

THE SLOPE DETECTOR

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The alcohol breath test is a single exhalation maneuver. The subject is asked to inhale (preferably a full inhalation to total lung capacity) and then exhale (preferably a full exhalation to residual volume) into the breath testing instrument. Very few restrictions (i.e., exhaled volume, exhaled flow rate, inhaled volume, pre-test breathing pattern, air temperature, etc.) are placed on the breathing maneuver. The constraints used vary among the different breath testing instruments and among the operators administering the test, and the level of cooperation of subjects, resulting in substantial uncontrolled variation in the precise maneuver used for the breath test.

Slope detectors currently used on breath testing machines have two primary functions. One is to detect the presence of mouth alcohol by identifying a declining slope as the subject is exhaling. The other is to identify the presence of "alveolar air" so that an alveolar sample can be presumed. Unfortunately, neither of these features works as intended.

In order to understand the slope detector problems, we must first purge from our thinking the notion that alcohol exchanges in the alveoli ("deep-lung" regions) of the lungs. Since the 1950's, it has been believed that the last part of the breath represents alcohol from the alveolar region, thus representing the blood alcohol by virtue of the blood-gas partition coefficient. However, computer simulation using basic gas exchange principles¹ has revealed that ethyl alcohol exchanges entirely within the airways of normal human lungs. During inhalation, alcohol is picked-up from the airway mucosa (airway mucous surface), reaching equilibrium before reaching the respiratory bronchioles (the beginning of the respiratory gas exchange region). No further alcohol exchange occurs in the alveoli. During exhalation, some alcohol is redeposited on the airway mucosa. As expiration goes on, less alcohol is deposited on the airways, and more reaches the mouth, accounting for the increasing breath alcohol concentration as exhalation continues. Thus it is impossible to reach an alveolar plateau during a single breath exhalation because alcohol is always interacting with the airway mucosa.

THE ALVEOLAR PLATEAU

The lungs have a relatively complex, non-uniform, anatomical structure. The airways are a branching, tree-like arrangement of tubes. Inspired air moves through progressively shorter, narrower and more numerous airways (see Hlastala and Berger²). These airways are lined with mucus at a temperature varying between approximately 34°C at the mouth and 37°C in the very smallest airways. However, this temperature range varies depending on the breathing pattern³. The airways bifurcate up to 23 times and eventually reach alveoli. The membranes separating the air in the alveoli and the blood in the pulmonary capillaries are so thin that inert gases such as alcohol equilibrate between blood and air very rapidly. With exhalation, air within the alveoli is conducted along the airways to the mouth.

During inspiration, air is heated and humidified as it passes through the upper airways^{3,4}. Some water within the mucous layer or watery sub-mucous layer will vaporize and heat stored in the airways will be picked up by the inspired gas and taken to the alveoli. During exhalation, the process reverses; fully humidified air at core body temperature is cooled by the cooler airway mucosa and water vapor condenses on the mucosa. This water and heat exchange process is vital because it conditions the inspired air to avoid damaging the delicate alveolar cells while conserving water and heat from major loss in the exhaled air. Under normal environmental conditions, exhaled gas has less heat and less water vapor than does alveolar air.

The dynamics of soluble gas exchange are similar to the dynamics of heat and water exchange. These processes are analyzed using analogous equations. The fact that respired air exchanges heat and water with the airways implies similar soluble gas exchange processes⁵. The degree of interaction is directly related to the solubility of the gas in the airway mucosa and mucous lining. The very high solubility of alcohol in water guarantees its strong interaction with airway tissue. Because this interaction depends on temperature and airflow characteristics, variations in tidal volume and frequency can have a substantial effect on the alcohol concentration in the breath sample^{6,7}. This variation is affected by the difference in temperature between the outside air and the alveolar air⁸.

The early basic assumption of the breath alcohol test was that the breath alcohol concentration was the same irrespective of the exhaled volume as long as the dead space volume is exhaled. However, Jones⁹, and Ohlsson et al¹⁰ have shown that the breath alcohol concentration depends on exhaled volume. The breath testing instrument takes a sample of air from the end of the breath whenever the subject stops but the volume of breath exhaled is neither controlled nor measured. Therefore, the apparent breath alcohol concentration depends on the volume of air delivered to the breath testing instrument.

The achievement of a flat slope during exhalation has been presented as a demonstration that "alveolar air" with its alveolar alcohol concentration is obtained at the end of an exhalation. However, this hypothesis is incorrect in that a flat slope will always be obtained when expiratory flow rate approaches zero whether alveolar air is reached or not. In fact, the interaction of expired air with the airway mucosa during expiration prevents any sampling of alveolar air without a change in alcohol concentration. Figure 1 illustrates a schematic example of an individual with a vital capacity of 6 liters who exhales into an alcohol breath testing instrument at a rate of 12 liters per second for a period of 30 seconds. The exhaled alcohol concentration rises until a plateau is reached after the end of exhalation (solid curve). If the same subject exhales for only 15

seconds, then a plateau in alcohol concentration will also be achieved at the end of exhalation (dashed curve). But in this case the plateau value is lower. A plateau is reached in both cases, but neither represents a true alveolar sample. If it were possible for the subject to continue to exhale beyond his residual volume (minimum lung volume), then the exhaled alcohol concentration would continue to rise until alveolar alcohol concentration (as represented by rebreathing¹⁰) were reached. As further evidence to this issue,

alterations in pre-test breath breathing pattern should not effect the end exhalation value if it is true alveolar air. However, hyperventilation decreases breath alcohol concentration while a breathhold increases breath alcohol concentration^{6,10}. End-exhalation air cannot be in equilibrium with respect to alveolar alcohol concentration because the conditions of the airways affects the breath alcohol concentration.

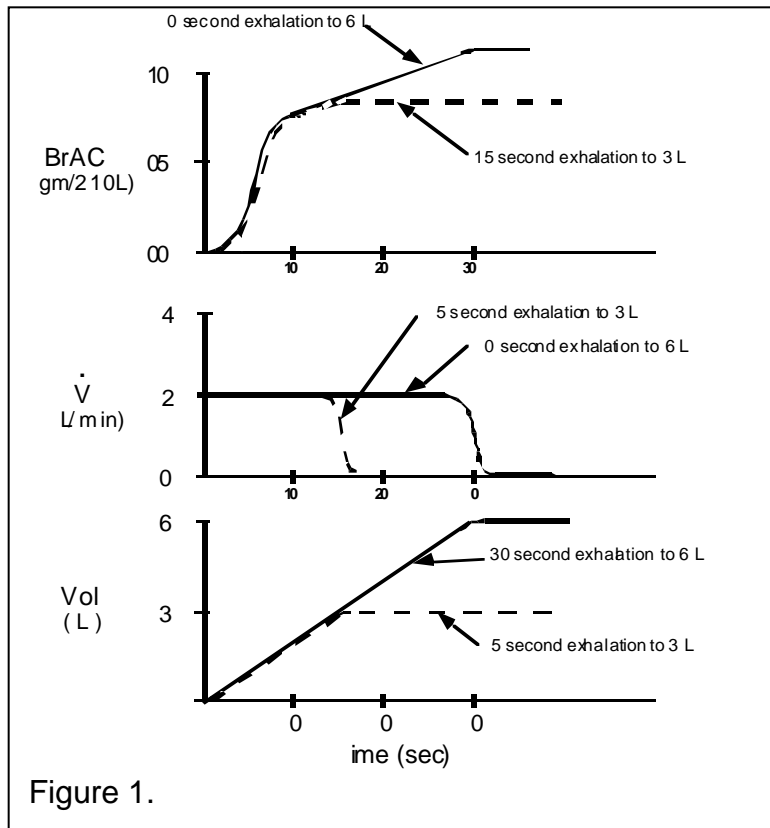


Figure 1.

MOUTH ALCOHOL

The detection of mouth alcohol does work as intended under some conditions. If an individual takes alcohol into the mouth, swishes it around and spits it out without swallowing, some alcohol will remain dissolved in the mucosal lining of the mouth. Then as he/she is blowing out into a breath testing machine, alcohol will be picked up as breath is passing through the mouth and an erroneously high breath test reading will be seen. Under normal conditions, during such a prolonged exhalation, the alcohol concentration first increases and then decreases. The detection of a decreasing slope by the breath testing machine is sufficient to register as an invalid sample due to the presumed presence of mouth alcohol. However, if the individual stops exhaling at just the point where the alcohol concentration reaches a maximum (before it starts decreasing), then the machine cannot distinguish this pattern from the normal exhalation profile and will not identify the presence of mouth alcohol.

There is another circumstance when the slope detector will not distinguish a contribution of mouth alcohol (Figure 2). If mouth alcohol is present in small quantities, it will add to the normal exhaled profile of alcohol coming from the blood and alveoli. The result is that a small amount of alcohol (and its decreasing concentration) will be added to the normal exhaled profile (and its increasing concentration) with a net effect of producing a constant (or slightly increasing) alcohol concentration. The slope detector will not work correctly when alcohol is present both in the blood and the mouth. The measured BrAC will be higher than it should be. However, the slope detector will not detect the contribution of mouth alcohol.

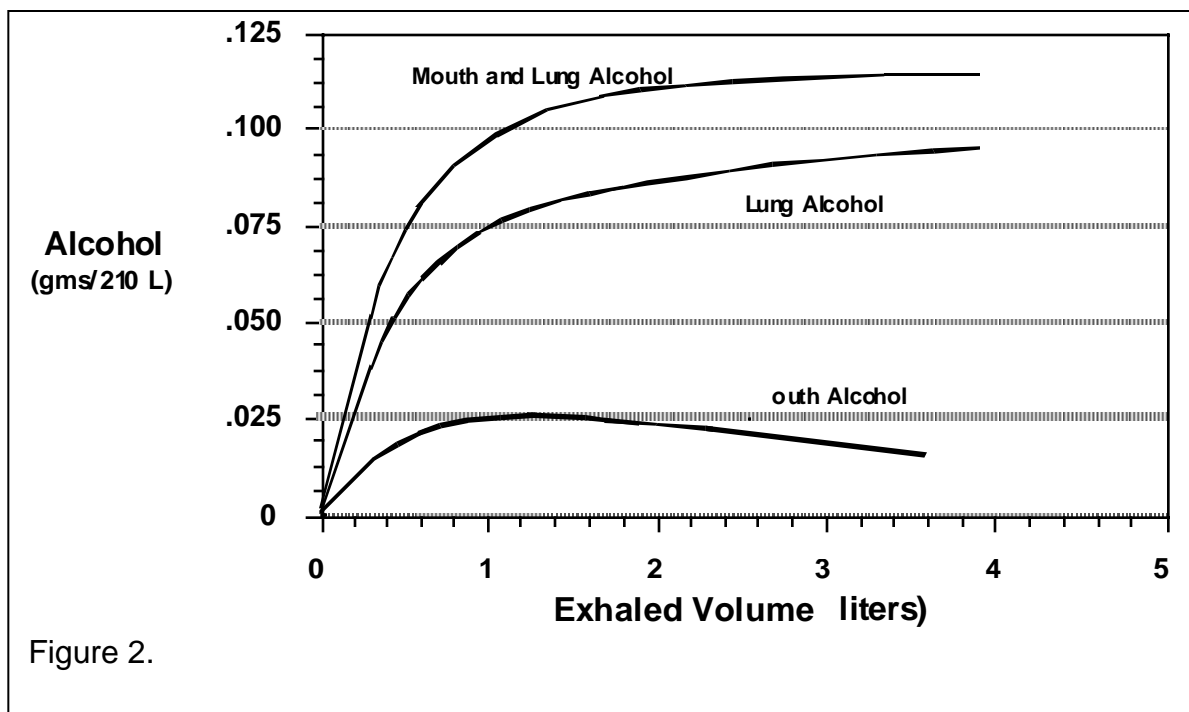


Figure 2.

IMPLICATIONS FOR THE ALCOHOL BREATH TEST.

The slope detector, as used on current infrared alcohol breath testing machines, does not carry out the intended functions. The fact that different exhalation volumes result in different BrAC values demonstrates that the "alveolar plateau" function has no purpose. There never is any guarantee of "alveolar air". In fact, the physiology of the lungs guarantees that alveolar air cannot be sampled (for alcohol concentration) as it was when in the alveoli. The observation that the mouth alcohol function only works when there is no alcohol in the blood stream argues that mouth alcohol may be contributing to high BrAC values up to a 0.03 to 0.04 error (in the increasing direction) on any given test.

FIGURE LEGENDS

FIGURE 1. A schematic example of a subject with a vital capacity of 6 liters showing breath alcohol concentration (BrAC), exhaled air flow rate and exhaled air volume. The solid lines represent an exhalation at a rate of 12 liters per second for a period of 30 seconds. The dashed lines represent an exhalation at the same rate for a period of 15 seconds.

FIGURE 2. Exhaled breath alcohol profiles. The lower curve is obtained with alcohol dissolved in the mouth with no alcohol in the blood. The middle curve is obtained with alcohol in the blood with no alcohol in the mouth. The top curve is the sum of the two other curves obtained with alcohol in the blood and alcohol dissolved in the oral mucosa.

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