

Cycloergometer-induced bronchospasm

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The Cycloergometer Exercise test is readily administered to children and adolescents for evaluating exercise-induced asthma. It offers the advantages of ready acceptance and full cooperation of the patients and ease of administration to a wide range of age groups, and it can be given under standard conditions with a known work load. The initial pulmonary-function values (VC and FEV₁) do not predict those patients most likely to have exercise-induced bronchospasm. This phenomenon appears limited to asthmatic patients.

Exercise-induced bronchospasm in asthmatic patients may be a significant disability, both physical and psychological. This has been well delineated in children, by Heimlich¹ and Jones,³ and in adults by Butler⁴ and McNeill.⁵ This response is not altered by alpha or beta adrenergic blockade or cholinergic blockade.^{2, 12} Altered lung compliance and also alveolar CO₂ tension have been postulated as etiologic agents, but the exact mechanism remains obscure.^{11, 13, 15}

Most studies have been done with a treadmill¹ or stairway test⁵ for exercise. Since these have certain shortcomings, we decided to develop an exercise system that would be: (1) reproducible under standard conditions; (2) accepted readily by children, thus assuring their full cooperation; and (3) easily adapted for administration to children and adolescents over a wide range of size and age. The system was then used to standardize a method for inducing and evaluating exercise bronchospasm in children and adolescents.

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SUBJECTS AND METHODS

Subjects

The 25 asthmatic patients studied all had a history of paroxysmal wheezing, with seasonal variation, and objective evidence of reversible airway obstruction by pulmonary-function tests. Second, they all gave a history of increased wheezing and dyspnea following strenuous exercise. Their ages ranged from 9 to 17 years, and the severity of their asthma ranged from mild and intermittent to chronic and severe. Three of the 25 required continuous corticosteroid therapy in addition to bronchodilators for control of their asthma. There were 16 boys and 9 girls in this group. Four normal subjects, i.e., no history of asthma, other pulmonary disease, or intolerance to exercise, were tested in the same manner as the asthmatic patients.

Methods

The study required observations of (1) pulse, (2) vital capacity (VC), and (3) forced expiratory volume in one second (FEV_1). In some cases airway resistance (R_A), which was expressed as the reciprocal (conductance), was measured. All of these tests were carried out during the same period of the day (1:00 to 3:00 P.M.) in order to avoid possible circadian variations in exercise tolerance of the subjects.⁶

At the beginning of each test period the base-line values of VC and FEV_1 were recorded 2 to 4 times with a Pulmonet (Godart) spirometer.* The resting pulse was recorded on a Sanborn electrocardiograph, also on 2 to 4 occasions. When reproducible base-line values were obtained, the patient climbed onto an electric cycloergometer† as shown in Fig. 1, and the seat level was adjusted individually to a comfortable pedaling position. The work load of the cycloergometer was set initially at 500 Kg.M. per minute per square meter of body surface area. The subjects then underwent a 5 minute exercise period on the machine with standard electrocardiographic leads in place for continuous pulse monitoring.

The work load was increased as necessary in about half the tests to raise the pulse above 180 beats per minute for the 5 minute exercise period. The increase in pulse was used as the index of maximal stress, and the subjects were exercised to the point of a pulse of 180 or more, which approaches maximum cardiac output and/or maximum oxygen consumption.^{7, 8} All subjects were able to finish the exercise period. Immediately following the exercise tests, the pulse was recorded, and the VC and FEV_1 were recorded in triplicate. The same determinations were carried out 5, 10, 15, and 20 minutes later.

The decrease in FEV_1 was interpreted as a reflection of increased airway resistance. The response of FEV_1 to exercise was then categorized as follows: (1) mild, decrease in FEV_1 of less than 10 per cent below resting FEV_1 ; (2) moderate, decrease in FEV_1 of 10 to 25 per cent below resting values; and (3) severe, decrease in FEV_1 of more than 25 per cent below resting values. These categories were then used to classify the FEV_1 response to the exercise tests.

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†Manufactured by Quinton Instrument Company, Seattle, Wash.

**Fig. 1**

The Quinton cycloergometer showing adjustable seat, handle bars, and work-load control.

Three asthmatic subjects and 3 normal control subjects were studied again in the same manner except that airway resistance (R_A) was measured with the use of the body plethysmography method of DuBois, Botelho, and Comroe.⁹ The times of measurement were the same as noted previously for spirometric determinations.

RESULTS

The changes in FEV_1 after the cycloergometer exercise tests are noted in Table I. Of the 25 subjects tested, 18 had a decrease in FEV_1 of more than 10 per cent some time during the 20 minutes following exercise.

Table 1. Response of FEV₁ to exercise in asthmatic subjects showing 18 of 25 with greater than 10 per cent decrease during 20 minute observation following test

Patient	Pre- dicted FEV ₁	Before	After	5 minutes	10 minutes	15 minutes	20 minutes
S. W.	1.10	1.75	1.80	1.10	1.70	1.35	1.50
D. T.	1.15	2.93	2.43	2.40	2.30	2.40	2.40
L. B.	1.64	3.20	3.45	2.80	2.70	2.50	2.20
J. O.	1.85	1.30	0.73	0.45	0.45	0.60	0.65
S. W.	2.20	3.15	2.30	2.56	3.20	2.65	2.75
D. L.	2.22	2.30	2.95	2.00	2.45	2.08	2.35
G. R.	2.20	1.20	1.75	1.60	1.60	1.65	1.65
K. R.	2.24	2.15	2.15	1.10	1.10	1.10	1.20
L. D.	2.21	0.95	0.85	1.00	0.95	0.80	1.00
A. D.	2.56	1.90	1.70	1.25	1.33	0.90	1.40
J. G.	2.65	2.25	1.45	0.83	0.85	1.40	1.03
T. G.	1.24	1.40	1.10	1.00	1.10	1.25	1.25
A. D.	2.40	1.70	1.70	1.75	1.65	1.75	1.85
S. R.	1.06	0.75	0.83	0.60	0.60	0.75	0.88
R. W.	0.77	0.60	1.10	0.75	0.70	0.80	0.90
G. Z.	3.05	2.85	3.30	2.25	2.80	2.40	2.85
J. H.	2.22	2.25	2.45	2.35	2.10	2.45	2.25
T. L.	1.08	0.98	1.05	1.10	0.90	1.00	1.05
M. G.	3.20	2.55	3.15	3.03	3.20	2.80	2.90
D. T.	2.65	2.00	2.00	2.05	2.05	2.00	2.55
J. W.	2.80	1.60	1.40	1.15	1.10	1.30	1.40
I. R.	2.85	2.90	2.35	1.85	1.80	2.15	2.05
M. D.	1.80	1.30	1.15	1.20	1.30	1.40	1.45
B. H.	3.01	2.60	2.70	1.80	1.63	1.45	1.25
N. F.	3.55	0.95	1.25	0.85	1.10	1.10	1.00
Mean	2.14	1.90	1.88	1.55	1.62	1.60	1.67
Variance	0.55	0.59	0.63	0.50	0.60	0.43	0.45
Standard deviation	0.74	0.77	0.79	0.71	0.78	0.65	0.67

The reproducibility of this exercise test was examined by testing 16 subjects on 4 different occasions. The results are given in Table II. These patients all showed a decrease in FEV₁ following exercise and these data showed the test to be reliable and reproducible. The responses of the normal subjects are given in Table III. They did not show any decrease in FEV₁ following exercise testing (as has been shown by others).

The pulse-response curves for all 25 subjects and the 4 healthy control subjects are shown in Fig. 2. The 16 subjects, who responded to exercise with decrease in FEV₁, had a similar pulse response to that of those 9 asthmatic subjects and 4 healthy control subjects who did not decrease their FEV₁ after exercise.

The values for resting initial FEV₁, taken on 6 different occasions over a 9 week period for the 16 asthmatic patients noted previously, are shown in Fig. 3. These values demonstrate the variability of initial values of FEV₁.

Three asthmatic subjects and 3 normal subjects had the Cycloergometer Exercise test administered, and the airway resistance (R_A) was measured by body plethysmography. These results, appearing in Fig. 4, showed the anticipated increase in airway resistance (reduced conductance) in asthmatic subjects but no increase in airway resistance in normal persons tested in a similar manner. The normal subjects actually reduced their airway resistance with exercise.

Table II. *The decrease in FEV₁ in asthmatic subjects who reacted to exercise is both constant and reproducible when tested on separate occasions*

<i>Patient</i>	<i>Pre-dicted FEV₁</i>	<i>Before</i>	<i>After</i>	<i>5 minutes</i>	<i>10 minutes</i>	<i>15 minutes</i>	<i>20 minutes</i>
S. W.	1.10	1.23	1.20	0.90	1.30	1.55	1.55
		1.50	1.60	0.70	0.63	0.75	0.80
		1.60	1.80	1.15	0.90	1.05	1.38
		1.65	1.23	0.60	0.65	0.80	0.50
D. T.	1.15	2.65	2.60	2.30	2.45	2.10	2.40
		2.50	2.73	2.60	2.20	2.08	2.55
		2.30	2.20	1.35	1.55	1.40	2.00
		2.00	2.10	2.15	2.00	2.10	2.30
L. B.	1.64	3.10	3.45	3.00	2.72	2.65	2.90
		3.10	3.00	2.73	2.80	2.90	2.80
		2.40	3.20	2.15	2.05	2.00	1.80
		2.30	3.50	2.90	2.30	2.60	2.40
J. O.	1.85	2.00	2.40	0.78	0.58	0.60	0.48
		1.05	1.35	0.60	0.45	0.55	0.50
		1.00	1.23	0.60	0.70	0.70	0.65
		1.05	2.00	1.05	0.90	0.70	0.90
S. W.	2.20	3.38	3.20	3.00	2.80	3.10	3.20
		2.90	3.40	1.50	2.00	2.00	2.50
		2.95	2.90	1.80	1.85	1.88	2.10
		3.20	3.20	2.90	2.63	3.00	3.00
D. C.	2.22	2.05	2.20	1.45	1.40	1.30	1.43
		2.30	2.20	1.35	1.20	1.20	1.20
		2.00	2.55	2.20	1.90	1.05	1.80
		2.70	2.00	2.70	2.20	2.25	2.10
G. R.	2.20	1.40	1.20	1.20	1.30	1.30	1.30
		1.40	1.70	1.10	1.30	1.30	1.58
		1.18	1.48	1.08	1.00	1.00	1.00
		1.50	1.25	0.95	0.70	1.25	1.65
L. D.	2.24	1.20	1.20	1.20	1.20	1.00	1.10
		1.30	1.03	1.28	1.05	1.05	1.55
		2.05	2.05	1.60	1.98	1.90	2.20
		2.00	1.78	1.80	2.00	1.70	1.80
J. G.	2.56	1.30	2.15	0.98	0.78	0.60	0.70
		1.80	2.10	0.90	0.70	0.70	0.55
D. T.	2.65	2.30	2.20	2.18	2.20	2.40	2.50
		2.35	2.08	1.65	1.65	1.75	1.70
		2.40	2.10	1.60	1.20	1.60	2.20
		2.65	2.75	2.00	2.23	2.20	2.50
J. W.	2.80	1.25	1.60	0.63	0.65	0.60	0.65
		1.65	1.30	0.80	0.68	0.80	0.80
		1.83	1.30	0.60	0.53	0.65	0.60
		1.20	1.10	0.83	0.90	0.90	1.10
I. R.	2.85	2.40	2.40	1.50	2.40	2.00	2.20
		2.20	2.30	2.05	1.80	1.60	2.00
		2.60	2.70	1.93	2.13	2.90	2.23
		2.80	2.40	1.78	1.80	2.00	2.65
M. D.	1.80	1.40	1.30	1.20	1.20	1.25	1.50
		1.20	1.15	0.90	1.20	1.40	1.30
		1.65	1.25	1.13	1.13	0.95	0.90
		1.55	1.58	1.30	1.40	1.20	1.30

Table II. Cont'd

<i>Patient</i>	<i>Pre- dicted FEV₁</i>	<i>Before</i>	<i>After</i>	<i>5 minutes</i>	<i>10 minutes</i>	<i>15 minutes</i>	<i>20 minutes</i>
B. H.	3.01	2.60	2.30	1.38	0.95	0.90	0.83
		1.65	1.85	1.00	0.80	0.80	0.70
		2.60	2.70	1.80	1.63	1.45	1.25
		2.48	2.03	0.75	0.45	0.53	0.58
N. F.	3.55	2.30	1.90	2.45	1.70	0.95	1.80
		0.90	1.20	0.70	0.60	1.00	0.70
		1.30	1.45	1.05	1.00	1.70	1.05
		1.05	1.60	0.90	0.75	0.70	1.00
Mean	2.25	1.97	2.02	1.49	1.43	1.45	1.56
Variance	0.43	0.42	0.46	0.48	0.45	0.48	0.55
Standard deviation	0.65	0.65	0.67	0.69	0.67	0.69	0.74

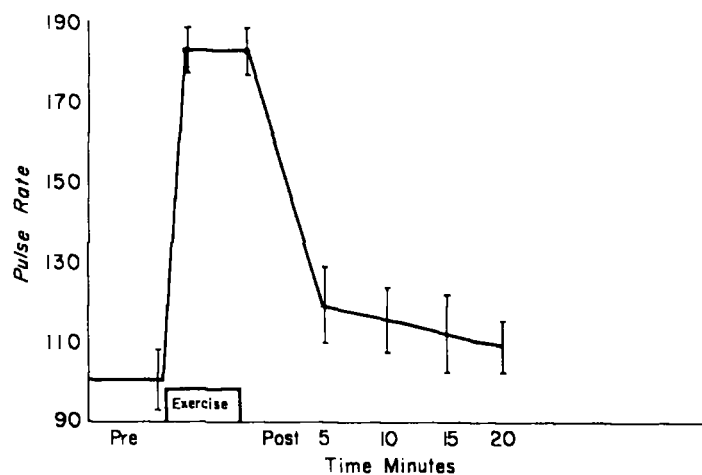
Table III. *The response(s) of normal subjects show no decrease in FEV₁ after exercise during 20 minute follow-up period*

<i>Patient</i>	<i>Pre- dicted FEV₁</i>	<i>Before</i>	<i>After</i>	<i>5 minutes</i>	<i>10 minutes</i>	<i>15 minutes</i>	<i>20 minutes</i>
B. B.	2.75	2.90	2.90	2.95	2.98	2.93	2.93
B. B.	2.98	3.05	3.00	3.30	3.20	3.10	3.18
P. M.	4.10	4.25	4.30	4.45	4.45	4.40	4.50
J. T.	5.21	5.40	5.30	5.60	5.65	5.65	5.65
Mean	3.75	3.90	3.87	4.07	4.07	4.02	4.06
Variance	0.96	1.02	0.98	1.08	1.14	1.20	1.19
Standard deviation	0.98	1.01	0.99	1.04	1.07	1.09	1.09

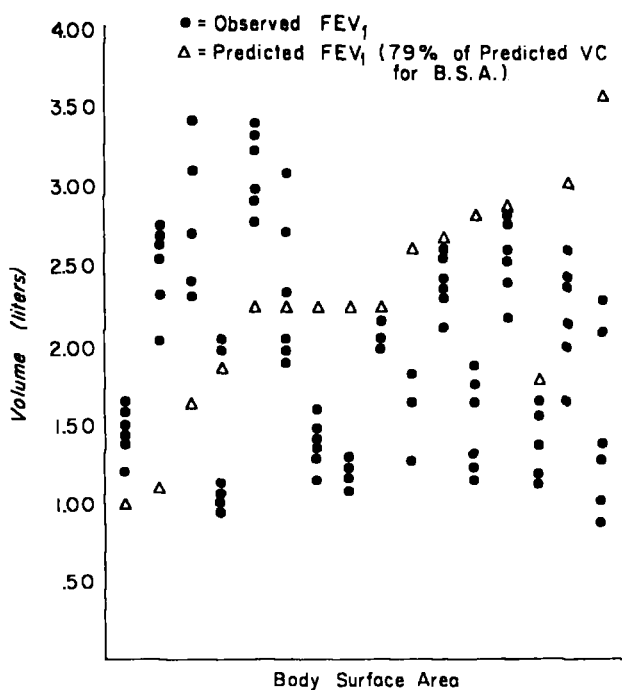
DISCUSSION

Studies by other investigators were done with the use of either treadmill^{1, 2} or stairway tests³ to induce exercise bronchospasm. In the Treadmill Test described by Heimlich and Sly, a treadmill was run at a constant speed and inclined sufficiently for the subject to accomplish a predicted work load. However, this test required at least 8 minutes of exercise, and some patients (including adolescents) could not complete the test. Thus, it was very difficult to estimate and standardize the total work performed. In the Stairway Test, patients simply run up and down a predetermined number of stairs for periods of 5 to 10 minutes.^{5, 11} This has the further disadvantage that the rate of work performed varies from patient to patient. Also, the rate of work performed by a single patient varies: Going upstairs is obviously more work than going downstairs. The advantages of using the cycloergometer are that the exact work load is known, the exercise is short in duration, the test is simple to administer, and patients of widely varying ages were able to give full cooperation and complete the test.

The initial values of FEV₁ varied considerably, and any change in FEV₁ needed to be related to resting values for the specific day of testing.¹⁰ By doing this, interpretation of response was more meaningful. We found that subjects who

**Fig. 2**

Pulse response to exercise work load showing a peak of 182 ± 11 per minute during test.

**Fig. 3**

Serial observations of initial pulmonary-function values show marked variability.

had abnormally low pre-exercise values could still have a severe decrease in FEV₁ following exercise, as well as subjects who had normal resting (initial) values for FEV₁. Thus, the test system applied equally well to subjects regardless of their initial pulmonary function. The observed drop in FEV₁ was not related to the resting pulmonary-function values.

The increased airway resistance (R_A) shown by body plethysmography correlated well with a decrease in FEV₁. Since measurement of FEV₁ is simpler and much more convenient to obtain than airway resistance by body plethysmography, the FEV₁ was made a part of the standard test.

In summary, we have drawn the following conclusions:

1. The Cycloergometer Exercise Test is readily administered to children and adolescents.
2. It offers the following advantages: (a) ready acceptance by subjects with full cooperation; (b) reproducibility with serial tests; (c) ease of administration to a wide range of age groups; and (d) standardized conditions of testing and monitoring exercise.

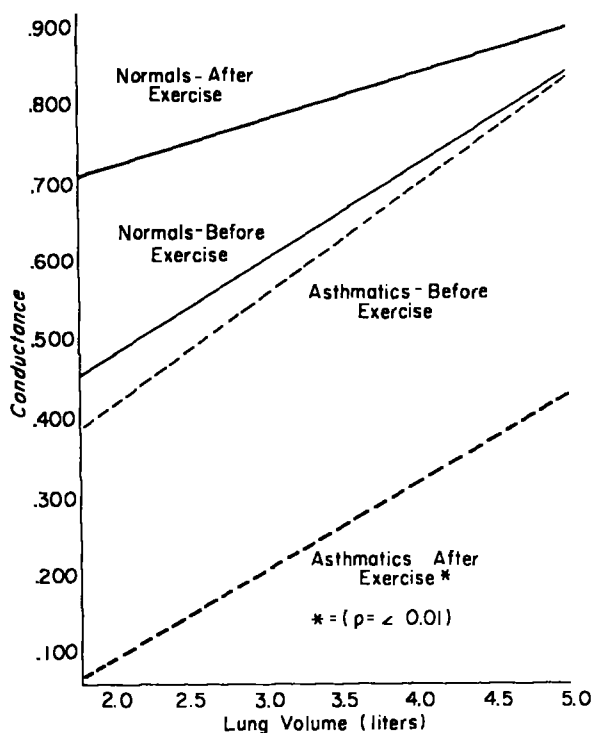


Fig. 4

The response to exercise of airway conductance (reciprocal of airway resistance) as measured by plethysmography to exercise showed an increase in normal subjects and a decrease in asthmatic subjects.

3. Initial (resting) pulmonary-function values fail to predict patients who may react with bronchospasm.

4. Resting pulmonary function values vary from day to day, though response to exercise test is consistent.

5. Exercise-induced bronchospasm appears limited to asthmatic subjects.

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