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Self-Administered Chest Physiotherapy in Cystic Fibrosis: A Comparative Study of High-Pressure Pep and Autogenic Drainage

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Abstract. Fourteen patients with cystic fibrosis were trained in 2 self-administered chest physiotherapy (PT) techniques: high-pressure PEP-mask physiotherapy (PEP), and autogenic drainage (AD). They then visited the clinic on 5 consecutive days, and, in a random order, performed 1 of the following: PEP, AD, PEP followed by AD (PEP-AD), AD followed by PEP (AD-PEP), and, no PT except for spontaneous coughing. Lung function was measured repeatedly before, during, and after PT; time needed for and sputum produced by each form of PT was recorded. PEP produced the highest amount of sputum, followed by PEP-AD, AD-PEP, and AD; all 4 forms of PT produced significantly more sputum than coughing. Lung function improved significantly after PEP, AD, and PEP-AD, but PEP-induced changes did not exceed those after AD. Within the investigated group, the PEP-induced lung function improvement per milliliter of sputum produced was significantly lower for those patients with airway hyperreactivity. The fact that the highest sputum yield with PEP was not reflected in higher PEP-effected lung function changes might thus be explained by PEP-induced bronchospasm in patients with airway hyperreactivity. PEP clears more sputum than AD or combined techniques; patients with airway hyperreactivity, however, should either prefer AD or should take a bronchodilator premedication before PEP.

Key words: Cystic fibrosis—Chest physiotherapy—Sputum production—Lung function—Airway hyperreactivity.

Introduction

Chest physiotherapy (PT) is a traditional component of the therapeutic regimen for patients with cystic fibrosis (CF) [16, 19, 20]. In addition to conventional PT

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(postural drainage, chest clapping and vibration, assisted coughing), a spectrum of alternative methods have been developed. These include the forced expiration technique [12], autogenic drainage [2], low-pressure PEP-mask PT [5], and high-pressure PEP-mask PT [9]. All these newer techniques are self-administered and thus provide a substantial amount of personal independence for the patient.

It is unclear if one of these new methods is more effective than another. The results of comparative studies from different centers contradict each other [5, 7, 8, 9, 13, 18]. Because the effects of PT will always depend on a variety of therapeutic details, the practice and efficacy of a given technique might vary substantially from one center to another. Furthermore, there is considerable interindividual variation in the pathophysiology of CF lung disease [20]; therefore, any technique, that might ideally suit the needs of one particular patient might not be as effective for another. So far, however, no clear criteria for individualizing PT in patients with CF have been established.

The present study assessed comparatively the short-term effects of high-pressure PEP-mask PT and autogenic drainage on the sputum production and lung function status of a random sample of patients with CF. The working hypothesis was that either one of the 2 techniques would prove consistently superior to the other, or, that some criteria for choosing between both techniques on an individualized basis might be identified. Two combinations of both techniques were investigated as well.

Methods and Patients

Fifteen subjects, older than 6 years of age, trained to cooperate with pulmonary function testing, and producing more than 20 ml of sputum per day, were randomly selected from the patients of the local CF clinic. One patient developed symptoms of an acute respiratory viral infection during the study and was excluded. The remaining 14 (5 male, 9 female) had a mean age of 16.0 years (range, 9.8–22.4), a mean clinical score [15] of 62.2 points (range, 26–90), and a mean chest roentgenographic score [1] of 13.8 points (range, 6–20). The diagnosis of CF had been previously confirmed in all patients by repeatedly positive sweat tests (6). The general therapeutic regimen at the onset of the study included high-caloric nutrition with pancreatic enzyme replacement, supplemental salt and vitamins, and chest physiotherapy, performed 1–3 times daily. In addition, 4 patients were taking oral and 6 inhaled antibiotic therapy at home. Eight used inhaled sympathomimetic bronchodilators (salbutamol) on a regular basis. The prescription of this bronchodilator therapy had been based on the clinical symptoms of hyperreactive airway disease plus a positive bronchodilator response, as assessed by measuring end-expiratory flow rates [21].

Six months before the study, each patient was trained in 2 self-administered PT techniques: high-pressure PEP-mask PT (PEP) and autogenic drainage (AD). Care was taken to ensure competence in either technique, and the intensity of training was individualized according to the repeatedly assessed progress of each patient. PEP has been developed locally as a combination of a Danish PEP-mask PT-method and the forced expiration technique [9]. AD was learned by one of the authors (BT) in the center in Belgium where the technique had been developed [2]. PEP uses an anesthesiology rubber mask connected to a 1-way breathing valve with an expiratory resistor. While pressing the mask against his or her face, the patient breathes in and out rhythmically for 8–10 cycles and then performs a forced expiratory maneuver against the stenosis. This results in the mobilization and expectoration of sputum. The dimension of the expiratory resistor is determined individually by a spirometer-assisted method [9]. AD is a special breathing technique, aiming at expiratory airflow rates high enough for mobilizing and transporting secretions, but avoiding higher positive transthoracic pressures that may result in expiratory airway compression. AD breathing commences at low lung volumes and, subsequently, responds to the transport of secretions with a stepwise elevation of the level of breathing. Coughing and forced expiratory maneuvers are avoided. After careful training, patients were encouraged to use each of the two techniques every day until the onset of the study.

Informed consent for the study was obtained from patients and parents.

Each patient was investigated in a stable clinical situation; antimicrobial chemotherapy remained unchanged throughout the study. Prior to each visit, PT and bronchodilator medication were withheld for 6 hr. The study consisted of a series of 5 outpatient visits made at the same time on 5 consecutive days. At each visit, 5 assessments of lung function (pulmonary function tests [PFTs]) were done (PFTs 1–5). The intervals between PFT 1 and 2, and the interval between PFT 4 and 5 were both 30 min. The intervals between PFT 2 and 3, and PFT 3 and 4, were chosen for each patient individually and equalled 50% of that amount of time that each patient needed to clear his or her lungs by AD, as judged from prestudy experience.

Patients rested from PFT 1 to PFT 2, and from PFT 4 to PFT 5. In a random order, the patients performed a different form of PT from PFT 2 through to PFT 4 on each of the 5 visits. These were as follows: PEP alone (PEP); AD alone (AD); PEP from PFT 2 to PFT 3, then followed by AD from PFT 3 to PFT 4 (PEP-AD); AD from PFT 2 to PFT 3, then followed by PEP from PFT 3 to PFT 4 (AD-PEP); and at one of the visits, no PT at all except for spontaneous coughing (0). Between PFTs, time to clear the lungs (i.e., that time spent with PT and expectoration) was recorded. Sputum produced by each form of PT and by spontaneous coughing on day 0 was collected by the patients and weighed by an investigator blinded to the method of PT used.

PFTs were done in accordance with standardized guidelines [17]. Forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV_1) were measured using a water-filled spirometer (Spiro-Junior, Jaeger, Wurzburg, FRG). Results were expressed as percentage of predicted normal values, as based on appropriate reference standards [11]. Residual volume was measured plethysmographically [3] in a constant-volume, whole-body plethysmograph (Body-Test, Jaeger, Wurzburg, FRG). Results were expressed as a fraction of total lung capacity (RV/TLC). Airway resistance (Raw) was also measured plethysmographically.

A maximum expiratory flow-volume curve was recorded on a pneumotachygraph spirometer. For the sake of brevity, these measurements are not reported in the Results section; data are available upon request.

For statistical evaluation of the results, analysis of variance, the t test, and Fisher's test were used, with $p = 0.05$ as the limit of significance. In addition, intraindividual lung function variability was determined from PFTs 1–5 on day 0. Individual lung function changes on the 4 PT days were considered significant when they exceeded the mean ± 2SD limits of these 5 zero measurements.

Results

PFTs 1 are compared to PFTs 5 in Table 1. FVC increased significantly from PFT 1 to 5 at day PEP, AD, and PEP-AD. FEV_1 increased significantly from PFT 1 to 5 at day PEP, and PEP-AD, and RV/TLC decreased significantly from PFT 1 to 5 at day PEP, and PEP-AD. Raw decreased with each form of PT but changes did not reach statistical significance. There was no significant difference between PFTs 1 and 5 on day 0. PFTs 2 did not differ significantly from PFTs 1, and PFTs 4 did not differ significantly from PFTs 5; PFTs 3 showed an intermediate situation between PFTs 2 and 4.

There was no significant difference between the baseline PFTs on day PEP, AD, PEP-AD, and AD-PEP. Post-PT PFTs 5 after AD-PEP differed significantly from post-PT PFTs 5 after AD (FVC, $p < 0.05$; FEV_1, $p < 0.05$; RV/TLC,

Table 1. PFTs 1 versus PFTs 5

	FVC (% predicted)		FEV$_1$ (% predicted)		RV/TLC (%)		Raw (% predicted)	
	PFT$_1$	PFT$_5$	PFT$_1$	PFT$_5$	PFT$_1$	PFT$_5$	PFT$_1$	PFT$_5$
0	69 ± 23	70 ± 21	53 ± 21	53 ± 19	51 ± 15	51 ± 14	247 ± 134	235 ± 117
	NS		NS		NS		NS	
PEP	66 ± 21	73 ± 20	52 ± 21	54 ± 20	52 ± 15	50 ± 14	241 ± 117	211 ± 113
	p < 0.01		p < 0.05		p < 0.05		NS	
AD	69 ± 21	74 ± 19	54 ± 20	56 ± 19	51 ± 14	49 ± 14	225 ± 108	212 ± 93
	p < 0.05		NS		NS		NS	
PEP-AD	68 ± 21	73 ± 20	51 ± 18	55 ± 18	52 ± 15	50 ± 13	240 ± 128	216 ± 91
	p < 0.01		p < 0.02		p < 0.02		NS	
AD-PEP	69 ± 22	71 ± 21	52 ± 21	54 ± 19	51 ± 15	51 ± 14	239 ± 141	219 ± 97
	NS		NS		NS		NS	

Values are given as mean ± 1 SD
NS, not significant

$p < 0.01$). PFTs 5 after PEP and PEP-AD differed neither from those after AD-PEP nor those after AD.

FVC increased significantly after PEP in 4, after AD in 6, after PEP-AD in 7, and after AD-PEP in 4 patients. FEV1 increased significantly after PEP in 3, after AD in 4, after PEP-AD in 5, and after AD-PEP in 3 patients. RV/TLC decreased significantly after PEP in 2, after AD in 3, after PEP-AD in 5, and after AD-PEP in 1 patient. The differences between the 4 forms of PT did not reach statistical significance.

The amount of sputum produced by PEP, AD, PEP-AD, AD-PEP, and by spontaneous coughing on day 0 is shown in Fig. 1. PEP produced the highest amount of sputum, and differed significantly from AD ($p < 0.001$) and from AD-PEP ($p < 0.001$) but not from PEP-AD. Sputum production by PEP-AD was second and differed significantly from AD ($p < 0.02$), but not from AD-PEP and PEP. AD-PEP was third and differed significantly from AD ($p < 0.001$) and from PEP (see above), but not from PEP-AD. AD showed the lowest sputum production. All 4 forms of PT produced significantly more sputum than spontaneous coughing on day 0 ($p < 0.001$). The highest individual sputum production was obtained by PEP in 11, and by PEP-AD in 3 patients.

For PEP as well as for AD, a quotient was calculated by dividing the PT-induced change of FVC (in % predicted) by the weight of produced sputum (in g). This quotient was lower for PEP than for AD (0.29 ± 0.55 vs. 0.48 ± 0.80), but this difference did not reach statistical significance. When comparing the hyperreactive 8 patients to the 6 without airway hyperreactivity for PEP, the hyperreactive subgroup had a significantly lower quotient (0.06 ± 0.11 vs. 0.63 ± 0.75, $p < 0.05$). The same comparison done for AD did not reach statistical significance (0.24 ± 0.33 vs. 0.79 ± 1.14).

Time needed to clear the lungs by PEP, AD, PEP-AD, and AD-PEP is

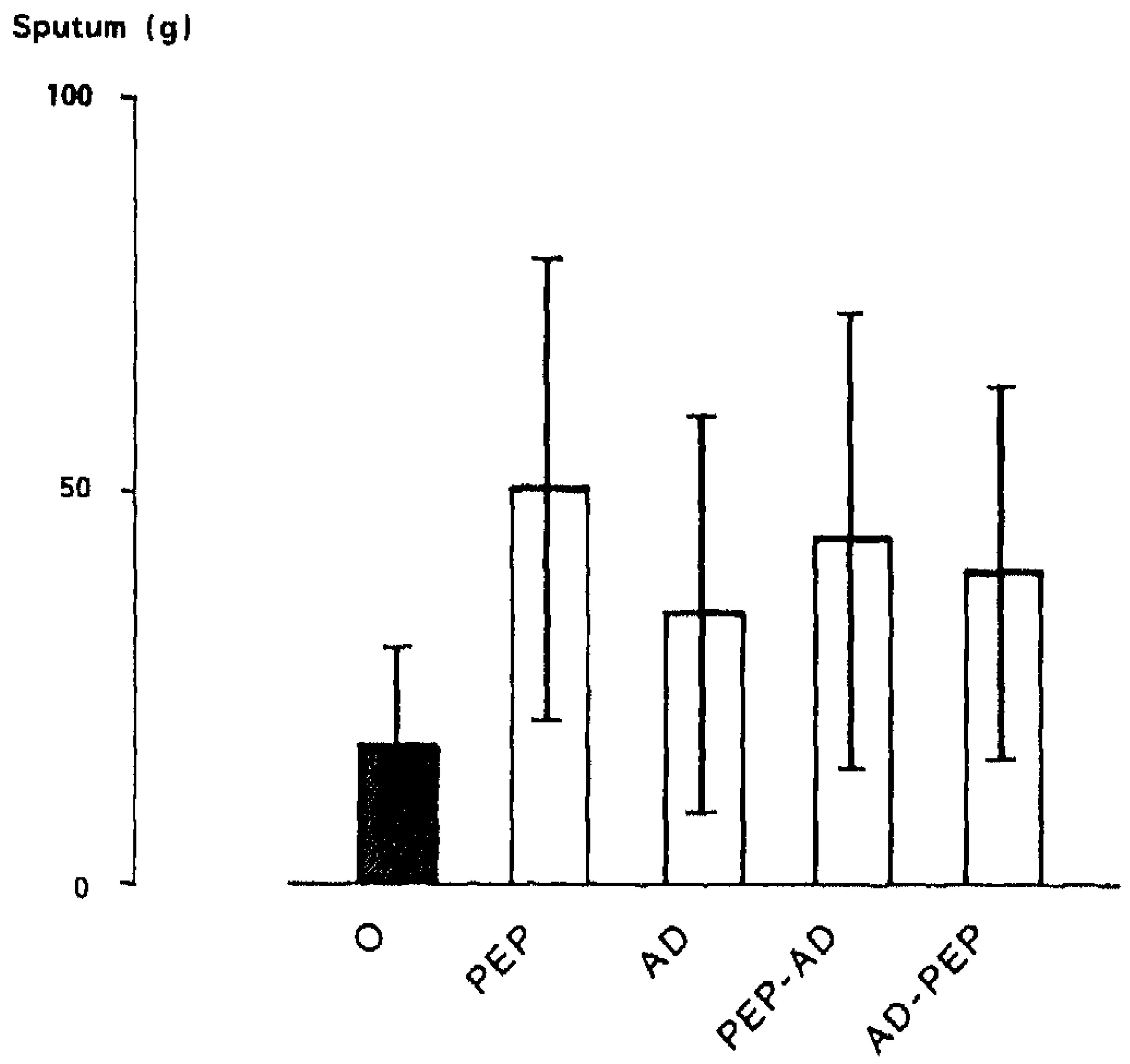

Fig. 1. Sputum production. Columns are means, vertical bars represent 1 SD.

shown in Fig. 2. There was no significant difference between AD, PEP-AD, and AD-PEP. Time needed for PEP, however, was shorter than for the other forms of PT and this difference reached statistical significance for AD ($p < 0.05$), PEP-AD ($p < 0.02$), and AD-PEP ($p < 0.05$).

Discussion

PEP produced more sputum in a shorter period of time than any of the other PT techniques. Sputum production by AD was lowest; both combined techniques led to an intermediate result. Thus, on the basis of mobilized, transported, and expectorated secretions, PEP was shown to be more effective than each of the 3 other forms of PT investigated.

This straightforward result, however, was not as clearly reflected in PT-induced lung function changes. After comparable baseline values, PEP, AD, and PEP-AD resulted in small but statistically significant lung function improvements, which indicated a decrease in expiratory airflow obstruction and hyperinflation. The best post-PT PFTs were observed after AD. A similar result was obtained when comparing individual lung function improvements; again AD led to the highest number of positive changes. Nevertheless, these lung function changes, while reaching statistical significance, remained relatively small. From a clinical viewpoint, they may indicate a tendency towards improvement,

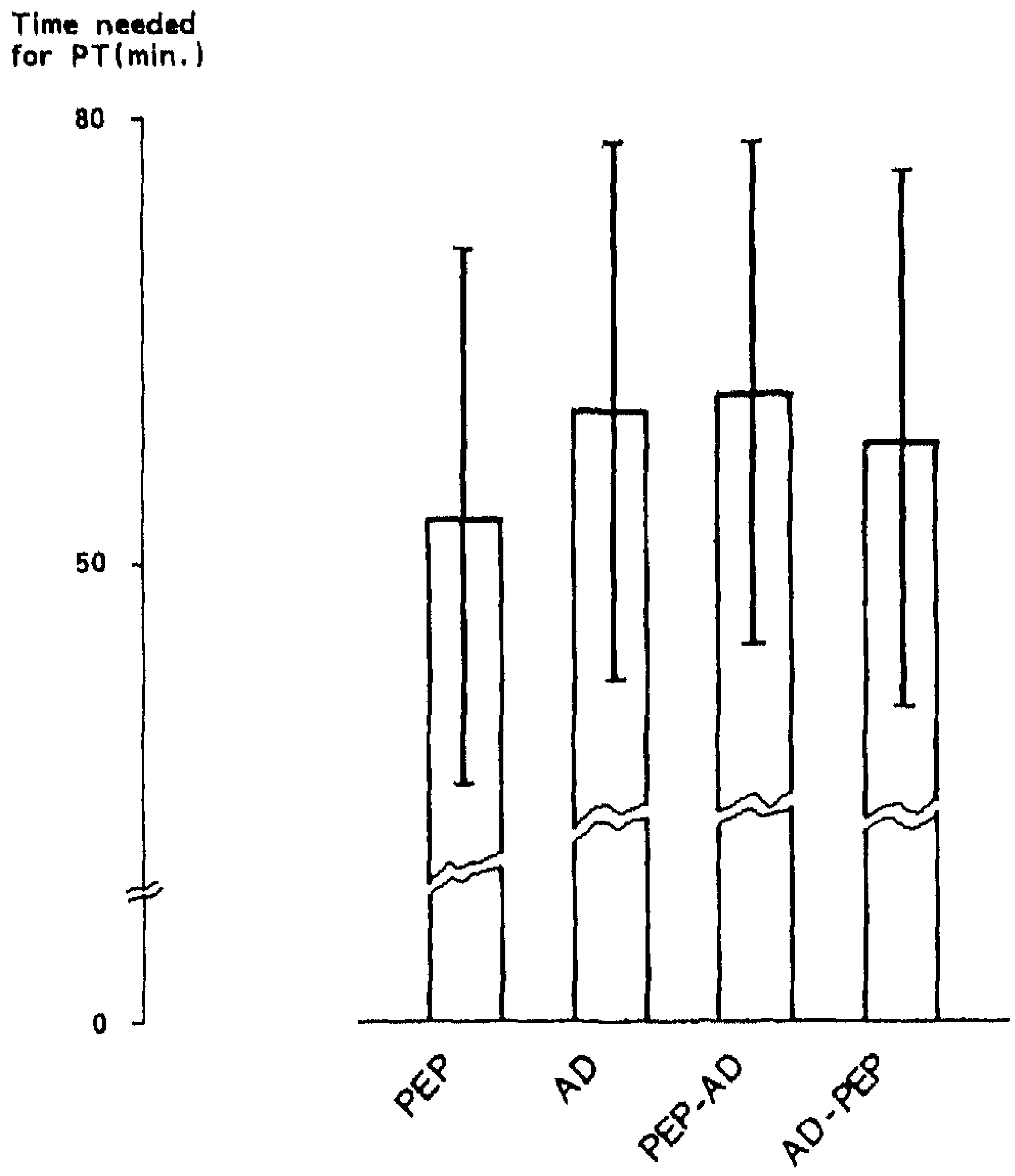

Fig. 2. Time needed for each form of physiotherapy (PT). Columns are means, vertical bars are 1 SD.

but any comparison of their relative magnitude must be interpreted with caution.

A previous investigation of PEP-induced short-term lung function changes succeeded in establishing a correlation between sputum production and improvements in PFTs [10]. As a consequence, one might expect to find the greatest lung function changes with the technique that produced the highest amount of sputum. For the present study, the question arises as to why highest sputum production with PEP was not reflected in superior PEP-effected lung function changes. This discrepancy suggests that for PEP another factor could have interfered with the translation of sputum production into lung function changes. Since mechanical irritation by PT can induce bronchospasm in patients with airway hyperreactivity [14, 20], this factor is most likely PT-induced bronchospasm. High-pressure PEP-mask PT employs forced expiratory maneuvers and thus should mechanically irritate intrathoracic airways more than AD, which tries to avoid high expiratory airway pressures [2, 9]. Furthermore, the investigated group included a high proportion of patients with airway hyperreactivity. In contrast to the above-quoted previous investigation of PEP-induced short-term function changes [10], there was no bronchodilator premedication before PT. As a further support for this speculation, the quotient relating PEP-induced FVC changes to sputum production was found to be significantly lower for the subgroup with airway hyperreactivity. Bronchospasm is a transient phenomenon. An increasing time-span between PEP and PFTs should decrease its influence on sputum-induced lung function changes. This is illustrated by the 2 combined forms of PT: the combination commencing with AD and ending with PEP produced consistently worse lung function results than PEP-AD. The speculation that PT-induced bronchospasm interferes with sputum-related lung function changes, when cleaning the airways of hyperreactive patients by PEP, is also supported by a previous study that compared low-pressure PEP-mask PT to AD and conventional PT, and, in hyperreactive patients, found a trend towards best lung function results with AD [8].

The results of the present study might have practical implications for the prescription of self-administered PT to individual patients. In general, one will recommend and teach that PT technique that produces most sputum in the shortest period of time, and, therefore, will tend to prefer PEP. In those patients with clinical and/or physiological signs of airway hyperreactivity, however, AD appears as an attractive alternative. Another way to neutralize any PEP-induced bronchospasm in these patients would be premedication with a bronchodilator. As shown previously, bronchodilators can reduce airway wall stability in patients with CF and thus might hamper the transport of secretions by enhanced expiratory airway compression [4, 21]. This negative mechanical effect, however, should be neutralized by the high-pressure PEP mask technique, which maintains a distending positive intraluminal pressure over the major part of a forced expiratory maneuver [9]. As a consequence, bronchodilator premedication should be considered when applying PEP in patients with CF who show airway hyperreactivity. In the present study, bronchodilator premedication was omitted and PEP-induced bronchospasm might not only have interfered with PFT changes but also hampered sputum production as well. Thus the question remains as to whether the sputum yield by PEP might be further increased after bronchodilator premedication. It should be of interest to assess PEP-induced sputum production and lung function changes comparatively in a similar group of patients with CF with and without bronchodilator premedication.

In theory, a combination of PEP and AD might be an alternative to using a single PT technique. In the present study, however, neither PEP-AD nor AD-PEP produced a higher sputum yield or a better lung function result than PEP or AD alone. There is thus no reason presently to recommend the use of such combinations.

In conclusion, this study documents the highest sputum production for PEP, but also illustrates an interesting discrepancy between sputum yield and lung function changes. Results suggest that this discrepancy is due to PEP-induced bronchospasm in patients with airway hyperreactivity. For such patients, one should either substitute AD as a less irritating technique, or consider the use of bronchodilator medication before PEP.

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