The Effects of Biofeedback Assisted Breathing Retraining on Lung Functions in Patients With Cystic Fibrosis*

Kerry K. Delk, Ph.D.; Richard Gevirtz, Ph.D.; David A. Hicks, M.D., F.C.C.P.; Frank Carden, Ph.D.; and Ralph Rucker, M.D.

This study examines the effects of respiratory muscle feedback and breathing retraining (BRT) on lung function in patients with cystic fibrosis (CF). Twenty-six patients with CF were matched for age and severity of disease. Standard respiratory spirometry was performed on all subjects before and after biofeedback training. Thirteen experimental subjects underwent eight sessions of pneumographic or strain-gauge feedback from the abdominal muscles and electromyogram feedback from accessory respiratory muscles to assist in learning diaphragmatic and pursed-lips breathing maneuvers. Control subjects received biofeedback-assisted (hand warming) relaxation training. Results revealed a significant improvement in FEV_1 and mean forced expiratory flow during the middle half of forced vital capacity (FVC) for the biofeedback group, while the control group showed no change. A similar trend was noted for FVC. These data suggest that respiratory muscle feedback and BRT may improve lung function in patients with CF.

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ANOVA = analysis of variance; BRT = breathing retraining; CF = cystic fibrosis; EMG = electromyogram; FEF25-75% = mean forced expiratory flow during the middle half of forced vital capacity; FVC = forced vital capacity; PLB = pursed-lips breathing; RLXT = relaxation training

Biofeedback-assisted breathing retraining (BRT) is a treatment technique which was described as early as 1969 as a therapy for lung disease in adults and children.[1] However, to date there is no empirical support for BRT or biofeedback-assisted BRT as an effective therapy in the treatment of cystic fibrosis (CF). The literature on breathing retraining appears to be limited to asthma and adult respiratory diseases (COPD, emphysema, etc). In these adult illnesses, breathing exercises have been shown to increase tidal volume and blood oxygen saturation, improve alveolar ventilation, strengthen respiratory muscles, improve mucus clearance by increasing the strength of cough, slow the rate of respiration, reduce dyspnea, reduce the work of breathing, and improve coordination of respiratory muscles in respiration.[2-6] Biofeedback increasingly has been used to enhance the BRT procedures, with positive effects on lung volume measures, blood oxygen saturation, respiratory muscle function, and subjective discomfort.[7-9] Despite these results in adult lung disease, the effects of BRT in CF remain unstudied.

Considering the evidence just discussed, we decided to apply a biofeedback-assisted BRT protocol to the treatment of CF. Our study tested experimentally the hypotheses that biofeedback-assisted BRT would produce a significant improvement in lung functions when compared with biofeedback-assisted relaxation training, which we hoped would serve as a credible "placebo" procedure.

*From Children's Hospital of Orange County, Orange, Calif (Drs. Delk, Hicks, Carden, and Rucker), and California School of Professional Psychology, (Dr. Gevirtz); San Diego.

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Reprint request: Dr. Delk, 351 Hospital, Road, Suite 617, Newport Beach, CA 92665

Materials and Methods

Subjects

Twenty six subjects were selected, ages 10 to 41 years, from a population of patients with CF seen at Children's Hospital of Orange County, Orange, Calif. In order to insure protection of the subject's rights and health, all subject selection was conducted in accordance with the Ethical Principles of the American Psychological Association and approved by the Children's Hospital Committee on Human Subjects.

Subjects were screened medically, matched by age and severity disease, and randomly assigned to either the experimental group receiving biofeedback-assisted BRT or to the control group receiving peripheral temperature biofeedback-assisted relaxation training (RLXT). Matching of the severity of disease was accomplished by Shwachman-Kulczycki[10] scoring, a standard comprehensive rating system. A series of three optimal lung function tests covering the previous year were collected from the patient's medical records. Subjects in both groups were given pretraining lung function measures. They completed eight sessions, over 4 weeks, of biofeedback training specific to the protocol for their group. Following the 4 weeks of training, their lung functions were again measured.

Physiologic Measurements

Following admission to the study all pre- and postmeasurements of lung function were determined by standard spirometry. The lung functions measured included forced vital capacity (FVC), FEV_1, and mean forced expiratory flow during the middle half of the maneuver (FEF25-75%). The lung function testing was performed on a computerized (Apple IIe) Sensormatic spirometer by Horizon Systems (9-L bellows by Ohio Medical Products). Each patient was assisted by a certified respiratory therapist. Biofeedback was performed with a Biocomp 2001 computerized, telemetric, four-channel system on an Apple IIe computer. Subjects in both groups were connected to a pneumograph or strain gauge placed on the lower abdomen (diaphragmatic excursion feedback), an electromyographic (EMG) sensor placed on the trapezius muscles (accessory muscle feedback), and a thermistor placed on the ventral side of the left middle finger (peripheral hand temperature).

Table 1—*Means, Standard Deviations, and Analysis of Variance for FEV$_1$, FEF25-75%, and FVC*

	Pretreatment		Posttreatment	
	Mean	SD	Mean	SD
FEV$_1$, L/s				
BRT group (n = 13)	1.56	0.78	2.06	0.88
RLXT group (n = 13)	1.28	0.56	1.39	0.58
FEF25-75%, L/s				
BRT group (n = 12)	0.91	0.51	1.32	0.56
RLXT group (n = 12)	0.76	0.46	0.78	0.40
FVC, L				
BRT group (n = 13)	2.46	1.07	3.18	1.58
RLXT group (n = 13)	2.14	0.81	2.31	0.80

Experimental Design

The experiment followed the pretest-posttest control group design. This experiment used students in psychology and biofeedback as trainers. Trainers were given basic education about CF, standards for subject care, and training specific to their assigned protocol.

Treatment Procedures

Subjects in the BRT group received only diaphragmatic excursion feedback and diaphragmatic breathing instructions for the first three sessions. Subjects were coached in producing maximal abdominal excursion. Electromyographic trapezius muscle feedback was introduced in session 4 and instruction in pursed-lips breathing (PLB) was begun. Subjects were then coached in maintaining the abdominal rhythm, coordination, and minimizing trapezius muscle activity while engaging in diaphragmatic and PLB. The BRT subjects practiced the combination of PLB and diaphragmatic breathing maneuvers at home with the aid of an incentive inspirometer and recorded inspired volumes. The results of home practice were turned in to the trainers as completed. The subjects receiving BRT did not receive temperature biofeedback.

Individuals in the RLXT group received training in relaxation and hand warming with temperature biofeedback. Relaxation was taught through the use of standard prerecorded relaxation tapes. Instruction in the actual conscious manipulation of the temperature feedback was begun in session 3. Subjects in the RLXT group were given audiocassette copies of the relaxation procedures and were asked to practice relaxation once a day at home. Subjects recorded results of home practice of relaxation and returned them to trainers on a regular basis. The RLXT subjects did not receive diaphragmatic or trapezius muscle feedback.

Statistical Design

The dependent variables in this study were standard spirometric assessment of lung functions, including FVC, FEV$_1$, and FEF25-75%.[11-13]

Separate 2 x 2 (group) (pre- vs post-) analyses of variance with one repeated measure were performed on all three dependent variables (FVC, FEV$_1$, and FEF25-75%). Bonferonni corrections for type 1 error were applied to all dependent variables. Changes in lung function also were evaluated for clinical significance (15 percent or greater improvement).

RESULTS

Group Equivalence

Differences between group means for the two matching variables and relevant premeasures were calculated by independent group Student's *t* tests. Groups did not differ significantly in age, severity of disease (as rated by the Shwachman-Kulczycki[10] scoring system), height, weight, or pretreatment lung functions (FVC, FEV$_1$, and FEF25-75%).

Three additional samples of optimal or "healthy" lung function were collected from each subject's medical record for a period of approximately 1 year prior to the study. A two (group) by four (pre-1, pre-2,

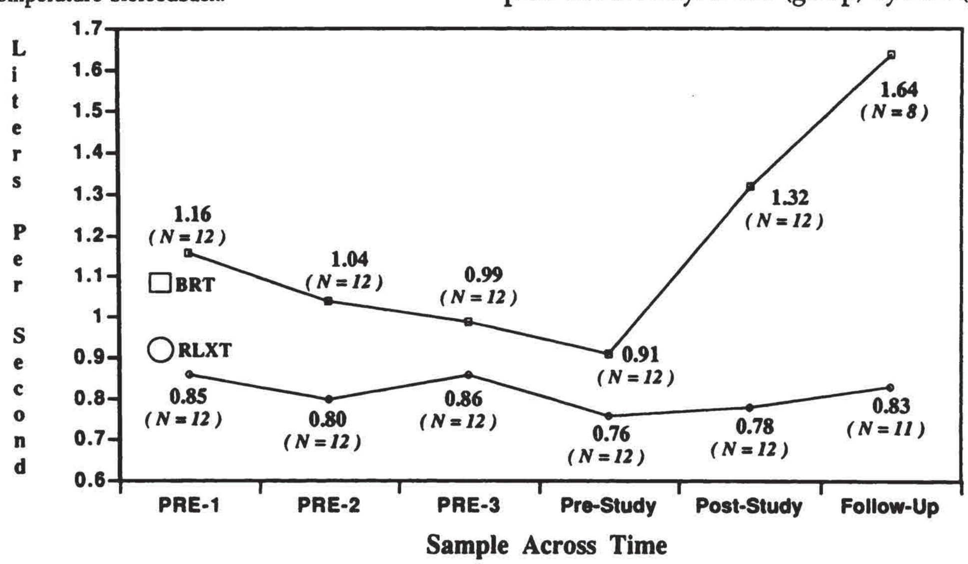

FIGURE 1. Means of FEV$_1$ group plotted across time. Three optimal or "healthy" samples of lung function (pre-1, pre-2, and pre-3) were collected from the subjects' medical records for a period of 18 months prior to the study. The two groups were found to be equivalent on all prestudy samples. A trend toward decreasing lung function measures is seen in both groups for that period (pre-1 to prestudy) but was not statistically significant. Comparison of results for the two groups from prestudy to poststudy shows a significant difference ($p < 0.01$). This improvement in the experimental group was clinically significant at 32 percent. Change in the control group was calculated to be a 9 percent increase. Limited follow-up data are presented.

pre-3, and prestudy) analysis of variance (ANOVA) was then performed on these four pretreatment lung function samples. Those data showed the BRT and RLXT groups to be equivalent on the basis of the mean lung function measures of FVC, FEV_2, and FEF25-75% for the previous year.

Documenting Treatment Effects

In order to evaluate the extent to which subjects learned to perform the prescribed biofeedback technique, separate two (pre- vs post testing) by two (BRT vs RLXT) analyses of variance were performed on all biofeedback data and examined for significant changes between the first and the eighth sessions. Evidence which demonstrates that the BRT subjects learned to perform the prescribed change in the pattern of respiratory muscle use is seen in a comparison of the two groups on the basis of mean diaphragmatic excursion feedback and trapezius EMG feedback (EMG). Over the eight sessions, the BRT group produced significant ($F1,11 = 10.85$, $p<0.01$) increases in diaphragmatic excursion compared with those in the RLXT group, while decreasing trapezius muscle activity ($F1,23 = 4.73$, $p<0.05$).

In the RLXT group, we wanted to document physiologic changes suggesting relaxation effects. To do this, finger temperature was monitored throughout each session. A significant increase in finger temperature was seen in the RLXT group when compared with the BRT group ($F4,400=28.63$, $p<0.001$).

Measures of Lung Function

The FEV_1 FEF25-75%, and FVC were used as the measures of change in lung function for this study.[14-15] Each lung function measure was recorded and subjected to independent 2x2 (group) (pre- vs post-) ANOVA and results are presented in Table 1.

The results of the ANOVA for FEV_1 (Fig 1) reveal a significant interaction between groups ($F1,24 = 7.33$, $p< 0.01$). Analysis of simple effects showed no significant pretreatment differences between the groups ($F1,24 = 1.15$, p = NS), and posttreatment means were significant in their differences ($F1,24 = 5.31$ $p<0.05$). The BRT group demonstrated a significant increase in FEV_1 ($F1,12 = 14.73$, $p<0.01$). This represents a change of 32 percent from pre- to post training and is considered clinically significant.[16] The RLXT group results for FEV_1 remained relatively stationary ($F1,12 = 3.73$, p = NS) with a 9 percent improvement.

The results of the ANOVA comparing FEF25-75% for the two groups (Fig 2) showed a significant interaction ($F1,22 = 6.92$, $p<0.05$). Simple effects analysis of FEF25-75% pretreatment means indicated there were no significant differences between the groups ($F1,22 = 0.57$, p = NS), whereas the posttreatment means were significantly different, favoring the BRT group ($F1,22 = 7.37$, $p<0.01$). For FEF25-75%, the BRT group improved significantly ($F1,11 = 9.41$, $p< 0.01$) from pretreatment to posttreatment values. This was calculated to be a 38 percent increase in FEF25-75% after training. The RLXT group showed no significant improvement between the pretreatment and posttreatment values ($F1,11 = 0.06$, p = NS). The mean percent improvement was 3 percent.

The results for the two (group) by two pre- vs posttraining) ANOVA of FVC were not significant

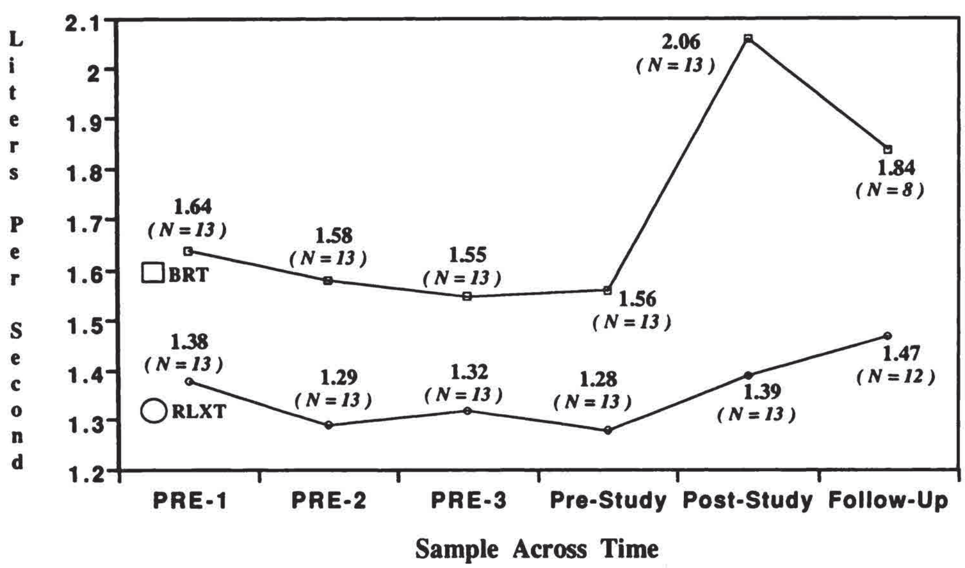

FIGURE 2. Means of FEF25-75% group plotted over time. Three optimal or "healthy" samples (pre-1, pre-2, and pre-3) were collected for a period of 18 months prior to the study. Groups are equivalent on all prestudy samples. A slight but statistically nonsignificant decrease is noted from pre-1 to prestudy for both groups. Prestudy to poststudy change in FEF25-75% is significant ($p < 0.01$) for the BRT group and represents a 38 percent change. The RLXT group data showed no change. Limited follow-up data suggest additional improvements are possible.

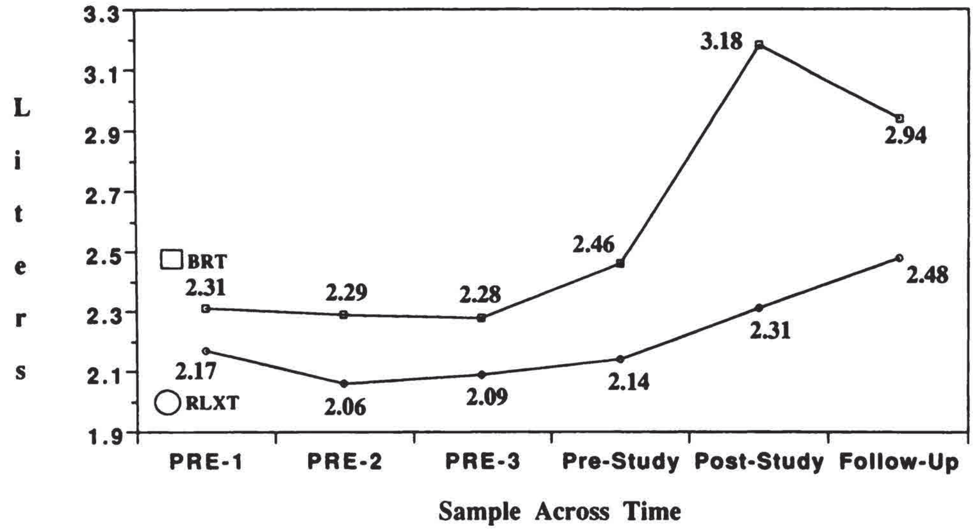

FIGURE 3. Means of FVC group across time. Pre-1 through prestudy measures for 18 months prior to the study are shown and groups were found to be equivalent. While a trend from prestudy to poststudy suggests greater improvement in the experimental group, it was not statistically significant when compared with the trend in the control subjects. However, the change in the experimental group alone appears to be clinically significant at 29 percent improvement. The 8 percent change in the control group is not.

($F_{1,24} = 3.75$, $p<0.10$), although changes were in the predicted direction (Fig 3). Analysis of simple effects showed that the groups were not significantly different at pretreatment or at posttreatment. The BRT group did show a significant increase in FVC from pretreatment to posttreatment ($F_{1,24} = 7.31$, $p< 0.05$). This was a 29 percent improvement in FVC (clinically significant). The change for the RLXT group from pretreatment to posttreatment was not significant, and the percent change was 8 percent.

Discussion

The results obtained in the present study yield support for the experimental hypotheses and demonstrate the utility of biofeedback-assisted BRT as a behavioral treatment for respiratory function in CF. These results are consistent with studies which dem onstrate the efficacy of biofeedback-assisted BRT ap plications to adult obstructive lung diseases.[7-9]

The increases in FEV_1 among the experimental subjects are probably the most reproducible and reliable measures of change among the lung functions we monitored.[17] These positive changes in the experimental subject's ability to expel air are both statistically and clinically significant. The ability to move significantly greater volumes of air may suggest an improvement in the clinical status of the subject. Several mechanisms may be at work to explain this change. Reduction in air trapping, improvements in lung compliance, and reduced airway resistance are possible effects of training, considering both PLB and diaphragmatic breathing maneuvers were employed. Significant improvement in FEF25-75% and a modest increase in FVC in the experimental group offer some support for these hypotheses.

Other possible mechanisms to explain improvement in FEV_1 may include increased respiratory muscle strength, increased use of the diaphragm in the expiratory maneuver, and better coordinated use of all musculature in expelling air. This mechanism receives support from clinical observation and recorded change in the use of the diaphragm, coordination, and reduction in the use of accessory muscles for experimental subjects during training. These changes were not seen in the control subjects.

Finally, it is possible that subjects in the experimental group produced changes as a function of greater effort or motivation. It is, therefore, useful to note that both experimental and control subjects believed that their training resulted in improvements in their condition. This would diminish the likelihood that differences in the groups were a function of differential motivation or effort.

The change in FEF25-75% for the experimental group from pretreatment to posttreatment also is both statistically and clinically significant. The FEF25-75% is a useful cross-reference in establishing the effect of training in that it is considered to be a more effort-independent and a more sensitive measure of small airway changes.[18] This sensitivity to the small airway change adds weight to the hypothesis that improvements may be a function of decreases in physiologic obstruction following training. The effort-independent nature of this measure also may suggest that improvements measured were not due to motivational differences between groups. The 38 percent increase in FEF25-75% in the BRT group may serve as an indication of the magnitude of the treatment effect.

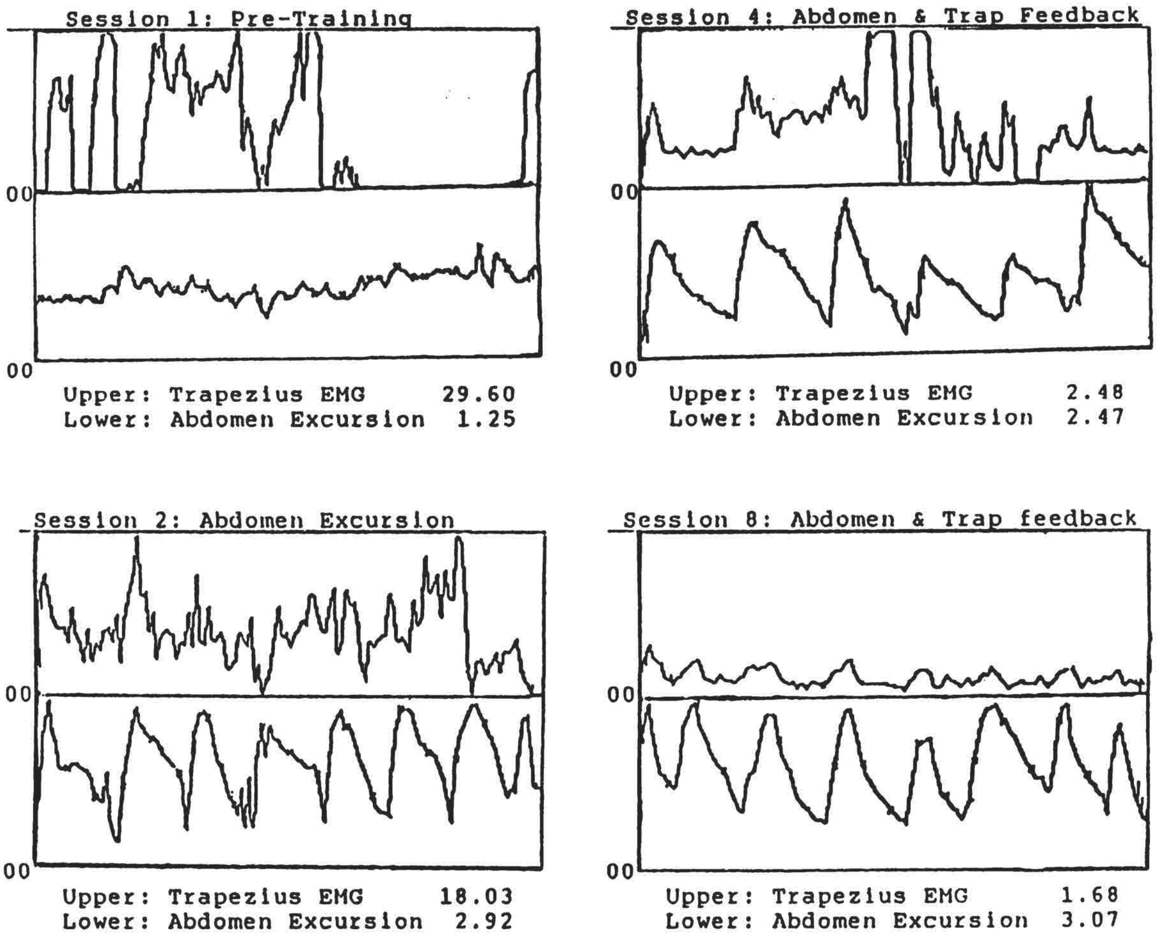

FIGURE 4. Samples of 30-s training graphs taken during study. The subject was an 11-year-old girl with severe lung disease as rated by the Schwachman-Kulczycki[10] score of 45. Pretraining *(top left)* shows poor respiratory muscle coordination with minimal use of the diaphragm and excessive trapezius muscle involvement. The introduction of diaphragmatic feedback at session 1 *(bottom left)* and trapezius feedback in session 4 *(top right)* allow the patient to greatly improve coordination and efficiency of respiratory effort. Session 8 *(bottom right)* shows virtually normal trapezius EMG and rhythmic diaphragmatic excursion. This subject showed a 120 percent improvement in FEF25-75% at poststudy sample.

Another indicator of treatment magnitude is that six subjects in the BRT group saw improvements in FEV_1 and FEF25-75% of approximately 100 percent or more. No subjects in the RLXT group produced changes even approaching this level of improvement. Which subjects will benefit most by these techniques and under what conditions remains a question worth pursuing.

A typical example of an individual BRT subject's progress may be instructive. Figure 4 shows 4 separate 30-s "snapshots" of abdominal/diaphragmatic excursion (the lower portion of each graph) and EMG muscle activity (the upper portion of each graph) occurring over the 8 training sessions. This particular example is from an 11-year-old girl with a Shwachman-Kulczycki[10] score of 45 (severe impairment). Pretraining (Fig 4, *top left*) shows a poorly coordinated use of primary and accessory respiratory musculature. Note the excessive trapezius muscle activity (29.60 μV); and the lack of excursion of the abdomen. By session two (Fig 4, *bottom left*); the subject is successfully producing a diaphragmatic breathing rhythm with abdominal excursion feedback alone. She has not yet begun to receive trapezius EMG feedback and trapezius activity remains quite high. During session four (Fig 4, *top right*), with the introduction of trapezius EMG feedback, the subject is able to reduce accessory muscle activity substantially while maintaining good abdominal excursion. By the eighth session (Fig 4, *bottom right*), the subject is able to perform deep diaphragmatic breathing with minimal accessory muscle use. This subject demonstrated a 120 percent increase in FEF25-75% from pre- to posttraining.

The changes depicted in these training graphs show an increased use of the diaphragm, decreasing frequency of respiration rate, improved coordination, and a reduction of trapezius muscle use. This is typical of the performance of most of the BRT subjects. Subjective impressions of the quality of change in breathing pattern seemed to correlate with lung function improvements.

References

1 Block JD, Lagerson J, Zohman LR, Kelly G. A feedback device for teaching diaphragmatic breathing. Am Rev Respir Dis 1969; 100:577-78

2 Motley HL. The effects of slow deep breathing on the blood gas exchange in emphysema. Am Rev Respir Dis 1963; 88:484-92

3 Thoman RL, Stoker GL, Ross JC. The efficacy of pursed-lips breathing in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 1965; 93:100-06

4 Muller RE, Petty TL, Filley GF. Ventilation and arterial blood gas changes induced by pursed lips breathing. J Appl Physiol 1970; 28:784-89

5 Sharp JT, Danon J, Druz WS, Goldberg NB, Fishman H, Machnach W. Respiratory muscle function in patients with chronic obstructive pulmonary disease: its relationship to disability and to respiratory therapy. Am Rev Respir Dis 1974; 110:154-67

6 Jones NL. Physical therapy: present state of the art. Am Rev Respir Dis 1974; 110:132-36

7 Johnson R, Lee K. Myofeedback: a new method for teaching breathing exercises in emphysematous patients. Phys Ther 1976; 56:826-29

8 Casciari RJ, Fairshter RD, Harrison A, Morrison JT, Blackburn C, Wilson AF. Effects of breathing retraining in patients with chronic pulmonary disease. Chest 1981; 79:393-98

9 Tiep BL, Burns M, Kao D, Madison R, Herrera J. Biofeedback augmented pursed lips breathing training in patients with chronic obstructive pulmonary disease. Chest 1986; 90:218-21

10 Shwachman H, Kulczycki LL. Long term study of one hundred five patients with cystic fibrosis. Am J Dis Child 1958; 96:6-15

11 Wessel H. Lung function in cystic fibrosis. In: Lloyd-Still JD, ed. Textbook of cystic fibrosis. Boston: John Wright, PSG, 1985; 165-97

12 Haas A, Pineda H, Haas F, Axen K. Pulmonary therapy and rehabilitation: principles and practice. Baltimore: Williams and Wilkins, 1979; 47-56

13 Hodgkin JE. Routine pulmonary function tests. In: Hodgkin JE. Chronic obstructive pulmonary disease. Philadelphia: WB Saunders, 1978; 231-39

14 Orenstein DM, Franklin BA, Doershuk CF, Hellerstein HK, Germann KJ, Horowitz JG, et al. Exercise conditioning and cardiopulmonary fitness in cystic fibrosis. Chest 1981; 80:392-403

15 Luce JM, Culver BH. Respiratory muscle function in health and disease. Chest 1982; 81:82-90

16 Pennock BE, Rodgers RM, McCaffree DR. Changes in measured spirometric indices, what is significant? Chest 1981; 80:97-99

17 Nickerson BG, Lemen RJ, Gerdes CB, Wegmann MJ, Robertson G. Within-subject variability and percent change for significance of spirometry in normal subjects and in patients with cystic fibrosis. Am Rev Respir Dis 1980; 122:859-66

18 Cropp GJ, Pullano TP, Cerny FJ, Nathanson IT. Exercise tolerance and cardiorespiratory adjustments at peak work capacity in cystic fibrosis. Am Rev Respir Dis 1982; 126:211-16