American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

Effects of Industrial Respirator Wear During Exercise in Subjects With Restrictive Lung Disease

THOMAS K. HODOUS , T CONNIE BOYLES & JOHN HANKINSON

To cite this article: THOMAS K. HODOUS , T CONNIE BOYLES & JOHN HANKINSON (1986) Effects of Industrial Respirator Wear During Exercise in Subjects With Restrictive Lung Disease, American Industrial Hygiene Association Journal, 47:3, 176-180, DOI: 10.1080/15298668691389540

To link to this article: https://doi.org/10.1080/15298668691389540

Published online: 04 Jun 2010.

Am. Ind. Hyg. Assoc. J. 47(3):176-180 (1986)

Effects of Industrial Respirator Wear During Exercise in Subjects With Restrictive Lung Disease*

THOMAS K. HODOUS,† CONNIE BOYLES and JOHN HANKINSON

Clinical Investigations Branch, National Institute for Occupational Safety and Health, 944 Chestnut Ridge Road, Morgantown, WV 26505

Few studies have examined the response of individuals with restrictive lung disease (RLD) to respirator wear. Such information should be of theoretical and practical interest when the need to determine fitness to wear respirators is considered. Seventeen females performed progressive submaximal treadmill exercise. Twelve control subjects with total lung capacity (TLC) = 5.71 ± .19L (mean ± SEM) and DLCO = 25.8 ± 1.0 mL/min/mmHg were compared to five RLD subjects with TLC = 3.70 ± 0.22 and DLCO = 14.5 ± 0.7. Mean age, height and weight were similar. Separate exercise trials were performed with no added resistance (NAR), and with 5 cm H_2O/L/sec inspiratory and 1.5 cm H_2O/L/sec expiratory resistance (R_2) to simulate widely used respiratory masks. Comparisons of exercise data were made at an oxygen consumption of 0.8 L/min. With NAR, RLD subjects had significantly higher minute ventilation ($\dot{V}_E$) (29.0 *vs.* 21.2 L/min for controls), higher respiratory rate (RR), and lower tidal volume (V_T). Heart rate, end-tidal PCO_2 ($P_{ET}CO_2$), and mouth pressure swing (Poral) were not different from control values. With R_2 compared to NAR, the controls had reduced RR and $\dot{V}_E$; and increased V_T, $P_{ET}CO_2$, and Poral. While changes with R_2 for the RLD subjects were in the same directions as controls, only the increase in Poral was statistically significant. Analysis of the differences showed that none of the changes with R_2 in RLD subjects was different from control changes except for the greater increase in Poral and the smaller increase in V_T. The former was explained by the RLD subjects' higher $\dot{V}_E$ and flow rates, and the non-linear nature of R_2 at higher flow rates. Our data suggest that the stress to RLD subjects of the resistance used is minor compared to that of mild exercise.

Introduction

Regulations of the Occupational Safety and Health Administration mandate that workers exposed to hazardous substances be provided with respiratory protective devices when engineering and adminstrative controls cannot protect the worker adequately.[1] These regulations also provide that the workers who are unable to wear these devices for reasons of health be exempted from doing so.

Although there are considerable experimental data in the literature concerning the effects of added resistance and dead space on the breathing of normal individuals, few studies address these effects in subjects with impaired function. One might expect workers with impaired cardiopulmonary function to be less likely to tolerate safely and comfortably the added stress of respirator wear. Preliminary studies suggest that individuals with mild to moderate obstructive lung disease can tolerate the stress of most respirators satisfactorily.[2-4] The other major type of pulmonary physiologic impairment is called restrictive, which could occur after partial lung resection or in a variety of interstitial lung diseases. Although the prevalence of subjects with restrictive lung disease is much lower than that with obstructive disease, it is important to know if the former individuals can safely tolerate respiratory protective devices. In order to study this question, we examined the responses of subjects with restrictive lung disease (RLD) to exercise with and without added resistance to breathing and compared those responses to a group of controls.

†To whom reprint requests should be sent: Thomas K. Hodous, M.D., ALOSH, 944 Chestnut Ridge Road, Morgantown, WV 26505.

*Mention of brand names does not constitute endorsement by NIOSH, CDC, USPHS, or DHHS.

Methods

Subjects

Healthy female volunteers and female patients with RLD were recruited from the West Virginia University Medical Center Outpatient Clinics, previous National Institute for Occupational Safety and Health (NIOSH) studies of coal miners, and personnel lists of the Morgantown facility of NIOSH. Informed consent was obtained from all subjects to perform the protocol, which had been approved by the NIOSH Human Subjects Review Board. Subjects were screened with a telephone questionnaire and then with a medical history, resting electrocardiogram, and physical exam; subjects with angina pectoris, significant aortic stenosis, or other contraindications to treadmill exercise were excluded. The study group consisted of 17 subjects: 12 control subjects, and 5 with restrictive disease. Restrictive lung disease was defined to include subjects with either diffusing capacity or total lung capacity (both determined by Hewlett-Packard Model 47404A) below 80% of predicted,[5,6] and no obstruction. Controls had normal spirometry and DLCO. Anthropomorphic data (Table I) show that there were no significant differences in age, height or weight between the

TABLE I
Anthropomorphic Data

	Control Females n = 12 Mean SEM	Restricted Females n = 5 Mean SEM
Age (Years)	35.2 ± 2.9	32.8 ± 5.1
Height (Inches)	64.6 ± 0.8	62.6 ± 1.0
Weight (Pounds)	151 ± 6.5	140 ± 8.7

No significant differences between controls and restricted subjects.

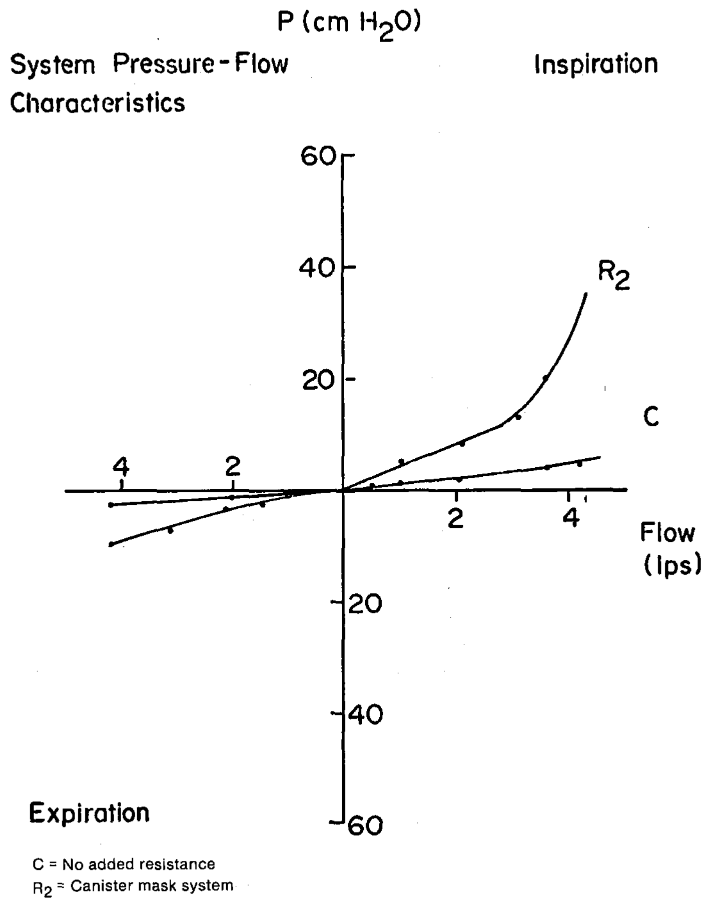

Figure 1 — System pressure-flow characteristics with and without added resistance.

two groups, although RLD subjects tended to be younger and smaller than controls. Five controls and three RLD subjects had a history of cigarette smoking, with an average of 5.3 and 9.0 pack-years, respectively. Four of the five RLD subjects had a diagnosis of sarcoidosis, and one was thought to have oxygen toxicity associated with an episode of adult respiratory distress syndrome.

Procedures

Airways resistance (Ohio No. 310 constant-volume body plethysmograph, Ohio Instruments, Madison, Wis.) and single-breath carbon monoxide diffusing capacity (Model 47404A; Hewlett-Packard, Waltham, Mass.) tests were performed with the use of previously published standard techniques.[7-9] Maximal inspiratory mouth pressure (Pmax) was determined also.[10] Fifteen-second maximal voluntary ventilation (MVV) maneuvers were performed with both no added resistance (NAR) and an added resistance (R_2) with the use of the exercise apparatus discussed below.

During exercise testing, subjects breathed from a mouthpiece attached to a Collins high velocity, low resistance, one-way valve. The inspiratory line was connected via wide-bore tubing to a pneumotachygraph and then to a Collins 5-way control valve (P 318). This could be opened either to air (NAR), or a respirator canister (Model 084-CL-R chlorine, dust, smoke, metal fumes and radioactive particles; Scott Laboratories, Fiskeville, R.I.) (R_2). Expired air was collected in a mixing chamber and then vented either to the atmosphere (NAR) or through a laminar 1.5 cm H_2O/L/sec resistance to simulate a respirator expiratory valve (for R_2). The apparatus dead space was 100 mL. The pressure-flow characteristics of R_2 and the NAR condition are shown in Figure 1.

Four trials of progressive treadmill exercise were performed by each subject. Treadmill speed was held constant at 3 mph, and the grade, starting at 0%, was increased 2% at the end of each minute. Subject monitoring during exercise included electrocardiogram, inspired air flow (Fleisch pneumotachygraph with Validyne pressure transducers) (Fleisch, Lausanne, Switzerland and Validyne Co., Northridge, Calif.) and mixed expired gases (Perkin-Elmer medical gas analyzer; Perkin-Elmer Medical Instruments, Pomona, Calif.). During the last 10 sec of each minute, end-tidal PCO_2 ($P_{ET}CO_2$) and mouth pressure swing (Poral) (Validyne pressure transducer) were recorded. On-line calculations of oxygen consumption ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$), tidal volume (V_T), respiratory rate (RR), heart rate (HR), and respiratory exchange ratio (R) were performed and displayed by a laboratory computer (LSI—11, Digital Equipment Corp.).

Exercise continued until either: (1) $\dot{V}O_2$ = 1.5 L/min (STPD) was reached; (2) a predetermined heart rate cut-off was reached (170 beats/min for subjects in their third decade and decreasing 10 beats/min for each subsequent decade);[11]

TABLE II
Pulmonary Function Data

Parameter	CONTROL FEMALES n = 12 Mean SEM	RESTRICTED FEMALES n = 5 Mean SEM
FEV_1 (L)	3.35 ± 0.19	1.87 ± 0.15[A]
FVC (L)	4.06 ± 0.17	2.51 ± 0.15[A]
FEV_1/FVC, %	82.3 ± 1.89	74.4 ± 3.41
TLC (L) (He)	5.71 ± 0.19	3.70 ± 0.22[A]
TLC, % of Pred.	109.0 ± 3.7	79.0 ± 3.8[A]
DLCO (mL/min/mmHg)	25.8 ± 1.0	14.5 ± 0.7[A]
DLCO, % of Pred.	97.2 ± 2.6	57.2 ± 4.7[A]
Raw (cmH_2O/L/s)	1.69 ± 0.17	2.37 ± 0.51
SGaw	0.17 ± 0.01	0.18 ± 0.03
MVV with NAR (L/min)	132.0 ± 6.5	86.8 ± 5.1[A]
MVV with R_2 (L/min)	107.0 ± 6.0	75.0 ± 5.1[A]
Pmax (cmH_2O)	77.4 ± 7.5	114.0 ± 33.0

Definition of abbreviations: FEV_1 = forced expiratory volume in one second; FVC = forced vital capacity; TLC = total lung capacity; DLCO = pulmonary diffusing capacity for carbon monoxide; Raw = airway resistance; SGaw = specific airway conductance; MVV = maximal voluntary ventilation; Pmax = maximal inspiratory mouth pressure; NAR = no added resistance; R_2 = with added resistance; SEM = standard error of means.

[A] = $p<.05$, comparing restricted group to control group.

(3) the subject stopped for any reason; or (4) the monitoring physician stopped the test for safety reasons. Rest periods between trials to allow the heart rate to return to baseline generally lasted 3 to 12 min. Because several subjects did not reach the 1.5 L/min endpoint, the groups were compared at $\dot{V}O_2$ = 0.8 L/min (the highest $\dot{V}O_2$ common to all subjects), with linear interpolation of values used.

The first trial was with no added resistance. Because we have found greater variability in first trial data, probably because of nervousness and unfamiliarity with the protocol, these data were not used in the analysis. The subsequent three trials were then run with R_2, NAR, and finally R_2 again. The average R_2 exercise parameters were used for analysis. An attempt was made to analyze subjective aspects of the different exercise trials. Subjects were asked to compare each trial to the first no added resistance trial and to score it according to criteria listed in Table IV.

Statistical Analysis

In an effort to test for a trial order effect, the last common minute of exercise shared by the first and second R_2 was compared for both control and restricted subjects. Average lung function indices, and changes in indices with added resistance were compared between controls and subjects with RLD with a t statistic used.[12] The average change with added resistance was determined to differ from zero based

TABLE III
Exercise Parameters at $\dot{V}O_2$ = 0.8 L/min:
Effects of Added Resistance and Restriction

Parameter	Control n = 12 NAR Mean SEM	Control n = 12 R_2 Mean SEM	Restricted n = 5 NAR Mean SEM	Restricted n = 5 R_2 Mean SEM
RR	20.4 ± 0.7	16.8 ± 0.9[c]	41.9 ± 4.0[B]	38.5 ± 5.2
V_T	1.05 ± 0.04	1.20 ± 0.6[c]	0.69 ± 0.02[B]	0.71 ± 0.03
$\dot{V}_E$	21.2 ± 0.8	19.4 ± 0.8[c]	29.0 ± 2.5[A]	26.9 ± 2.7
$P_{ET}CO_2$	35.8 ± 0.8	37.6 ± 0.8[c]	33.4 ± 1.8	34.7 ± 1.8
R	0.77 ± 0.02	0.75 ± 0.02	0.84 ± 0.03	0.82 ± 0.03
HR	128.0 ± 4.1	127.0 ± 4.0	134.0 ± 3.6	134.0 ± 3.6
HR/Pred Max	81.0 ± 2.5	80.0 ± 2.5	83.0 ± 2.6	83.0 ± 2.7
Poral	2.09 ± 0.11	7.05 ± 0.28[c]	2.38 ± 0.26	9.10 ± 0.80[c]
Poral/Pmax, %	3.36 ± 0.59	10.8 ± 1.6[c]	3.00 ± 1.4	13.3 ± 6.7

Definition of abbreviations: $\dot{V}O_2$ = oxygen consumption; RR = respiratory rate; V_T = tidal volume; $\dot{V}_E$ = minute ventilation; $P_{ET}CO_2$ = end-tidal PCO_2; R = respiratory exchange ratio; HR = heart rate; Poral = mouth pressure swing; NAR = no added resistance; R_2 = with added resistance.

[A]$p<0.05$ compared to control NAR value.
[B]$p<0.01$ compared to control NAR value.
[C]$p<0.05$ compared to NAR value of same group.

TABLE IV
Subjective Assessment of Exercise Trials[A]

Trial	Control n = 12	Restricted n = 5
Average R_2	1.79	2.20
NAR	1.25	1.20

[A]Each trial was compared to the preliminary (no added resistance) trial and scored:
0 = Easier
1 = Not noticeably different
2 = Different but not uncomfortable
3 = Somewhat uncomfortable
4 = Very uncomfortable.
Values represent arithmetic means. No significant differences found by non-parametric testing.
R_2 = Added resistance.
NAR = No added resistance.

on the results of a paired t-test. The results of all statistical tests were evaluated at the 5% and 1% levels of significance.

Results

Resting Pulmonary Function Tests

Table II gives spirometric, plethysmographic airways resistance, diffusing capacity (DLCO), and maximum voluntary ventilation (MVV) data. Comparison of the RLD group to controls showed reduction in all values except those indicative of airway obstruction (forced expiratory volume in one second/forced vital capacity, %; airways resistance; and specific airways conductance) and P max.

Trial Effect

No significant differences between the two R_2 trials were found in either group for any variable (Data not shown.).

Exercise Parameters

Exercise parameters at $\dot{V}O_2$ of 0.8 L/min with and without added resistance are presented in Table III. With exercise alone (NAR) the RLD group's RR was more than double the controls' (42 *vs.* 20), V_T was smaller, and $\dot{V}_E$ larger. The markedly increased RR was related both to the restricted group's higher $\dot{V}_E$ (37% greater than the controls') and lower V_T (34% less than the controls'). Despite the much higher total ventilation, the RLD group's $P_{ET}CO_2$ was not statistically lower than the controls' (33.4 *vs.* 35.8, p = 0.28), reflecting the former's increased dead space to tidal volume ratio. Although R values were quite different (0.84 for RLD subjects *vs.* 0.77 for controls), the difference was not statistically significant (p = 0.06).

With added resistance, the controls showed an increase in V_T, $P_{ET}CO_2$, and Poral, and a decrease in RR and $\dot{V}_E$. Heart rate and R were unchanged. Among RLD subjects, only the Poral difference between NAR and R_2 was significant, although changes in RR, V_T, $P_{ET}CO$, and R were in the same directions as for controls. The changes with added resistance of the controls were compared to those of the RLD subjects also. Here, two differences were found at the $p < 0.05$ level: the increase in the RLD group's Poral was greater, and the increase in their V_T was less than comparable control changes.

Each subject's separate trials were stopped for the same reason, and with rare exception, after the same minute of exercise. Two control subjects reached the desired 1.5 $\dot{V}O_2$ endpoint. All other control trials were stopped by heart rate criteria. In contrast, none of the RLD subjects reached the 1.5 $\dot{V}O_2$ endpoint. Two were stopped by heart-rate criteria, and three voluntarily stopped each trial, complaining of being "tired" and/or "dizzy."

The subjective comparison of each trial compared to the initial (NAR) trial is shown in Table IV. Non-parametric testing did not show any differences to be significant.

Discussion

Control and restricted subjects were fairly well matched for anthropomorphic parameters (Table I). The restricted females had a moderate degree of impairment (Table II). Comparison of the first and second R_2 trials showed no difference in any parameter, suggesting that trial order effects were minimal. Any such effects present when R_2 is compared to NAR should be reduced by averaging the results for the two R_2 trials which were done immediately before and after the NAR trial.

In general, the control group showed the same response to added resistance as found in other studies,[4,13-15] that is, a decrease in RR, $\dot{V}_E$, and R and an increase in V_T, $P_{ET}CO_2$, and Poral.

The most dramatic findings in the RLD females under NAR conditions were a RR twice that of controls, and a V_T 1/3 smaller ($p < 0.01$ for both) (Table III). Restricted females also had a higher $\dot{V}_E$ than controls at the $\dot{V}O_2$ of 0.8 L/min. Despite this increased $\dot{V}_E$, alveolar ventilation was only minimally increased, as evidenced by the small non-significant decrease in $P_{ET}CO_2$. All these findings were expected in this substantially impaired population who, because of their disease and restricted V_T, have increased dead space to tidal volume ratio (V_D/V_T) and must increase ventilation primarily by increasing RR.

In response to added resistance, the RLD group showed trends in cardiopulmonary parameter values similar to those in controls noted above. Only the increase in Poral, however, was statistically significant. The lack of significant changes is thought to reflect the small number of subjects involved. When the difference of NAR-R_2 for RLD subjects was compared to that for controls, however, two significant differences arose: the increase in Poral was greater, and the increase in V_T was less in the impaired group. The greater increase in Poral with R_2 in RLD subjects is due to their increased $\dot{V}_E$ and flow rates and the non-linear nature of the R_2 pressure-flow curve at higher flows (Figure 1). This difference in Poral with added resistance represents an added stress to RLD subjects wearing respirators.

With regard to V_T, RLD subjects may be unable substantially to increase V_T in response to added resistance because of their disease. The restricted subjects, however, did not reach their maxium V_T as previously predicted.[16] These authors studied 43 normal subjects and 6 with interstitial lung disease, and found the following equation to reasonably predict maximum V_T (greatest V_T at maximum voluntary bicycle workload) for both groups: V_T max = 0.65 VC - 0.64 (r=0.958; SD=0.21). When this equation is used, the predicted V_T max for the RLD females is 1.04 L, compared to their measured V_T's of approximately 0.71 ($p<0.05$). If their data can be applied to our subjects, it would suggest that they *could* increase V_T, but did not. Presumably, their decreased compliance makes increased V_T at the measured RR inefficient or unduly uncomfortable. An alternative explanation for the RLD subjects' unchanged V_T with added resistance would be that they did not "detect" the resistance as well as the controls. The subjective assessment data (Table IV), however, suggest that the impaired subjects were equally aware of the added resistance. To the extent that RLD subjects were unable or unwilling to increase V_T, added resistance may have represented a relatively greater stress than it did in normal subjects.

Based on this small study including only female subjects, it seemed that the main stress of mild exercise with a respirator in subjects with restrictive lung disease is the exercise itself. Most changes with added resistance during exercise in the cardiopulmonary parameters measured were not statistically significant, but followed the normal response pattern. While subjects with restrictive lung disease may be unable to increase V_T like normals in response to respirator wear, the overall results do not suggest that this possible difference is of major practical importance. The RLD subjects often stopped the exercise at a low level because of fatigue or dyspnea, suggesting that their disease led to undue discomfort with exercise. Because of this substantial impairment in the restricted group (as well as the small numbers), one should be cautious in extrapolating these results to the working population with restrictive lung disease. Whether these results apply to long-term (hours) respirator wear, other respirators and other groups of RLD subjects awaits further study.

References

1. "Occupational Safety and Health Standards (Labor)," *Code of Federal Regulations,* Title 29, Occupational Safety and Health Standards, Pt. 1910.134. 1985.
2. **Raven, P.B., A.W. Jackson, K. Page, R.F. Moss, O. Bradley and B. Skaggs:** The Physiological Responses of Mild Pulmonary Impaired Subjects While Using a "Demand" Respirator During Rest and Work. *Am. Ind. Hyg. Assoc. J. 42*:247-257 (1981).
3. **Raven, P.B., O.Bradley, D. Rohm-Young, L. McClure and B. Skaggs:** Physiological Response to "Pressure-Demand" Respirator Wear. *Am. Ind. Hyg. Assoc. J. 43*:773-781 (1982).
4. **Hodous, T.K., L. Petsonk, C. Boyles, J. Hankinson and H. Amandus:** Effects of Added Resistance to Breathing During Exercise in Obstructive Lung Disease. *Am. Rev. Respir. Dis. 128*:943-948 (1983).
5. **Biliet, L., W. Baisier and J.P. Neadts:** Effect of Height, Sex, and Age on the Pulmonary Diffusing Capacity in Normal Adults. *J. Physiol. (Paris) 55*:199-200 (1963). In *Lung Function* by J.E. Cotes. 4th ed. London: Blackwell Scientific Publications, 1979.
6. **Hall, A.K., C. Heywood and J.E. Cotes:** Lung Function in Healthy British Women. *Thorax 34*:359-365 (1979).
7. **DuBois, A.B., S.Y. Botelho and J.H. Comroe:** A New Method for Measuring Airway Resistance in Man Using a Body Plethysmograph. *J. Clin. Invest. 35*:327-335 (1956).
8. **DuBois, A.B., S.Y. Botelho, G.N. Bedell, R. Marshall and J.H. Comroe:** A Rapid Plethysmographic Method for Measuring Thoracic Gas Volume. *J. Clin. Invest. 35*:322-326 (1956).
9. **Ogilvie, C.M., R.E. Forster, W.S. Blackmore and J.W. Morton:** A Standardized Breath Holding Technique for the Clinical Measurement of the Diffusing Capacity of the Lung for Carbon Monoxide. *J. Clin. Invest. 36*:1-17 (1957).
10. **Black, L.F. and R.E. Hyatt:** Maximal Respiratory Pressures: Normal Values and Relationship to Age and Sex. *Am. Rev. Respir. Dis. 99*:696-702 (1969).
11. **American Heart Association:** *Exercise Testing and Training of Apparently Healthy Individuals: A Handbook for Physicians.* Dallas, Tex.: AHA, 1972.
12. **Dixon, W.J. and F.T. Massey:** *Introduction to Statistical Analysis.* 3rd ed. New York: McGraw Hill, 1969.
13. **Gee, J.B.L., G. Burton, C. Vassallo and J. Gregg:** Effects of External Airway Obstruction on Work Capacity and Pulmonary Gas Exchange. *Am. Rev. Respir. Dis. 98*:1003-1012 (1968).
14. **Cerretelli, P., R.J. Siskand and L.E. Farhi:** Effects of Increased Airway Resistance on Ventilation and Gas Exchange During Exercise. *J. Appl. Physiol. 27*:597-600 (1969).
15. **Hermansen, L., Z. Vokac and P. Lereim:** Respiratory and Circulatory Response to Added Air Flow Resistance During Exercise. *Ergonomics 15*:15-24 (1972).
16. **Jones, N.L. and A.S. Rebuck:** Tidal Volume During Exercise in Patients with Diffuse Fibrosing Alveolitis. *Bull. Europ. Physiopath. Resp. 15*:321-327 (1979).

29 April 1985; Revised 8 May 1985