EasyOne Pro LAB MBW FAQ

C. Buess, March 2025

1. Introduction

Performing Multiple Breath Washout (MBW) tests with the EasyOne Pro LAB requires the patient to perform tidal breathing over a period of 2 to almost 10 minutes (depending on the patient). Due to the long duration, the test can, in some cases, be challenging to perform.

This document describes problems and errors that may occur during the test procedure. Some of these problems and errors cannot currently be detected automatically by the software. This document pertains to V3.2.0.6 or higher of EasyOne Connect, the software used on the EasyOne Pro LAB.

Please note that the issues described in this document are not caused by the design of the EasyOne Pro LAB but are problems generally encountered in MBW tests.

This Application Note mainly focuses on how to perform good-quality MBW tests for the determination of FRC (Functional Residual Capacity) and LCI (Lung Clearance Index).[1]

2. MBW Test Procedure

According to the 'Consensus statement for inert gas washout measurement using multiple- and single-breath tests' [1], LCI is defined as follows:

> *LCI is the most commonly reported MBW index in current pediatric literature, and defined as the number of FRC lung turnovers (TO; calculated as CEV/FRC) required to reduce alveolar tracer-gas concentration to a given fraction of its starting concentration, historically 1/40 (2.5%).*

The text below explains that LCI is normally determined at the point where three consecutive breaths are detected below 2.5% of the initial tracer, i.e., nitrogen (N_2), concentration.

EasyOne Connect is based on this definition and only marks a test as acceptable if three consecutive breaths with N_2 concentrations below 2% are detected.[2]

When an MBW test is performed with the EasyOne Pro LAB, the end-tidal N_2 concentration is computed on-line (i.e., while the test is being performed). The on-line N_2 concentrations are displayed in the bar-graph window. However, these values are not identical to the final end-tidal N_2 concentrations computed at the end of the test, where a more precise 'off-line' computation is used. The error between the 'on-line' values and the final values computed during the final evaluation is normally within $\pm$0.2% N_2.

If the automatic test mode[3] is selected, the system ends a test when 5 consecutive N_2 concentration values below 1.8% are detected. This approach ensures that the LCI criterion (three consecutive N_2 concentrations below 1/40th of the start concentration) is met in almost all cases.

When the manual test mode is selected, please make sure that enough breaths below 2% are recorded, and be aware that a maximum error of ~0.2% is possible between on-line and final N_2 concentration computation.

If only one or two consecutive breaths with an N_2 concentration below 2% are measured, then the LCI is still computed, but the test is marked as not acceptable. In this case, the error

[1] Computation of S_{cond} and S_{acin} based on N_2 concentration slope analysis is even more challenging and requires steady breathing throughout the washout (see Reference [1] below and our Application Note *MBW Phase-III Slope Analysis* available on our website at www.nddmed.com under *Resources* / *Downloads*.

[2] An N_2 concentration of 2% corresponds to 1/40th = 2.5% of the initial N_2 concentration of ambient air (1/40th of 78.1% equals 2% N_2).

[3] To select the test mode, go to *Utilities* / *Configuration* / *Test* / *FRC (MBW)*.

message 'N2 concentration at end of test too high — Longer washout required' is shown (message number 31).

Preparing the Patient

To perform a test, patients must be introduced to the system and the MBW procedure needs to be explained to them in detail. We propose performing the following:

- Show patients the equipment with a focus on the breathing mouthpiece (*Spirette*) and the nose clip.
- Demonstrate what noises are to be expected during the test procedure. For this purpose, the valve can be closed and opened "manually" (*Utilities* / *Configuration* / *Device* / *DLCO Valve*).
- Explain to patients that they will probably not feel any difference between breathing in 100% oxygen and normal air. The oxygen might feel 'drier', which can lead to increased saliva production and, in rare cases, to coughing.
- Tell patients that they should breathe calmly, continuously, and steadily. Patients should not laugh, speak, or yawn during the test.
- Patients should hold the *Spirette* firmly between their teeth but without biting down on it. They should also seal their lips tightly around the *Spirette*'s mouthpiece. Swallowing is OK if necessary.
- According to the Consensus Statement [1], sighing during the washout phase should lead to exclusion of the test (as it may significantly elevate FRC).
- Each test takes about three to five minutes.
- The time between two tests must be twice as long as the testing time for the preceding test. During the intervals, patients should remove the breathing mouthpiece and may remove the nose clip as well. They may have something to drink between tests, but drinks should not be carbonated (can cause artifacts due to CO_2).

3. Errors and Problems in MBW Tests

3.1 Start of Washout

The Consensus Statement [1] says that the pre-washout phase must have:

> ***stable VT and end-expiratory lung volume over the preceding 30 s.***

This is also true for measurements with the EasyOne Pro LAB, where the first three breaths before the washout are used as a reference.

In the software for the EasyOne Pro LAB, the start of a washout is controlled by three settings (accessible via *Utilities* / *Configuration* / *Test* / *MBW*):

Test mode	This setting defines whether the washout-start and -end are automatically or manually controlled.
Min. no. of breaths	This setting defines the minimum number of 'stable' breaths required before the washout-start. Please note that, in both manual and automatic mode, the number of breaths defined here must fulfill the stability criteria (see below).
Target volume range	This setting defines if a large tidal volume range is used (i.e., for adults, SnIII analysis) or if a small Vt range is used (i.e., for pediatric applications).

The stability criteria for the tidal volume Vt (in- and expiratory volume) before the washout are defined as follows:

Large Vt range				
	Vt min	Vt max	Bar-graph min	Bar-graph max
Patient weight available	5 ml/kg (max. 350 ml)	30 ml/kg	950 ml	1400 ml
Patient weight not available	250 ml	3000 ml	950 ml	1400 ml
Small Vt range				
Based on ideal body weight [2]	6 ml/kg	16 ml/kg	8 ml/kg	13 ml/kg

Note: For the small Vt range, the ideal body weight is determined from the patient's height, age, and sex. For details, please refer to reference [2] below.

These stability criteria may lead to a situation in which a washout cannot be started. Example for 'Large Vt range': If a patient's weight is 50 kg, then the Vt is limited to a range between 250 ml to 1500 ml. If the min. no. of breaths is set to 5, then all 5 breaths must be within that limit; if even one out of 5 breaths is slightly above 1500 ml, the test will not start. In order to resolve the problem, please ask the patient to breathe at a smaller tidal volume.

3.2 Hyperventilation

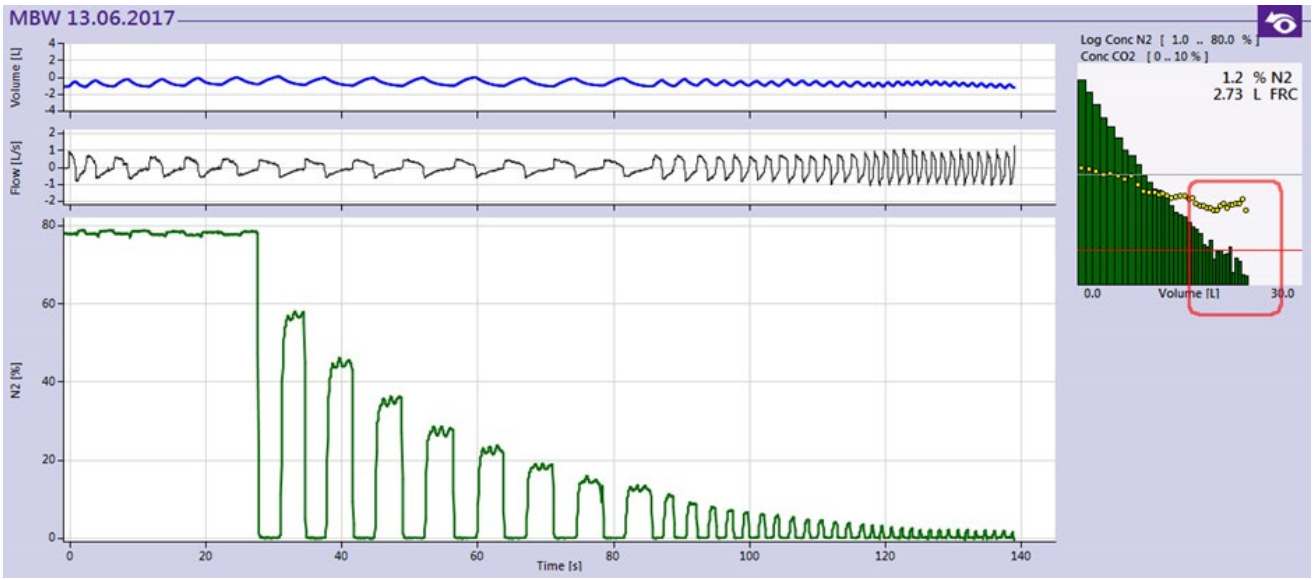
If the patient hyperventilates during the MBW test procedure, the end-tidal N_2 and CO_2 values cannot be determined due to an incomplete phase III of the expirogram. The Consensus Statement [1] says the following in this regard:

> *If available, monitor end-tidal CO_2 values during MBW to screen for hyperventilation.*

In order to monitor end-tidal CO_2 concentration please activate the option in *Utilities / Configuration / Test / MBW / Show CO_2 curve*. The end-tidal CO_2 concentration is plotted within the N_2 bar graph display. The gray line indicates a level of 5% CO_2.

Hyperventilation can be recognized in two ways: First, the end-tidal CO_2 values decrease; second, the breathing frequency increases, which can be detected in the graphs for flow, volume, and N_2.

The screenshot below shows a test with hyperventilation during the last part of the MBW test:



At the start of the washout, the breathing frequency is normal and complete N_2 expirograms can be identified (i.e., N_2 signals with a clearly identifiable phase III). During the MBW test above, the breathing frequency is increased. Due to the increase in frequency and the decrease in tidal volume, end-expiratory CO_2 concentrations (indicated by yellow dots on top of the semi logarithmic N_2 concentration plot) and, therefore, end-expiratory N_2 concentrations, cannot be measured accurately (no clear plateau in phase III). As a result, the end-expiratory N_2 concentrations differ significantly from breath to breath (see diagram on the right side). As a consequence, LCI cannot be measured accurately since there is no clear point at which the N_2 concentrations fall below the red line, indicating $1/40^{th}$ of the initial N_2 concentration.

Recommendation: Make sure that the breathing frequency and the tidal volume are constant throughout most of the test. Apart from showing flow, volume, and N_2 traces, the display indicates in the N_2 diagram the end-expiratory CO_2 concentrations by means of yellow dots; in the diagram above, the falling concentrations of CO_2 can clearly be seen. During the same phase, the end-expiratory N_2 concentrations do not decrease in a regular fashion and make a precise determination of LCI impossible.

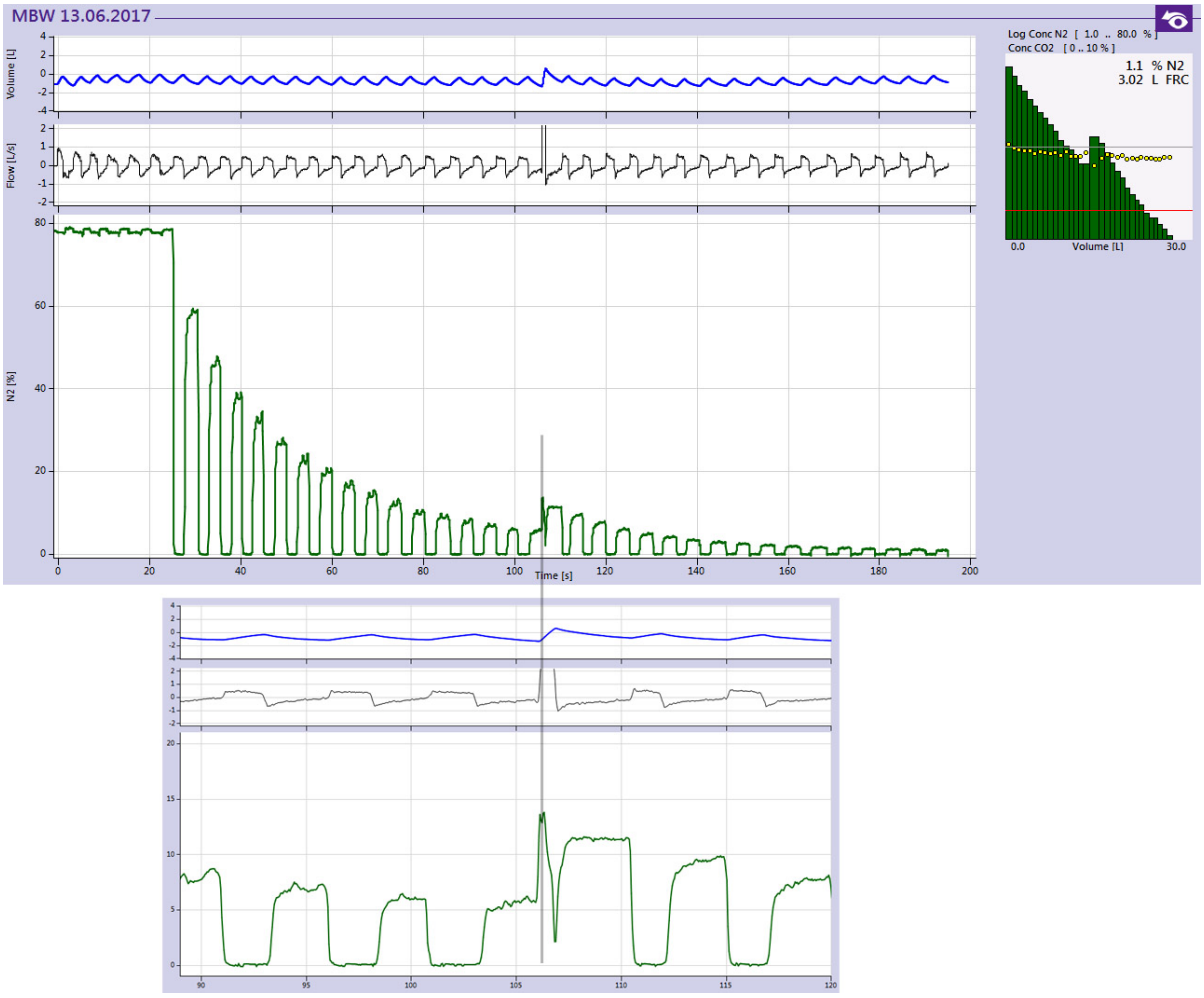
3.3 High Inspiratory Flow / Room Air Inspiration

The N_2 MBW test relies on the patient's inspiring only 100% O_2 during the washout phase. If the patient inhales room air during the washout, the N_2 concentration will rise again. Inspiration of room air can occur for several reasons:

- The patient inhales room air due to a leak at the mouthpiece.
- The patient inhales room air due to excessive inspiratory flow combined with a leak in the check-valve.

The following two pictures show how inspiration of room air can be detected: At a testing time of approx. 105 sec, the patient inhaled deeply and exceeded the maximum flow level of 2 L/s. The check-valve was blocked manually and, due to this additional error, inspiration of room air occurred. The excessive flow can also be detected in the flow and volume signals. At the end of the test, the warning 'High inspiratory or expiratory pressure detected' is displayed and the test is automatically marked as 'not acceptable'.

In the zoomed display mode (the second of the following two pictures), the inspiratory N_2 can be recognized easily. The image also shows how the end-expiratory N_2 concentration rises immediately after room air inspiration.



In order to prevent inspiration of room air, the following recommendations should be followed:

- Make sure that the pressure of the O_2 supply to the EasyOne Pro LAB is set to 4 bar. Also make sure that the pressure does not drop below 3 bar during the washout phase when the patient inhales O_2.
- Make sure that a new original ndd *Spirette* and FRC *Barriette* are used. Both items are essential for patient hygiene and for good tightness during a washout test.
- Use a nose-clip and mount it properly.
- Make sure that the *Spirette* is positioned properly in the patient's mouth during the entire test: Patients should hold the *Spirette* firmly between their teeth but without biting down on it. They should also seal their lips tightly around the *Spirette*'s mouthpiece.
- Make sure that the patient does not exceed the limit of 2 L/s inspiratory flow.

4. MBW Acceptability and Quality Grades

The current software of the EasyOne Pro LAB contains a quality grading system for spirometry and for DLCO. For Multiple-Breath Washout tests, however, a quality grading system has not yet been introduced by ATS/ERS.

For MBW, a grading system similar to those used in spirometry has been implemented in the software of the EasyOne Pro LAB in order to provide a defined quality grading system and a defined 'end-of-test' criterion. The grading system is mainly based on the ATS/ERS Consensus Statement [1]. Quality grades A to F are defined on the basis of this publication. Trial acceptability and test quality assessment are explained below.

4.1 MBW Acceptability

In order for a trial to be acceptable the following criteria need to be fulfilled:

1. End-of-test criterion for LCI is met (3 consecutive breaths with end-tidal N_2 concentration <1/40th of the starting N_2 concentration).
2. Mouth pressure <$\pm$5 mbar detected during the test procedure.
3. Flow <$\pm$2 L/s during the test.
4. Mean inspiratory volume during washout is within limits defined in section 3.1.
5. No large volume drift detected.
6. ERV and IRV can be computed when a 'linked' MBW test is performed.

Please note that the following criteria are, at present, not quantified and therefore not considered for test acceptability:

1. Breathing pattern: According to the Consensus Statement [1], the breathing pattern should be similar among patients.

2. Irregular breathing pattern at start of test: The breathing pattern should be similar throughout the washout test.
3. Sighs during the test: According to the Consensus Statement [1], sighs visible in the graph should prompt for test exclusion.
4. Inspiratory Leaks during washout: Sudden increases of end-tidal N_2 concentrations during the washout indicate leaks. Such tests must be excluded.
5. Hyperventilation: May lead to test exclusion (however, this is not mentioned in the Consensus Statement [1]).

Since these criteria are not quantified, they should be checked by the technician performing the tests and acceptability should be adapted manually when a test has been performed. The quality grading will be recomputed as soon as acceptability is changed by the user.

4.2 MBW Quality Grades

The following quality grading system, based on the ATS/ERS MBW Consensus Statement [1], is defined:

Grade A	A minimum of 2 acceptable maneuvers with LCI variability <5% and FRC variability <10%	→ *Session complete*
Grade B	A minimum of 3 acceptable maneuvers with LCI variability < 10% and FRC variability <25%	→ *Session complete*
Grade C	2 acceptable maneuvers with LCI variability < 10% and FRC variability < 25%	
Grade D	1 acceptable maneuver or multiple maneuvers with LCI variability ≥10% or FRC variability ≥ 25%	
Grade F	no acceptable maneuver	

Remark: FRC- and LCI-variability are defined as the largest difference to the median FRC or LCI value respectively. In statistics and probability theory, the median is the numerical value separating the higher half of a data sample, a population, or a probability distribution from the lower half. The median of a finite list of numbers can be found by arranging all the observations from lowest value to highest value and picking the middle one (e.g., the median of {3, 3, 5, 9, 11} is 5). If there is an even number of observations, then there is no single middle value; the median is then usually defined to be the mean of the two middle values (the median of {3, 5, 7, 9} is (5 + 7) / 2 = 6), which corresponds to interpreting the median as the fully trimmed mid-range (Wikipedia).

Additional restrictions:

- At present, the FRC and LCI values are reported as the average of all acceptable trials. The additional criterion that only trials within ±25% of the median must be considered is not implemented.
- There is, at present, no warning message when only 2 acceptable trials are performed (a warning message is recommended in the Consensus Statement [1]).

5. Accuracy

Regarding FRC (and LCI) accuracy, the Consensus Statement [1] says the following:

> *Formal FRC repeatability criteria for MBW indices should not be routinely applied, but FRC values within 10% should be viewed as encouraging. FRC values differing by more than 25% from the median of three test values should be excluded.*

6. Conclusions

All the recommendations mentioned above should be followed carefully.

The most important general recommendation is that patients must breathe regularly in order to perform qualitatively acceptable tests (see Consensus Statement [1]):

> *Breathing patterns during testing should be kept similar between subjects to facilitate comparison of results. In adults this is achieved by using strict breathing regimens where feasible and in younger children (aged <16 years) by distraction to encourage relaxed tidal breathing.*

For details, please refer to the Consensus Statement [1].

7. References

[1] Consensus statement for inert gas washout measurement using multiple- and single-breath Tests. *Eur Respir J* 2013; 41: 507-522.

[2] E.L Horton, R. Jensen, S. Stanojevic, F. Ratjen. Estimating physiologically appropriate tidal volume ranges for multiple breath washout tests, *AJRCCM* 2017; 195.