

VENTILATORY LIMITATION IN EXERCISE

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Cardiopulmonary exercise testing traces its roots to the development of personal computers and the ability to integrate data from flow sensors and gas analyzers to measure not only ventilation (VE) but oxygen consumption (VO₂) and CO₂ production (VCO₂). Many modern exercise laboratories include equipment to monitor exhaled gases, often in the breath-by-breath mode. It is somewhat surprising that in spite of the ability to assess breathing during exercise, oftentimes it is not measured.

Why measure ventilation during exercise?

There are several traditional reasons why measuring ventilation during exercise is important. For patients who present with 'dyspnea on exertion,' assessment of the maximal ventilation achieved at peak exercise provides

important clues as to whether the lungs play a significant role in exercise limitation. The classical method of making this determination has been to compare V_Emax with indices of the maximal ventilatory capacity such as the MVV (maximal voluntary ventilation), or the FEV₁ multiplied by a factor of 35 or 40. Another method of expressing this is to calculate the 'breathing reserve' as $1.00 - V_{E\max} / MVV$ (usually reported as a %). If the V_Emax during exercise approaches the MVV, then the patient's exercise capacity may indeed be limited by their ability to move air into or out of the lungs. This would be equivalent to a breathing reserve of less than 30% (in other words, the subject is breathing at more than 70% of his/her MVV). For subjects with MVV values greater than about 100 L/min, this happens infrequently. If the MVV is decreased, for example as happens in obstructive lung disease, the patient may stop exercising when his/her V_Emax reaches about 70% of the MVV. Wasserman and colleagues have suggested that an absolute difference (between the MVV and exercise ventilation) of 10-15 L/min is consistent with a ventilatory limitation. However, some patients may have exercise limitation with symptoms of breathlessness at much lower levels of ventilation. In the absence of cardiovascular causes, this type of dyspnea may be difficult to categorize.

A second traditional indication for measuring ventilation during exercise is to assess the breathing pattern, specifically the tidal volume (V_T) and respiratory rate. Normal subjects increase their tidal breathing up to about 50-60% of their VC, and then accomplish further increases in ventilation by increasing the breathing frequency. Some patients may exhibit a different pattern depending on the mechanical constraints of their respiratory system. For example, individuals with fibrotic lung disease may not be able to increase their VT, and hence compensate by very rapid respiratory rates. And some subjects without lung disease adopt unusual breathing strategies that can result in a sensation of dyspnea. Without measuring VT and breathing frequency, these patterns can be difficult to detect.

A third reason for measuring ventilation during exercise involves analysis of expired CO₂. Breath-by-breath systems allow determination of end-tidal CO₂ (PetCO₂) as well as mixed-expired CO₂ (P_ECO₂). End-tidal CO₂ can be substituted for PaCO₂ in the Bohr equation to estimate the V_D/V_T ratio (non-invasively). This method works reasonably well for patients without lung disease, and can provide additional information as to why the patient may be experiencing dyspnea on exertion.



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Other reasons for measuring ventilation during exercise

There are a few additional indications for measuring V_E during exercise testing. The 1999 ATS "Guidelines for Methacholine and Exercise Challenge Testing" suggests testing for exercise-induced bronchospasm (EIB) using a ventilatory target of 40 - 60% of the subject's MVV. In view of the fact that EIB is triggered by heat and/or water loss in the large airways, it is appropriate to use a target level of ventilation so that the stimulus can be related to the response. Use of a target heart rate of 80-90% of predicted is also suggested, but many subjects will achieve a high heart rate (e.g. deconditioning) without necessarily increasing their ventilation to a level that triggers the bronchospastic response. Measuring V_E during EIB testing allows a target level of ventilation to be used. Additionally, a low level of ventilation achieved during exercise may explain a negative result (little or no fall in FEV1) in a subject who reports a history suggesting exercise-induced asthma.

Perhaps the best reason to measure V_E during exercise is to assess whether expiratory airflow limitation (EFL) occurs when the subject exercises. Subjects who develop flow limitation during exercise typically have reduced exercise capacity. Simple evaluation of the $V_{E,max}$ may not reveal the true cause of ventilatory limitation because there is often an adequate breathing reserve.

How to measure flow limitation during exercise?

There are two techniques to assess whether flow limitation occurs during exercise. The first method measures flow during tidal breathing. By superimposing the tidal breathing loops over a maximal flow-volume loop, expiratory (and inspiratory) flow limitation can be visualized. In order to make a valid comparison of tidal flow and maximal flow, the tidal breathing loop must be plotted at the correct point in the lung volume history. This can be accomplished by measuring inspiratory capacity (IC) and then plotting the tidal breathing loop so that its end-expiration point coincides with the end-expiratory point of the IC. Figure 1 shows tidal breathing loops plotted in this manner. In the same figure the tidal breathing loops can be seen to increase with increasing workload during exercise; however none of the tidal breathing curves impinge on the maximal flow-volume envelope. Figure 2 shows data plotted similarly but in this case for a patient with airway obstruction (concave expiratory limb of the F-V curve). Increased tidal breathing during exercise reveals expiratory flows that equal the maximal values over a significant portion of the tidal breath. This pattern is consistent with EFL during exercise.

Figure 1

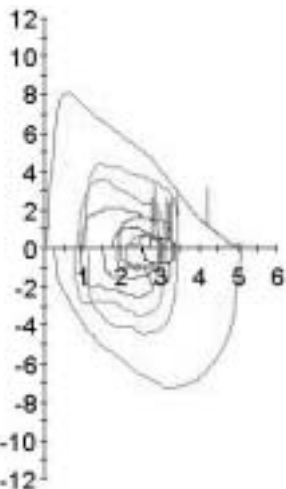
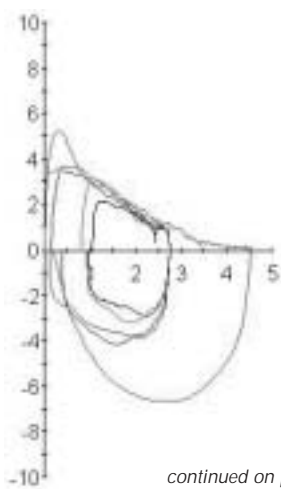


Figure 2



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An additional advantage of plotting tidal breaths over the MEFV curve is that dynamic hyperinflation can be detected as a decreasing IC with exercise (V_T curves become shifted to the left, towards TLC). While this technique can be useful in assessing EFL, it depends largely on obtaining a valid IC maneuver while the patient exercises.

Another technique for detecting EFL during exercise is the negative pressure method. Kosmas, Calverly, and others have used a source of negative pressure (vacuum cleaner) applied to the expiratory limb of a one-way breathing circuit to look for flow limitation. When negative pressure is applied during exhalation one of two flow patterns occurs (See Figure 3). If the subject is not flow-limited, the negative pressure causes an increase in flow; if there is EFL, the negative pressure does not change the flow (flow is limited in the patient's airways).

Using the negative pressure method, Kosmas and colleagues have shown that EFL can occur *during* exercise in subjects suspected of having EIB, and that the degree of flow limitation is related to the maximal workload tolerated. EIB was not always found in the subjects who had EFL during exercise. Although this was a small study, these findings suggest that airway changes can occur during exercise that are distinct from the bronchospasm usually observed post-exercise.

If you have the ability to measure ventilation (and exhaled gases) in your exercise lab, use it. Measurements of ventilation provide targets and feedback in EIB testing, and together with assessment of flow limitation, help us to better understand dyspnea brought on by exertion.

Figure 3

