optimal. To prevent further deterioration, endurance training in these muscles has been proposed. To improve muscle endurance without adverse effects, a viable option is inspiratory muscle training (IMT) in patients with prior polio who use daily part-time assisted ventilation. To our knowledge, this training in patients with prior polio has not been studied previously. Furthermore, it is not known if IMT might cause adverse effects in patients with prior polio. Improved ability to breathe for prolonged periods against added loads would be beneficial for these patients, because increased work of breathing might occur, for example, during chest infections.

The aim of this study was to evaluate whether endurance training of inspiratory muscles in patients with prior polio who use part-time assisted ventilation could improve respiratory muscle function, spirometric measurements, the possibility to perform activities of daily living (ADL), and relieve dyspnea without causing any adverse effects.

METHOD

Patients

Inclusion criteria were: (1) prior poliomyelitis and living in the Stockholm area, and (2) independence of assisted ventilation after the acute polio infection, but now for some years using part-time noninvasive intermittent positive pressure ventilation (NIPPV) as a result of symptoms of hypoventilation, but not P_{CO_2} above 6.5kPa before starting assisted ventilation. Daytime P_{CO_2} was less than 6kPa for all patients included in the

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study. Patients were excluded if they had pulmonary or cardiovascular diseases that could interfere with training. It also had to be possible for the patients to perform the training at home daily over the 10-week period and visit the hospital for measurements 11 times during 4 months. The study was approved by the local ethics committee at Huddinge Hospital.

Assessments

To obtain baseline values, the patients were tested three times during 4 weeks before the start of training. The first measurement was for familiarization with the equipment and was not further used. A mean of results from the second and third tests was used as baseline data. During the 10-week period, the patients visited the clinic for assessments every other week. The patients were assessed after the training period three times within 5 weeks, and the final (fourth) assessments were performed after 2 months. The assessments, every other week at the hospital, were to ensure a proper training load and the correct use of the training device, and to ensure that no signs of subjective muscle fatigue appeared or other assessments were deteriorating (fig 1).

Measurements of endurance were performed with a threshold inspiratory trainer, Threshold®.[a] The same Threshold was also used for training. This device produces reliable inspiratory pressure loads independent of airflow.[30] To make certain that the inspiratory load of the Threshold was stable during the measurements, the devices were controlled with an external pressure transducer[b] both before and during the tests. A noseclip was used and the patients breathed into the device for 5 minutes and pointed at the end of every minute on a 6- to 20-degree rating scale of perceived exertion (Borg's rating of perceived exertion [RPE] scale).[31] The resistance (pressure) was chosen through two to three sets with rest intervals between, so that the patients at the end of the 5-minute period rated "15" (hard) on the RPE scale. After 10 to 15 minutes of rest, resistance was increased, so that at the end of the 5-minute period, the patients rated "17" (very hard) on the RPE scale. The patients were encouraged to interrupt the test if they reached "17" before the end of the 5 minutes. The resistance (pressure) at "15" and "17" on the RPE scale was used as the "endurance value."

Maximal inspiratory (Pi_{max}) and expiratory (Pe_{max}) pressures at the mouth were measured with a mouth pressure meter[c,32] from residual lung volume and from total lung capacity (TLC) and expressed in cm H_2O. A flanged-styled mouthpiece and noseclip were used, and the maneuvers were performed with a minimal interval of 1 minute to avoid short-term fatigue of the respiratory muscles. The maneuvers were repeated until a reproducible value was obtained, usually after four to five times. The mouth pressure meter measures both the peak pressure and the average maximal and minimal mouth pressure achieved over a period of 1 second. Average pressure sustained over 1 second was used in this study[32] and expressed as absolute values in cm H_2O and as a percentage of predicted normal value.[33]

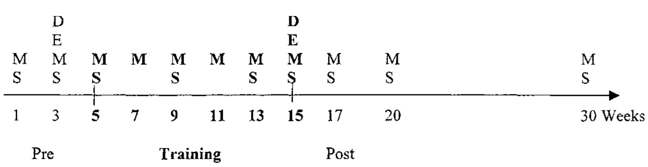

Fig 1. Sequence of the testing sessions during the study period of 30 weeks. Pretraining period comprises weeks 1 through 4, the training period weeks 5 to 15, and the posttraining period weeks 15 to 30. D, assessment of dyspnea; E, answered expectations; M, performed respiratory muscle function tests; S, performed spirometry.

Oxygen saturation was monitored by an ear oximetry[d] and recorded continuously during the measurements of Pi_{max}, Pe_{max}, and endurance.

Static and dynamic spirometry were performed by an independent laboratory technician. Functional residual capacity was determined by the helium dilution method.[34] Vital capacity was measured and TLC and residual volume calculated. Forced vital capacity and forced expiratory volume in 1 second (FEV_1) were measured separately. The best FEV_1 value of three measurements was accepted, and all indices of forced airflow were read off that recording. Maximal voluntary ventilation (MVV) was measured for 15 seconds at a breathing frequency of 40 breaths per minute. All measurements were performed using a pulmonary function laboratory 2400 Sensor Medics.[e] Values were presented in absolute values and as percentage of predicted normal value.[35] All patients were already familiar with the spirometric measurements.

Baseline dyspnea index (BDI) was used to rate the severity of dyspnea.[36] BDI is a 3-category index including functional impairment, magnitude of task, and magnitude of effort, which evaluates dyspnea-induced functional limitation.[36] At the baseline state, dyspnea was scored across 5 grades from 0 (severe) to 4 (unimpaired) for each category. The ratings for each of the 3 categories were added to a baseline score range of 0 to 12. At the transition period, after the training period, a structured interview was performed in which changes in dyspnea were rated by 7 grades from -3 (major deterioration) to $+3$ (major improvement). The scores for each of the 3 categories were added to form a transition dyspnea index (TDI)[36] that ranged from $+9$ to -9, with positive numbers indicating improvement in relation to baseline conditions, and negative numbers indicating worsening. The TDI score was obtained by adding the scores for each component.

The patients were also asked to estimate degrees of breathlessness during one or two ADL that they perceived as being influenced by difficulties of dyspnea. Questions were asked after the training period as to whether the breathlessness had changed during the named activities.

Outcome expectations were defined as the perceived benefit of a risky behavior.[37,38] The patients' expectations were collected before and after training with the questions: (1) "How do you like to exercise regularly?" and (2) "What do you think are your own benefits from exercise?" Each question was followed by a scale of 0 to 10cm, in which 0 indicated "not at all/very harmful" and 10 "very much/very useful." The patients responded by putting a mark on the scale. Efficacy expectations were defined as the perceived ability and likelihood or motivation to perform the training. The patients' opinions were collected before training using the question (3) "How sure are you that you will exercise daily during the next 10 weeks for 20 minutes and rest in your ventilator before and after the training?" The question was followed by a scale of 0 to 10cm, in which 0 indicated "very uncertain" and 10 "very certain" and the patients responded by putting a mark on the scale.

IMT was performed at home with the Threshold loading device. A noseclip was used during the training. The training intensity was initially chosen to approximately 30% of Pi_{max} and was not to be perceived as more than "15" (hard) at the RPE scale at the end of the training. The patients performed the training for 20 minutes (1 minute of training and 1 minute of rest, repeated 10 times) once every day for a period of 10 weeks. At the last minute of training, the patients graded their perceived inspiration exertion using the RPE scale. The patient was asked to provide a log after every training session, which was reviewed on a weekly basis. These logs and the tests every

Table 1: Individual Data of Patients in Training Group and Nontraining Group

Patient	Gender	Age (yrs)	Polio at Age (yrs)	BMI (kg/m²)	VC		Functional Status	Assisted Ventilation	
					L	% Pred		Yrs	Use
Training group									
1	F	66	6	20.9	0.9	52	Walks	7	Night
2*	M	55	3	27.7	1.1	23	EW	8	Night
3	M	70	17	26.4	1.8	45	Walks	3	Night
4	M	74	8	22.9	2.0	56	Walks	3	Night
5	M	71	23	18.0	1.6	37	EW	4	2h/d
6	M	66	12	25.9	1.5	36	EW	6	Night
7	M	69	24	27.7	1.6	41	Walks	5	Night
Median		69	12	25.9	1.6	41			
Nontraining group									
8	F	57	1	39.0	1.5	61	EW	10	Night
9*	M	54	3	17.8	1.0	33	W	10	2h/d
10	F	64	7	22.3	1.2	49	EW	10	2h/d
Median		57	3	22.3	1.2	49			

Abbreviations: BMI, body mass index; VC, vital capacity; % Pred, percent of predicted normal value; F, female; M, male; EW, electric wheelchair; W, manual wheelchair.
* Patient with thoracic spinal fusion.

other week were assessed to ensure that no adverse effects appeared.

Before and after every training session, the patients used their own ventilator with a mouthpiece or a nasal mask for at least 30 minutes. Five weeks after the training, when all posttraining assessments had been performed, the patients were allowed to restart training if they wished.

Statistics

Values are presented as medians, means, and range. Differences between the training group and the nontraining group were analyzed with the Mann-Whitney *U* test. Results over time were analyzed using a one-way analysis of variance with repeated measures. The repeating factor was time, with 8 to 10 time points. If the correlations between each pair of repeated measures were not the same (test of sphericity), the degrees of freedom (*df*) of the *F* test were reduced by multiplying each of the *df* by the Greenhouse and Geisser epsilon. When the *F* ratio for the factor, time, was significant, planned comparisons were performed between the repeated measures. The *p* values were then corrected according to the Bonferroni procedure.[39]

RESULTS

Ten patients from two outpatient clinics in Stockholm fulfilled the inclusion criteria, and they were all willing to take part in the study. All patients had been using part-time NIPPV with volume-controlled ventilators for 3 to 10 years. Nine patients used PLV 100,[f] and 1 patient used Breas 501.[g] Seven patients constituted a training group. They were 55 to 74 years of age and contracted polio at 3 to 24 years of age. Four patients were able to walk; 3 used wheelchairs.

Three patients constituted a nontraining group. They could not fulfil the desired training for different reasons. One of the patients experienced pain in the chest during training; the pain was assumed to be located to the ribs and probably as a result of earlier surgery in the area. However, this patient was positive about participating in the nontraining group and continuing the measurements. The second patient would participate only if the visits to the hospital were limited; this patient was also included in the nontraining group with a restricted number of visits. The third patient was not able to perform training on the desired load. The patients in the nontraining group were between 54 and 64 years of age, contracted polio at 1 to 7 years of age, and were unable to walk and used wheelchairs (table 1).

From the reviewed logs, all patients in the training group completed 10 weeks of training, with a training compliance of 97%. Five of the patients trained every day (70 training sessions); 1 patient did not train during 2 days; and 1 patient did not train during three periods of 6, 3, and 3 days, respectively, during the initial weeks of training because of family reasons. The training load was 26% to 49% of the Pi_{max}, and the patients rated the load on the RPE from ''11'' (rather easy) to ''15'' (hard), as reported in the daily training protocols. After 8 weeks, 1 patient reported fatigue for 3 days after increased training load (41% of Pi_{max} and perceived as ''15''). After decreasing the load to 35%, the sensation of fatigue disappeared and his rated training intensity was returned to ''13.'' There were no other reports of muscle fatigue or breathing difficulties during the 10 weeks of training. The patients reported that they rested by using assisted ventilation for at least 30 minutes before and after training.

In the training group, the increase in endurance from baseline to end of training was significant, $p < .05$ at RPEs of both ''15'' and ''17'' (table 2). The endurance values did not change further as an average after finishing the training period. For the nontraining group, the endurance values did not change signifi-

Table 2: Results of Endurance Values at Baseline and During 10 Weeks of Training

	RPE Score 15 (cm H_2O)	RPE Score 17 (cm H_2O)
Baseline	10.7 (5.0-16.5)	11.9 (6.0-18.0)
Week 7*	13.8 (10.0-20.0)	15.3 (11.0-21.0)
Week 9	13.7 (10.0-20.0)	14.8 (12.0-21.0)
Week 11	15.6 (12.0-19.0)	16.9 (13.0-20.0)
Week 13	15.7 (13.0-19.0)	17.1 (14.0-21.0)
Week 15	16.7 (14.0-21.0)	17.7 (15.0-22.0)

Values measured as inspiratory pressure (cm H_2O) at ''15'' (hard) and ''17'' (very hard) on the rating of perceived exertion scale (RPE), presented as mean (range).
* Week 7 = after 2 weeks of training, see figure 1.

cantly from baseline either during or after the control period. For individual values at RPE "15," see figure 2.

Neither Pi_{max} and Pe_{max}, nor spirometry measurements in any group showed any significant changes during the assessment period (table 3). The values of oxygen saturation during the measurements of endurance Pi_{max} and Pe_{max} for all patients averaged 95%. In 2 patients, the SaO_2 decreased to 90% when the patients perceived exertion of RPE "17" (very hard) during the measurements of endurance.

The median BDI was 4 scores (range, 2 to 7). After the training period, the TDI was 0 in five patients and +2 in two patients in the training group. The TDI was 0 in the nontraining group. Two patients, with TDI of +2, could walk up a steep road after the training period (7min) without rest, which was not possible without rest before the training. One of them also reported less dyspnea while cleaning the bathroom floor. Of 5 patients with TDI of 0, 2 reported a perception of it being easier to take deep breaths and controlling breathing after using assisted ventilation, a situation that made them panic earlier. The third patient reported a subjectively better sleep quality (this patient did not use assisted ventilation during sleep) and felt less tired during the daytime. The remaining two patients reported no difference in ADL, but a favorable feeling of the possibility of performing the training without any adverse effects.

All patients had a constructive attitude to the training. On the 10-cm scale, the patients indicated on question 1 a median of 7.2cm (range, 5.0 to 9.7), on question 2 a median of 9.0cm (range, 8.3 to 10.0), and on question 3 a median of 9.9cm (range, 6.3 to 10.0). After the training period, the patients indicated on question 1 a median of 7.5cm (range, 4.0 to 9.9) and on question 2 9.3cm (range, 6.6 to 9.9). There were no significant differences of scoring expectations between the training group or the nontraining group before or after training.

Table 3: Spirometric Values and Maximal Inspiratory and Expiratory Pressures at Baseline in Training Group (*n* = 7) and Nontraining Group (*n* = 3)

	Training Group Median (range)	Nontraining Group Median (range)
VC (L)	1.6 (0.9-2.0)	1.2 (1.0-1.5)
VC %	41 (23-56)	49 (33-61)
TLC (L)	2.9 (1.5-4.8)	2.5 (2.1-2.9)
TLC%	44 (26-67)	59 (42-64)
FRC (L)	1.6 (0.8-3.5)	1.4 (1.2-2.0)
FRC%	45 (28-95)	50 (49-78)
FEV_1 (L)	1.2 (0.7-1.3)	0.9 (0.9-1.4)
FEV_1 %	42 (24-51)	42 (38-69)
RV (L)	1.3 (0.6-3.2)	1.1 (1.0-1.7)
RV%	53 (35-122)	60 (58-91)
MVV (L/min)	41.5 (20.5-46.5)	28.5 (26.5-29.0)
MVV%	40 (21-48)	34 (22-35)
Pi_{max} cmH_2O	38.5 (35.0-66.0)	36.0 (22.0-52.5)
Pi_{max} %	42 (34-64)	42 (29-49)
Pe_{max} cmH_2O	75.0 (30.0-134.5)	58.0 (46.5-58.5)
Pe_{max} %	40 (14-73)	32 (25-41)

Abbreviations: VC, vital capacity; L, liter; %, percent of predicted normal; TLC, total lung capacity; FRC, functional residual capacity; FEV_1, forced expiratory volume in 1 second; RV, residual volume; MVV, maximal voluntary ventilation; Pi_{max}, maximal inspiratory pressure at the mouth; Pe_{max}, maximal expiratory pressure at the mouth.

DISCUSSION

This study showed that patients with prior polio using daily part-time assisted ventilation were able to perform IMT with no adverse effects. The majority of patients in the training group improved in ADL and reported well-being. However, 3 patients were not able or would not perform inspiratory training, which was why the group was separated into two, a training group and a nontraining group. The nontraining group, however, cannot be seen as a control group. These patients were not able to participate because of pain or inability to perform training load. The nontraining group was not different from the training group, except for the 1 patient who contracted polio at age 1 year. Further, 1 woman in the nontraining group was grossly obese. Some of the patients in the training group were also in wheelchairs, and 3 of them had contracted polio before age 10. The nontraining group had baseline endurance values that were 4 and below. Although this group could not be distinguished

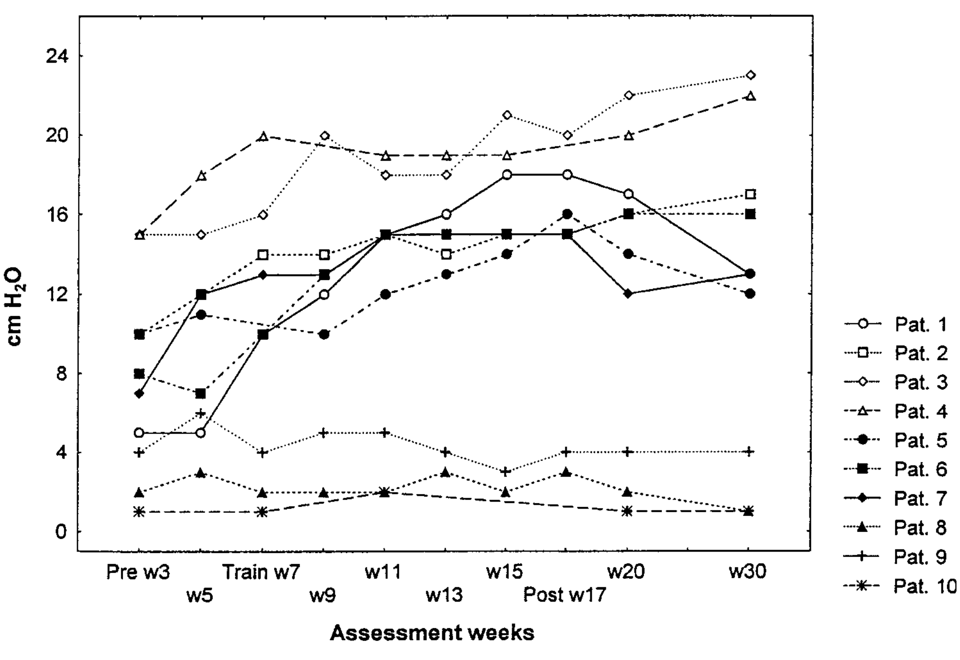

Fig 2. Individual endurance values after 5 minutes at pressure "15" (hard) on the RPE scale. Pre w3 and w5, tests before training (weeks 3 and 5); Train w7 through w15, tests during training (weeks 7 through 15); Post w17 to w30, tests after training (weeks 17 to 30). The training group includes patients (Pat.) 1 through 7; the nontraining group, Pat. 8 through 10.

from the participating group in the respiratory function tests, it may be that any postpolio patient with an endurance value this low will find inspiratory training too difficult. However, testing more subjects would be needed to prove this.

The number of patients in the training group is small, which can be explained by the fact that the number of polio survivors who would require assisted ventilation part-time is not large. A multicenter trial would have been necessary to obtain a larger number of participants as well as controls.

The chosen initial training intensity in this study was about 30% of Pi_{max}. This load, chosen as a submaximal intensity, would affect inspiratory muscle endurance more than strength, because training on submaximal levels will stimulate an increased capillary density, myoglobin content, and improve oxidative metabolism.[40]

Was the training intensity too low? It is questionable whether 30% of Pi_{max} was enough to reach optimal effects or the highest tolerated effects without adverse effects in these patients. However, other inspiratory training studies have shown effects of this training load. Lisboa[41] and Larson[42] and their colleagues have reported beneficial effects in patients with chronic obstructive pulmonary disease and chronic airflow limitation of 30% of the patients Pi_{max} to improve inspiratory muscle strength and reduce dyspnea. Cahalin and associates[43] reported beneficial effects with a training load of 20% in patients with chronic heart failure.

Was the training intensity too high? If the training program is too excessive, it may lead to further loss of function instead of improvement.[4,44] These polio survivors had respiratory impairments as a result of both the costodiaphragm muscle weakness and scoliosis. They have all been at a respiratory stable condition for more than 35 years, and have developed new respiratory weakness, PPMD, diagnosed at the time of starting assisted ventilation. When the PPMD patients performed the IMT, it was important not to overload their muscles. To prevent this, the patients were instructed not to exceed the training intensity ‘‘15’’ (hard) on the RPE scale. This instruction, together with the weekly contact with either the daily training protocols the patients were reporting or the assessments performed every other week, ensured this. It is possible that the training load of about 30% of Pi_{max} is close to maximal in these patients. One patient in our study felt more fatigued during the days when his training load exceeded 42% for a couple of days and then perceived more than ‘‘hard’’ (RPE 15); this went back to normal after returning the load closer to 30% of his Pi_{max}. Therefore, we concluded that 30% Pi_{max} or somewhat above seemed to be the optimal training load.

The importance of balance between activity and rest for patients with PPMD is believed to minimize fatigue and prolong the patient's ability to endure physical activity through the day.[45] Symptomatic postpolio patients have a deficit in recovery of muscle strength after fatiguing exercise.[25] Therefore, the combination of muscular rest and training might have enhanced the effect of training. There are studies indicating that only assisted ventilation without training improves respiratory muscle strength[46] and endurance.[47] However, even if 3 patients in the nontraining group could not be seen as controls, it must be noted that their values of endurance did not change over time. This also indicates that the frequent measurements did not improve endurance per se.

For measurement of endurance over 5 minutes, the Threshold was used in this study instead of MVV that assesses endurance during 15 seconds, which represents endurance over a short time. The Threshold works in the same way as the weighted plunger device used by Nickerson and Keens,[48] designed for measurement of inspiratory muscle endurance. The Threshold was also used in the studies of Larsson[42] and Harver[49] and their colleagues to ensure consistent inspiratory pressure loads regardless of the inspiratory flow rate.

The patients in this study improved in endurance. The results are, however, difficult to compare with results from other studies on patients with neuromuscular disorders, because both patients and methods for training vary considerably. No studies of IMT of patients with PPMD have been found, but other studies on patients with neuromuscular disorders such as muscular dystrophy[19-21,50] and tetraplegia[15-17,51] have been reported. The training designs differ in the studies, both with regard to intensity, duration, and time of performance.[16,17,19-21,50,51] In contrast to most of the other studies, in which the patients trained maximally or to the point of discomfort,[16,17,19-21,50,51] the patients in our study trained at a submaximal level. Despite that, endurance improved in our patients. Spirometric values did not change during the assessed period. These were added to control for adverse effects and whenever possible to be used as a selection of patients without training potential.

There are only a few reports of subjective effects or improvements in ADL as a result of IMT on patients with neuromuscular disorders. Hornstein and Ledsome[51] reported a decreased shortness of breath after resistive breathing while eating and talking in patients with acute tetraplegia. Biering-Sørensen and associates[17] reported that 4 of 10 patients with chronic tetraplegia perceived improved breathing during the training period. Gross and Meiner[52] reported improved functional activities with less fatigue in a varied group of patients with neuromuscular disorders. Because daily inspiratory training affects the daily routines for these often very handicapped patients, it is of great importance that the outcome is also evident and clinically significant. In this study, all patients reported some subjective benefit from the training, and 4 of the 7 patients chose to restart training after week 20. This reinforces our belief that the effect of training was real and worth more than the effort of 1 hour of training time per day.

Four patients in the training group were functional walkers, which means that when walking, the demands on the ventilatory capacity are much larger than when moving in an electric wheelchair. It is possible that walking patients put an extra load on their respiration during daily activities and, therefore, do not benefit from extra training. This was not observed in this study, because 2 of the walkers had increased dyspnea when walking up hills before training and improved in hill walking after training. However, 2 of the walking patients did not improve subjectively. One of these patients had trained regularly in water for many years and might have trained to a level above the demands of this training. The other patient probably trained maximally when out for her daily walks, which were 50 meters of level walking before resting because of dyspnea. Three patients in electric wheelchairs improved subjectively. This might be an effect of improved coordination that may improve ventilatory muscle performance.

We conclude that IMT can increase inspiratory muscle endurance, and improve ADL and well-being in patients with PPMD who also use daily part-time assisted ventilation for respiratory muscle rest. To ensure proper training load and no adverse effects, close contact with assessments of the patients is recommended.

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References

1. Einarsson G, Grimby G. Electromyographic and morphological functional compensation in late poliomyelitis muscular atrophy. Muscle Nerve 1990;13:165-71.
2. Wiechers DO. New concepts of the reinnervated motor unit revealed by vaccine-associated poliomyelitis. Muscle Nerve 1988; 11:356-64.
3. Wiechers DO, Hubbell ST. Late changes in the motor unit after acute poliomyelitis. Muscle Nerve 1981;4:524-8.
4. Jubelt B, Cashman NR. Neurological manifestations of the post-polio syndrome. Crit Rev Neurobiol 1987;3:199-220.
5. Halstead LS, Rossi CD. New problems in old polio patients: results of a survey of 539 polio survivors. Orthopedics 1985;8:845-50.
6. Borg K, Borg J, Stålberg E. Post-polio muscle dysfunction. In: Emery AEH, editor. Diagnostic criteria for neuromuscular disorders. 2nd ed. London: Royal Society of Med Press; 1997. p. 99-100.
7. Stevenson FH, Wilson ABK, Bottomley AH, Airey DM. Rehabilitation of respiratory function after poliomyelitis. J Bone Joint Surg Br 1963;45:326-36.
8. Howard RS, Wiles CM, Spencer GT. The late sequelae of poliomyelitis. Q J Med 1988;251:219-32.
9. Newsom Davis J, Goldman M, Loh L, Casson M. Diaphragm function and alveolar hypoventilation. Q J Med 1976;45:87-100.
10. Dean E, Ross J, Road JD, Courtenay L, Madill KI. Pulmonary function in individuals with a history of poliomyelitis. Chest 1991;100:118-23.
11. Blomstrand A, Bake B. Post-polio lung function. Scand J Rehabil Med 1992;24:43-9.
12. Bach JR, Alba A, Shin D. Management alternatives for post-polio respiratory insufficiency. Assisted ventilation by nasal or oral-nasal interface. Am J Phys Med Rehabil 1989;68:264-71.
13. Bach JR, Alba AS. Pulmonary dysfunction and sleep disordered breathing as post-polio sequelae: evaluation and management. Orthopedics 1991;14:1329-37.
14. Leith DE, Bradley M. Ventilatory muscle strength and endurance training. J Appl Physiol 1976;41:508-16.
15. Gross D, Ladd HW, Rilev EJ, Macklem PT, Grassino A. The effect of training on strength and endurance of the diaphragm in quadriplegia. Am J Med 1980;68:27-35.
16. Loveridge B, Badour M, Dubo H. Ventilatory muscle endurance training in quadriplegia: effects on breathing pattern. Paraplegia 1989;27:329-39.
17. Biering-Sørensen F, Knudsen JL, Schmidt A, Bundgaard A, Christensen I. Effect of respiratory training with a mouth-nose mask in tetraplegics. Paraplegia 1991;29:113-9.
18. Rutchik A, Weissman AR, Almenoff PL, Spungen AM, Bauman WA, Grimm DR. Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. Arch Phys Med Rehabil 1998;79:293-7.
19. Wanke T, Toifl K, Merkle M, Formanek D, Lahrmann H, Zwick H. Inspiratory muscle training in patients with Duchenne muscular dystrophy. Chest 1994;105:475-82.
20. DiMarco AF, Kelling JS, Sajovic DiMarco M, Jacobs I, Shields R, Altose MD. The effect of inspiratory resistive training on respiratory muscle function in patients with muscular dystrophy. Muscle Nerve 1985;8:284-90.
21. Estrup C, Lyager S, Naeraa N, Olsen C. Effect of respiratory muscle training in patients with neuromuscular diseases and in normals. Respiration 1986;50:36-43.
22. Einarsson G, Grimby G. Strengthening exercise program in postpolio subjects. In: Halstead LS, Wiechers DO, editors. Research and clinical aspects of the late effects of poliomyelitis. White Plains (NY): March of Dimes Birth Defects Foundation; 1987. p. 275-83.
23. Spector SA, Gordon PL, Feuerstein IM, Sivakumar K, Hurley BF, Dalakas MC. Strength gains without muscle injury after strength training in patients with postpolio muscular atrophy. Muscle Nerve 1996;19:1282-90.
24. Agre JC, Rodriquez AA, Franke TM. Strength, endurance and work capacity after muscle strengthening exercise in postpolio subjects. Arch Phys Med Rehabil 1997;78:681-6.
25. Agre JC, Rodriquez AA, Tafel JA. Late effects of polio: critical review of the literature on neuromuscular function. Arch Phys Med Rehabil 1991;72:923-31.
26. Peach PE, Olejnik S. Effect of treatment and noncompliance on post-polio sequelae. Orthopedics 1991;14:1199-1203.
27. Ellis ER, Bye PTB, Bruderer JW, Sullivan C. Treatment of respiratory failure during sleep in patients with neuromuscular disease. Am Rev Respir Dis 1987;135:148-52.
28. Klefbeck B, Remmer L, Weinberg J, Borg J. A new nasal mask for nocturnal home ventilation in chronic neuromuscular disorders. Scand J Rehabil Med 1993;25:7-9.
29. Simonds AK, Elliott MW. Outcome of domiciliary nasal intermittent positive ventilation in restrictive and obstructive disorders. Thorax 1995;50:604-9.
30. Johnson PH, Cowley AJ, Kinnear WJM. Evaluation of the THRESHOLD® trainer for inspiratory muscle endurance training: comparison with the weighted plunger method. Eur Respir J 1996;9:2681-4.
31. Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377-81.
32. Hamnegård C-H, Wragg S, Kyroussis D, Aquilina R, Moxham J, Green M. Portable measurement of maximum mouth pressures. Eur Respir J 1994;7:398-401.
33. Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. Am Rev Respir Dis 1969;99:696-702.
34. Quanjer PD. Standardized lung function testing. Report from Working Party ''Standardization of lung function tests,'' European Community for Coal and Steel. Bull Eur Physiopathol Respir 1983;19(Suppl 5):11-21.
35. Quanjer PD. Standardized lung function testing. Report from Working Party ''Standardization of lung function tests,'' European Community for Coal and Steel. Bull Eur Physiopathol Respir 1983;19(Suppl 5):45-51.
36. Mahler DA, Weinberg DH, Wells CK, Feinstein AR. The measurement of dyspnea. Contents, interobserver agreement, and physiologic correlates of two new clinical indexes. Chest 1984;85: 751-8.
37. Grembowski D, Patrick D, Diehr P, Durham M, Beresford S, Kay E, et al. Self-efficacy and health behavior among older adults. J Health Soc Behav 1993;34:89-104.
38. Stenström CH, Boestad C, Carlsson M, Edström M, Reuterhäll Å. Why exercise? A comparative study among persons with rheumatic conditions and healthy subjects. Physiother Res Int 1997;2:7-16.
39. Kirk RE. Experimental design: procedures for the behavioral sciences. Pacific Grove (CA): Brools/Cole; 1995.
40. Åstrand P-O, Rodahl K. Physical training. In: Textbook of work physiology. Physiological bases of exercise. 3rd ed. New York: McGraw-Hill; 1986. p. 412-85.
41. Lisboa C, Munoz V, Beroiza T, Levia A, Cruz E. Inspiratory muscle training in chronic airflow limitation: comparison of two different training loads with a threshold device. Eur Respir J 1994;7:1266-74.
42. Larson JL, Kim MJ, Sharp JT, Larson DA. Inspiratory muscle training with a pressure threshold breathing device in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 1988;138:689-96.
43. Cahalin LP, Semigran MJ, Dec GW. Inspiratory muscle training in patients with chronic heart failure awaiting cardiac transplantation: results of a pilot clinical trial. Phys Ther 1997;77:830-8.
44. Cosgrove JL, Alexander MA, Kitts EL, Swan BE, Klein MJ, Bauer RE. Late effects of poliomyelitis. Arch Phys Med Rehabil 1987;68: 4-7.
45. Dean E. Clinical decision making in the management of the late sequelae of poliomyelitis. Phys Ther 1991;71:752-61.

46. Piper AJ, Sullivan CE. Effects of long-term nocturnal nasal ventilation on spontaneous breathing during sleep in neuromuscular and chest wall disorders. Eur Respir J 1996;9:1515-22.
47. Goldstein RS, De Rosie JA, Avendano MA, Dolmange TE. Influence of noninvasive positive pressure ventilation on inspiratory muscles. Chest 1991;99:408-15.
48. Nickerson BG, Keens TG. Measuring ventilatory muscle endurance in humans as sustainable inspiratory pressure. J Appl Physiol 1982;52:768-72.
49. Harver A, Mahler DA, Daubenspeck A. Targeted inspiratory muscle training improves respiratory muscle function and reduces dyspnea in patients with chronic obstructive pulmonary disease. Ann Intern Med 1989;111:117-24.
50. Martin AJ, Stern L, Yeates J, Lepp D, Little J. Respiratory muscle training in Duchenne muscular dystrophy. Dev Med Child Neurol 1986;28:314-8.
51. Hornstein S, Ledsome JR. Ventilatory muscle training in acute quadriplegia. Physiother Can 1986;38:145-9.
52. Gross D, Meiner Z. The effect of ventilatory muscle training on respiratory function and capacity in ambulatory and bed-ridden patients with neuromuscular disease. Monaldi Arch Chest Dis 1993;48:322-6.

Suppliers

a. Healthdyne International, Av general Dumonceau 56, B-1190 Brussels, Belgium.
b. Vacuum Pressure Gauge 0-40cm H_2O; Bird, Rium Medical KB, Turebergsvägen 7, S-191 47, Sollentuna, Sweden.
c. Morgan MPM (Mouth Pressure Meters); P.K. Morgan Ltd, 4 Bloors Lane, Rainham-Gillingham, Kent ME8 7ED, UK.
d. OXI; Radiometer A/S, Åkandevej 21, Dk-2700 Brønshøj, Denmark.
e. Sensor Medics Corp, 22705 Savi Ranch Parkway, Yorba Linda, CA 92887-4645.
f. Lifecare; Rium Medical KB, Sollentuna, Sweden.
g. Breas Medical, Göteborgsvägen 91B, S-431 37 Mölndal, Sweden.