The Effect of Breathing Frequency on Inspiratory Muscle Endurance During Incremental Threshold Loading*

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We tested whether there were differences in measures of respiratory muscle endurance between tests with spontaneously chosen breathing patterns and tests with fixed breathing rates in normal volunteers. Measures of respiratory muscle endurance-maximum load tolerated, mean mouth pressure at maximum load and peak pressure at maximum load were reproducible over three tests with the spontaneously chosen breathing pattern. There was no difference in these measurements between the three tests with fixed breathing frequency. There was no difference in tidal volume, inspiratory time, and the ratio of inspiratory time to total breath duration between the tests in which breathing pattern was spontaneously chosen; there was a difference in these measurements between the tests with a fixed breathing frequency. We conclude that regulation of breathing frequency is unnecessary in the two-minute threshold loading test to obtain reproducible results for measures of respiratory muscle endurance.

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Respiratory muscle (RM) endurance may be measured in a variety of ways.1-3 The most frequently reported method for assessment of RM endurance incorporates inspiratory resistive loading devices. Endurance may be measured either as the time a particular load is tolerated or as the maximum load tolerated for a specific time. However, recent reports4-6 indicate that variability in breathing pattern and pressure generation by the inspiratory muscles may substantially alter the time a particular load is tolerated. It is apparent that regulating the breathing pattern and fixing the breath by breath pressure generation is necessary to evaluate RM endurance by resistive loading, which makes this test more complex than originally anticipated.

In our laboratory a modification of the threshold loading device designed by Nickerson and Keens4 (Fig 1) was used to measure RM endurance. The pressure load on the inspiratory muscles is determined by the amount of weight applied to the intake valve. A two-minute incremental test was developed7 that uses a system of progressively adding weights until the subject can no longer maintain ventilation.

This test was found to be relatively simple and reproducible in normal young, normal elderly and COPD subjects.8-10 Although subjects may vary the maximum weight lifted, the mean pressure at the maximum weight does not change significantly from test to test. The subjects are free to set their own breathing pattern. We questioned whether this test would be affected by variations in breathing frequency as the resistive loading test is so affected. To test this hypothesis, we studied normal young subjects with breathing frequency fixed at different rates.

Methods

Subjects and Techniques

Ten normal subjects volunteered for the study. Subjects had no history of respiratory illness. Spirometry was measured (FEV, and FVC) and expressed as percent predicted using the prediction equations of Morris et al.11 The MIP and MEP were measured according to the method of Black and Hyatt12 and expressed as percent predicted using their prediction equations. The MVV was measured over 12 s and expressed as percent predicted using the prediction equations of Kory et al13 for men and Lindall et al14 for women.

Respiratory muscle endurance was measured using a two-minute incremental threshold loading test (Fig 1). Section A of Figure 1 shows the weighted plunger and inspiratory port with an orifice of 6.6 cm.4 Increased weights on the plunger required increased pressure to open the inspiratory port when the stopper was in place. Section B shows the turbine flow transducer which measured Vt. Section C shows the one-way valve and mouthpiece. A ± 100 cm H2O differential pressure transducer (model 45-32, Valdyne Co, Northridge, CA) was attached to the mouthpiece. All signals (time, volume, pressure) were recorded on a strip chart (Gould Instruments, Ballain Villiers, France). The Pkg with each breath and Pmean during the whole respiratory cycle were recorded. The Pmean was obtained on line by passing the mouth pressure signal through a second order low-pass filter with a time constant of 20 s.

To perform the two-minute incremental test, subjects began at a low load (100 g) and 100 g was added every two minutes until the subject could not continue. Only weights which subjects could
tolerate for the full two minutes were included in calculating the maximum results. The average Ppk (generated over six breaths), Pmean, Vt, Ve, Ti and Tr for each breath were recorded for each weight. The maximum values of Ppk, Ppk/MIP, Pmean and max load were taken as measures of RM endurance.

The subjects were tested on three separate days to a maximum tolerated weight with spontaneously chosen breathing frequency. The subjects were subsequently tested on three separate days to a maximum tolerated weight with breathing frequency fixed at 5, 10, and 20 breaths per minute. Breathing frequency was fixed by having the subjects watch a clock to indicate when to breathe every 5, 10 and 3 s, respectively. Therefore, the fixed breathing frequencies were exactly the same for all subjects. For both the spontaneous breathing frequency and fixed frequency, subjects were free to choose Ti and Vt. The subjects were seated and wore nose clips during the tests.

Data Analysis

Data are shown as individual points and/or expressed as mean ± standard deviation. A repeated measures analysis of variance was done to test for differences between visits for the three tests of unfixed breathing frequency and for the three tests with fixed breathing frequency for the following variables: fb, max load, Ppk at max load, Ppk/MIP, Pmean, Vt, Ve, Ti, and Ti/Tr.10

RESULTS

Spirometry (FEV₁, FVC) and tests of RM strength (MIP, MEP) and MVV are shown in Table 1. All subjects had values within normal limits. Although the mean MEP appears low, 75.6 ± 15.8 percent predicted, other studies have been unable to reproduce the results of Black and Hyatt12 for MEP in normal subjects.9,10

For the three tests with an unfixed breathing frequency, there was no significant difference between tests in any of the variables tested (fb, max load, Ppk at max load, Ppk/MIP, Pmean at max load, Vt, Ve, Ti, Ti/Tr all p > 0.02). There was no significant difference between tests with unfixed or fixed breathing frequency for any of the measures of RM endurance (max load, Ppk, Ppk/MIP, Pmean). Figure 2 shows individual data and group means and standard deviations for RM endurance in all six tests. There was a significant difference in Vt, Ve, Ti, and Ti/Tr between tests with a fixed breathing frequency (p < 0.02). Figure 3 shows means and standard deviations for the breathing pattern at max load (Vt, Ve, Ti, Ti/Tr) for the six tests.

DISCUSSION

This study showed that measures of inspiratory muscle endurance, as measured by the two-minute incremental threshold loading test, are not affected by breathing frequency in normal young subjects. The test gives reproducible results whether breathing frequency is spontaneously chosen or fixed at 5, 10, or 20 breaths per minute. We chose this range of fixed frequencies as our subjects' spontaneous breathing frequencies during the test ranged from 6 to 20 breaths per minute. In addition, this covered a range of frequencies that might be found in patients with chronic obstructive or restrictive lung diseases.

The horizontal lines in Figure 2 and the bars in Figure 3 show mean data for all of the subjects combined. One subject (open pentagon symbol in Fig 2) did not satisfactorily complete the first test (unfixed 1). This subject had high values for max load, Ppk, Pmean, Ve, Ti, and Ti/Tr, so consequently the mean values for the first test are somewhat lower than for the other two unfixed tests. However, the analysis of differences between tests compared the variability of each individual's data between tests and no significant differences were found for any of the measures of RM endurance. Similarly, bars expressing standard deviation.

Table 1—Spirometry and Tests of RM Strength in Ten Subjects

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exhausting for the subject, so an incremental threshold loading test was developed by Martyn et al. They tested subjects with spontaneously chosen breathing frequencies and then fixed the breathing frequency and found no difference in their results. However, they fixed the breathing frequency at 12 breaths per minute, which was very similar to the spontaneously chosen breathing frequency. Clanton et al. used a threshold-loading device to test the effects of changes in breathing pattern on endurance time. During their tests, mouth pressure was kept constant. They found that alteration of the inspiratory flow rate or Ti/Tt changed the endurance time, but changes in breathing frequency did not (Ve and Ti/Tt were fixed). By using Pmean and Ppk rather than the length of time of the test, as measures of endurance, our incremental test avoids the problems of varying endurance time with changes in breathing pattern. The RM endurance, in our test, did not change with changes in Ve. However, the pressures that a subject achieves at the max load are dependent on the size of the inspiratory port.

We did not directly measure energy expenditure (oxygen consumption) or work of breathing. We did measure Pmean which reflects mouth pressure over time and is an estimate of the inspiratory pressure-time index. This provides an indirect measure of energy utilization. McGregor and Becklake first showed that the force of contraction developed by the respiratory muscles is a more meaningful parameter of energy consumption than mechanical work. Rebecca and Guglielmina subsequently demonstrated that diaphragmatic oxygen consumption had a high degree of correlation with the force of contraction determined by the pleural pressure-time index which represents the average pressure developed per minute by the inspiratory muscles. Bellemare and Grassino noted that the tension-time index of the diaphragm could be used to predict diaphragmatic fatigue. Therefore, in this study, since Pmean did not change with changes in breathing frequency, we conclude that energy expenditure was probably not significantly different between tests.

Chen et al. used a threshold-loading device to measure the effects of an inspiratory muscle training program. They found increases in inspiratory muscle endurance, but since they did not fix the breathing pattern, they were concerned that changes in breathing frequency could have influenced their results. Our data suggest that breathing frequency is not an important variable with threshold loading.

We conclude that measurement of inspiratory muscle endurance by the two-minute incremental threshold loading test is not influenced by the breathing frequency. Therefore, this test is relatively simple to perform and the results of a subject's first attempt are reproducible.

**Figure 2.** Respiratory muscle endurance of ten subjects for three tests with unfixed breathing frequency and three tests with breathing frequency fixed at 6, 12 and 20 breaths per minute. Individual data for the ten subjects are shown. Horizontal and vertical bars represent group means and standard deviations, respectively. The top panel shows max load in grams; the middle panel, Ppk at max load in cm H2O; and the bottom panel, P mean at max load in cm H2O. There was no significant difference in max load, Ppk or Pmean between the six tests (p > 0.05).

**action** are large, as they express the difference between individuals. We observed that a large, heavy-set subject was able to lift more than twice the load lifted by a much thinner, smaller subject.

The initial use of a threshold-loading device by Nickerson and Keens allowed a spontaneous breathing frequency. The design of their test had subjects performing the test with very high loads (to produce a Ppk near MIP) and repeating the test until the subject could continue for 10 min. This could be
FIGURE 3. Breathing pattern at max load. Data are shown as mean ± SD. The upper left panel shows Vt in milliliters; the upper right panel, Ve in liters per minute; the lower left panel, Ti in seconds; and the lower right panel, T/Vt. There was no significant difference in Vt, Ve, Ti or T/Vt between tests with an unfixed breathing frequency (p>0.02) but there was a significant difference for these variables between tests with a fixed breathing frequency (p<0.02).

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