GE Healthcare

CARESCAPE R860 Lung Protection Tools Appliguide

Contents

Introduction

Scope of this appliguide

This appliguide covers the following clinical tools available with the CARESCAPE R860:

- FRC INview, used to determine a ventilated patient's FRC*
- PEEP INview, used to perform sequential FRC measurements at varying levels of increasing or decreasing PEEP levels
- Lung INview, which is a PEEP INview procedure with combined data obtained from Spirodynamics.

** Functional Residual Capacity (FRC) is measured on non-ventilated patients. For ventilated patients with elevated PEEP, the parameter is defined as End Expiratory Lung Volume (EELV). Throughout this guide, the term FRC is used instead of EELV for simplicity.*

Structure of this appliguide

This appliguide follows the following structure to guide you at the bedside application of these measurements and allow you to implement data driven and patient specific strategies for lung protection, recruitment and optimum ventilation.

Chapter 1: FRC procedure workflow overview,
An overview of the optimum workflow and bedside techniques for successful results

Chapter 2: Steps in ensuring valid FRC results,
Specific advice and checklists on how to perform an artifact free and valid INview measurement

Chapter 3: Interpretation of the results
Providing guidance on how to use the various clinical decision support tools and displays and how to interpret technically the various INview measurements

Chapter 4: FRC measurement theory
In depth theory and technology behind the INview FRC measurements with the CARESCAPE R860

INview measurement procedure steps

To obtain a valid and accurate FRC INview measurement or series of measurements (PEEP or Lung INview) requires both valid and accurate gas exchange measurements with the CARESCAPE R860 respiratory gas module inserted in the CARESCAPE R860 as well as a metabolically stable patient condition.

The software of the ventilator and the graphical user interface provide special displays to aid you during the bedside application of INview measurements.

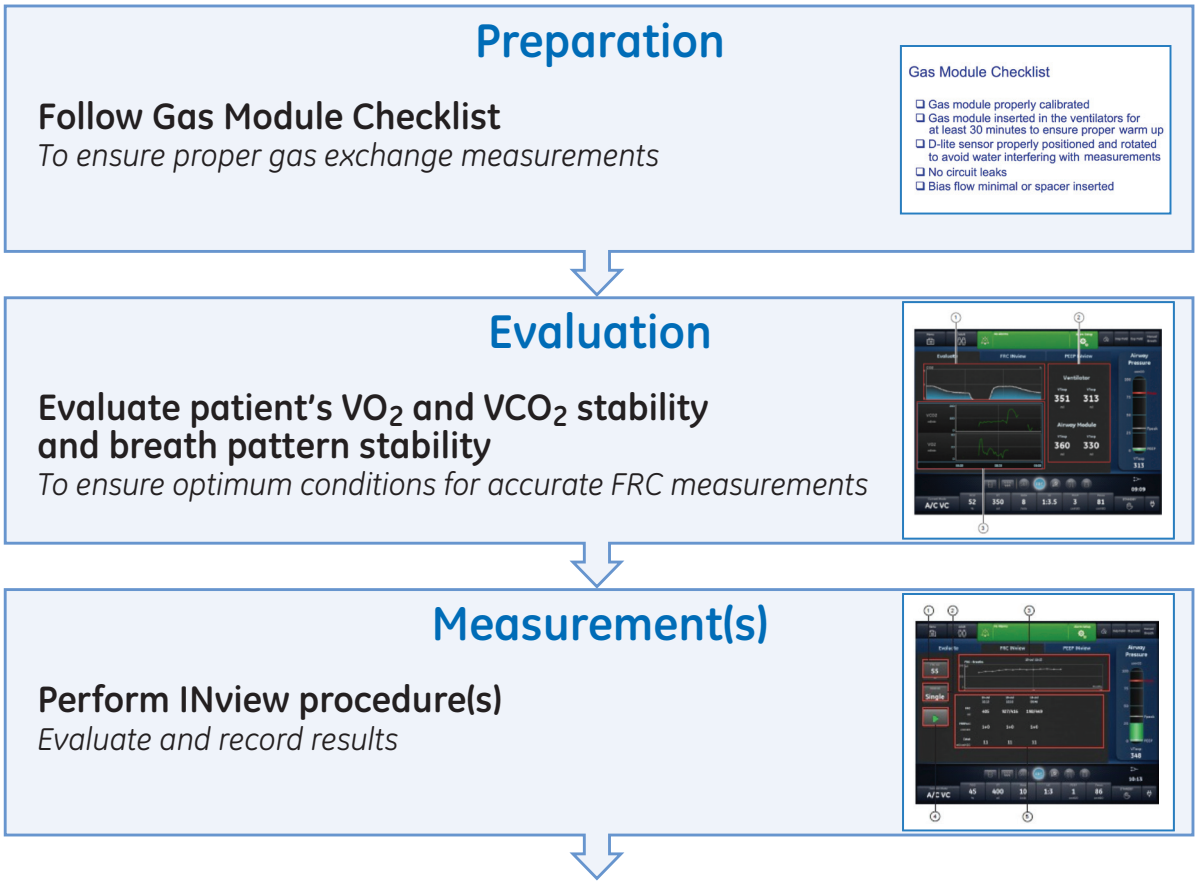


Figure 1: INview measurement flow chart

Preparation

This step ensures that the ventilator with the module is prepared and connected with the appropriate connections and accessories to minimize artifacts and ensure valid gas exchange measurements

Evaluation

This step is to ensure that the patient condition as far as VO_2 and VCO_2 stability and ventilator status is appropriate for a valid INview measurement.

Measurements

This step is to setup and perform the INview measurements and technically evaluate the results

Ensuring accurate COVX Gas Module measurements

First of all ensure that the gas module has a valid calibration. Insert the module and wait for around 30 minutes before performing InView measurements.

Managing humidity in the patient circuit

If active humidification is used instead of an HME (Heat and Moisture Exchanger) type humidifier it is important that the D-lite sensor and the sampling tubes remain free from condensation. Condensation in the sampling tubes can affect the flow/volume measurements and/or the gas composition measurements.

During ventilation with active (heated) humidification, it is recommended to use D-lite(+) and Pedi-lite(+).

D-lite (+) and Pedi-lite(+) sensors have a hydrophobic coating to repel condensation from its inner surface and minimize possibility of entry in the sampling tubes.

If an active (heated) humidifier is used ensure that the sampling tubes are on the top and that the D-lite+ or Pedi-lite+ sensor is placed at a 20 – 45 degrees tilt to minimize chances of condensation entering the sampling tubes and interfering with the measurements.

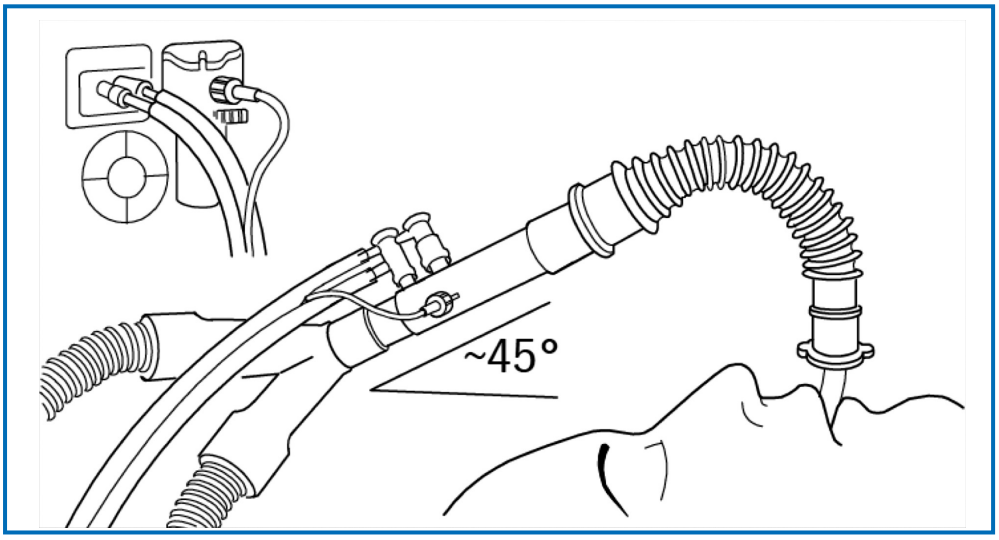


Figure 2: Minimizing the effects of humidity in the airway gases

Condensation and droplets in the sampling tubes tend to create sudden and large inaccuracies and variations especially in the volume measurements and as such they are relatively easy to detect. If an HME (Heat and Moisture Exchanger) is used ensure that it is placed between the D-lite sensor and the patient.

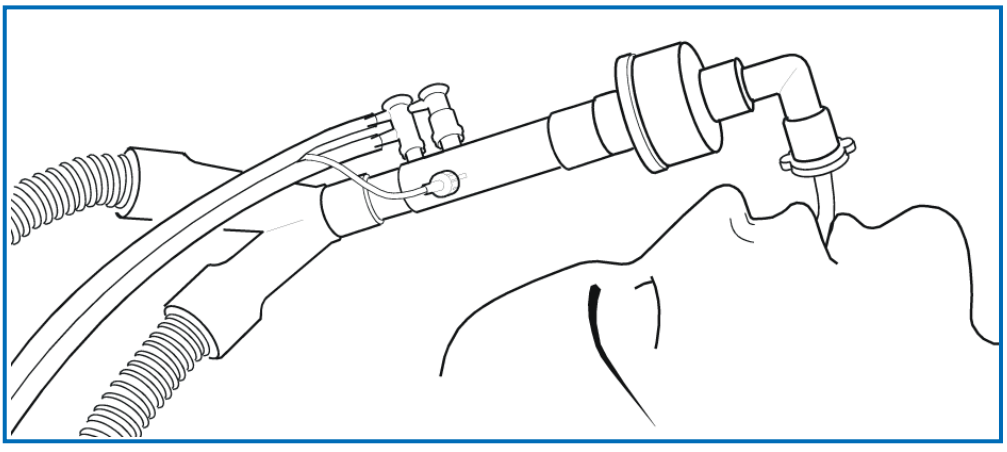


Figure 3: Correct position of an HME device

Bias Flow dilution effect

The CARESCAPE R860 employs continuous flow through the patient circuit for triggering and response latency purposes. This flow could interfere with the gas measurements by mixing patient gas and fresh gas during long expirations. This condition can be observed by looking at the shape of the CO_2 waveform.

A further indication that this effect might be playing a role is obtained by observing the patient's flow waveform: Periods of zero flow at the end of expiration indicate higher chances of this dilution effect.

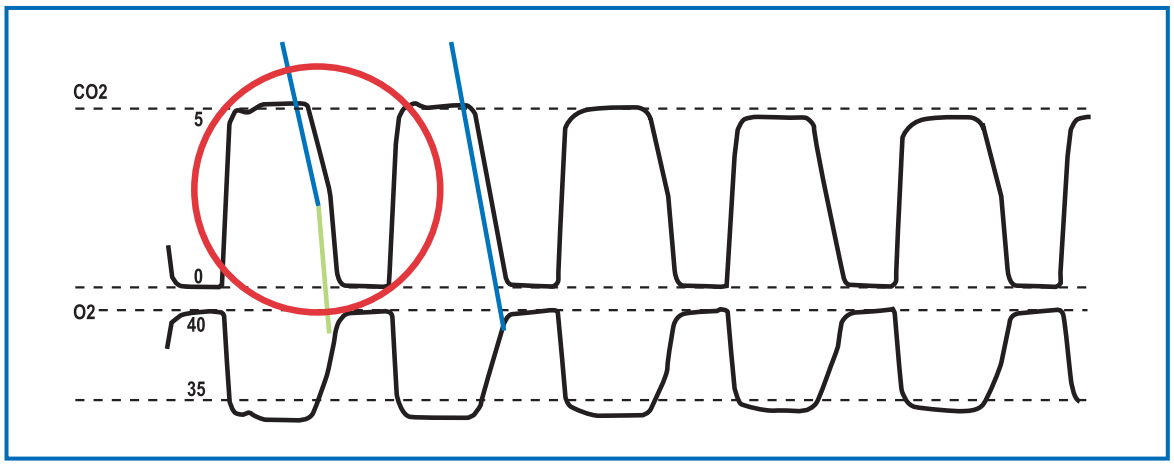
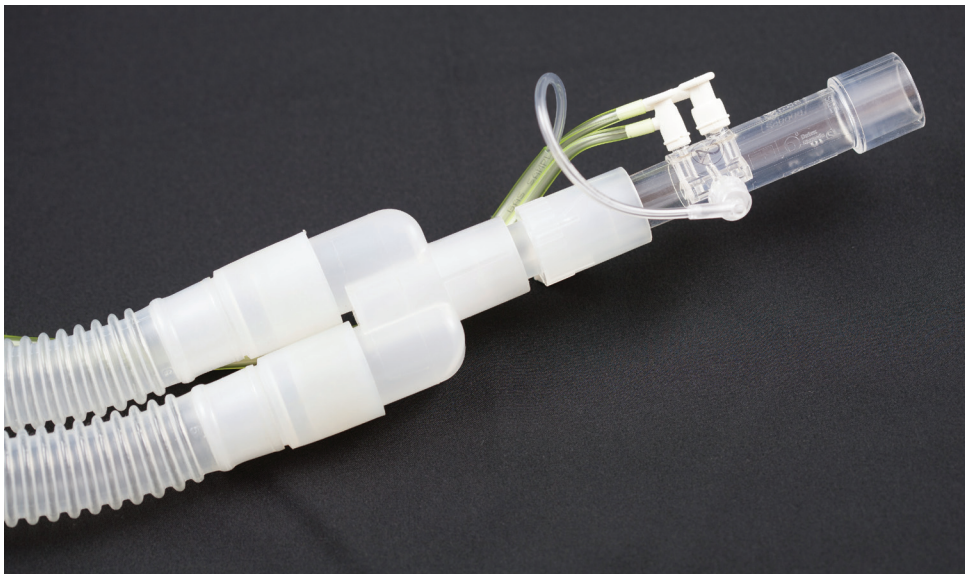


Figure 4: CO_2 waveform affected by Bias Flow

In this example the effect of high bypass flow is visible:

- Double (or variable) slope on the CO_2 curve at start of inspiration.

To minimize this dilution effect, reduce the bias flow setting if clinically appropriate or alternatively add a spacer or adaptor with approximately 5 ml of dead space between the circuit "Y" piece and the D-lite sensor if this increase of dead space is not deemed to be detrimental to the patient's ventilation.



Verify that there are no leaks in the circuit

For optimum results there should be no leaks in the patient circuit or around the artificial airway.

Ensure patient is stable

For an accurate measurement it is important that the patient is in a steady state with stable ventilation.

Use the special evaluation tab under FRC view to get a quick overview of the relevant patient condition before starting an FRC measurement:

Figure 5: Evaluate tab under FRC view

The data displayed in this page can help you evaluate the status before proceeding with the measurement. This way you ensure optimum conditions for a valid INview procedure.

The elements are as follows:

1. VCO_2 and VO_2 1 hour trend. This graph will help you verify that the patient is in steady state. Strive for starting the procedure after patient's VCO_2 and VO_2 are stable for at least 10 minutes, preferably longer
2. CO_2 waveform. This waveform is displayed to allow evaluation of breathing pattern stability. Avoid starting an INview procedure if the waveform is not regular because this could indicate tidal volume variations.
3. Airway module and internal Ventilator tidal volume measurements. This data will help you evaluate the validity of the proximal flow and volume data. If there are large discrepancies check the D-lite sensor and sampling lines for humidity.

Starting and reviewing INview measurements

FRC INview measurements are performed and analyzed from the 2 remaining tabs of the FRC view as follows:

FRC INview tab: To perform and analyze one (or a repeated series of) single FRC measurements.

PEEP INview tab: To perform and review FRC measurements during a PEEP ramp, where the ventilator will automatically change set PEEP between a starting and an ending value for up to 5 steps. The PEEP ramp can either be incremental or decremental.

FRC INview tab:

A single FRC INview measurement or a series can be performed. The following elements allow you to monitor and review the procedure:

FRC graph: This graph shows the accumulated single breath FRC values (see Theory of FRC measurement) and indicate the pattern of Nitrogen wash in or wash out of the lung. A lung with short time constant (like a healthy lung) will typically result in a curve that quickly reaches the final FRC value. On the contrary a lung with long time constant or compartments with long time constants will result in a curve which takes longer to reach the final FRC value, indicating the longer times for the new N_2 value to equilibrate in the lung.

At the end of the FRC procedure the ventilator automatically performs an inspiratory pause procedure to calculate and display the static compliance of the lung at that moment.

FRC INview measurements comprise of 2 symmetrical FRC measurements. The first when the FiO_2 changes from the clinical setting to the $FRCO_2$ setting and the second when FiO_2 reverts to the clinical FiO_2 setting.

The ventilator software will initially display both these measurements and associated FRC curves. During a subsequent measurement the numeric FRC value and FRC curves will be averaged provided they not differ by more than 20% of each other.

Results which are not averaged (differ by more than 20%) indicate that the patient's breathing pattern and/or VO_2 and VCO_2 varied during and prior to the FRC procedure initiation and it is best to repeat the procedure after ensuring patient stability.

At the end of the FRC INview procedure the system automatically performs an inspiratory pause and measures the static compliance.

PEEP INview

Before starting a PEEP INview procedure set the start PEEP, end PEEP and Steps settings. Via these settings you can perform a decremental PEEP ramp (start PEEP > end PEEP) or an incremental PEEP ramp (start PEEP > end PEEP).

After each PEEP level has been reached the procedure will wait for an equilibration time before measuring FRC at that PEEP level. This time is 10 minutes by default but can be changed by Step Time. Please note that a longer Step Time will result in a longer overall procedure.

Use the evaluate tab and look at VO_2 and VCO_2 trend to evaluate if the current Step Time is adequate.

The estimated (approximate) procedure time based on the number of PEEP steps and the Step Time is displayed to allow you to plan patient care. Any ventilator setting changes carried out while the procedure is in progress will interfere and terminate the procedure.

The PEEP INview tab displays the results both graphically and numerically.

Lung INview

If an Intratracheal Pressure Sensor (SpiroDynamics catheter) is present during the PEEP INview procedure it is possible to combine FRC and SpiroDynamics data and get enhance information about lung volumes by comparing the volume at the same pressure level when this pressure is achieved under dynamic tidal inflation and when the same pressure is applied as PEEP at the subsequent PEEP level of the procedure.

INview procedure workflow

Step	Action
Gas module stable	• Insert gas module at least 30 minutes before the procedure to ensure adequate warm up time • Follow recommended calibration intervals and ensure module is properly calibrated
D-lite sensor	• Insert D-lite or Pedi-lite sensor as appropriate • Angle sensor to prevent condensation entering the sampling tubes • Use the comparison between the inspired and expired tidal volumes to ensure that the D-lite sensor sampling lines are free of condensation (evaluate tab).
Leaks	• Compare inspiratory and expiratory tidal volumes (evaluate tab) to make sure that there are no leaks in the circuit or airway
Bias Flow	• Set minimum Bias Flow if possible • As an alternative Insert a 5 ml spacer between D-lite and patient Y
Patient Stability	• Observe VO_2 and VCO_2 trends to ensure that they are stable for around the last 20 to 30 minutes.
Breathing pattern stability	• Observe the CO_2 waveform to ensure that the patient breathes quietly and with a repeating pattern.

Theory of FRC measurement

Measuring FRC in the pulmonary function lab is routine and frequently performed on patients. Measuring however FRC of the ventilated patient at the bedside is far from simple and not generally available.

The CARESCAPE R860 performs FRC measurements based on monitoring the change of N_2 (nitrogen) concentration measured at the airway (Modified Nitrogen Dilution method). The concentration of inspired N_2 is changed by changing the delivered FiO_2 Concentration.

Note: The measured parameter of this method is referred to by convention as FRC. As the measurement occurs in general at elevated PEEP on a ventilated patient the proper term is EELV (End Expiratory Lung Volume).

Dilution technique

The principle of using dilution to probe a volume, which is not accessible to be measured is well known and widely applied. The principle can be explained as follows:

We have an unknown volume, which we would like to measure, let us say a bucket of clear water. We can use a known volume of dye, which has a known concentration. When the clear and the dyed fluids are mixed, the dye will be diluted in proportion to the two volumes. Hence by knowing the dye volume and the initial dye concentration plus measuring the diluted dye concentration we can easily calculate the volume of the bucket. This is shown in the following illustration:

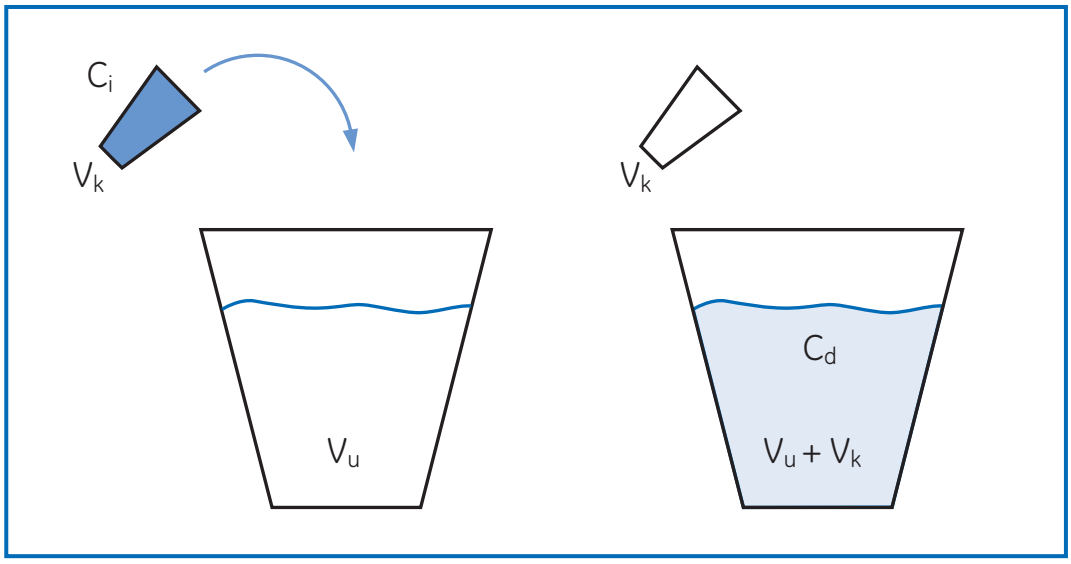


Figure 6: Dilution method illustration

V_k is the known volume of dye we use to measure the unknown volume in the bucket

V_u is the unknown volume we like to measure

C_i is the initial dye concentration

C_d is the diluted dye concentration, which is sampled and measured to determine the dilution factor

Calculating volumes with the dilution method

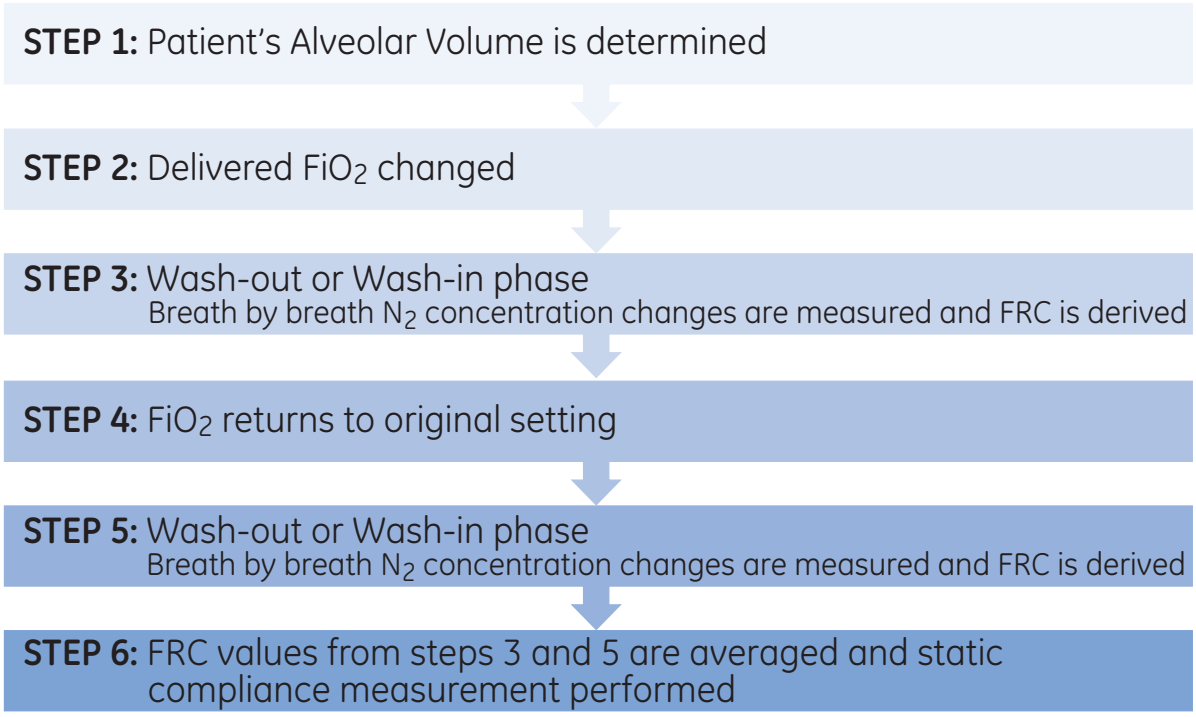
The equation to measure the unknown volume is:

$$V_u = V_k \frac{C_i}{C_d} - V_k$$

FRC Measurement phases

A typical FRC measurement with the CARESCAPE R860 follows several steps as depicted in the following flow chart:

Figure 7: FRC measurement flow chart



FRC, when performed as a single measurement, is actually measured twice as shown in the above flow chart. The first time is when the FiO_2 is changed to the FRC-FiO_2 and the second time shortly after the first measurement when the FiO_2 is returned to the original FiO_2 setting. That is why there are 2 anti-symmetrical steps called wash-out/wash-in (if FiO_2 is initially increased) or wash-in/wash-out (if FiO_2 is initially decreased). The final reported FRC is the average of the two measured values, in general increasing accuracy and confidence in the result.

When FRC measurement is part of a series e.g. during PEEP INview or Lung INview, in the interest of time, only a single step is performed at each PEEP setting, alternating between the wash-in and wash-out phases.

At the end of this appliguide there is a tracing during an actual FRC measurement with the CARESCAPE R860, where the wash-out and wash-in of nitrogen can be visualized.

FRC calculation equations

Step 1: Determine Patient's Alveolar Volumes

Alveolar inspiratory and expiratory volumes are measured first from averaged VCO_2 (CO_2 uptake), averaged $ETCO_2$ (End Tidal CO_2 concentration) and averaged RR (Respiratory Rate) data collected from a 10 min period prior to the FiO_2 change. The volumes are calculated as follows:

$V_t^{alv(E)} = \frac{\overline{VCO_2}}{\overline{ETCO_2} * \overline{RR}}$ [eq. 1] Expiratory Alveolar Tidal Volume

and

$V_t^{alv(I)} = V_t^{alv(E)} + \frac{\overline{VO_2} - \overline{VCO_2}}{\overline{RR}}$ [eq. 2a] Inspiratory Alveolar Tidal Volume

Using VO_2 measurements in this equation [2a] will limit the method to low or moderate FiO_2 values. This limitation is circumvented by using only VCO_2 measurements as follows:

$V_t^{alv(I)} = V_t^{alv(E)} + \frac{\overline{VCO_2}/_{0.8} - \overline{VCO_2}}{\overline{RR}}$ [eq. 2b] Inspiratory Alveolar Tidal Volume

Steps 3 and 5: Perform Wash-out/Wash-in and calculate FRC

The FiO_2 delivered to the patient is changed to the set FRC FiO_2 causing an equal but opposite step in Nitrogen (N_2) concentration in the breathing gas. Knowing the alveolar volumes (step 1) and measuring the breath by breath change in N_2 concentration, we calculate FRC. N_2 is not measured directly but as balance gas from measured O_2 and CO_2

$N_2\% = 100\% - CO_2\% - O_2\%$ [eq. 4] where N_2, O_2, CO_2 are the instantaneous values

Knowing the N_2 concentration allows determination of ETN_2 (End Tidal Nitrogen concentration) and FiN_2 (Fractional Inspiratory Nitrogen Concentration) for each breath. Combining with the alveolar volumes measured at step 1 allows the calculation of the actual N_2 volumes as follows:

$V_E^{N2} = ETN_2 * V_t^{alv(E)}$ [eq. 5] Expiratory N_2 Minute Volume

$V_I^{N2} = FIN_2 * V_t^{alv(I)}$ [eq. 6] Inspiratory N_2 Minute Volume

FRC is measured breath by breath as the Nitrogen concentration in the lungs does not equilibrate in a single breath. The formula to calculate FRC is a cumulative formula:

$(single\ breath)FRC = \frac{\Delta V^{N_2}}{\Delta ETN_2}$ [eq. 7] "Alveolar" FRC calculated from a single breath where

$\Delta V^{N2} = V_E^{N2} - V_I^{N2}$ [eq. 8] and

$\Delta ETN_2 = ETN_2^{baseline} - ETN_2^{(1)}$ [eq. 9] where baseline is the previous breath and (1) the current breath and to obtain the total FRCalv we sum the (single breath)FRCs

$(total)FRC = \frac{\Sigma_{breaths} \Delta V^{N2}}{ETN_2^{baseline} - ETN_2^{(1)}}$ [eq. 10]

The breaths are integrated for as long as, $\Delta V^{N2} > 0$ which is the point where the N_2 concentration in the lungs reaches equilibrium.

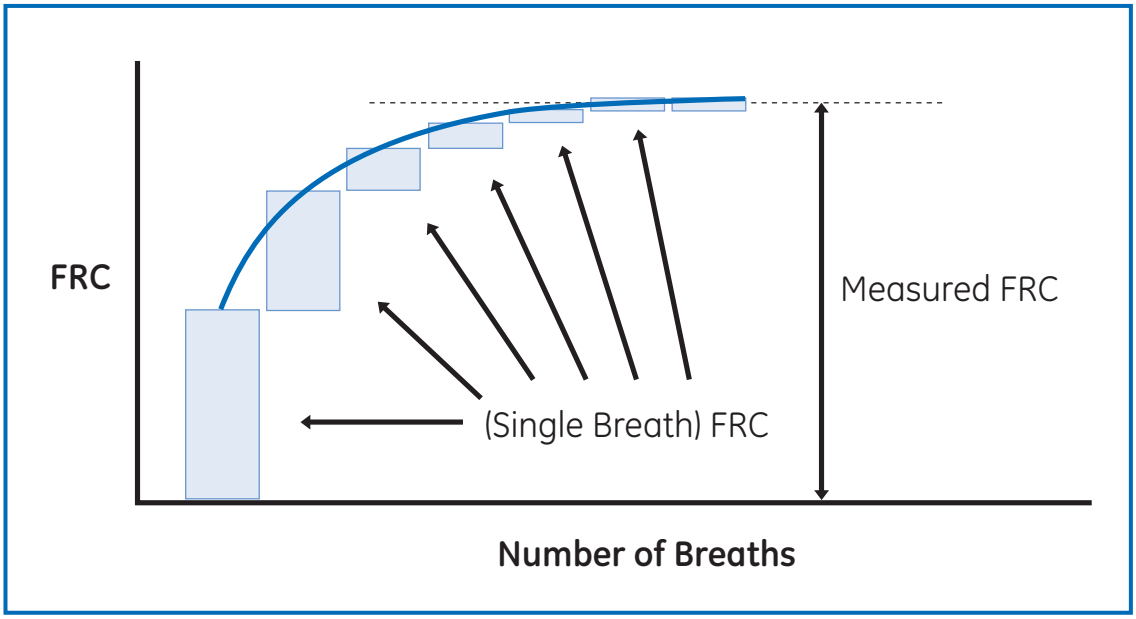


Figure 8: Multi breath FRC accumulation and FRC curve

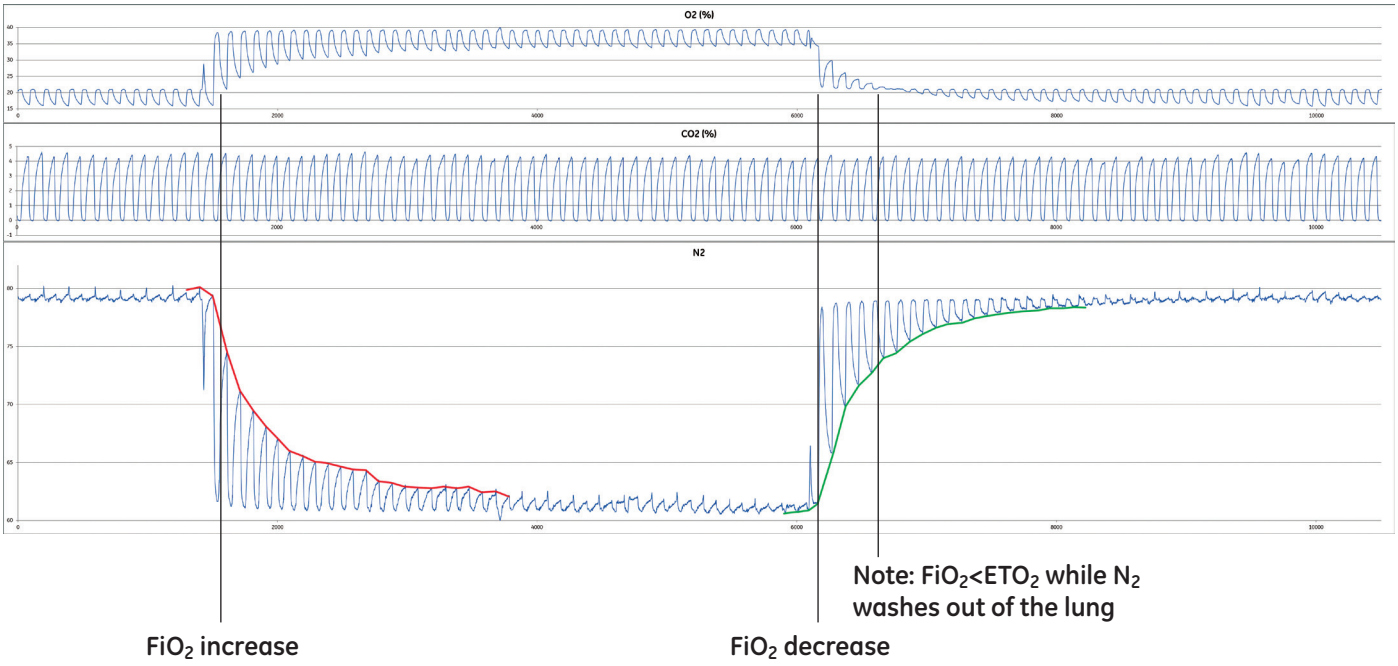
This schematic shows how the method accumulates breath by breath measurements. It uses an FRC example for a lung condition where it took seven consecutive breaths to reach equilibrium i.e. for all the lung areas to be filled with the same level of N_2

FRC measurement example

Healthy volunteer breathing via mask in CPAP/PS mode with no set PEEP and minimal Pressure Support at FiO_2 set to 21%

FRC O_2 has been set to 40%. The upper O_2 and CO_2 tracings are measured directly by the gas sensors and the lower N_2 tracing calculated as balance gas: $N_2\% = 100 - O_2\% - CO_2\%$

After the step in FiO_2 from 21% to 40% we clearly observe the multi breath wash-out of Nitrogen which enables the FRC calculation. The reverse happens when the FiO_2 returns back to 21%. $ETCO_2$ remains relatively constant throughout the procedure.



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