The accuracy Issue of “True” Breath-by-Breath VO2 measurements

By John Hoppe and Andrew Huszczuk Ph.D.

What does it mean when a Metabolic Measurement System offers Breath-By-Breath (BBB) measurements?

What is so-called “true” BBB?

Early publications about measurement of VO2 and VCO2 date back to the early 1900’s, with collection of exhaled gases in bags.

Then in the 1930’s Douglas used gas collection bags during his expedition to the Andes; the resulting publicity credited him with the term “Douglas Bag”. The collected gases were subsequently analyzed and their volume measured.

Douglas bag and mixing chambers measurements using discrete gas analyzers were the standard until computers made on-line measurements with mixing chambers relatively easy.

Traditional (meaning older) instruments calculated data in fixed time intervals only, typically 60 seconds. This was because gas analyzers were slow and unable to follow the exhaled gases breath contour. When faster gas analyzers and reasonably priced computers became available, fast on-line breath-by-breath computations promised more, or better information.

In the late 1960’s, Beaver and Wasserman of Harbor-UCLA developed the first Breath-by-breath measurement system and later with Brian Whipp became the gurus and advocates of BBB measurements. It was hoped that the intra-breath information of BBB measurements would yield information about the dynamics of muscle O2 uptake.

The first attempts at BBB computations are now referred to as “true BBB”. Proponents of “true BBB” would like you to believe that “true” means “correct”, “better” or “more advanced”.

The purpose of this paper is to dispel that notion.

With the strong influence of the Harbor–UCLA team on purchasing decisions of new customers, many instrument manufacturers were eager to follow what was thought to be the future trend in VO2 measurements. However, the promise of measurement of muscle dynamics using BBB measurements failed totally.

Today, the prevailing opinion among experts in the field of VO2 measurements is that there is not a single advantage to “true” BBB measurements, and in fact definite disadvantages due to much more noisy data and unavoidable measurement errors as described below.

To understand the problems and difficulties with “true” BBB systems, one must fully comprehend how “true” BBB calculations are made.

Two major problems with “True” BBB:

The essence of the BBB approach is a separate analysis of the metabolic content of every consecutive breath with the aim to improve dynamics of respiratory gas exchange variables on transition from rest to exercise and back to rest. However, the ensuing noise of data required considerable filtering (averaging) by means of moving average spanning across several breaths, thus, essentially compromising the whole concept. The “true” BBB method consists in the fast-response measurement of the expiratory flow and the concomitant tidal concentrations of the exhaled O2 and CO2 gases. After temporal alignment these three variables are chopped into tiny time slivers (200 times per second), cross multiplied as symbolized in figure 2 below, (flow sliver 140 x ΔCO2 sliver 140 for the CO2 content and the flow sliver 140 x Δ02 sliver 140 for the O2 consumed during that breath sliver) and summed (integrated) to derive the metabolic content of the whole breath.

Consequently, two gas conduits and the respective flows have to be considered:

1. Large conduit (I.D. ~ 20-25 mm) carrying the respiratory flow typically ranging from 0.1 to 6 L/sec (perhaps up to 8 L/s for elite athletes) and

2. Small conduit (I.D. ~1mm), i.e., the gas sampling line with usually constant flow of ~0.4 to 0.5 L/min (~7.5 mL/s)

Expiratory Flow ›

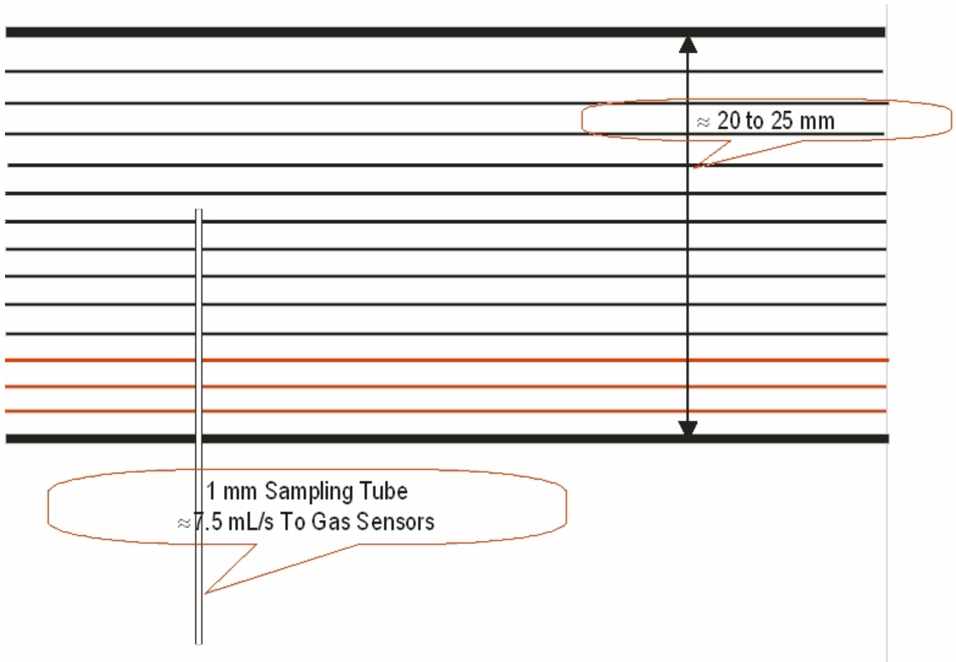

Figure 1

For the further consideration the term: "density of flow" has to be introduced as Liters per second per cross section area of the conduit. Since the circular cross section areas are proportional to the respective I.D.s squared, the conduits considered here (assuming 25mm ID) remain as

1 : 625, therefore, the exhalation flow has to be at least:

7.5 mL/s x 625 = 4.69 L/s

to make a drawn gas sample representative of a given time sliver. Consequently, it is apparent that the lower the exhalation flow, the bigger measurement error ensues, as the tip of the sampling line has to "borrow" by over-sampling from a growing number of the adjacent flow slivers up and down-stream from the gas sampling tip. This-in turn causes severe "smudging" of the measured temporal gas concentration profile at low respiratory flows, especially so near end-expiration when CO_2 concentration is highest and O_2 the lowest.

And, indeed, it can be fully confirmed by the metabolic calibration of "true" BBB systems at low respiratory flow rates (such as at rest or during stress tests of children or severely ill patients) where the measurement error can easily reach, or exceed 10%.

This is complicated by “Delay” time, which is comprised of “Travel” time and sensor response time. Travel time is the time it takes gas to flow from its source, usually a sampling port near the mouth, until it arrives at the actual gas sensor and is a function of the inner diameter of the sampling tube, tube length, pumping speed, gas viscosity and gas humidity. Sensor response time is the time it takes the sensor to respond to a step change in gas concentration. Flow and volume measurements can be considered instantaneous; there is no time delay between the exhalation and the measured expiratory flow.

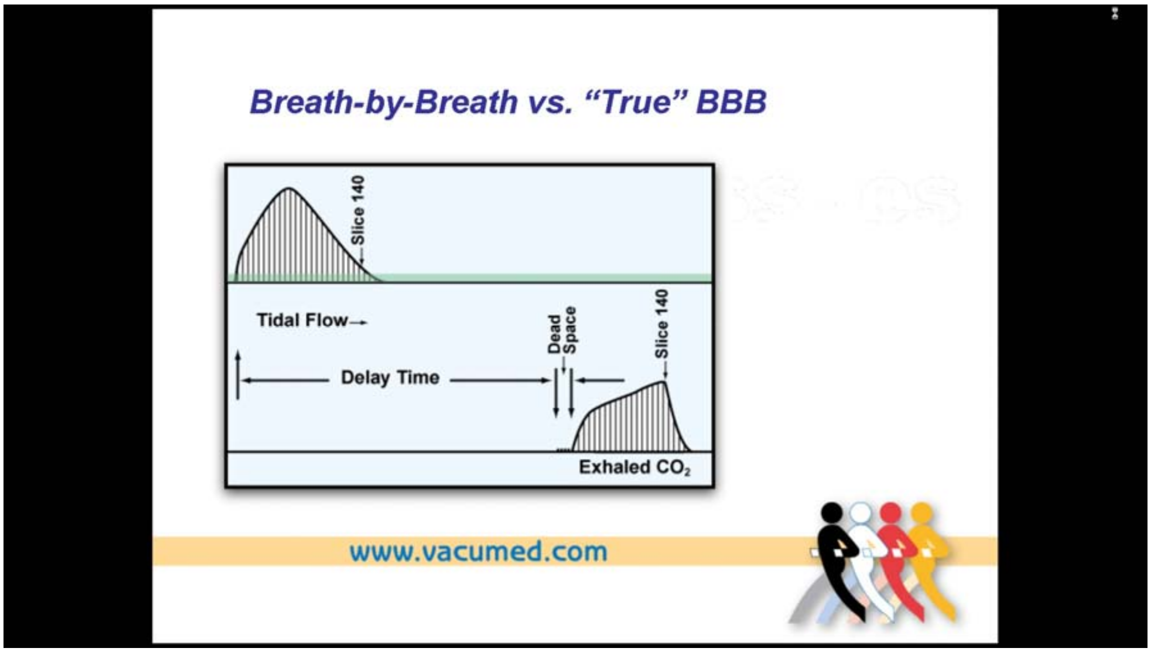

Figure 2

As mentioned earlier, this cross-multiplication, if combined with just a little change in delay time could seriously affect the sampling alignment, thus accuracy.

What physiological process is so time-sensitive that you need to know the intra-breath variation in VO2 and VCO2? Surely there are a handful of people out there who actually have an answer. But as far as we know none of the metabolic measurement systems on the market report intra-breath VO2, they only report the result for each completed breath. Even that data is unacceptably noisy, so typically, several breaths are averaged to obtain usable results.

Vacu•Med offers two types of metabolic measurement systems that make better, simpler BBB calculation.

One is the standard mixing chamber system, where, using a non-rebreathing valve, all of the exhaled breath is routed to a mixing chamber, typically a 4 to 6 liter chamber filled with baffles or other arrangements in order to effect homogeneous mixing so the gas exiting the mixing chamber shows little or no short-term variation in gas concentration. The gas sensors sampling this mixed exhaled gas therefore need not have a fast response time.

The other Type, Vacu•Med's Mini-CPX, uses proportional sampling.

With proportional sampling we draw a small sample of the exhaled gas at the mouth. "Proportional" means that at low exhaled gas flow, our sample pump runs slow, at high exhaled gas flow, the sample pump runs proportionally faster. A mixing motor rapidly mixes the gas so that the gas analyzer only sees constant mixed exhaled values for any given breath. Therefore, the sampling flow is matched to the expiratory flow.

Vacu•Med's BBB calculation, as does every other mixing chamber system, simply uses the total breath volume and multiplies it by the averaged gas concentration. We do not multiply slice by slice, but total by total*.

It should be obvious here that a minor change in delay time using Vacu•Med's method has no effect on the result.

This is one of the reasons Vacu•Med can guarantee the accuracy of the VO2 and VCO2 measurement to be better than 3%, while the manufacturers of true BBB systems are suspiciously silent about the accuracy of their systems.

Australia so far is the only country in the world that requires all VO2 systems to be tested by the Australian Institute of Sport.

FACT:
There is not a single advantage to "True" BBB!

Not a single "True" BBB system has passed the Australian Institute of Sport accuracy testing.

*For the purpose of simplifying this explanation, we are ignoring the effects of ambient conditions and the Haldane transformation.

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